Ammonia observation and modeling simulation 3

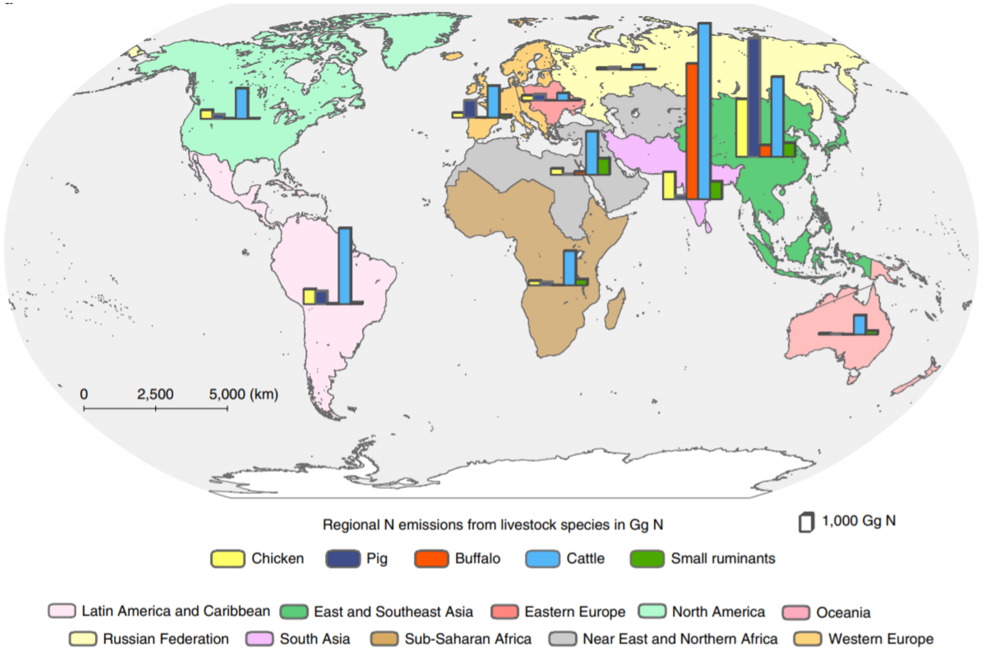
IASI data and GEOS-Chem model

2020.10

- Accomplished:
  - 1. literature: global nitrogen emissions from livestock chain
  - 2. literature: global nitrous oxide budget
  - 3. literature: nitrous oxide emission of livestock enclosures in Sub-Saharan Africa
  - 3. literature: Industrial and agricultural ammonia point sources
  - 4. literature: improved nitrogen use efficiency scenarios in China
  - 5. fix the floating invalid bug of GEOS-Chem
  - 6. 2010.1-2010.2 output from GEOS-Chem
  - 7. Simulating GEOS-Chem Tropchem manual
- Ammonia Data:
  - IASI (2008-2016), 1°×1°, monthly, land area
    - Reanalyzed IASI/Metop-A (2008-2016) L3
- Ongoing:
  - 1. running the GEOS-Chem Tropchem over 2010
  - 2. calculating the column concentration from GEOS-Chem output (47 levels integration)

Nitrogen emissions along global livestock supply chains

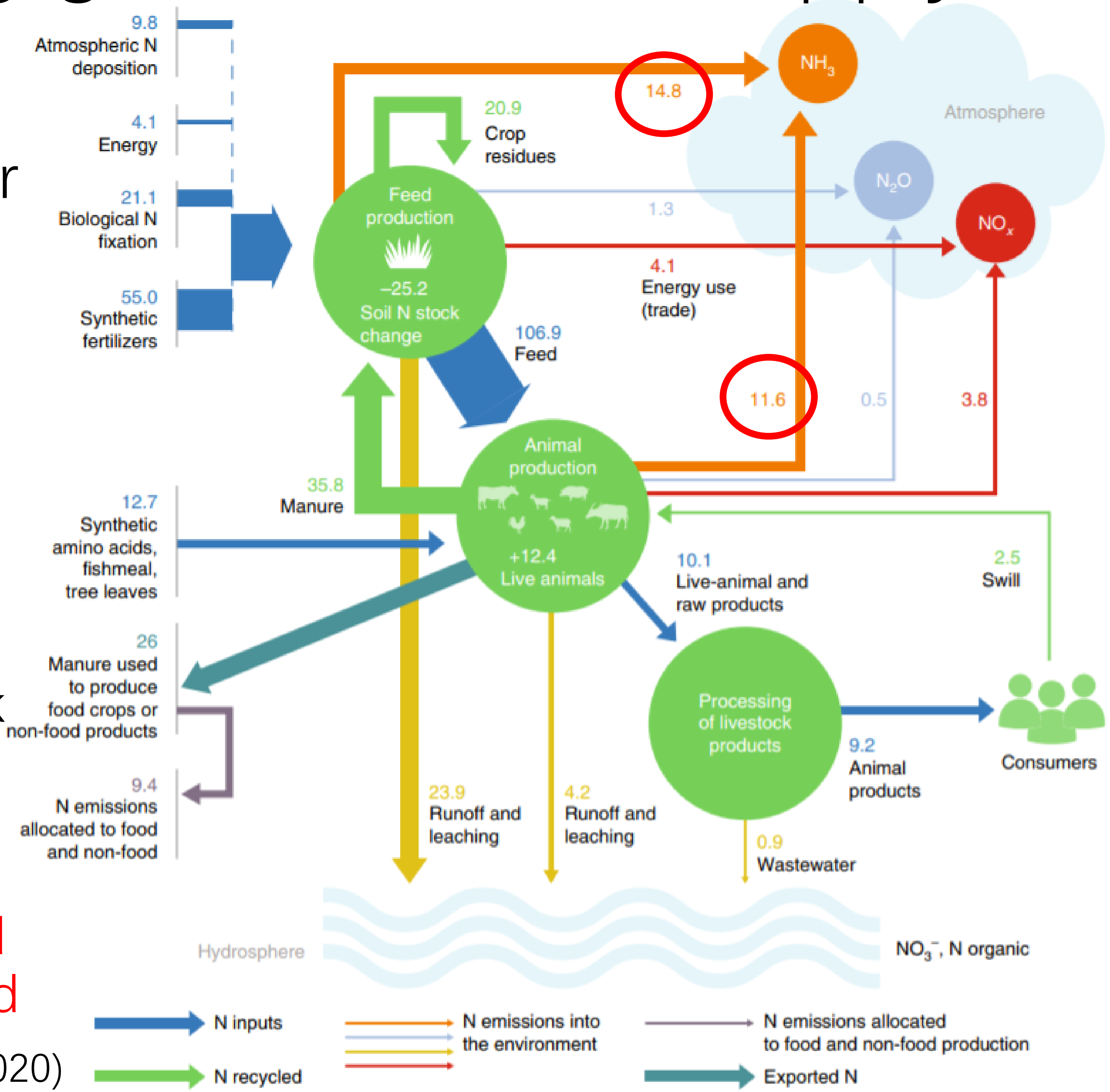
- highlight the diversity of livestock supply chains and international trade.
- quantify N-use indicators of life-cycle nitrogen use efficiency and life-cycle net nitrogen balance
- identify hotspots of N emissions and ultimately suggesting targeted interventions to reduce emissions



(Uwizeye et al., 2020)

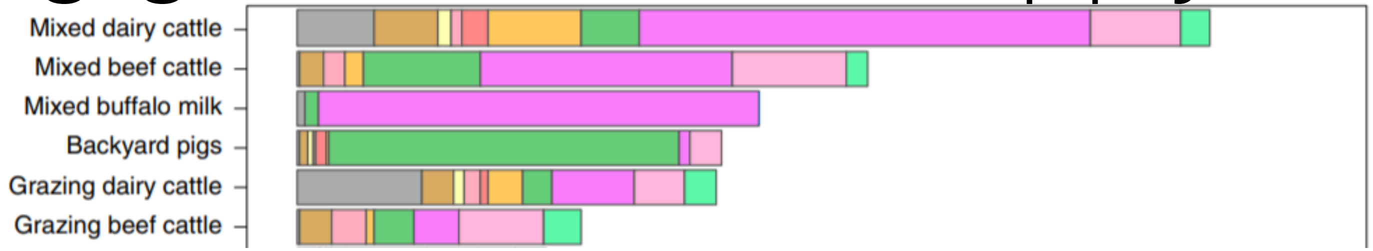
Nitrogen emissions along global livestock supply chains

- N emissions from the livestock sector
  - Global N flows and sources of N compound emissions allocated to the livestock sector: livestock supply chains contributed 25.4 Tg N to Atmosphere
    - 14.8 from feed production
    - 11.6 from animal production
- N emissions per supply chain
  - Distribution of N emissions by livestock species for 10 regions: South Asia, East and Southeast Asia and Latin America and the Caribbean given the high numbers of livestock held in mixed and grazing ruminant systems and backyard monogastric systems

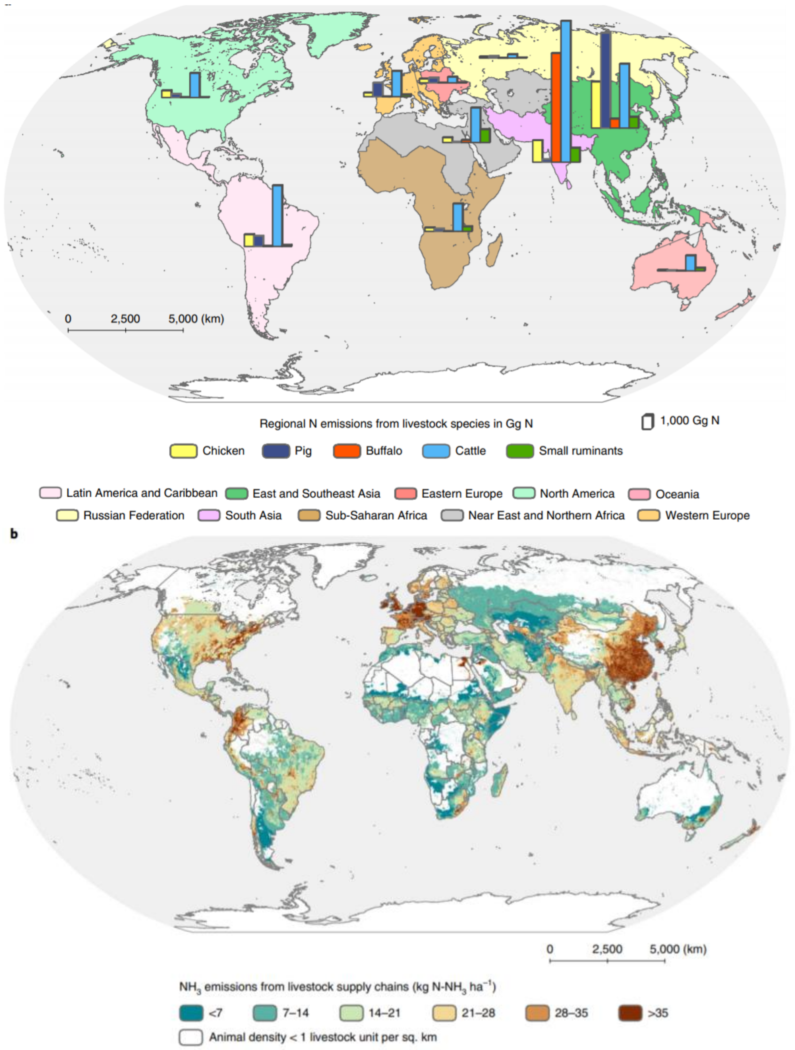


(Uwizeye et al., 2020)

Nitrogen emissions along global livestock supply chains



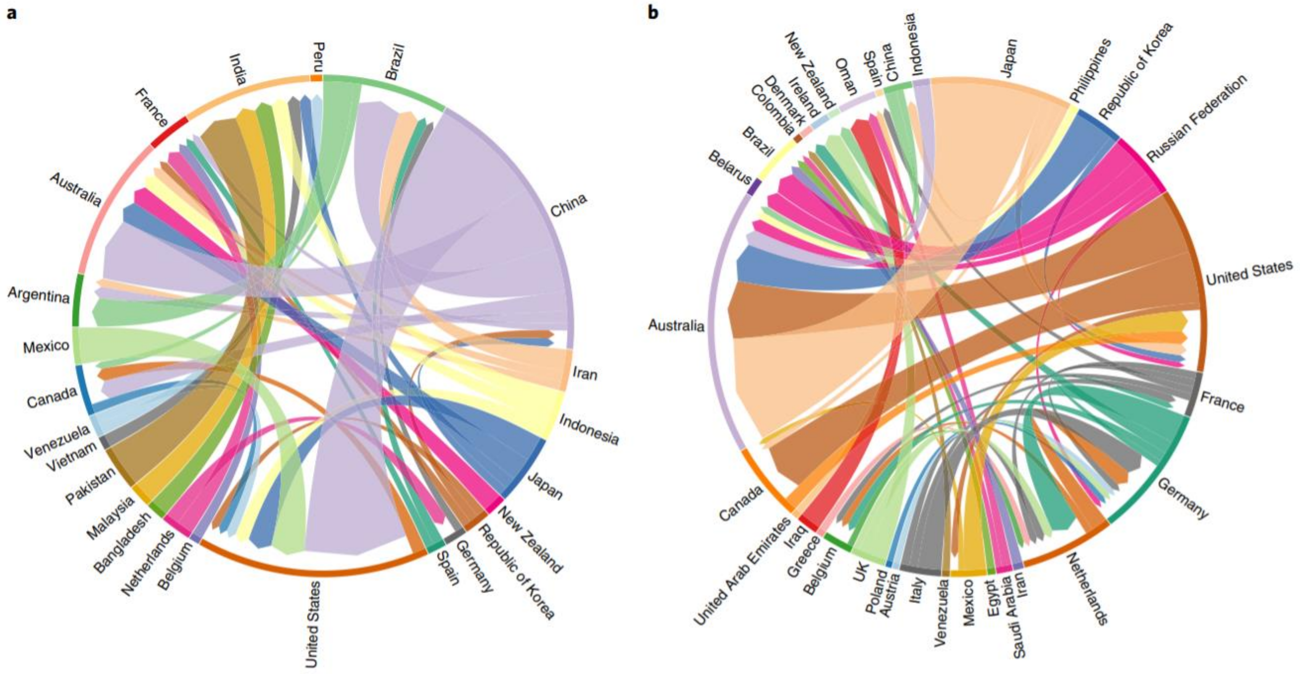
- N emissions per supply chain
  - mixed cattle and buffalo supply chains alone are responsible for 44% of the total N emissions Regional hotspots of N emissions
- Regional hotspots of N emissions
  - Most N emissions take place in the regions of South Asia, East and Southeast Asia and Latin America and the Caribbean
  - NH3 emissions are concentrated in East and Southeast Asia, East Australia and New Zealand, Western Europe, Colombia, east coast of the United States and the Nile Delta



(Uwizeye et al., 2020)

Nitrogen emissions along global livestock supply chains

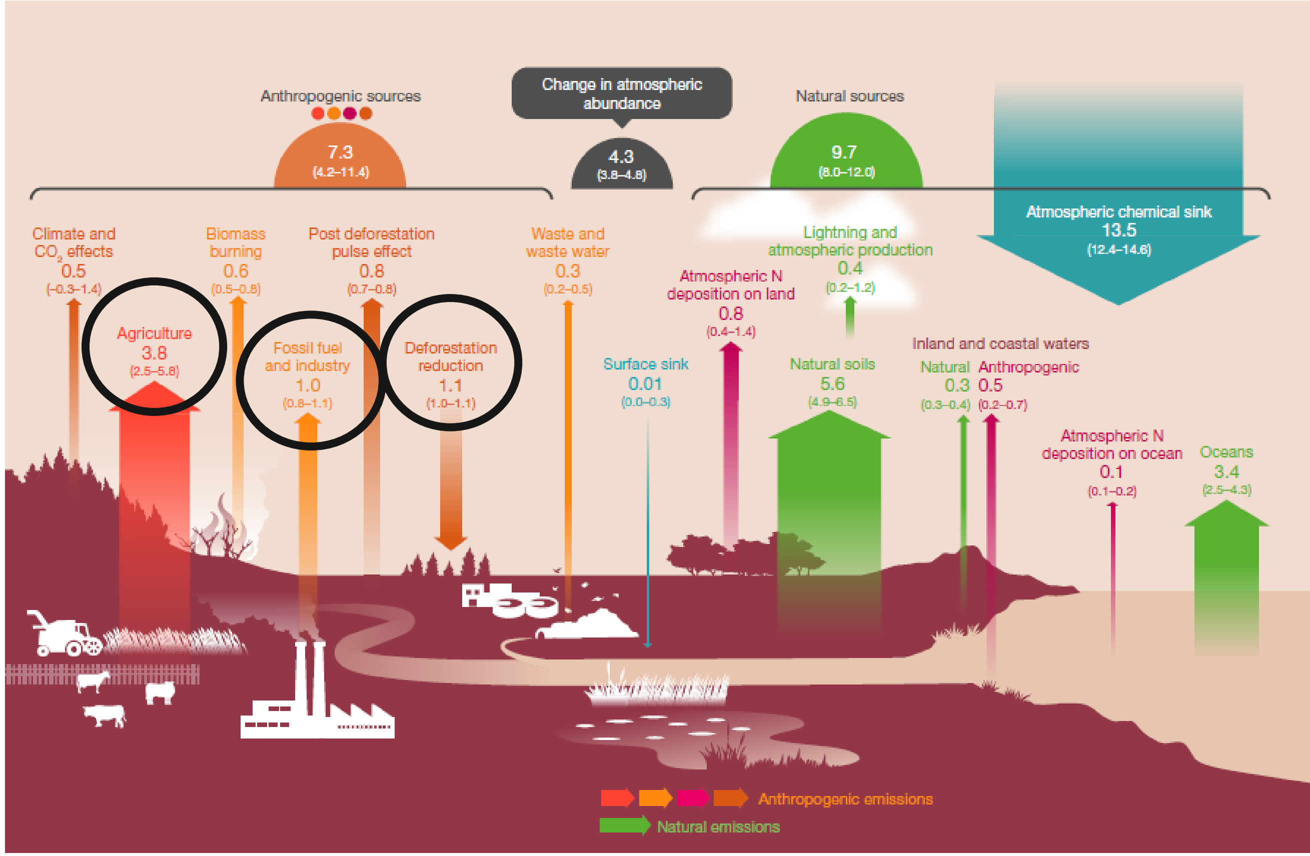
- N emissions from domestic consumption
  - Feed commodities relate mostly to the fertilization of feed, 59% is associated with the trade of cereals, 39% with soybean and soybean cake and 2% with the trade in palm products and cassava
  - Livestock commodities stem from the production of beef (41%), milk (31%), pork (15%), chicken meat (8%), sheep meat (3%) and eggs (1%).



(Uwizeye et al., 2020)

A comprehensive quantification of global nitrous oxide sources and sinks

- constructed a total of 43 flux estimates:
  - 30 using bottom-up approaches,
  - 5 using top-down approaches,
  - 8 other estimates using observation and modelling approaches
- The global N2O budget (2007–2016)
  - Anthropogenic sources contributed 43% to the total N2O emission of which direct and indirect emissions from nitrogen additions in agriculture and other sectors contributed around 52% and around 18%, respectively.



(Tian et al., 2020)

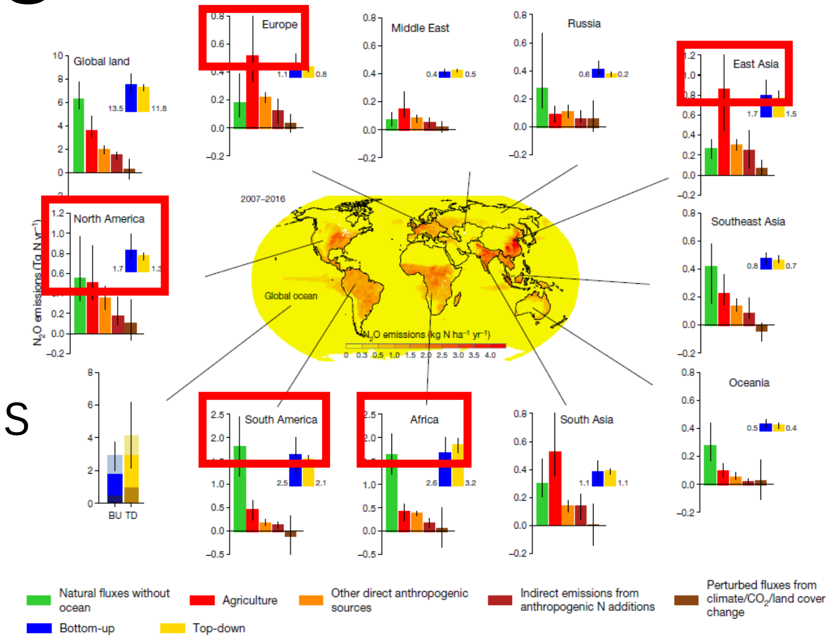
A comprehensive quantification of global nitrous oxide sources and sinks

- Four decades of the global N2O budget
  - a substantial increase in global N2O emissions that is primarily driven by anthropogenic sources, as natural sources remained relatively steady throughout the study period.
  - recent climate change—particularly warming could have boosted soil nitrification and denitrification processes, contributing to the growing trend in N2O emissions together with increasing nitrogen additions to agricultural soils

		1980s			1990s			2000s			2007–2016		
Anthropogenic sources		**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
Direct emissions from nitrogen additions in the agricultural sector (Agriculture)	Direct soil emissions	1.5	0.9	2.6	1.7	1.1	3.1	2.0	1.3	3.4	2.3	1.4	3.8
	Manure left on pasture	0.9	0.7	1.0	1.0	0.7	1.1	1.1	0.8	1.2	1.2	0.9	1.3
	Manure management	0.3	0.2	0.4	0.3	0.2	0.4	0.3	0.2	0.5	0.3	0.2	0.5
	Aquaculture	0.01	0.00	0.03	0.03	0.01	0.1	0.1	0.02	0.2	0.1	0.02	0.2
	Subtotal	**2.6**	**1.8**	**4.1**	**3.0**	**2.1**	**4.8**	**3.4**	**2.3**	**5.2**	**3.8**	**2.5**	**5.8**
Other direct anthropogenic sources	Fossil fuels and industry	0.9	0.8	1.1	0.9	0.9	1.0	0.9	0.8	1.0	1.0	0.8	1.1
	Waste and waste water	0.2	0.1	0.3	0.3	0.2	0.4	0.3	0.2	0.4	0.3	0.2	0.5
	Biomass burning	0.7	0.7	0.7	0.7	0.6	0.8	0.6	0.6	0.6	0.6	0.5	0.8
	Subtotal	**1.8**	**1.6**	**2.1**	**1.9**	**1.7**	**2.1**	**1.8**	**1.6**	**2.1**	**1.9**	**1.6**	**2.3**
Indirect emissions from anthropogenic nitrogen additions	Inland waters, estuaries, coastal zones	0.4	0.2	0.5	0.4	0.2	0.5	0.4	0.2	0.6	0.5	0.2	0.7
	Atmospheric nitrogen deposition on land	0.6	0.3	1.2	0.7	0.4	1.4	0.7	0.4	1.3	0.8	0.4	1.4
	Atmospheric nitrogen deposition on ocean	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2
	Subtotal	**1.1**	**0.6**	**1.9**	**1.2**	**0.7**	**2.1**	**1.2**	**0.6**	**2.1**	**1.3**	**0.7**	**2.2**
Perturbed fluxes from climate/CO_2/land cover change	CO_2 effect	−0.2	−0.3	0.0	−0.2	−0.4	0.0	−0.3	−0.5	0.1	−0.3	−0.6	0.1
	Climate effect	0.4	0.0	0.8	0.5	0.1	0.9	0.7	0.3	1.2	0.8	0.3	1.3
	Post-deforestation pulse effect	0.7	0.6	0.8	0.7	0.6	0.8	0.7	0.7	0.8	0.8	0.7	0.8
	Long-term effect of reduced mature forest area	−0.8	−0.8	−0.9	−0.9	−0.8	−1.0	−1.0	−0.9	−1.1	−1.1	−1.0	−1.1
	Subtotal	**0.1**	**−0.4**	**0.7**	**0.1**	**−0.5**	**0.7**	**0.2**	**−0.4**	**0.9**	**0.2**	**−0.6**	**1.1**
Anthropogenic total		**5.6**	**3.6**	**8.7**	**6.2**	**3.9**	**9.7**	**6.7**	**4.1**	**10.3**	**7.3**	**4.2**	**11.4**

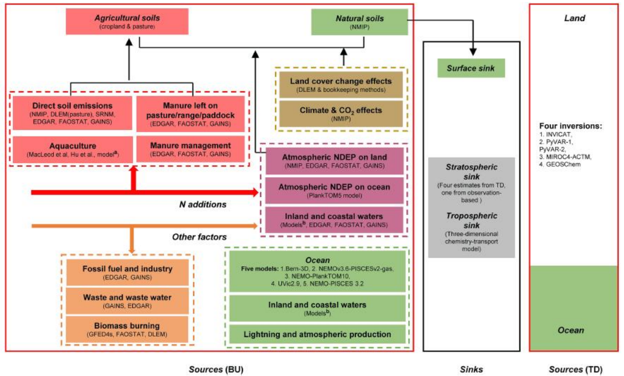
(Tian et al., 2020)

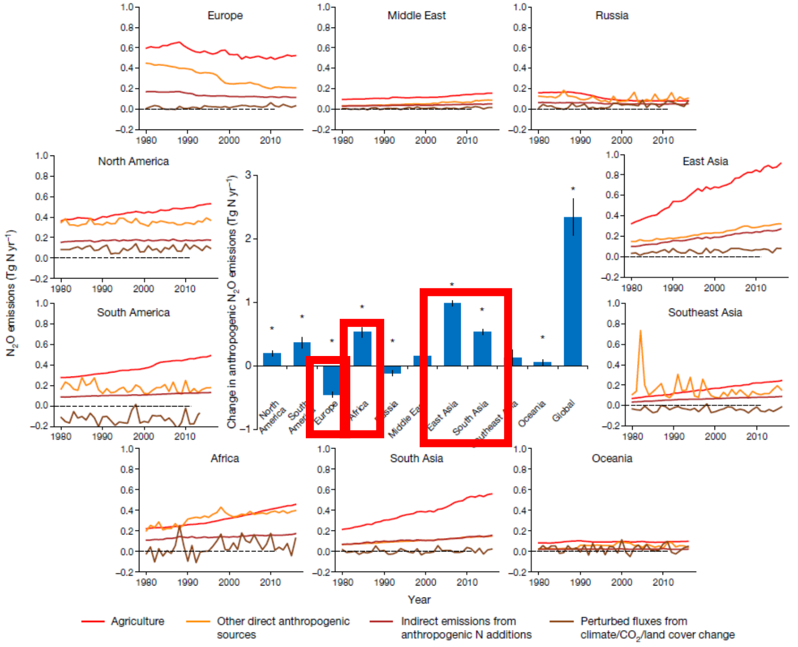
A comprehensive quantification of global nitrous oxide sources and sinks



- Regional N2O budgets (2007–2016)
  - Africa was the largest source of N2O in the last decade, followed by South America
  - Total anthropogenic emissions in the 10 terrestrial regions were highest in East Asia, followed by North America, Africa and Europe

- Four decades of anthropogenic N2O emissions
  - over the period 1980–2016:
    - Fluxes from Europe and Russia decreased
    - Increased: East Asia (34%), Africa (18%), South Asia (18%), South America (13%) and North America (6%)

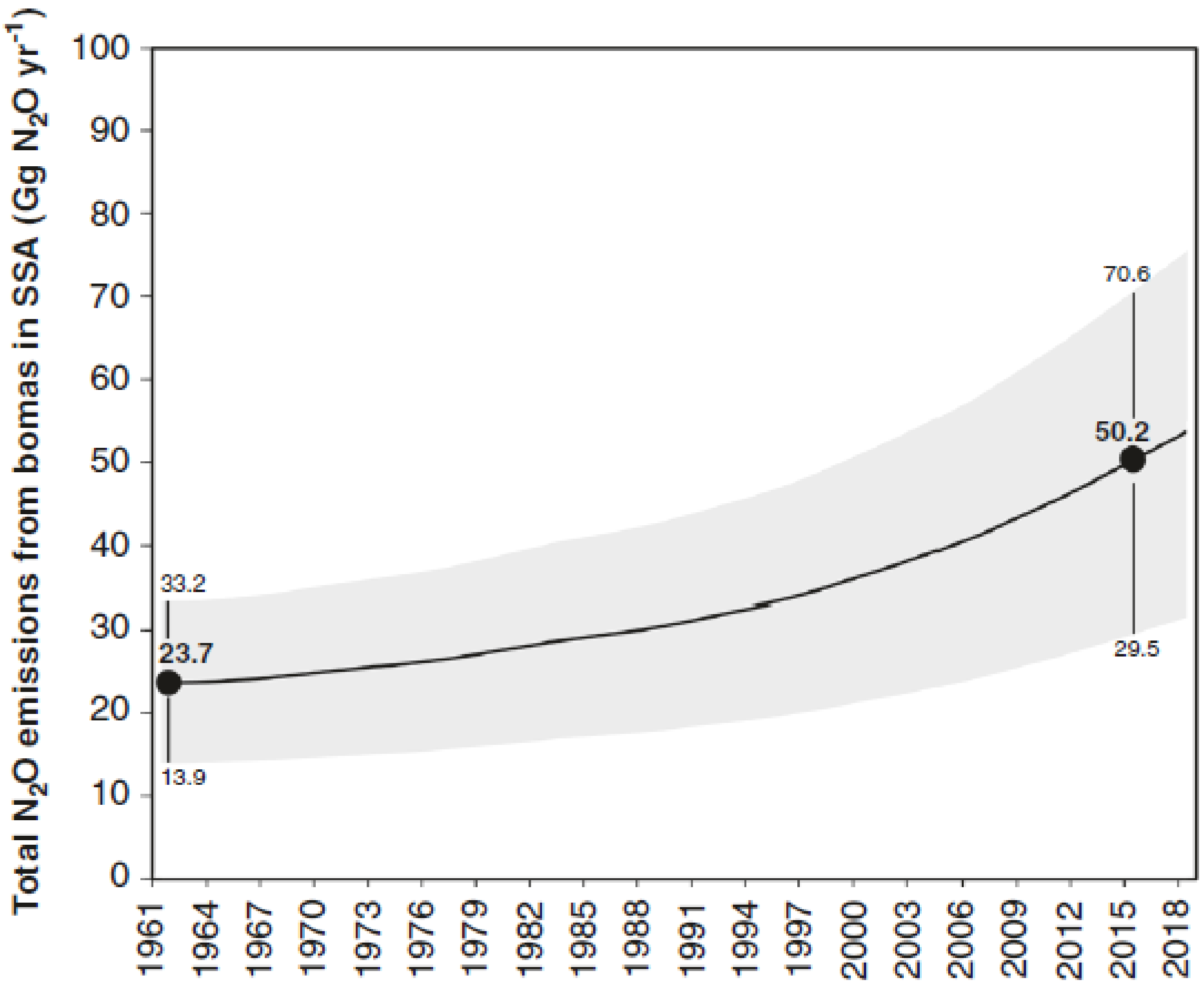




(Tian et al., 2020)

N_2O emissions from bomas in drylands of Sub-Saharan Africa (SSA)

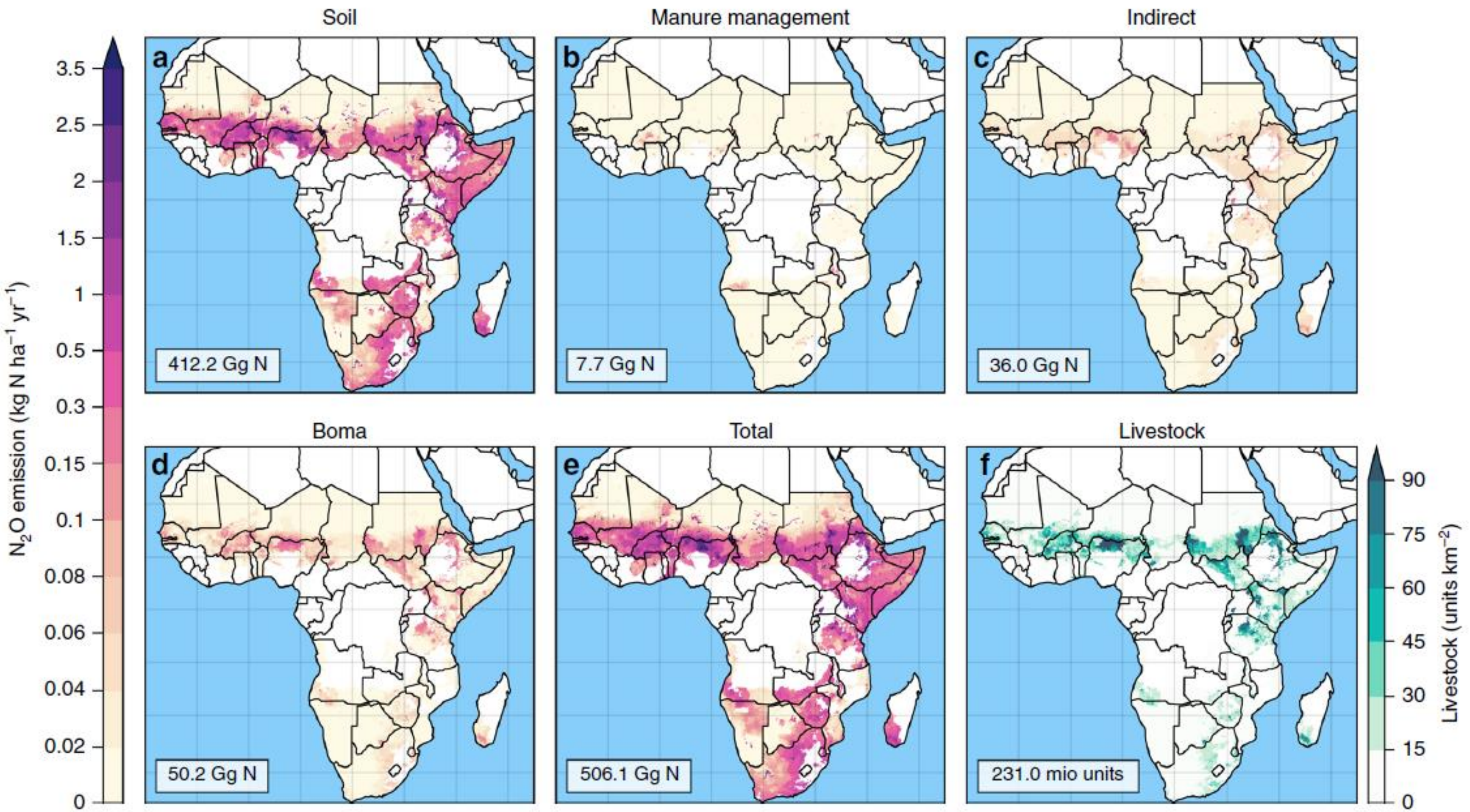
- Change in the source strength of abandoned bomas from 1961 to 2018
  - Step 1: total livestock numbers (TLN)
    - $TLN = \sum c + \frac{(s\times0.1+g\times0.1)}{0.7}$
    - c, s, g: total number of cattle, sheep, goat
  - Step 2: boma use intensity (BUI):
    - $BUI = \frac{BAL\times NB\times FMB}{YB}$
    - BAL: boma area per livestock
    - NB: number of bomas in use at the same time
    - FMB: Fraction of bomas without use of manure
    - YB: years of boma use
  - Step 3: N_2O emission intensity (N_2O_int)
    - $N2O\_int = N_2O \times N_2O_{\_years} \times \frac{4}{28}$
    - N_2O: mean average annual N_2O flux from bomas
    - N_2O_years
    - $\frac{4}{28}$: conversion of N_2O-N to N_2O
  - Step 4: total N_2O emissions from bomas (N_2O_FB)
    - $\sum N_2O\_FB = TLN \times BUI \times N2O\_int$



(Butterbach-Bahl et al., 2020)

N_2O emissions from bomas in drylands of Sub-Saharan Africa (SSA)

- Sources of agricultural N_2O fluxes
  - EDGAR5
    - a: soil
    - b: manure management
    - c: indirect emission
  - in-situ measurements
    - d: total emissions from bomas (this study)
  - total agricultural N2O emissions
    - e=a + b + c + d
- livestock units: livestock density
  - $N = \sum cattle + \frac{(sheep\times0.1+goat\times0.1)}{0.7}$

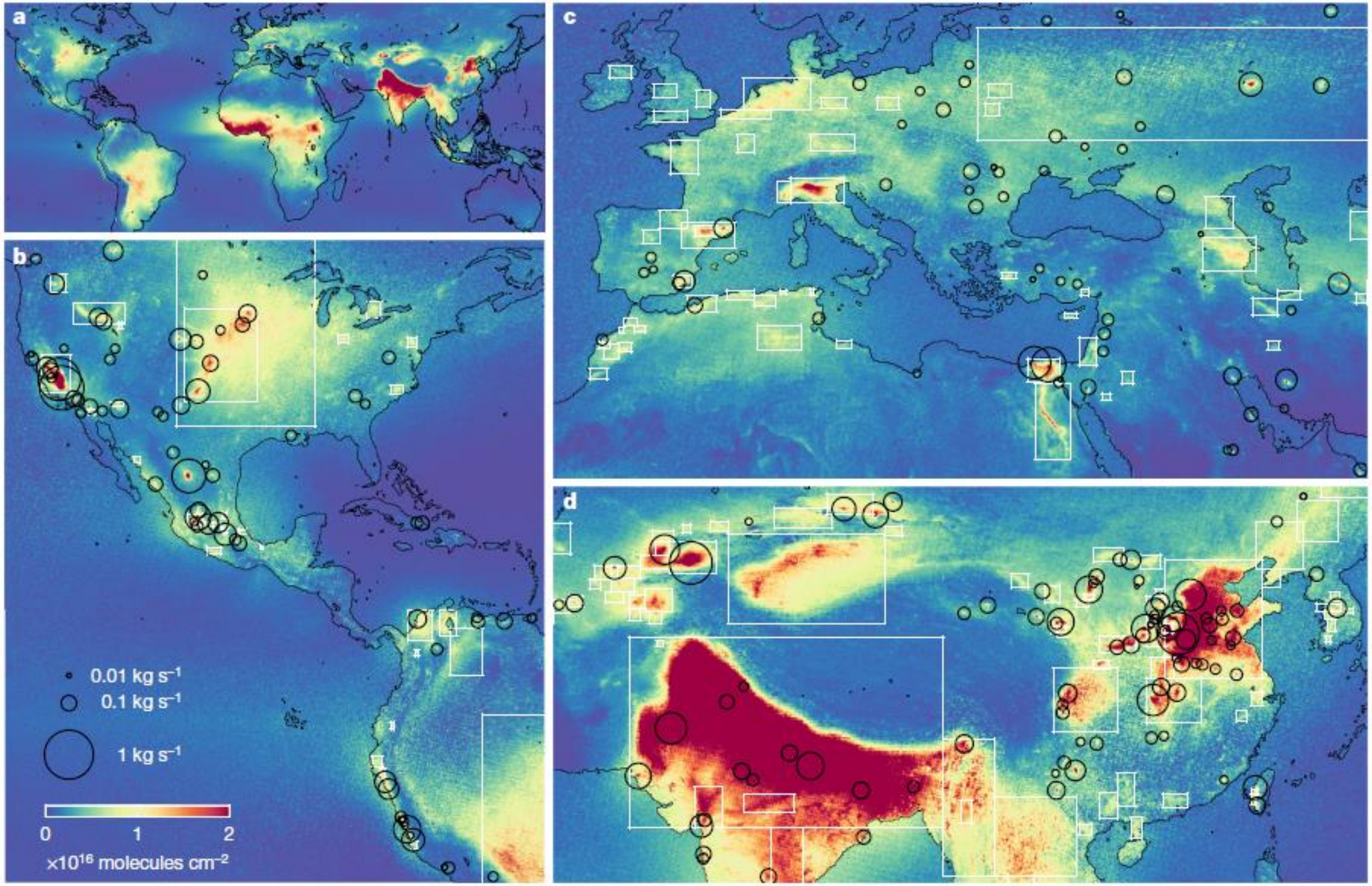


(Butterbach-Bahl et al., 2020)

Industrial and agricultural ammonia point sources exposed

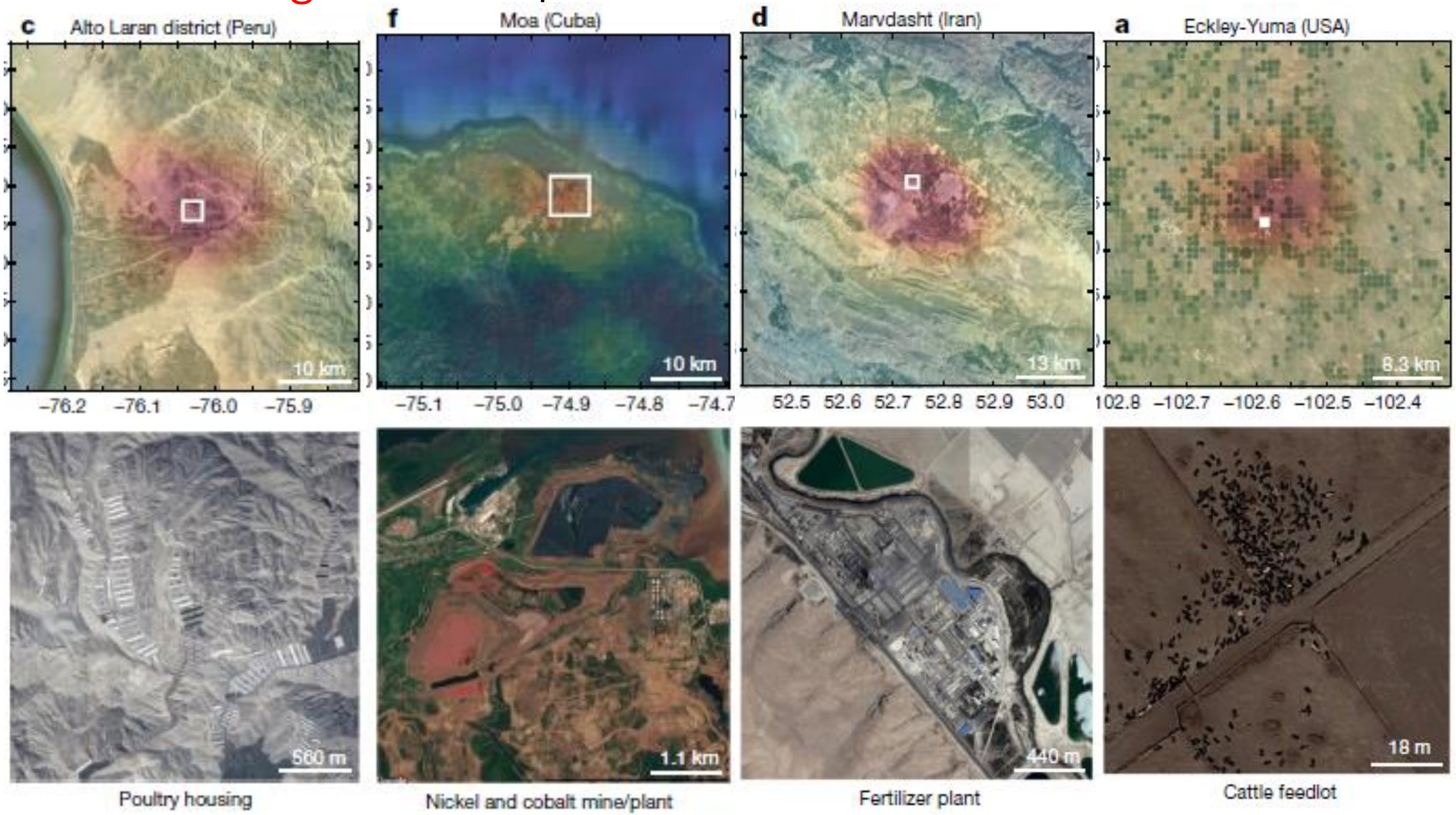
- identify, categorize and quantify the world's ammonia emission hotspots using a high-resolution map of atmospheric ammonia obtained from 9 years daily IASI satellite observations.
    - Indo-Gangetic Plain
    - North China Plain
    - West Africa and Amazonia

(Damme et al., 2018)



Industrial and agricultural ammonia point sources exposed

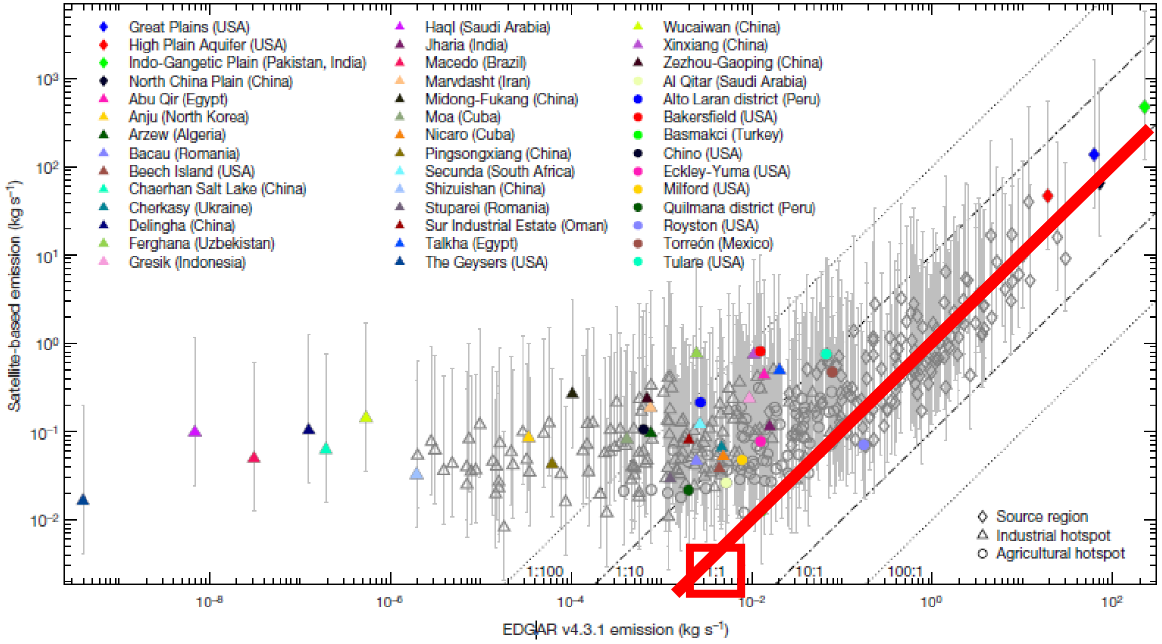
- Examples of industrial and agricultural point sources.
  - agricultural
  - Industrial
  - natural

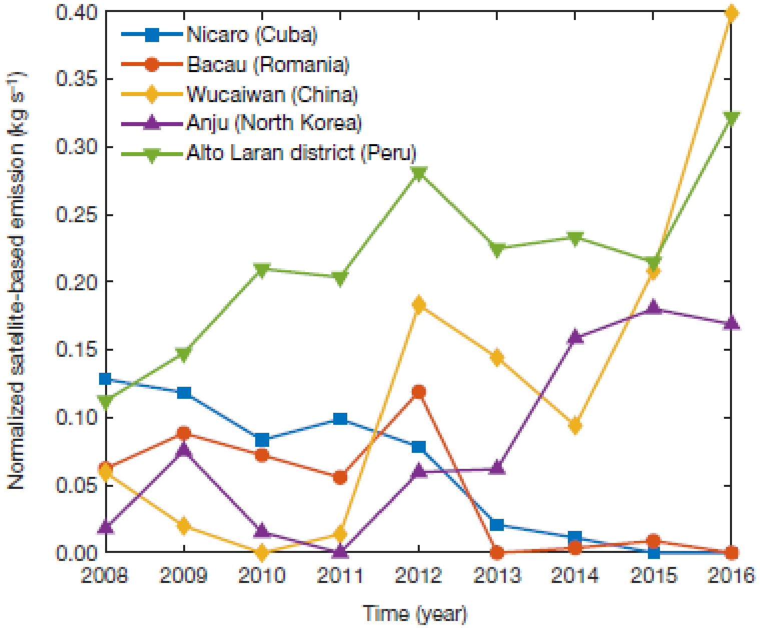


(Damme et al., 2018)

Industrial and agricultural ammonia point sources exposed

- compared Satellite-derived emission with the bottom-up emission inventory EDGAR
    - emissions from almost all identified hotspots are underestimated in EDGAR
- satellite-based ammonia emission trends
    - the onset or the discontinuation of anthropogenic activity could be detected unambiguously



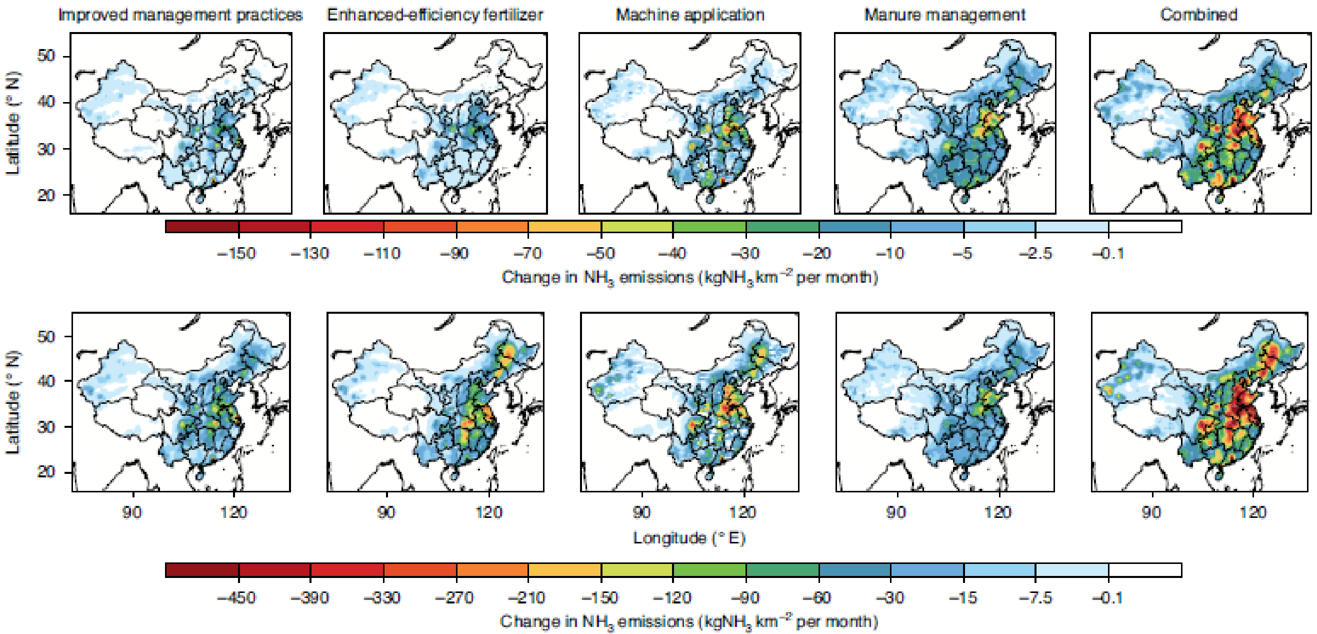


(Damme et al., 2018)

Air quality, nitrogen use efficiency and food security in China are improved by cost-effective agricultural nitrogen management

- an integrated assessment of four improved nitrogen management strategies:
  - improved farm management practices with nitrogen use reductions;
  - machine deep placement of fertilizer;
  - enhanced-efficiency fertilizer use;
  - improved manure management

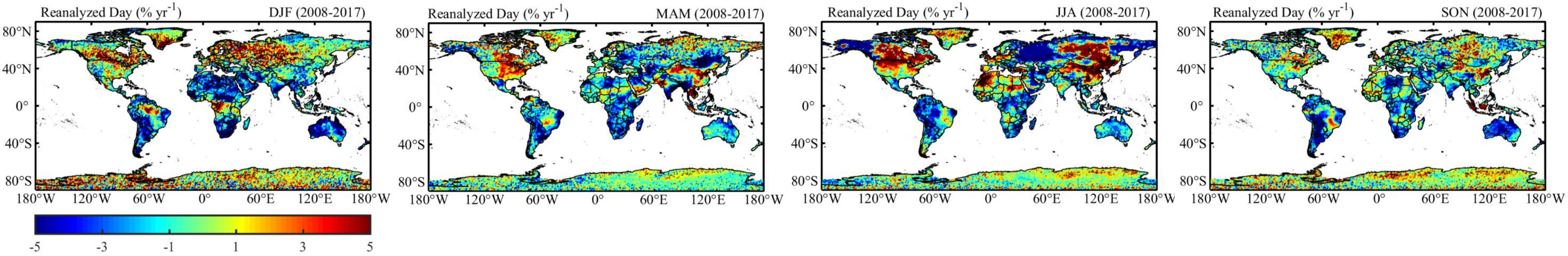
Scenario	NH_3 emissions (Tg)		
	Annual	January	July
Baseline	14.0	0.66	1.66
Improved management practices	13.1	0.64	1.54
Enhanced-efficiency fertilizer	12.5	0.65	1.45
Machine application	12.5	0.62	1.43
Manure management	12.5	0.58	1.50
Combined	9.3	0.51	1.01



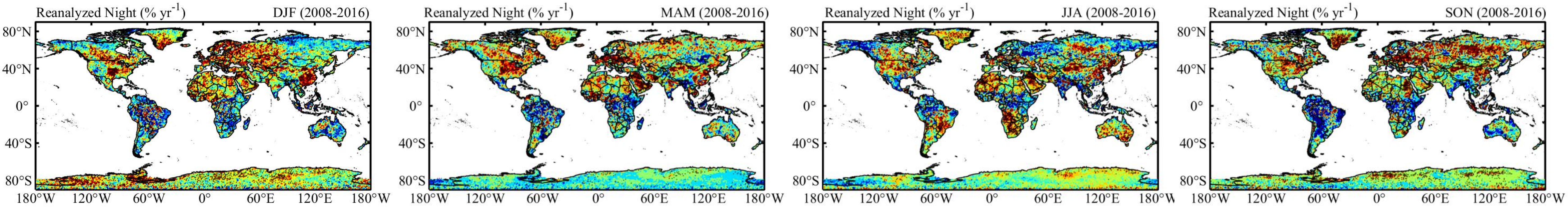
(Guo et al., 2020)

Spatial distribution of ammonia observations trend/mean

(a) day



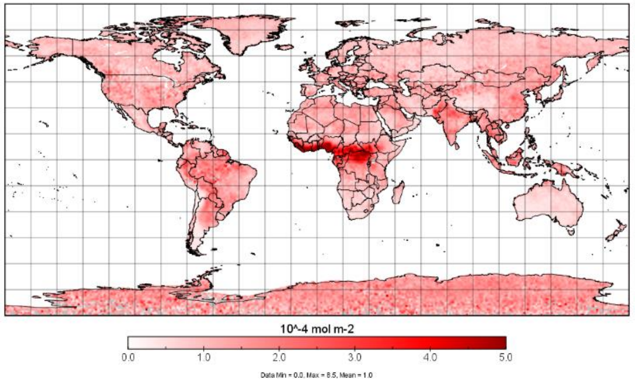
(b) night



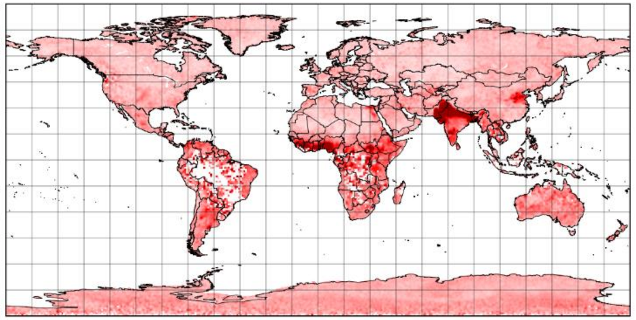
NH3 concentration from GEOS-Chem output

2010.1 **IASI** **GEOS-Chem daily**

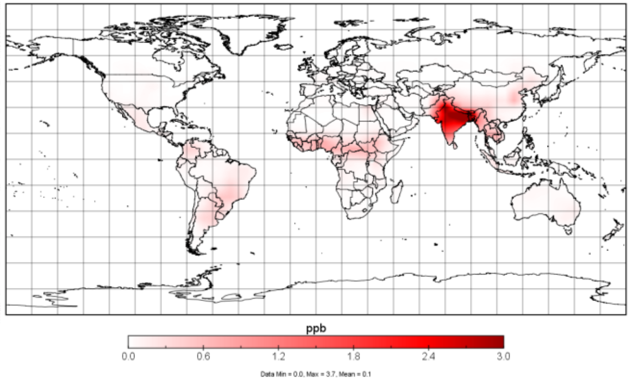
average of the total ammonia columns for IASI daytime observations



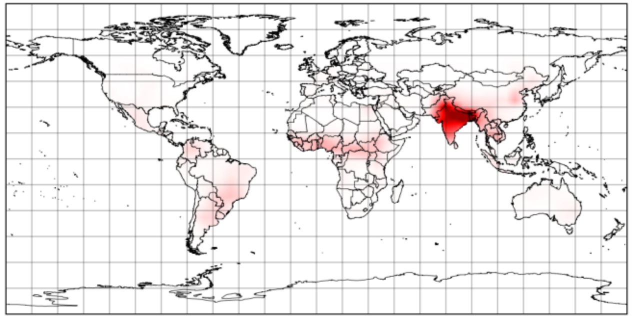
average of the total ammonia columns for IASI nighttime observations



average of the total ammonia columns for GEOS-Chem daytime simulation

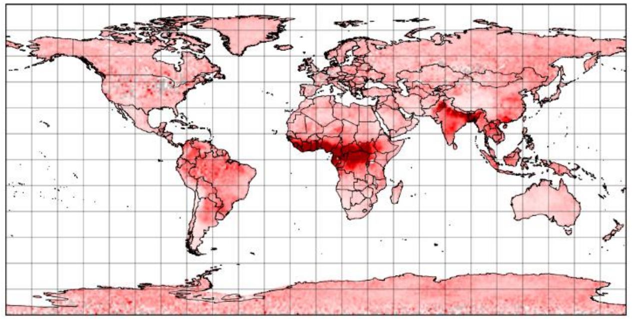


average of the total ammonia columns for GEOS-Chem nighttime simulation

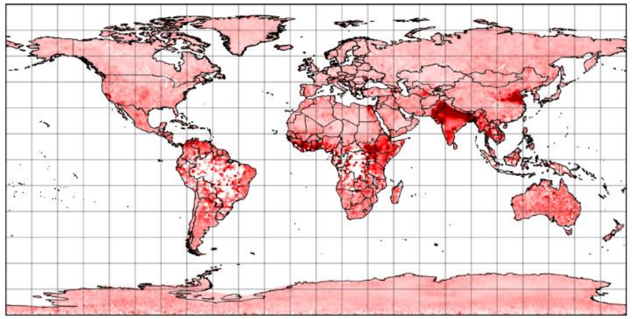


2010.2

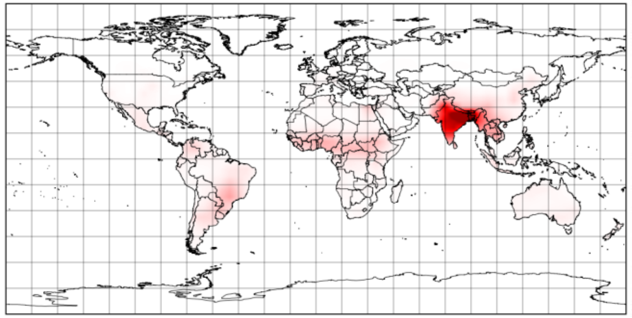
average of the total ammonia columns for IASI daytime observations



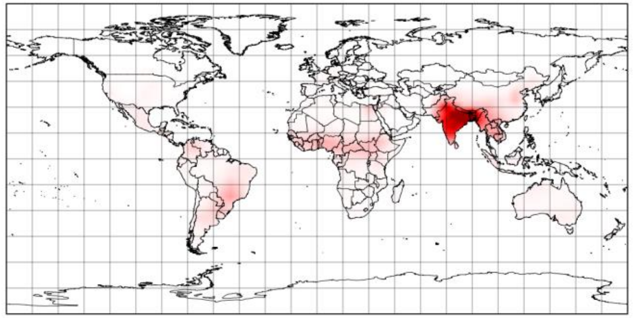
average of the total ammonia columns for IASI nighttime observations



average of the total ammonia columns for GEOS-Chem daytime simulation



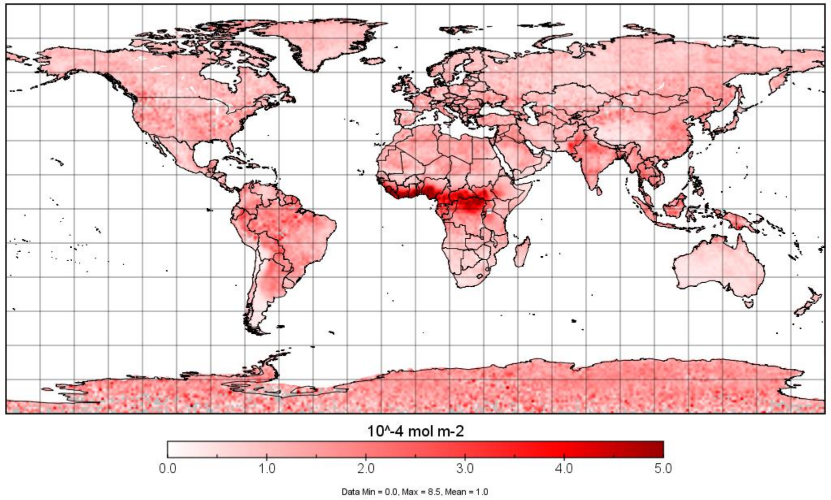
average of the total ammonia columns for GEOS-Chem nighttime simulation



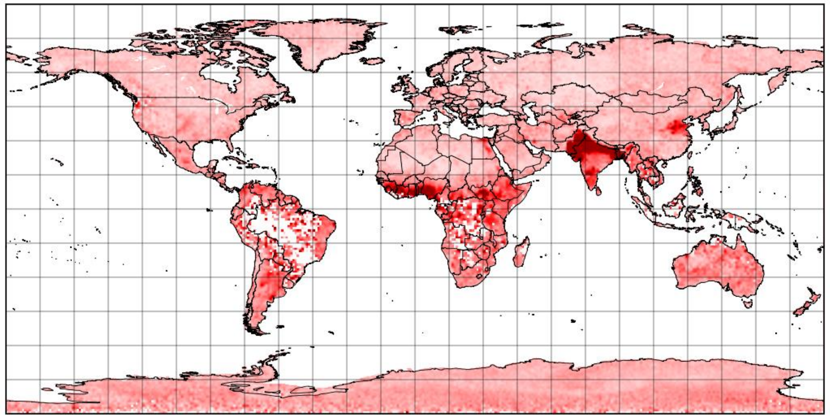
NH3 concentration from GEOS-Chem output

2010.1 **IASI** **GEOS-Chem monthly**

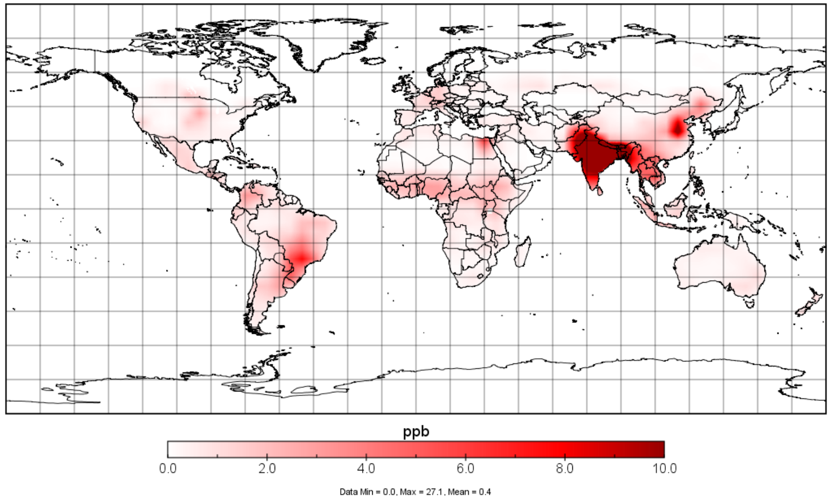
average of the total ammonia columns for IASI daytime observations



average of the total ammonia columns for IASI nighttime observations

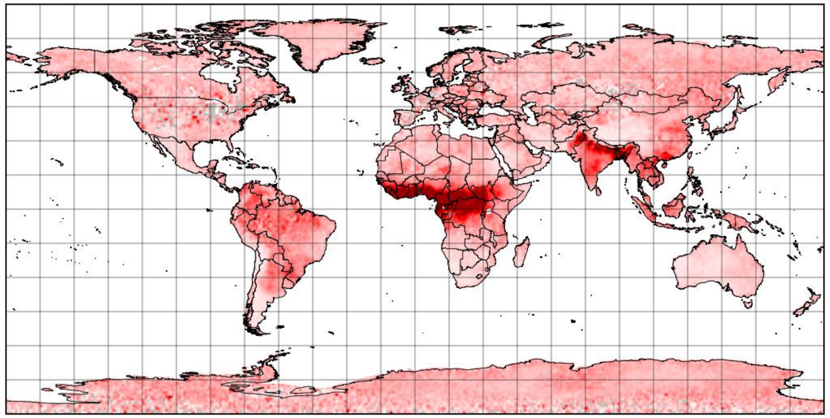


Dry mixing ratio of species NH3

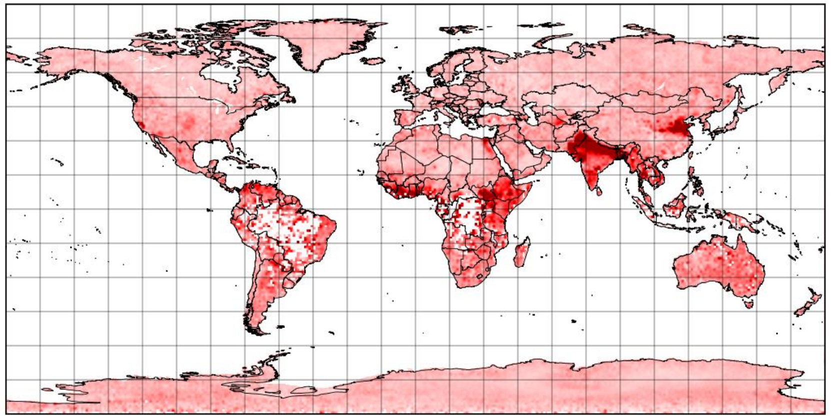


2010.2

average of the total ammonia columns for IASI daytime observations



average of the total ammonia columns for IASI nighttime observations



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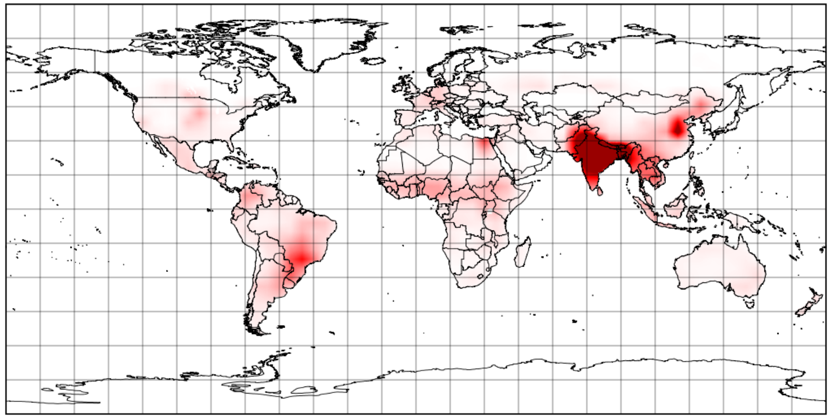
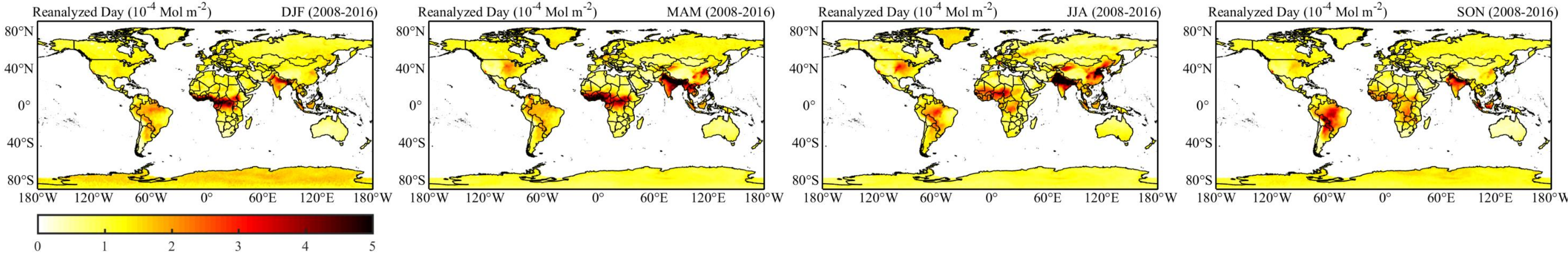
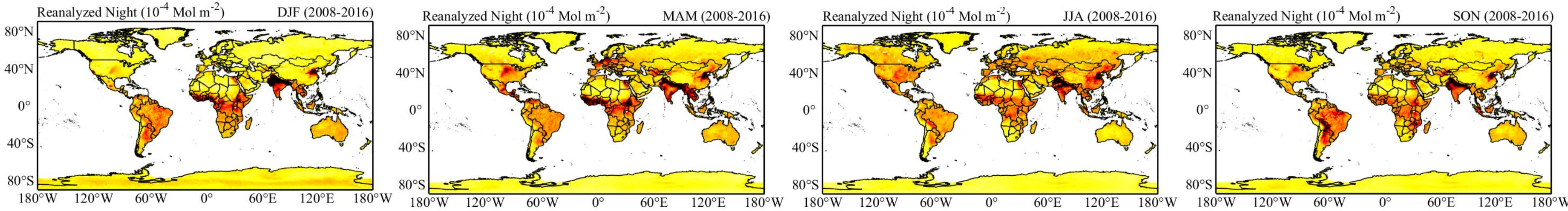


Spatial distribution of ammonia observations mean

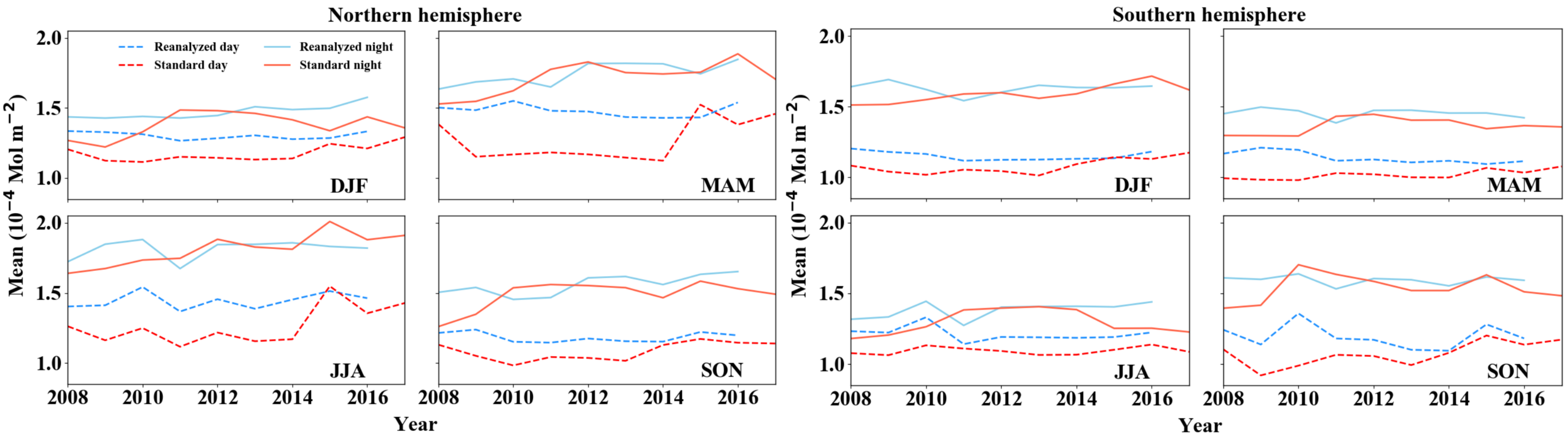
(a) day



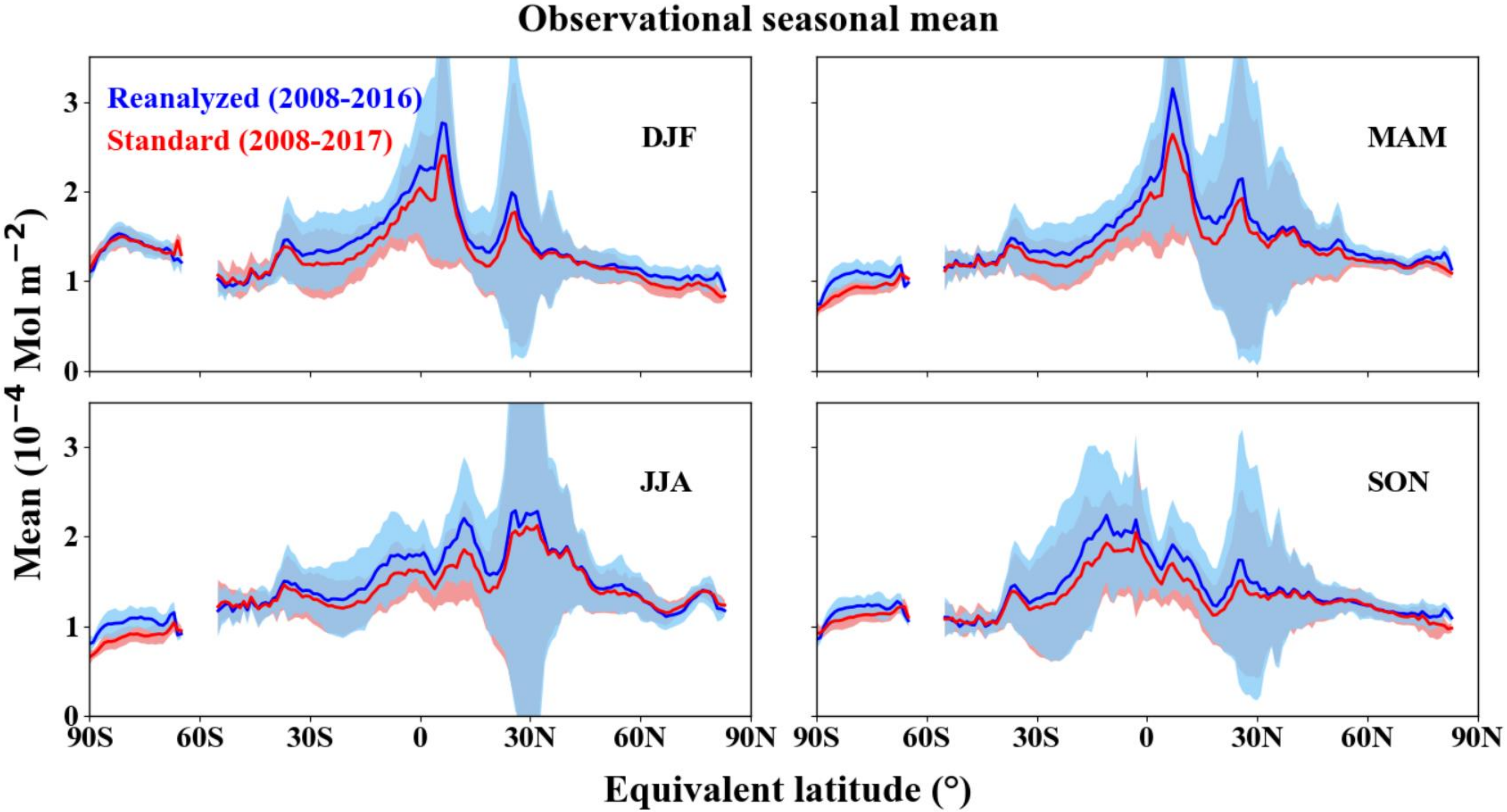
(b) night



Seasonal change for NH and SH (day and night)

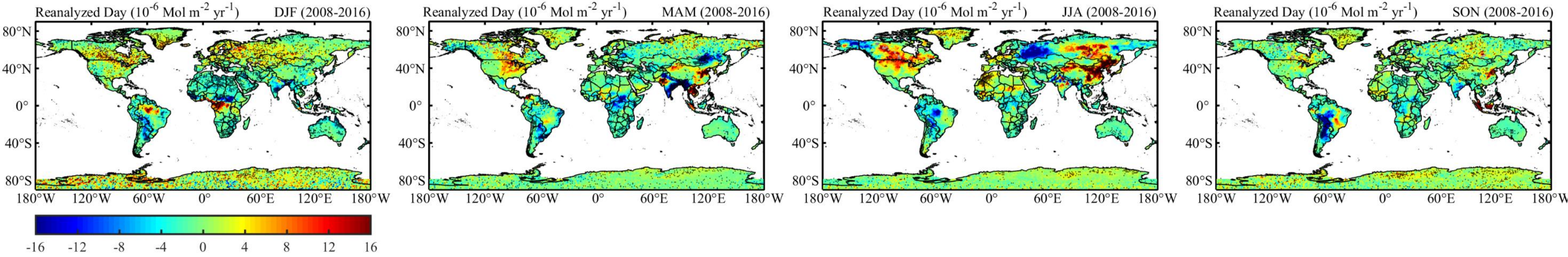


Seasonal mean of Land for equivalent latitude (within 1 sigma standard deviations)

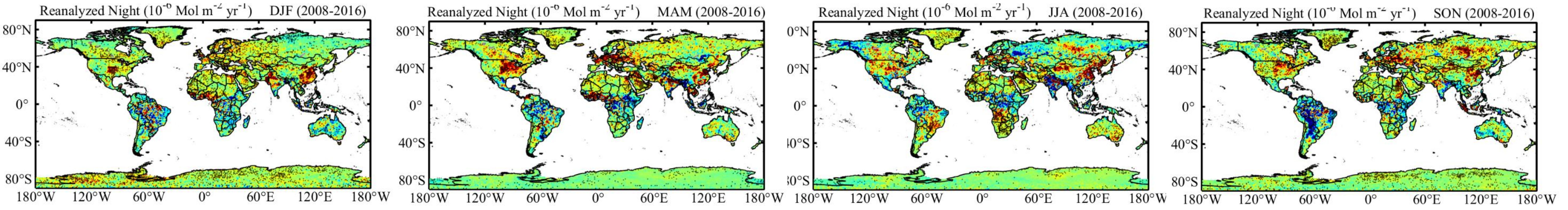


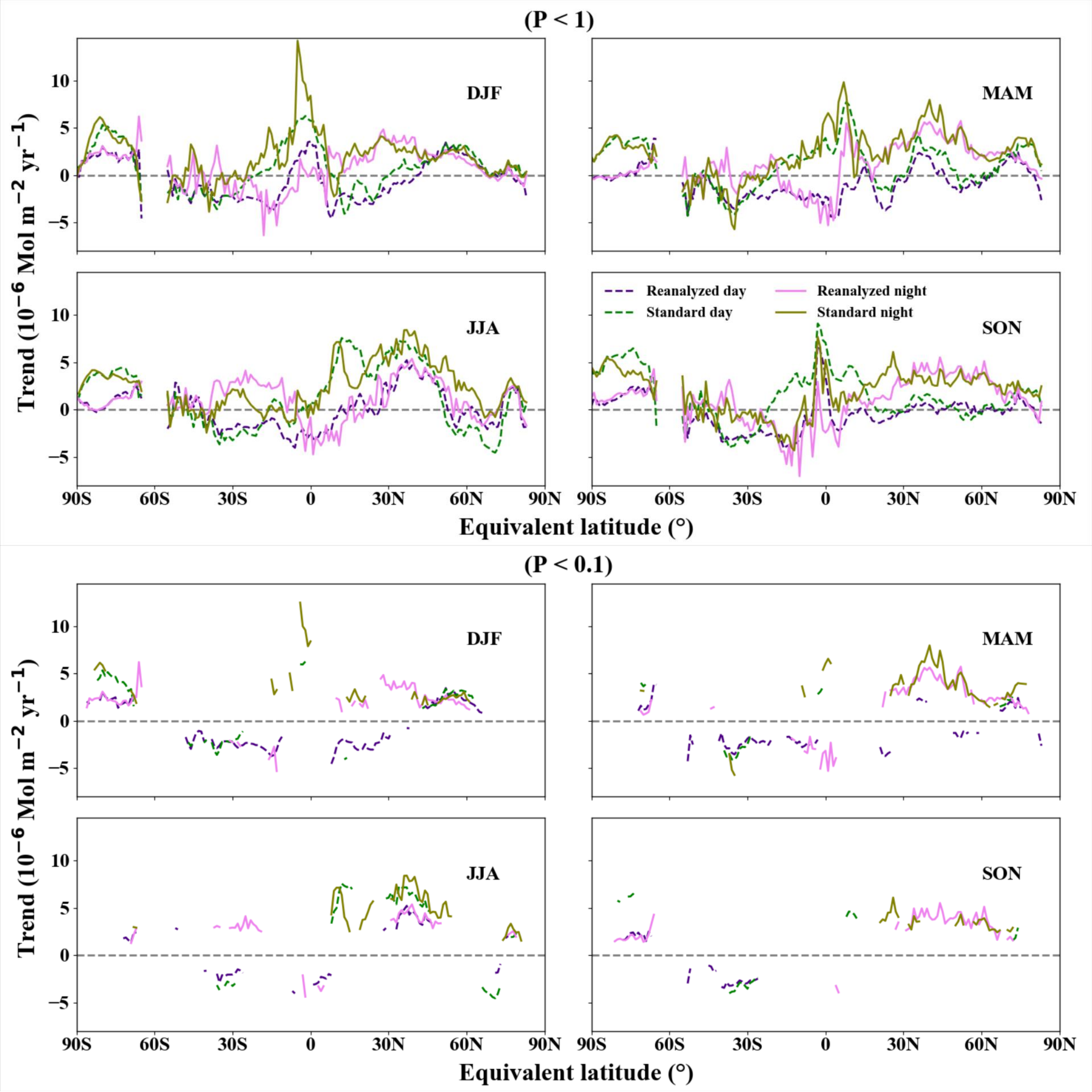
Spatial distribution of ammonia observations trend

(a) day



(b) night

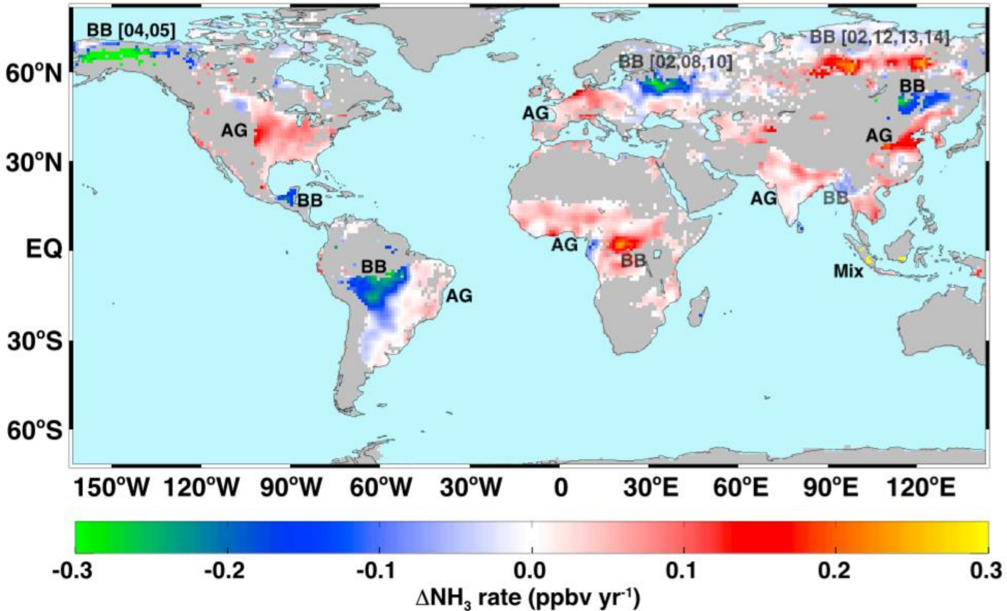




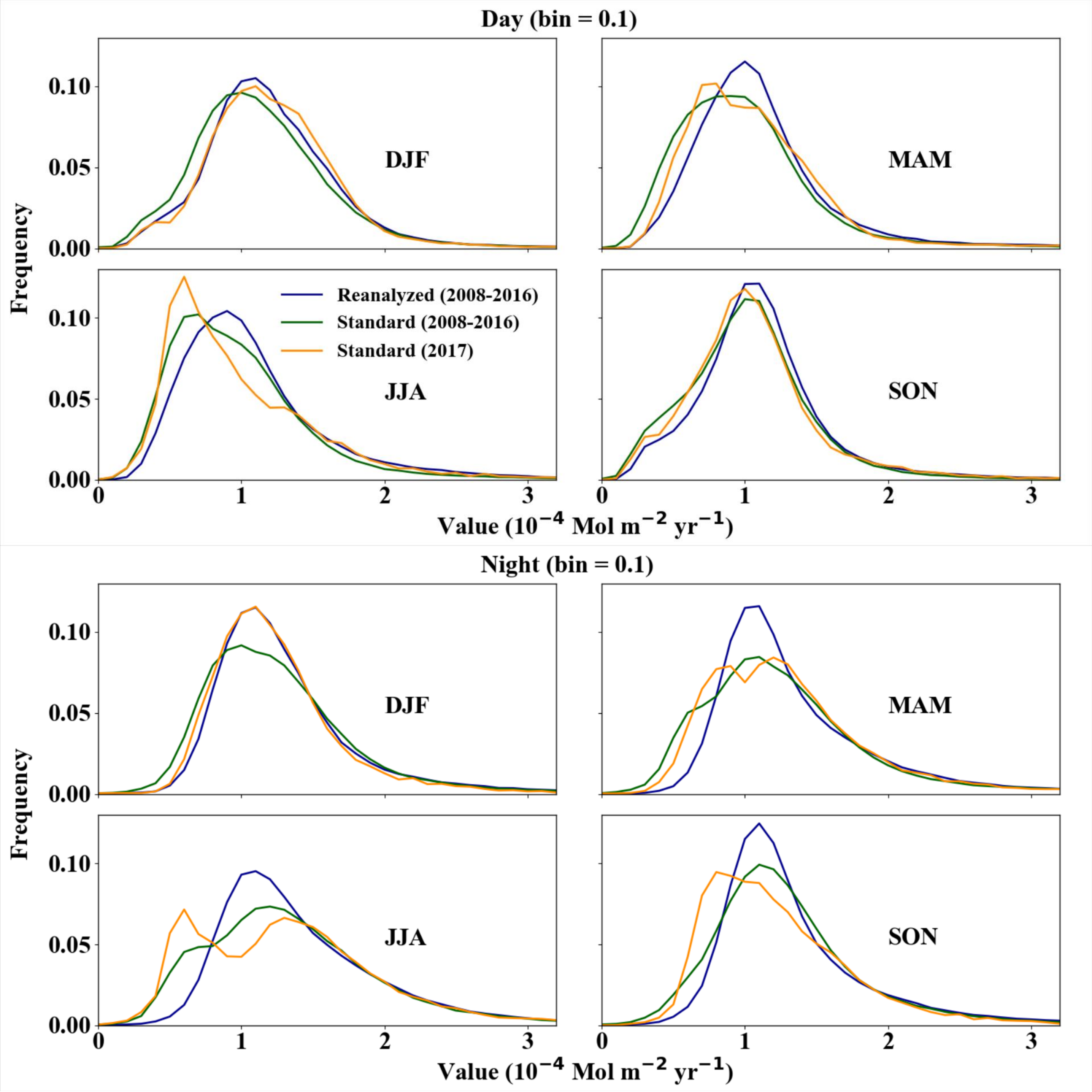
Seasonal trend in the equivalent latitude over 2008-2016 (day and night)

Increased atmospheric ammonia over the world's major agricultural areas detected from space

- provides evidence of substantial increases in atmospheric ammonia (NH3) concentrations (14year) over several of the worlds major agricultural regions
- The rate of change of NH3 volume mixing ratio (VMR) in parts-per-billion by volume (ppbv) per year computed
  - BB: biomass burning
  - AG: agricultural

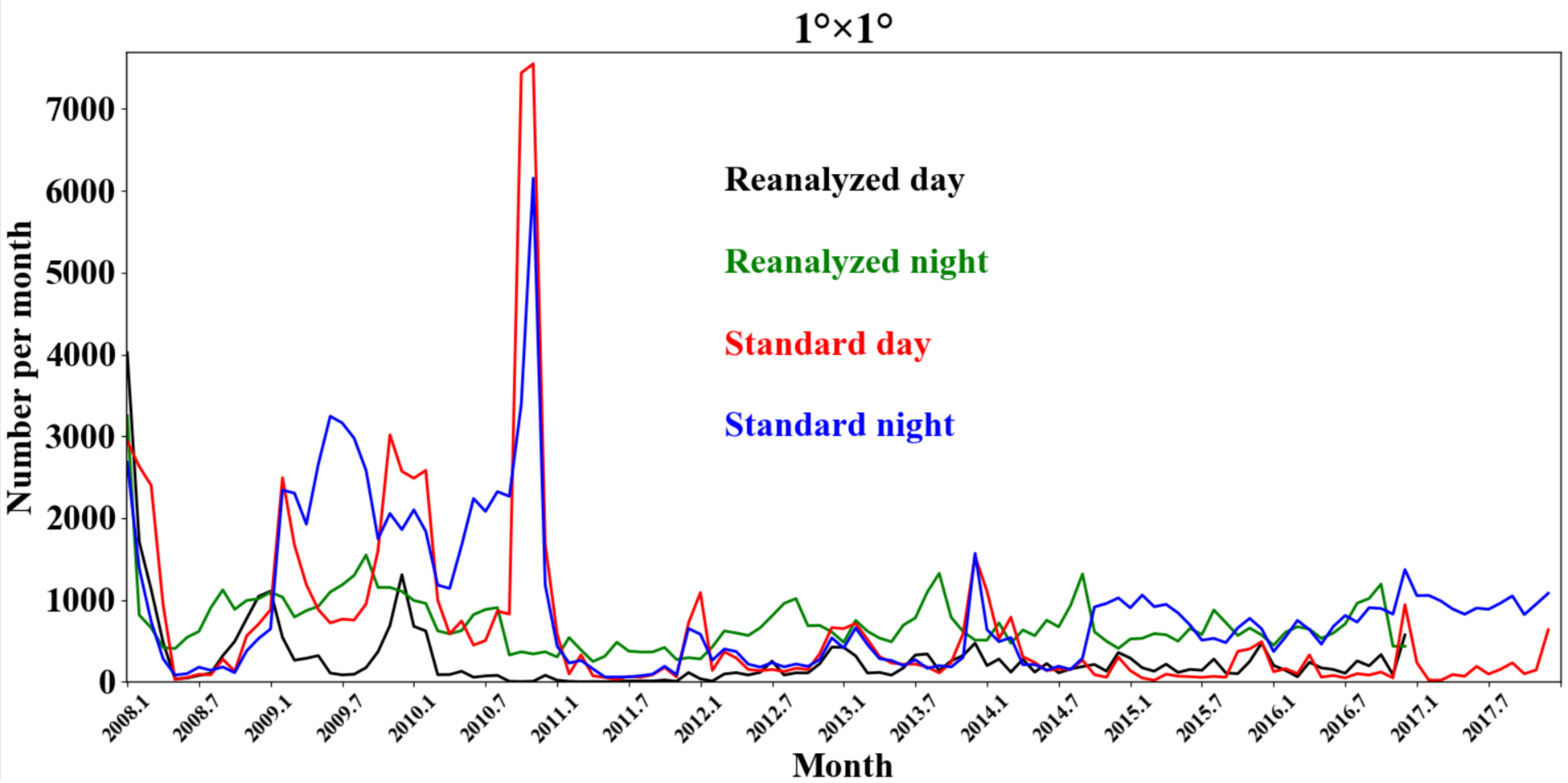


(Warner et al, 2016)



PDF of the 2008-2016 and 2017 (day and night)

Missing value of datasets over 2008-2017 (per month)



End

GEO-Chem

GEOS-Chem simulation

- 4°x5° "standard" simulation
  - Memory: 8+ GB RAM
  - Disk: ~30 GB/yr
  - Version: 12.9.3
- Editing the CopyRunDirs.input file
  - UnitTest.input: all possible run directories can add
    - GEOS-Chem benchmark: benchmark
    - Transport Tracers: TransportTracers
    - Mercury, Tagged Mercury: Hg
    - POPs: tagHg
    - Methane: POPs
    - Tagged O3: CH4
    - Tagged CO: tagO3
    - Carbon Dioxide: tagCO
    - Carbon Dioxide: CO2
    - Offline Aerosols: aerosol
    - Standard: standard
    - Tropchem: tropchem
    - Complex SOA: complexSOA/complexSOA_SVPOA
    - Acid uptake on dust: aciduptake
    - Marine POA: marinePOA
    - APM aerosol microphysics: APM
    - TOMAS aerosol microphysics: TOMAS15/TOMAS40

GEOS-Chem simulation

- Editing the CopyRunDirs.input file
  - Section 1: INPUTS
    - Version: An ID tag
    - DESCRIPTION: the purpose of this specific file
    - DATA_ROOT: root-level data directory
    - HEMCO_ROOT: the top-level path for the HEMCO data directory tree
    - VERBOSE: the level of debug output (0-3)
    - WARNINGS: the level of warning messages (0-3)
    - UNIT_TEST_ROOT: the path to the GEOS-Chem Unit Tester
    - RUN_ROOT: the top-level unit test run directories
    - RUN_DIR: the run directory subdirectory
    - PERL_DIR: the directory where the unit test Perl scripts are found
    - COPY_PATH: the directory on your disk server where copies of the GEOS-Chem run directories will be created
    - COPY_CMD: the command used to copy run directories from the GEOS-Chem Unit Tester to COPY_PATH
      - cp –rfL: create a new copy of the directory
      - cp –L: create "hard" copies of files that are symbolic links (differ)

GEOS-Chem simulation

- Editing the CopyRunDirs.input file
  - Section 2: RUNS
    - met fields uesed
    - GEOS-Chem horizontal grid
    - GEOS-Chem simulation item
    - Starting time
    - Ending time

```
## ======= Tropchem ==========================================================
# geosfp   4x5        -       tropchem        2016070100   2016080100     -
  merra2   4x5        -       tropchem        2010010100   2011010100     -
```

- Generating a GEOS-Chem Run Directory
  - Once edited: type ./gcCopyRunDirs
  - create a new GEOS-Chem run directory
- configuration files
  - User inputs
    - input.geos
      - Simulation: Start & end time
      - Grid: definitions
      - Timestep: from minutes to seconds
      - Advected Species: The type of GEOS-Chem simulation that perform
      - Transport: TPCORE
      - Convection: cloud convection, PBL mixing,
      - Emissions:
      - Aerosols
      - Deposition
      - Chemistry
      - Planeflight diagnostic
      - ObsPack diagnostic
      - ND51 and ND51b diagnostics: satellite timeseries diagnostics
      - Passive Species Menu

GEOS-Chem simulation

- configuration files
  - User inputs
    - HEMCO_Config.rc: emission inventories, Enabling and disabling emissions
      - GEIA_NH3
      - SEABIRD_NH3
    - HEMCO_Diagn.rc: diagnostic archival options for emissions and related quantities
    - HISTORY.rc: which GEOS-Chem diagnostics will be archived to netCDF output

GEOS-Chem simulation

- Compiling
  - Cmake: a platform-independent build system
    - Obtaining Cmake: /pdiskdata/zhangyuzhonggroup/zhangyuzhong/Software/bin
    - Compiling GEOS-Chem "Classic" with Cmake
      - Run directory contents
        - CodeDir: a symbolic link to the code directory
        - Makefile: the run-directory Makefile
        - OutputDir: where diagnostic files will be placed
        - input.geos/*.rc: configuration files
        - download_data.py: data download script for the GEOS-Chem dry-run simulation
        - validate.pl: only used for GEOS-Chem unit tests and difference tests (ignore)
      - Create a build subfolder in your run directory
        - Build directory used to compile GEOS-Chem: mkdir Subbuild
        - switch to the Subbuild folder: configure and build GEOS-Chem
      - Configure the build (gcbuild folder)
        - Configuring with default options: cmake ../CodeDir (failed, version `GLIBCXX_3.4.14' not found)
      - Compiling the code

GEOS-Chem simulation

- Compiling
  - GNU Make (retired after 13.0)
    - Compiling GEOS-Chem "Classic"

```
------------------------------------------------------------
OPTIONAL-FLAGS may be one of the following:
------------------------------------------------------------
DEBUG=y            Compiles GEOS-Chem with various debugging options
BOUNDS=y           Compiles GEOS-Chem with out-of-bounds error checks
FPE=y              Compiles GEOS-Chem with floating-point math error checks
TRACEBACK=y        Compiles GEOS-Chem with traceback error printout (this is the default)
```

      - Determining available compilation options: make help
      - Clean up files in the run directory: make cleanup_output
      - Build the GEOS-Chem executable: make -j4 build [option]
      - Log files created by the compilation
        - compile.log: Contains echo-back of the GEOS-Chem compilation output
        - lastbuild: Contains a summary of all of the options that were used to build the GEOS-Chem executable

- Running
  - qlogin (test)
  - qsub [options] job.sh:
  - qstat
  - qstat -g c
  - qdel

GEOS-Chem simulation

- Output files
    - Log files
        - compile.log: echo-back of the GEOS-Chem compilation output
        - lastbuild: a summary of all of the options that were used to build the GEOS-Chem executable
        - GC_*.log: an "echo-back" of all input options that were specified in input.geos,
            - the list of diagnostic quantities that are being archived
            - the list of files that are being read
            - information about the operations that are being done at each GEOS-Chem timestep
        - log.dryrun: the full path names of all input that are read by GEOS-Chem.
        - HEMCO.log: information about how emissions, met fields, and other relevant data are read from disk and processed by HEMCO for input into GEOS-Chem
        - slurm-JOBID.out: used a batch scheduler such as SLURM, PBS, LSF, etc. to submit your GEOS-Chem simulation
    - Restart files
        - GEOSChem.Restart.YYYYMMDD_hhmmz.nc4: species concentrations that are read in at simulation startup
        - HEMCO_restart.YYYYMMDDhhmm.nc: save out certain quantities in order to facilitate long GEOS-Chem simulations with several run stages
    - Diagnostic output files

GEOS-Chem simulation

- Output files
  - Log files
    - compile.log: echo-back of the GEOS-Chem compilation output
    - lastbuild: a summary of all of the options that were used to build the GEOS-Chem executable
    - GC_*.log: an "echo-back" of all input options that were specified in input.geos,
      - the list of diagnostic quantities that are being archived
      - the list of files that are being read
      - information about the operations that are being done at each GEOS-Chem timestep
    - log.dryrun: the full path names of all input that are read by GEOS-Chem.
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    - HEMCO_restart.YYYYMMDDhhmm.nc: save out certain quantities in order to facilitate long GEOS-Chem simulations with several run stages
  - Diagnostic output files

Error fixed by Dr. Zhang

```
Set HEMCO clock to 2010-01-31 06:40:00
The weekday is (0=Sun,...,6=Sat): 0
Is this an emission time step   : T

 Now reading always list!
 HEMCO emissions successfully calculated!
Calculate air-sea flux for HEMCO species   40
 Module species name: DMS
Calculate air-sea flux for HEMCO species    1
 Module species name: ACET
Calculate air-sea flux for HEMCO species  122
 Module species name: MOH
Calculate air-sea flux for HEMCO species    4
 Module species name: ALD2
Calculate air-sea flux for HEMCO species  120
 Module species name: MENO3
Calculate air-sea flux for HEMCO species   47
 Module species name: ETNO3
 HEMCO emissions successfully calculated!
```

```
forrtl: error (65): floating invalid
Image              PC                Routine            Line        Source
libintlc.so.5      00002AB4F8A9F961  Unknown               Unknown  Unknown
libintlc.so.5      00002AB4F8A9E0B7  Unknown               Unknown  Unknown
libnetcdff.so.7    00002AB4F668D432  Unknown               Unknown  Unknown
libnetcdff.so.7    00002AB4F668D286  Unknown               Unknown  Unknown
libnetcdff.so.7    00002AB4F6673E2C  Unknown               Unknown  Unknown
libnetcdff.so.7    00002AB4F6678172  Unknown               Unknown  Unknown
libpthread.so.0    00000035E7C0F130  Unknown               Unknown  Unknown
geos               0000000001C8F65E  gckpp_hetrates_mp         503  gckpp_HetRates.F90
geos               00000000009204A2  flexchem_mod_mp_d         801  flexchem_mod.F90
libiomp5.so        00002AB4F87F6BB3  Unknown               Unknown  Unknown
libiomp5.so        00002AB4F87CB617  Unknown               Unknown  Unknown
libiomp5.so        00002AB4F87CAD3A  Unknown               Unknown  Unknown
libiomp5.so        00002AB4F87F6EAD  Unknown               Unknown  Unknown
libpthread.so.0    00000035E7C07DF3  Unknown               Unknown  Unknown
libc.so.6          00000035E78F62CD  Unknown               Unknown  Unknown
/home/jointforce/default/spool/ibnode135/job_scripts/851352: line 25: 22528 Aborted
```

```
---> DATE: 2010/01/31  UTC: 06:30  X-HRS:    726.500000
     - DIAG51: Accumulation at 2010/01/31 06:40
     - DIAG51b: Accumulation at 2010/01/31 06:40
---> DATE: 2010/01/31  UTC: 06:40  X-HRS:    726.666687
```

Nitrogen-containing compounds

- Nitrous oxide (N2O): an extremely potent greenhouse gas
    - Source: tropical soil, biomass burning, degassing of irrigation water, agricultural activities, industrial processes, ocean
    - Sink: photodissociation in the stratosphere (90%), reaction with excited oxygen atoms (10%)

TABLE 2.5 Global N_2O Budget ($Tg\ N\ yr^{-1}$) for 2006

Anthropogenic sources	
Fossil fuel combustion and industrial sources	0.7
Agriculture	4.1
Biomass and biofuel burning	0.7
Human excreta	0.2
Other	0.6
Total anthropogenic sources	6.9
Natural sources	
Soils	6.6
Oceans	3.8
Atmospheric chemistry	0.6
Total natural sources	11.0
Total natural + anthropogenic sources	17.9
Stratospheric sink (see Chapter 5)	14.3
Observed growth rate	3.6

Source: IPCC (2013).

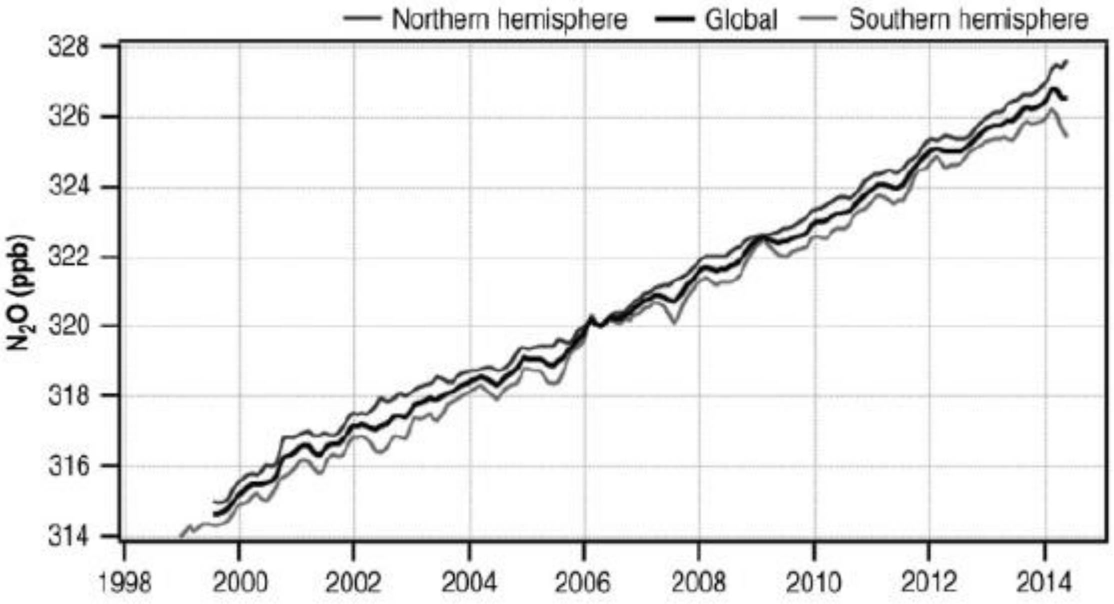


FIGURE 2.3 Global atmospheric mixing ratio of N_2O from 1999 through 2013 (*Source*: NOAA/ESRL; available at www.esrl.noaa.gov/gmd/hats/insitu/cats/conc/mlon20.html.)

Nitrogen-containing compounds

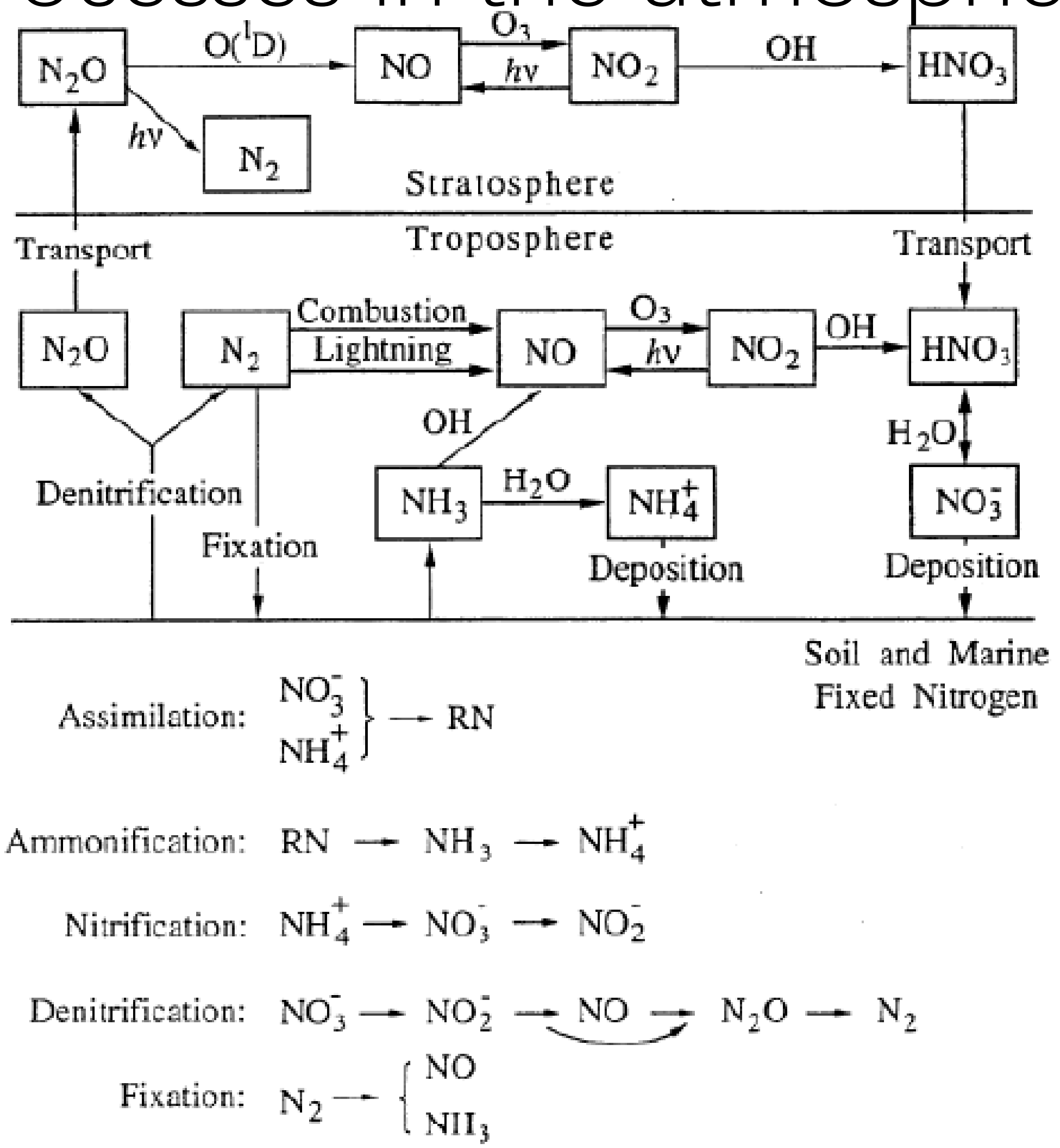
- Nitrogen Oxide ($NO_x \equiv NO + NO_2$)
- Reactive odd nitrogen (NO_y): major in urban-suburban areas
- Ammonia (NH_3): the most abundant nitrogen-containing compound
  - Source: animal waste, ammonification of humus from soils, losses of fertilizers from soils, industrial
  - Residence time: 10 days
- Amines: organic

TABLE 2.8 Estimated Annual Global Ammonia Emissions

Source	Amount ($Tg\,N\,yr^{-1}$)
Agricultural (domestic animals, synthetic fertilizers, crops)	37.4
Natural (oceans, undisturbed soils, wild animals)	10.7
Biomass burning	6.4
Other (humans and pets, industrial processes, fossil fuels)	3.1
Total	57.6

Source: Bouwman et al. (1997).

Nitrogen compounds processes in the atmospheric cycle



Nitrogen Oxide Radicals (NOx ≡ NO + NO2)

- The largest source is combustion:
  - thermal Nox (2000K): N2 + O → NO + N, N + O2 → NO + O
  - fuel Nox (low flame temperatures)
- the main source of Nox in stratosphere:
  - O (1D) + N2O → NO + NO
- A dominant sink for NO in both the troposphere and stratosphere:
  - null cycle: NO + O3 → NO2 + O2 $NO_2 + h\nu\,(\lambda < 400\ \mathrm{nm}) \xrightarrow{O_2} NO + O_3$
- Alternate reaction cycles for NO and NO2:
  - rate-limiting step for ozone loss: NO2 + O → NO + O2
- Loss of Nox:
  - Daytime: NO2 + OH + M → HNO3 + M
  - Night: NO2 + O3 → NO3 + O2, NO2 + NO3 + M → N2O5 + M $N_2O_5 + H_2O \xrightarrow{\text{aerosol}} 2HNO_3$