The global ammonia budget, simulated with the chemistry-climate model UKCA-CLASSIC

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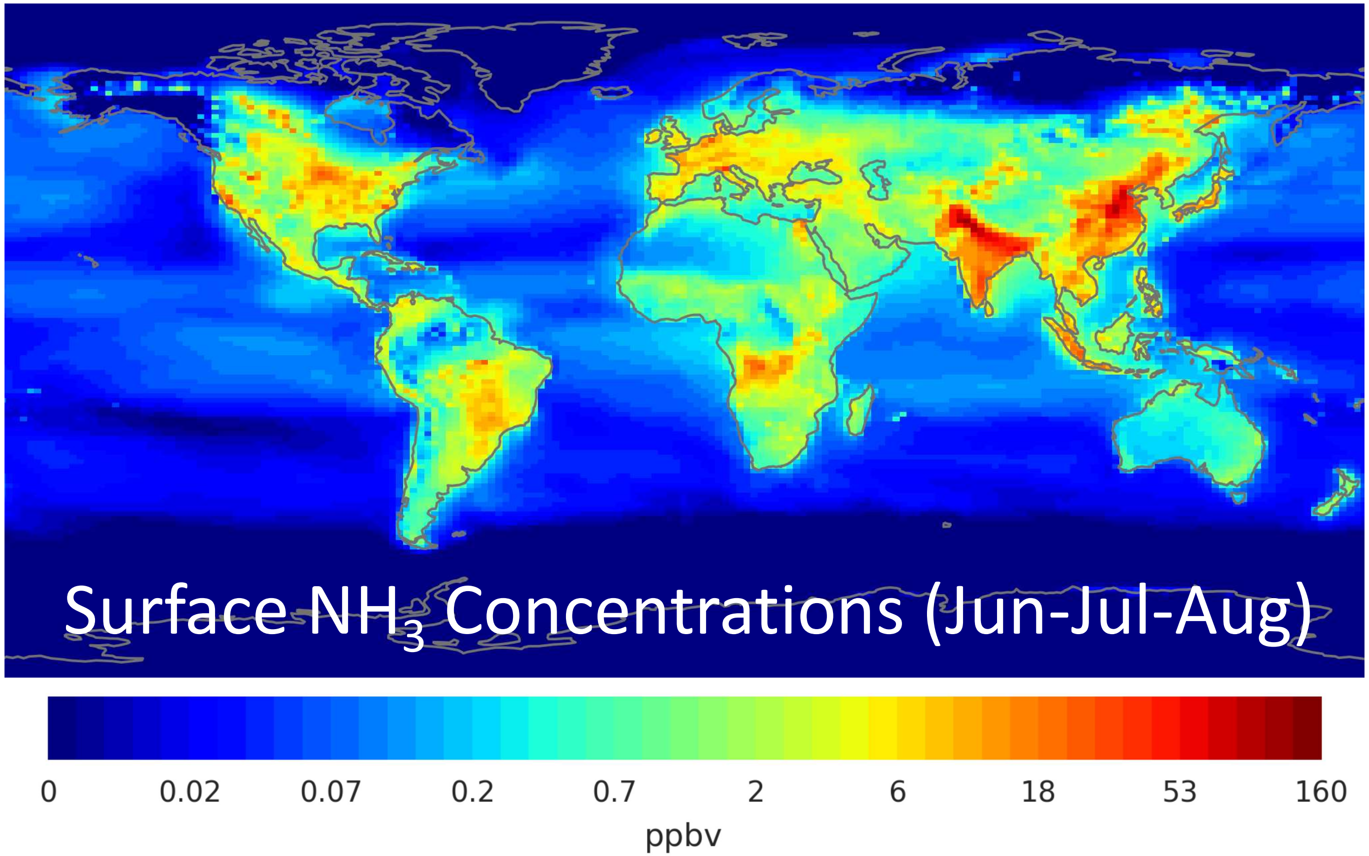
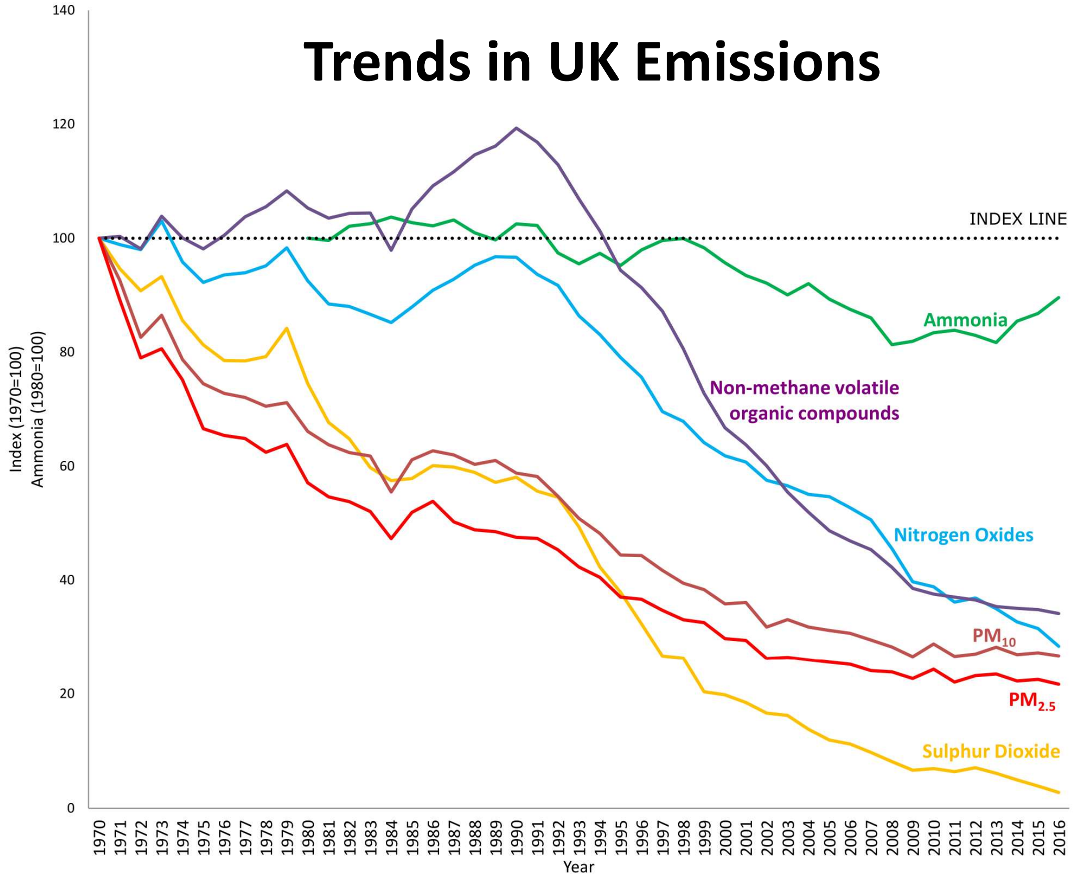
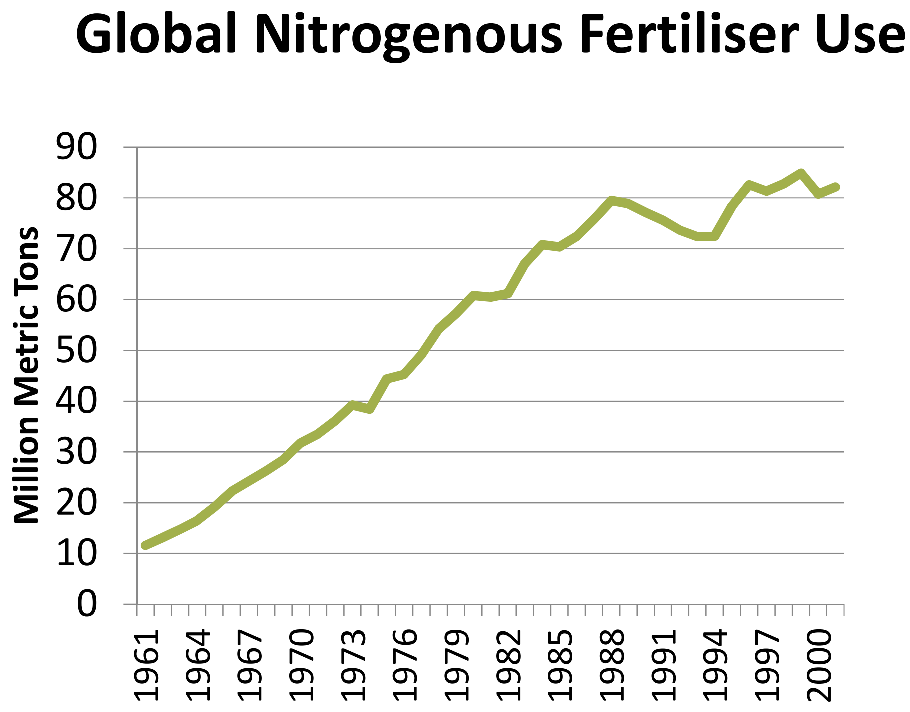


Regulations have resulted in a decrease in other emissions…



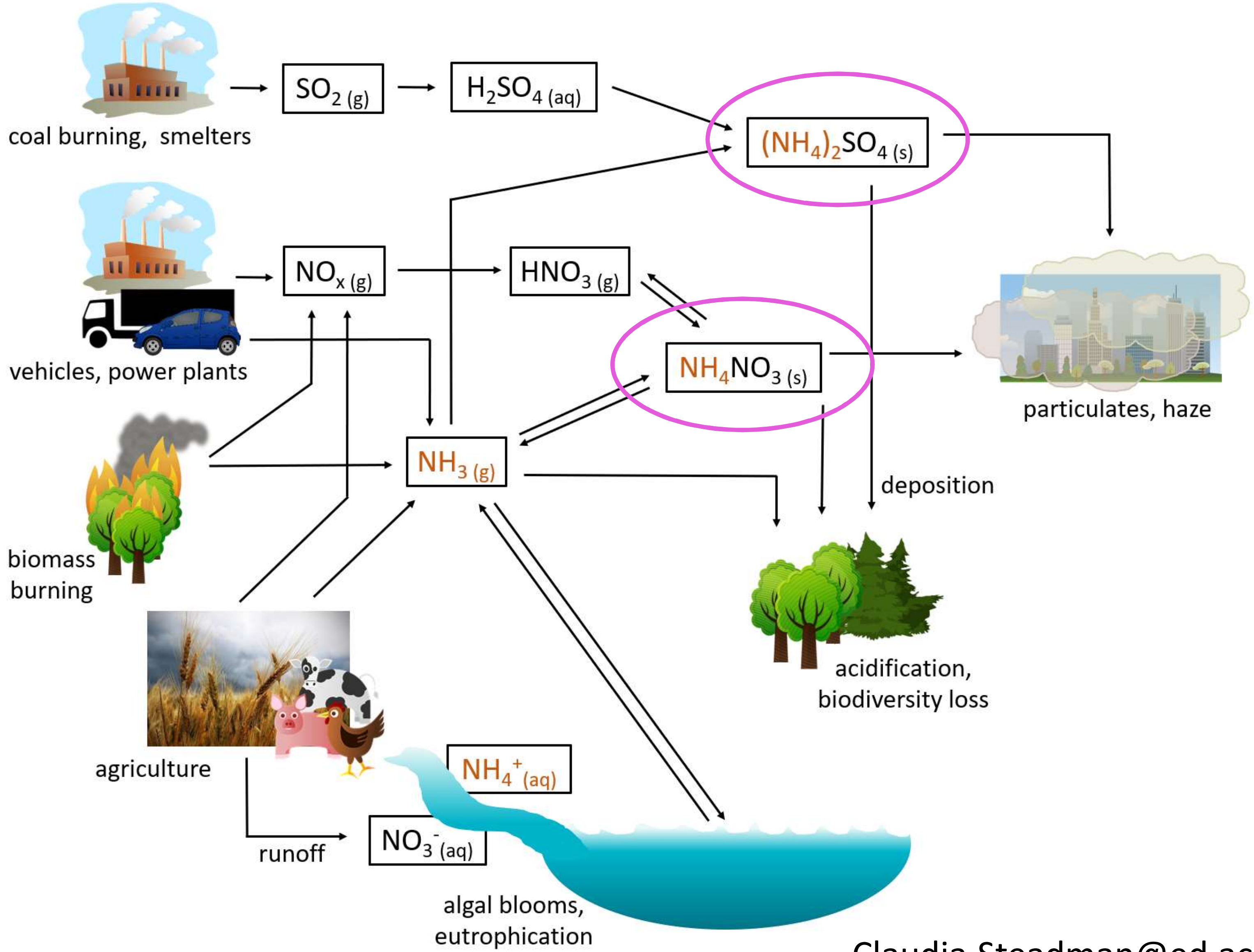
DEFRA

Global fertiliser use has increased



Data: UN FAOSTAT

Ammonia and ammonium processes and impacts



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How weather influences ammonia concentrations

- Precipitation
  - Wet deposition
  - Vegetation → dry deposition
- Temperature
  - Partitioning of aerosol vs gas phase
  - Volatilisation of NH_3
- Boundary layer → less concentrated at surface
- Convection → can travel longer distances
- Wind → transport

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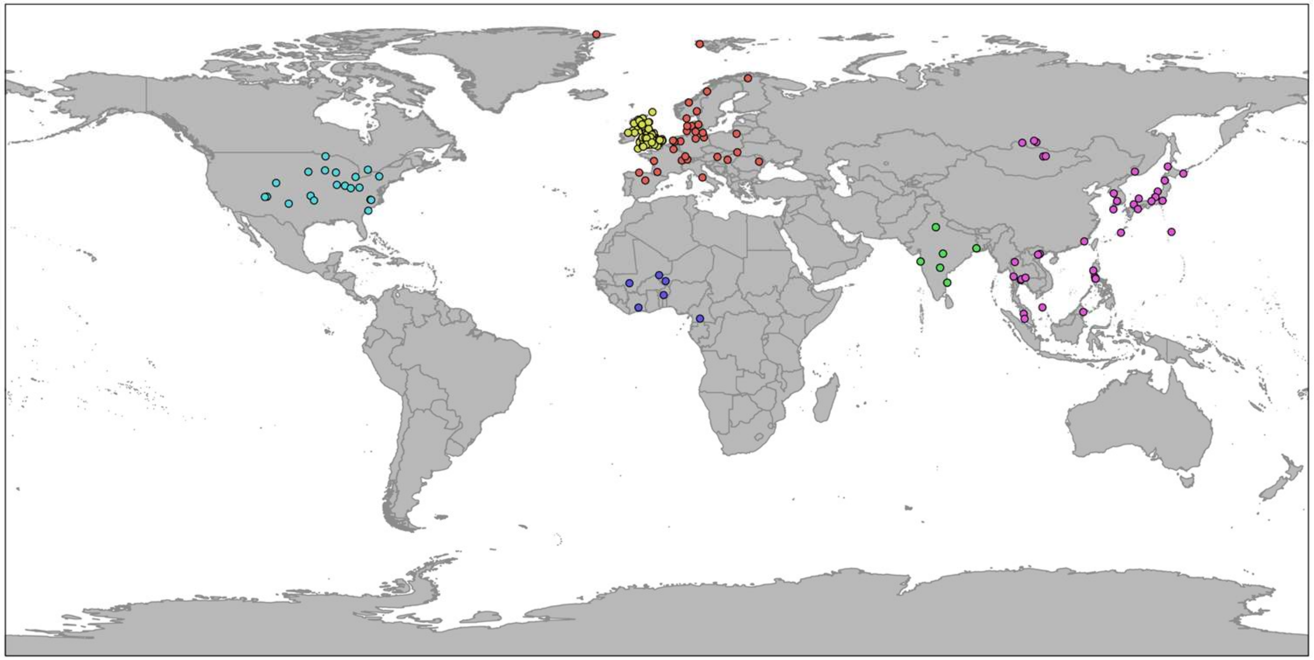
Surface NH_3 Concentration Networks

	Network	Region	Sites
●	EMEP	Europe	37
●	AMoN	North America	20
●	India NAMP	India	18
●	EANET	East Asia	36
●	INDAAF	Africa	6
●	UK NAMN	United Kingdom	109
	Total		226



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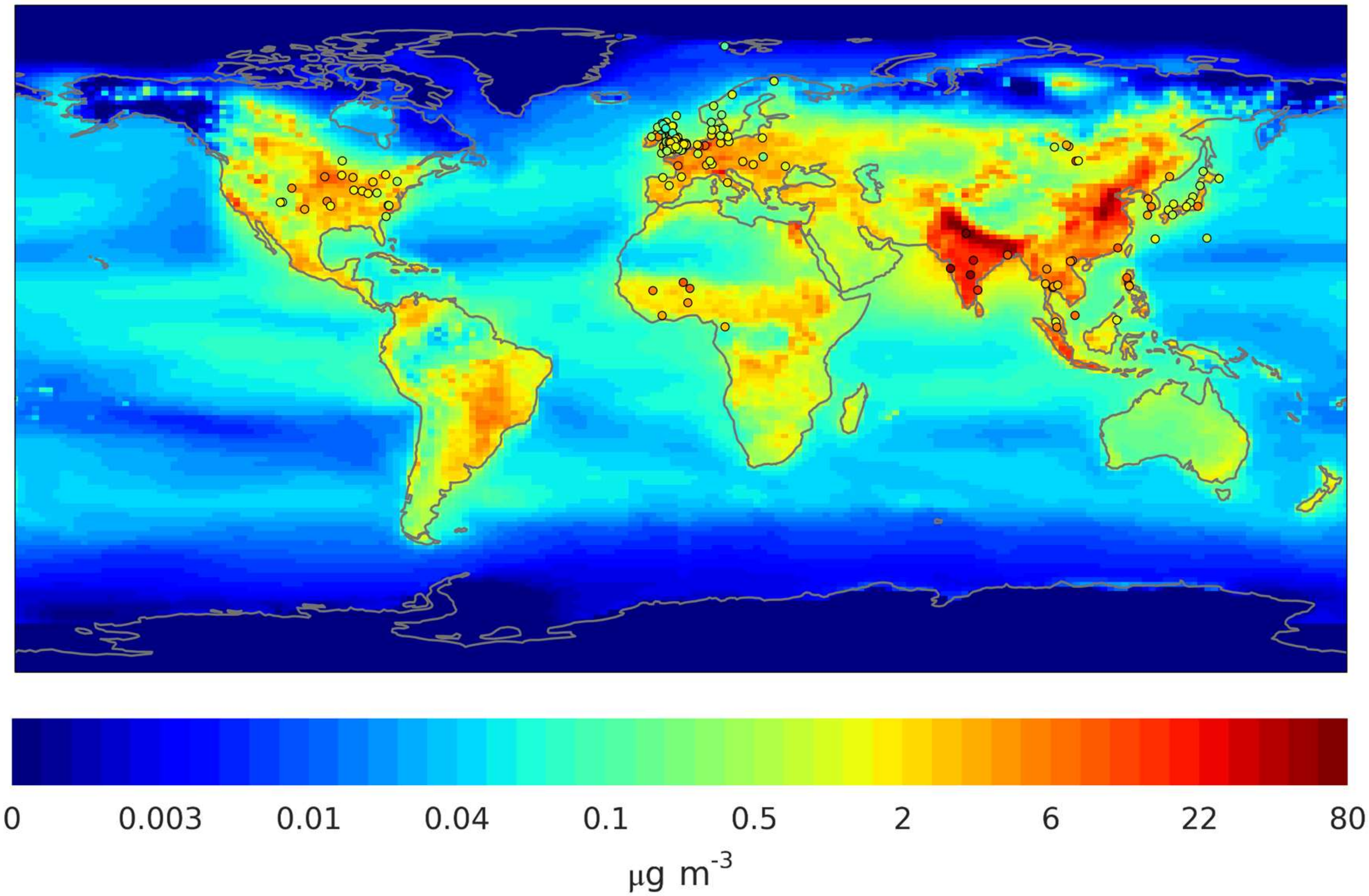
Comparing model NH_3 to observations

NH_3 surface concentrations
UKCA-CLASSIC
Annual mean
Year 2008



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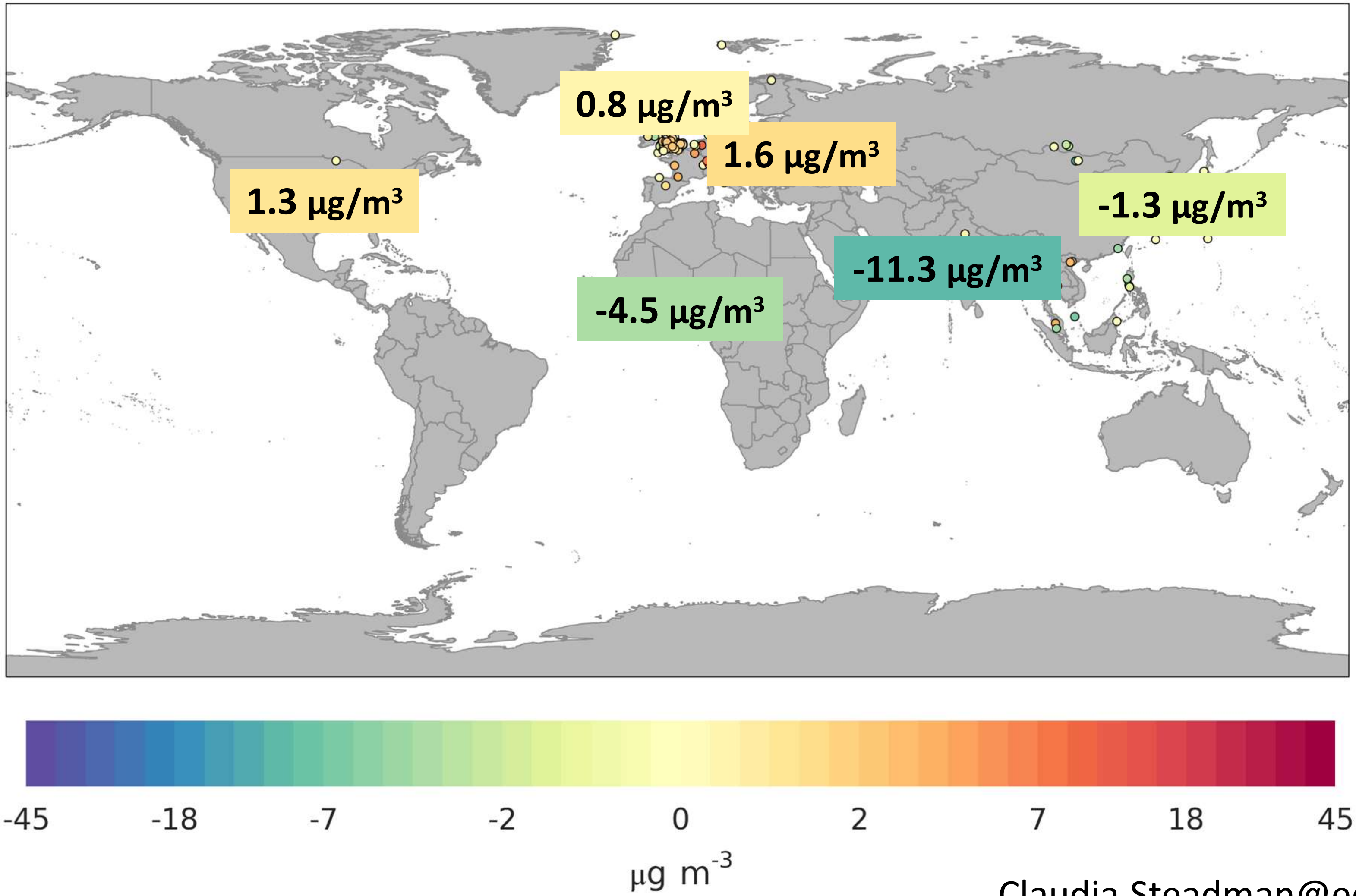
Differences NH_3 model - observations

UKCA-CLASSIC
Annual mean
Year 2008

global mean bias
-0.4 µg/m³
(model – observations)



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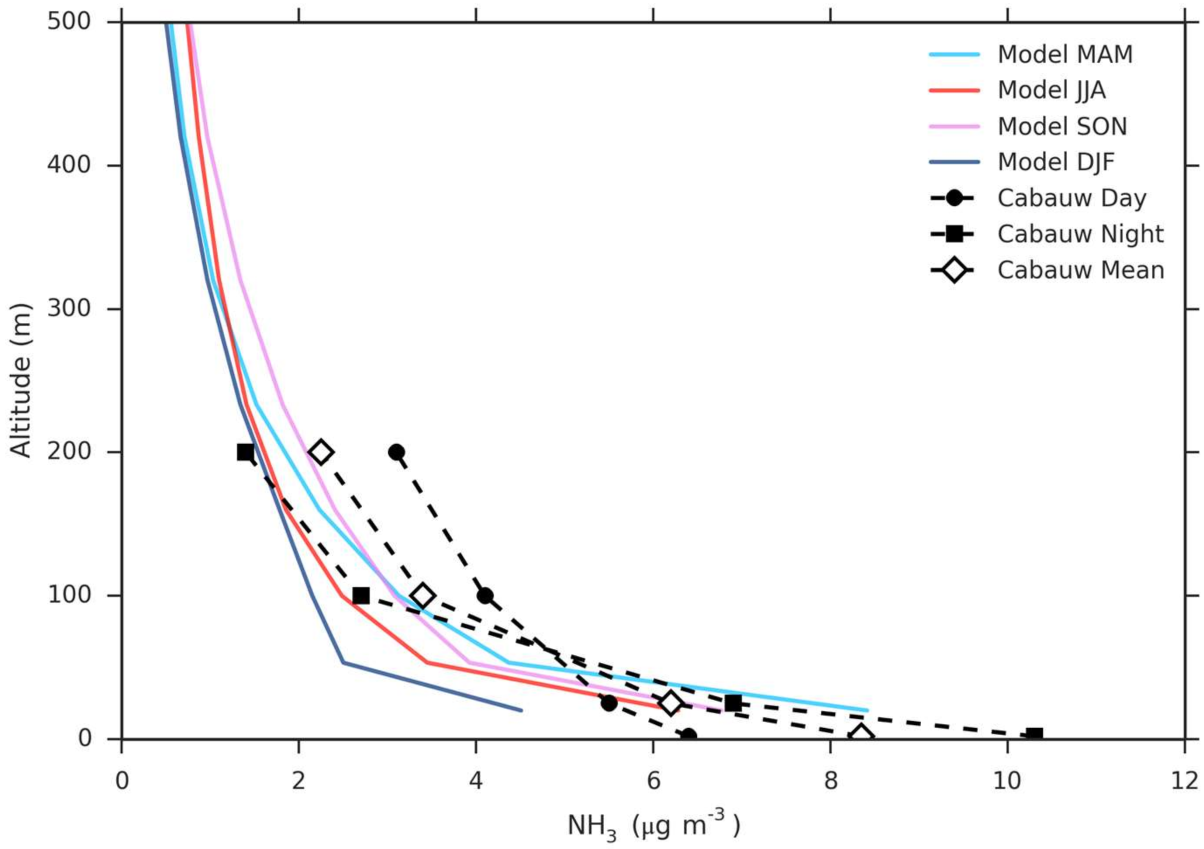
Vertical profile of NH_3 represented well



Observation data: Erisman et al., 1988

Measurements from Cabauw, Netherlands tower at heights of 2, 25, 100, and 200 m, during different seasons and meteorological conditions

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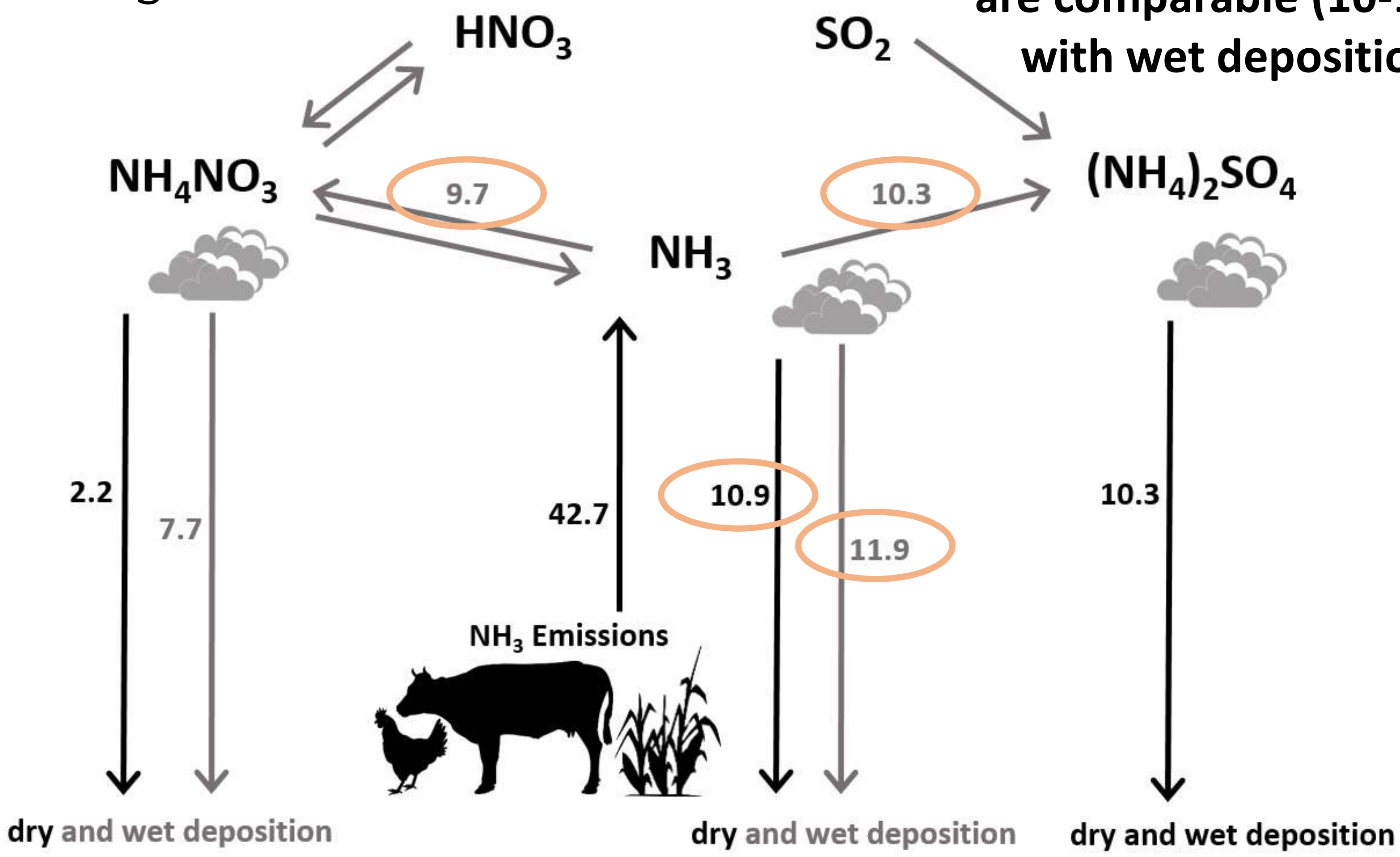
Global NH_3 Budget

Globally, the sinks for ammonia are comparable (10-12 Tg N/yr), with wet deposition largest



UKCA-CLASSIC Year 2008 (Tg N/yr)

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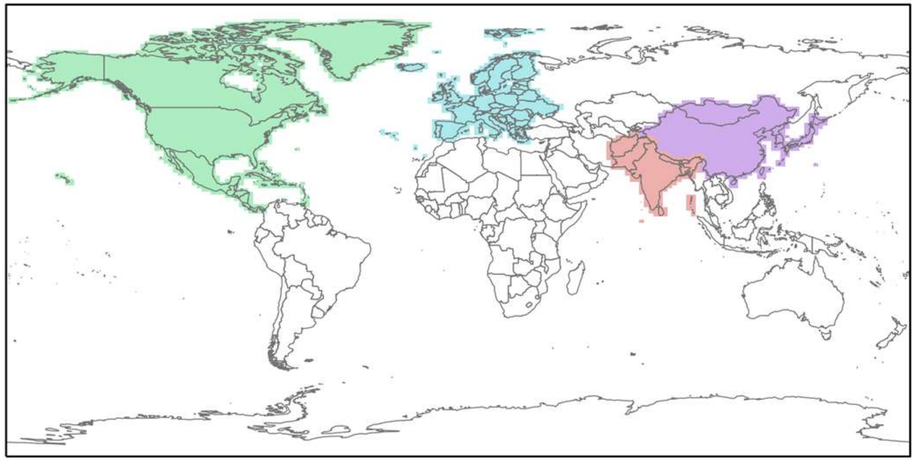
Regional differences in the NH_3 budget



Together, these regions contain 64% of global NH_3 emissions

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Regional atmospheric NH_3 budgets (Tg N/yr)

	North America	Europe	South Asia	East Asia
Sources				
Total Emissions	4.6	3.8	10.4	8.5
Sinks				
Deposition				
Dry (to land)	1.1	0.9	3.0	2.4
Dry (to ocean)	0.1	0.2	0.3	0.2
Total Dry	1.2	1.1	3.3	2.6
Wet (scavenging by large scale precip.)	0.4	0.3	1.7	0.9
Wet (scavenging by convective precip.)	0.4	0.1	1.7	0.6
Total Wet	0.8	0.4	3.5	1.5
Total Deposition (Dry + Wet)	2.0	1.5	6.8	4.2
Aerosol Formation				
NH_4NO_3	1.1	1.1	5.1	2.7
$(NH_4)_2SO_4$	1.0	0.6	1.3	2.1
Total NH_3 Chemical Loss	2.0	1.8	6.4	4.8
Sources - Sinks	0.6	0.5	-2.7	-0.4
% Difference	14%	13%	-26%	-5%
Burden (Tg N)	0.01	0.005	0.05	0.02
Lifetime (days)	1.0	0.5	1.4	0.7

Regional differences in the NH_3 budget

- The largest sinks for ammonia in these regions are typically dry deposition and ammonium nitrate formation (exception is South Asia where wet deposition is larger than dry).
- Globally, wet deposition is a larger sink, indicating that the relative importance of sinks differs in regions with high and low ammonia emissions.

Regional atmospheric NH_3 budgets (Tg N/yr)

	North America	Europe	South Asia	East Asia
Sources				
Total Emissions	4.6	3.8	10.4	8.5
Sinks				
Deposition				
Dry (to land)	1.1	0.9	3.0	2.4
Dry (to ocean)	0.1	0.2	0.3	0.2
Total Dry	1.2	1.1	3.3	2.6
Wet (scavenging by large scale precip.)	0.4	0.3	1.7	0.9
Wet (scavenging by convective precip.)	0.4	0.1	1.7	0.6
Total Wet	0.8	0.4	3.5	1.5
Total Deposition (Dry + Wet)	2.0	1.5	6.8	4.2
Aerosol Formation				
NH_4NO_3	1.1	1.1	5.1	2.7
$(NH_4)_2SO_4$	1.0	0.6	1.3	2.1
Total NH_3 Chemical Loss	2.0	1.8	6.4	4.8
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Regional differences in the NH_3 budget

- The proportion of aerosol ammonium formed that is ammonium nitrate is 52 - 65% across North America, Europe, and East Asia; notably the aerosol ammonium formed in South Asia is 80% ammonium nitrate.
- The ammonia burden over South Asia is 33% of the global burden
- Lifetime longest in South Asia

Regional atmospheric NH_3 budgets (Tg N/yr)

	North America	Europe	South Asia	East Asia
Sources				
Total Emissions	4.6	3.8	10.4	8.5
Sinks				
Deposition				
Dry (to land)	1.1	0.9	3.0	2.4
Dry (to ocean)	0.1	0.2	0.3	0.2
Total Dry	1.2	1.1	3.3	2.6
Wet (scavenging by large scale precip.)	0.4	0.3	1.7	0.9
Wet (scavenging by convective precip.)	0.4	0.1	1.7	0.6
Total Wet	0.8	0.4	3.5	1.5
Total Deposition (Dry + Wet)	2.0	1.5	6.8	4.2
Aerosol Formation				
NH_4NO_3	1.1	1.1	5.1	2.7
$(NH_4)_2SO_4$	1.0	0.6	1.3	2.1
Total NH_3 Chemical Loss	2.0	1.8	6.4	4.8
Sources - Sinks	0.6	0.5	-2.7	-0.4
% Difference	14%	13%	-26%	-5%
Burden (Tg N)	0.01	0.005	0.05	0.02
Lifetime (days)	1.0	0.5	1.4	0.7

Regional differences in NO_3^- budget

- Over half (53%) of net NH_4NO_3 production occurs in South Asia, and over a quarter (28%) occurs in East Asia.
- The burden of nitrate over South Asia is 49% of the global burden
- Of nitrate that does not decompose to form ammonia and nitric acid, wet scavenging by large scale precipitation is the largest sink in all four regions.
- The lifetime is longest is South Asia

Regional atmospheric NO_3^- budgets (Tg N/yr)

	North America	Europe	South Asia	East Asia
Source				
NH_4NO_3 production (net)	1.1	1.1	5.1	2.7
Sinks				
Deposition				
Dry	0.2	0.2	0.9	0.5
Wet (scavenging by large scale precip.)	0.6	0.6	1.4	1.9
Wet (scavenging by convective precip.)	0.1	0.1	1.0	0.4
Total Wet	0.7	0.7	2.5	2.3
Total Deposition (Dry + Wet)	1.0	0.9	3.3	2.8
Sources - Sinks	0.1	0.3	1.8	-0.1
% Difference	9%	24%	35%	-4%
Burden (Tg N as NO_3^-)	0.004	0.004	0.04	0.02
Lifetime (days)	1.3	1.6	4.2	2.0

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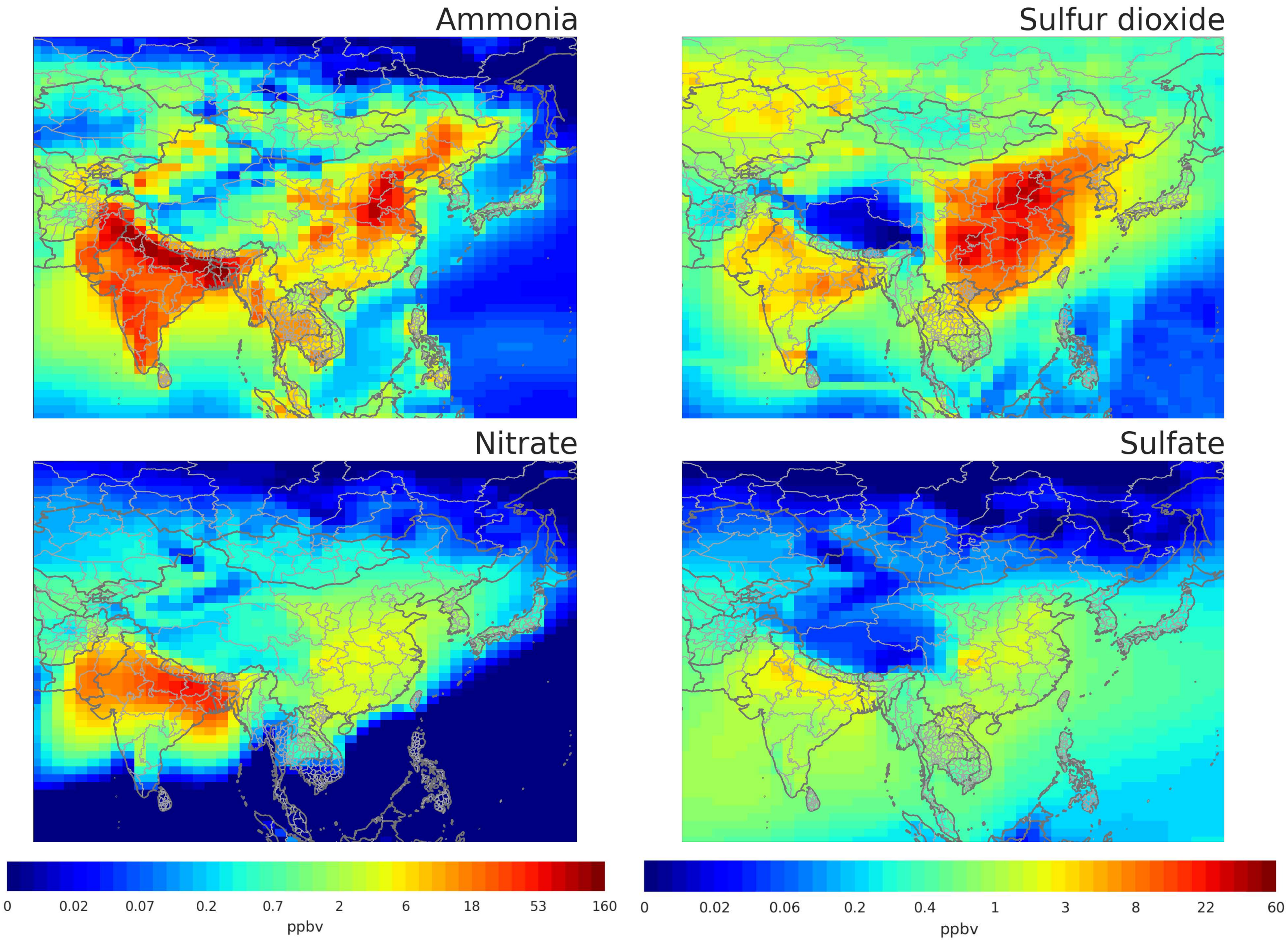
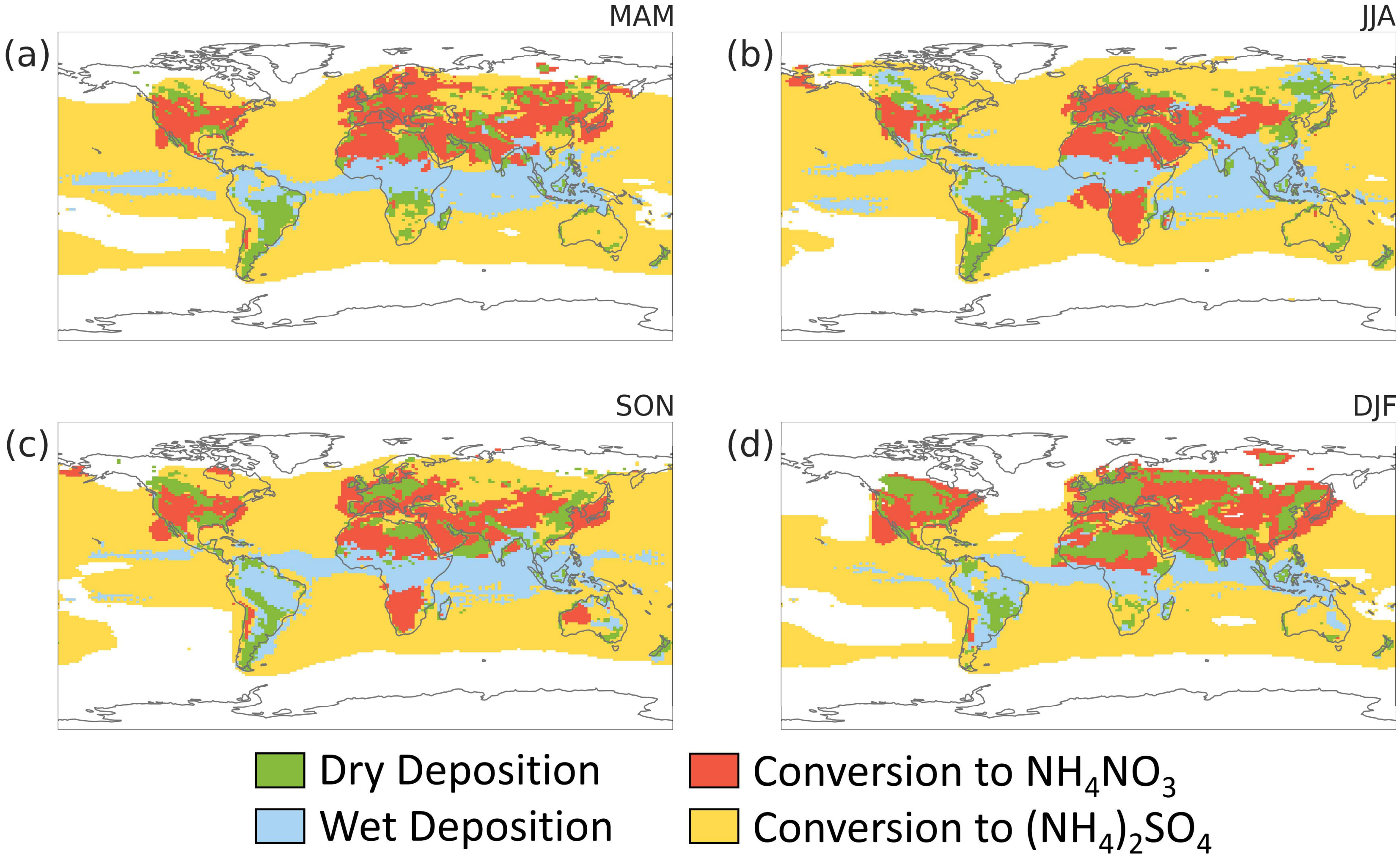
Dec-Jan-Feb Mean Surface Concentrations (0-36.7m)



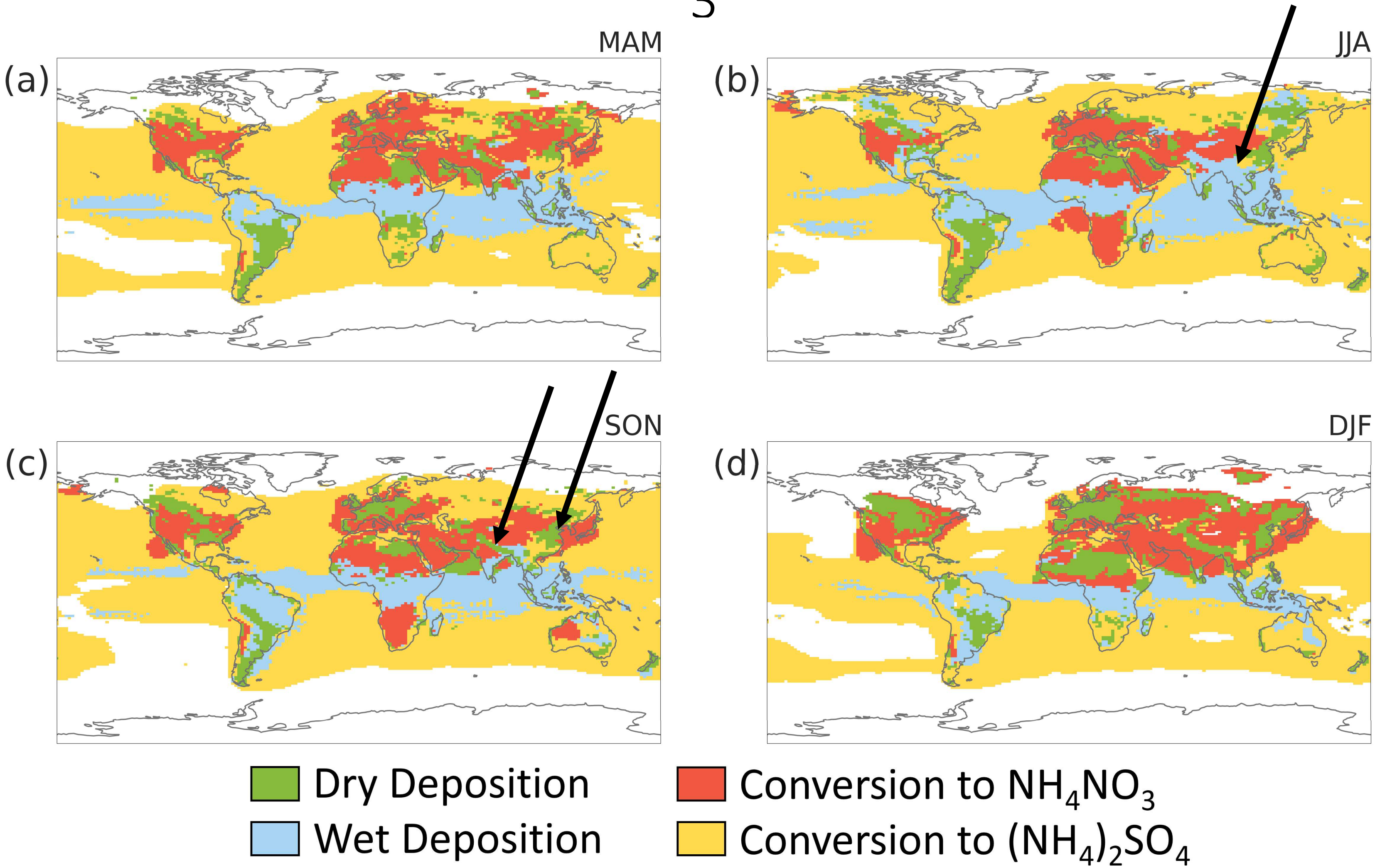
- Consistent with regional budgets, ammonium nitrate is a greater sink for ammonia than ammonium sulphate
- In South Asia 80% of ammonium aerosol formed is nitrate

Dominant sink of NH_3



Sinks calculated for lowest 10 km of atmosphere. Sinks not shown where NH_3 column < 10 μg N/m^2.

Dominant sink of NH_3

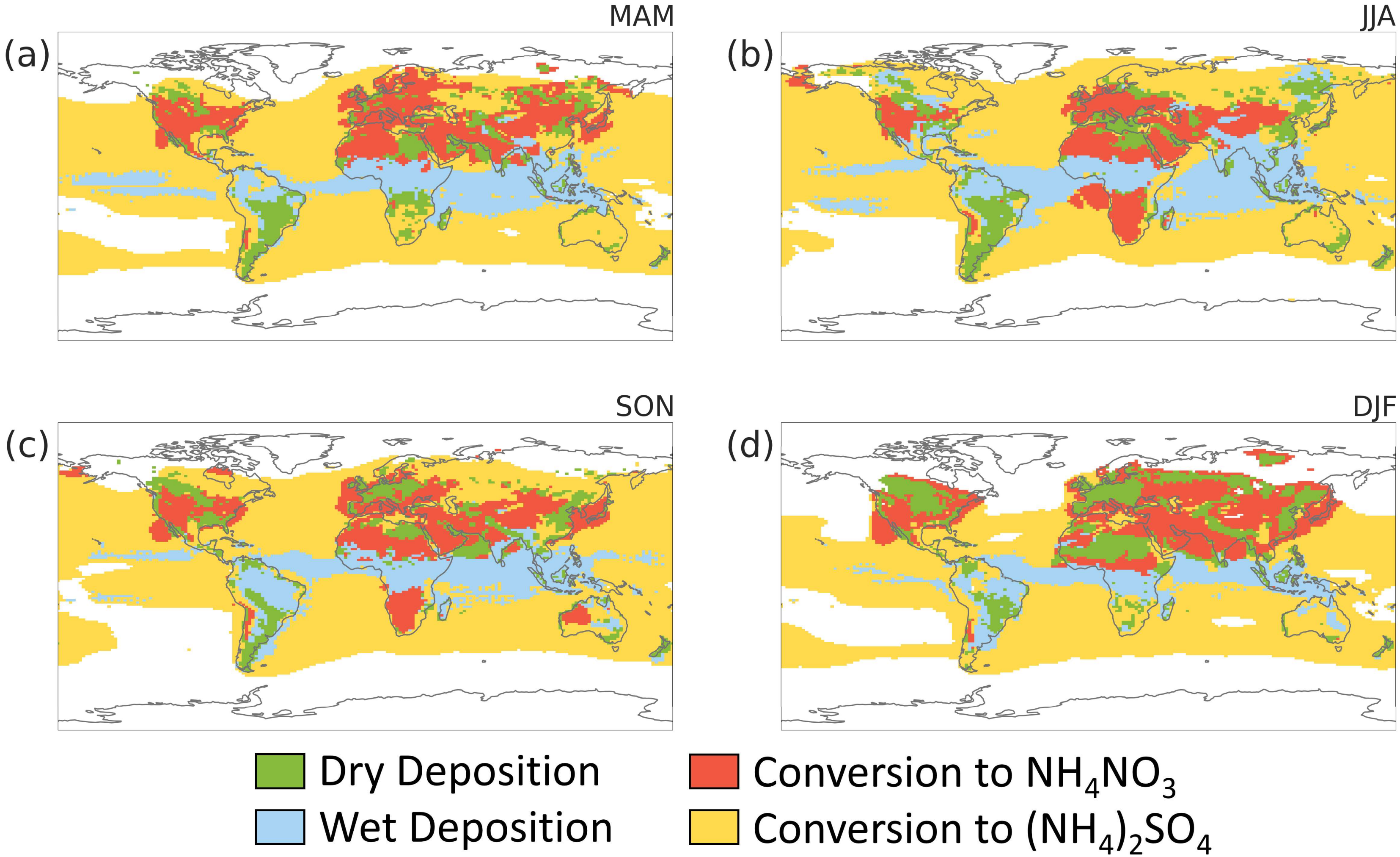


Over the IGP and the North China Plain, the dominant sink is generally dry deposition, (Jun-Jul-Aug monsoon wet deposition)

During the rest of the year the dominant sink is conversion to nitrate in most of India south of the IGP; in the southernmost part of India it is generally wet deposition.

Sinks calculated for lowest 10 km of atmosphere. Sinks not shown where NH_3 column < 10 μg N/m^2.

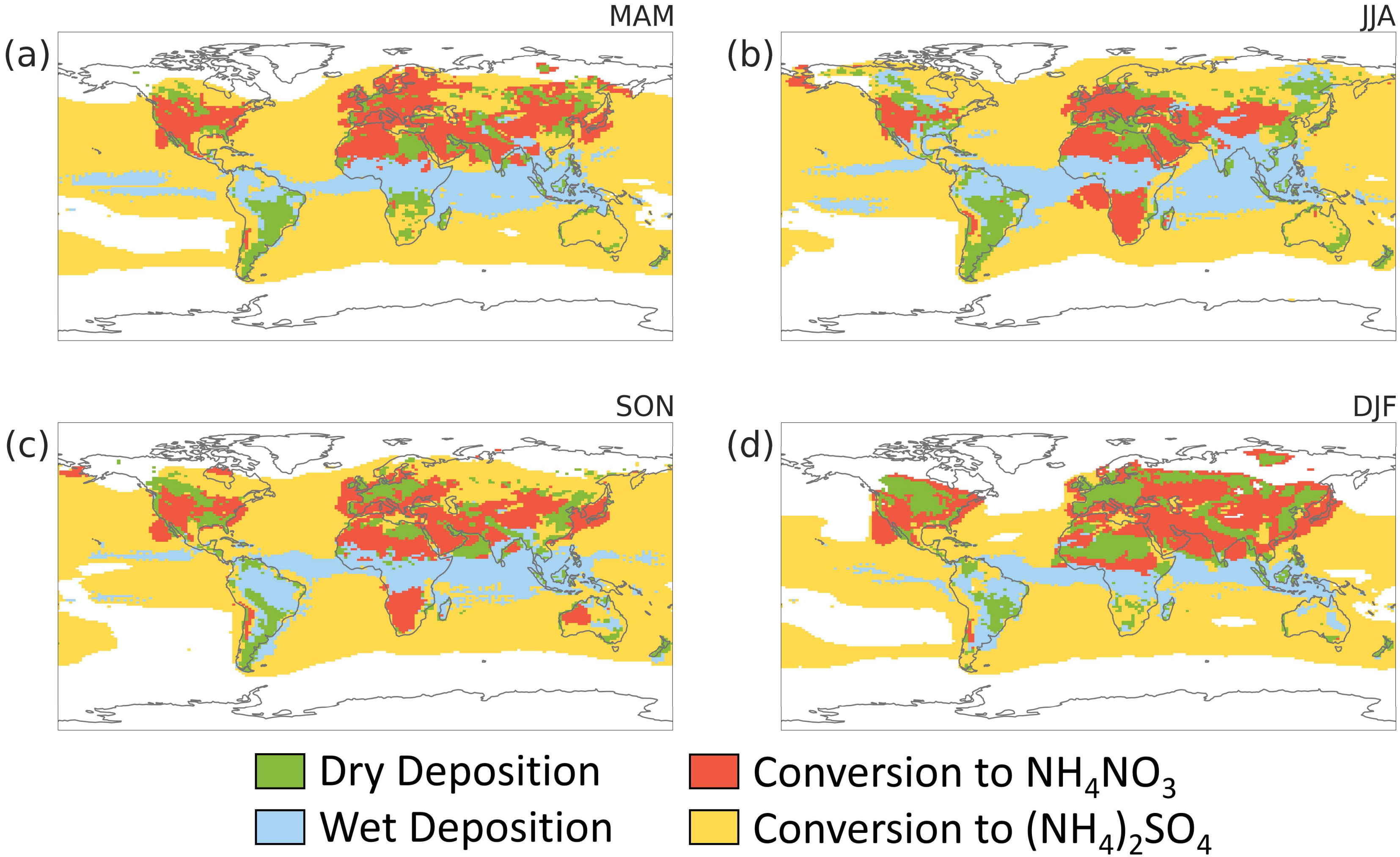
Dominant sink of NH_3



Sinks calculated for lowest 10 km of atmosphere. Sinks not shown where NH_3 column < 10 μg N/m^2.

- North America: dry deposition and conversion to nitrate for most seasons.
- In Europe, the primary sink is dry deposition in autumn and winter; conversion to nitrate generally dominates in spring and summer.

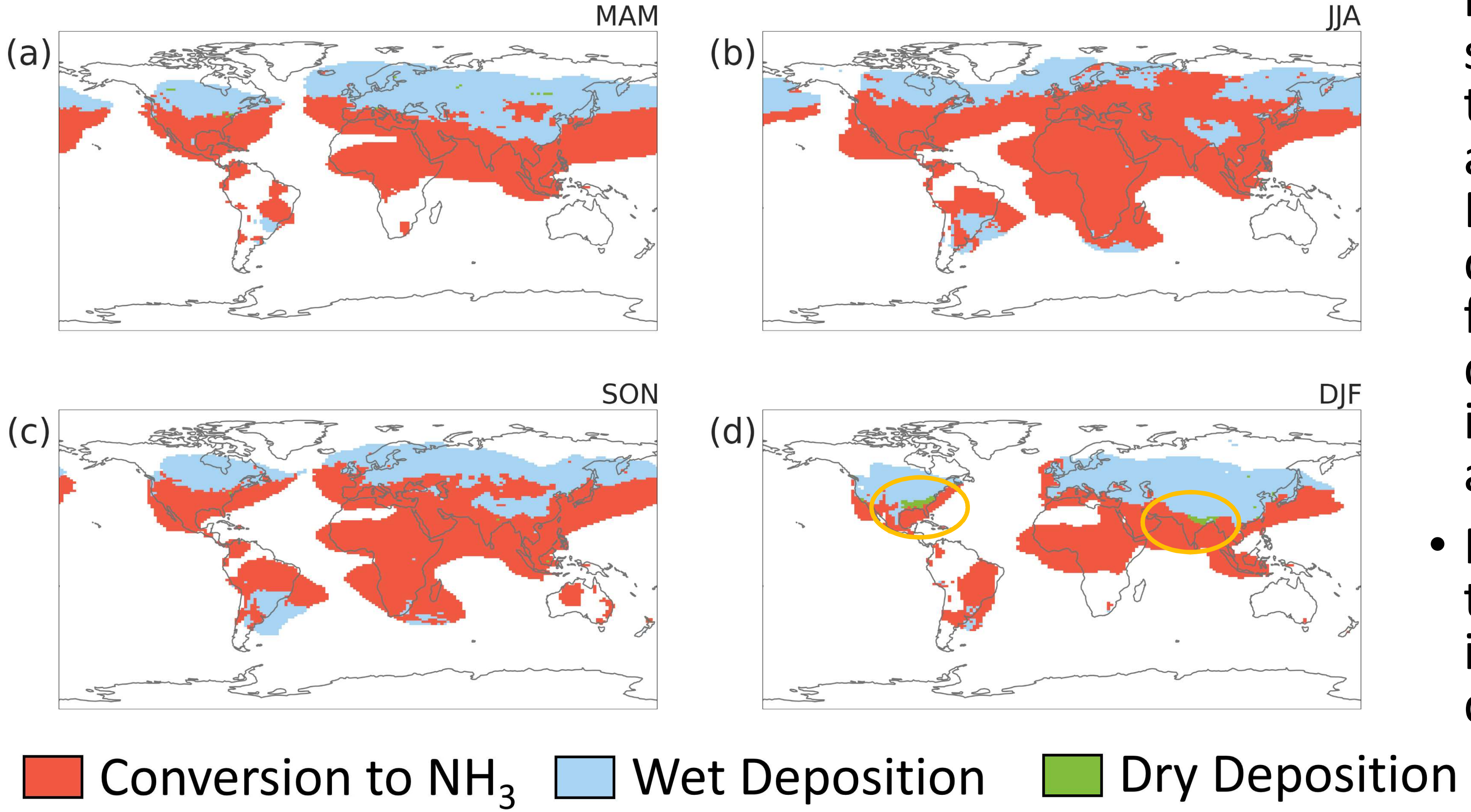
Dominant sink of NH_3



Sinks calculated for lowest 10 km of atmosphere. Sinks not shown where NH_3 column < 10 μg N/m^2.

- Ocean: generally wet deposition in the equatorial rain band.
- Open ocean at midlatitudes: conversion to ammonium sulfate dominates, as ammonia reacts with sulfur from DMS emitted from the ocean.
- Coastal waters in the NH, ammonium nitrate formation can be the biggest sink.

Dominant sink for NH_4NO_3



Sinks calculated for lowest 10 km of atmosphere. Sinks not shown where NH_4NO_3 column < 10 (µg N as NO_3^-)/m^2.

- Ammonium nitrate is less stable at warmer temperatures, and between 45° N and S, the dominant sink for nitrate is the decomposition into ammonia and nitric acid.
- Poleward of 45°, the biggest sink is generally wet deposition.

Atmospheric ammonia budget

- Large ammonia concentrations over South and East Asia
- Surface ammonia concentrations in reasonable agreement with observations in many regions
- The model underpredicts ammonia concentrations over West Africa and India (satellite suggests model overpredictions over India)
- Ammonia concentrations depend on emissions, chemistry (SOx, NOx) and weather
- Budgets for ammonia and ammonium nitrate vary by region due to a combination of these factors
- Dominant sinks vary dramatically, important processes driving ammonia concentrations differ across regions

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