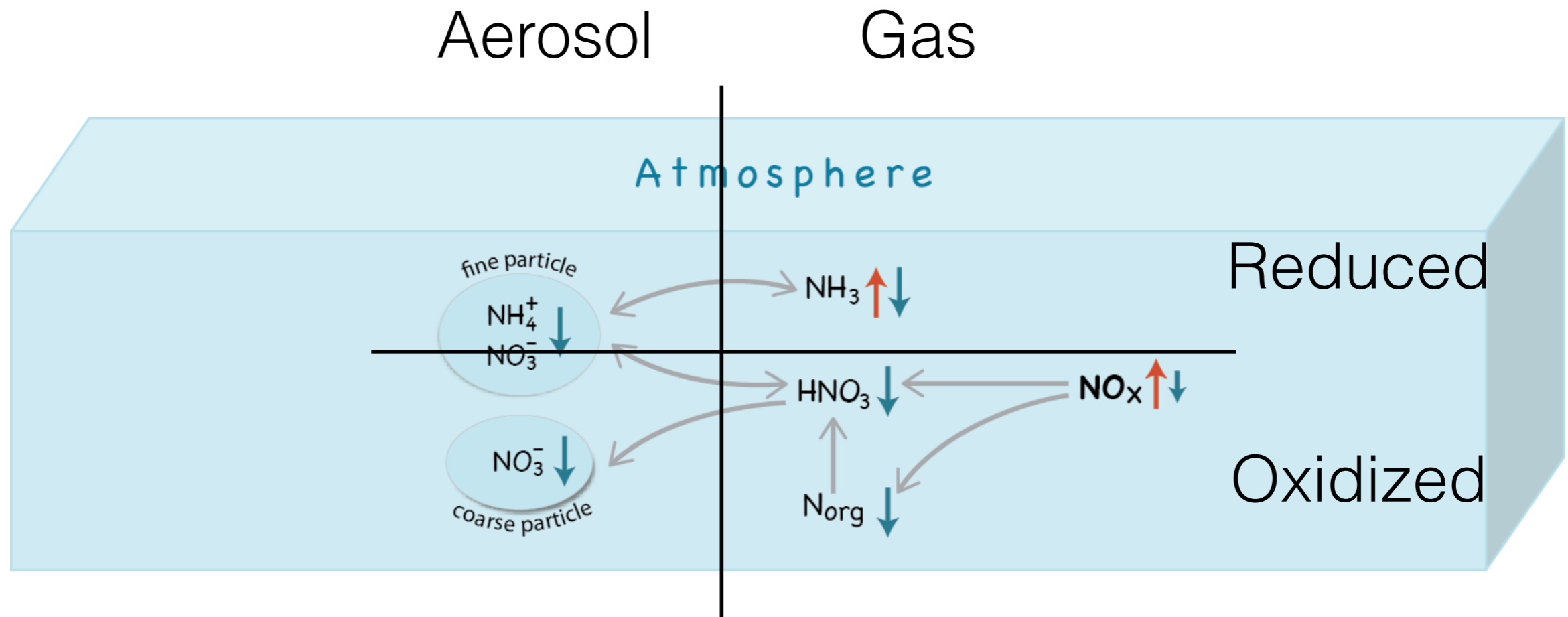


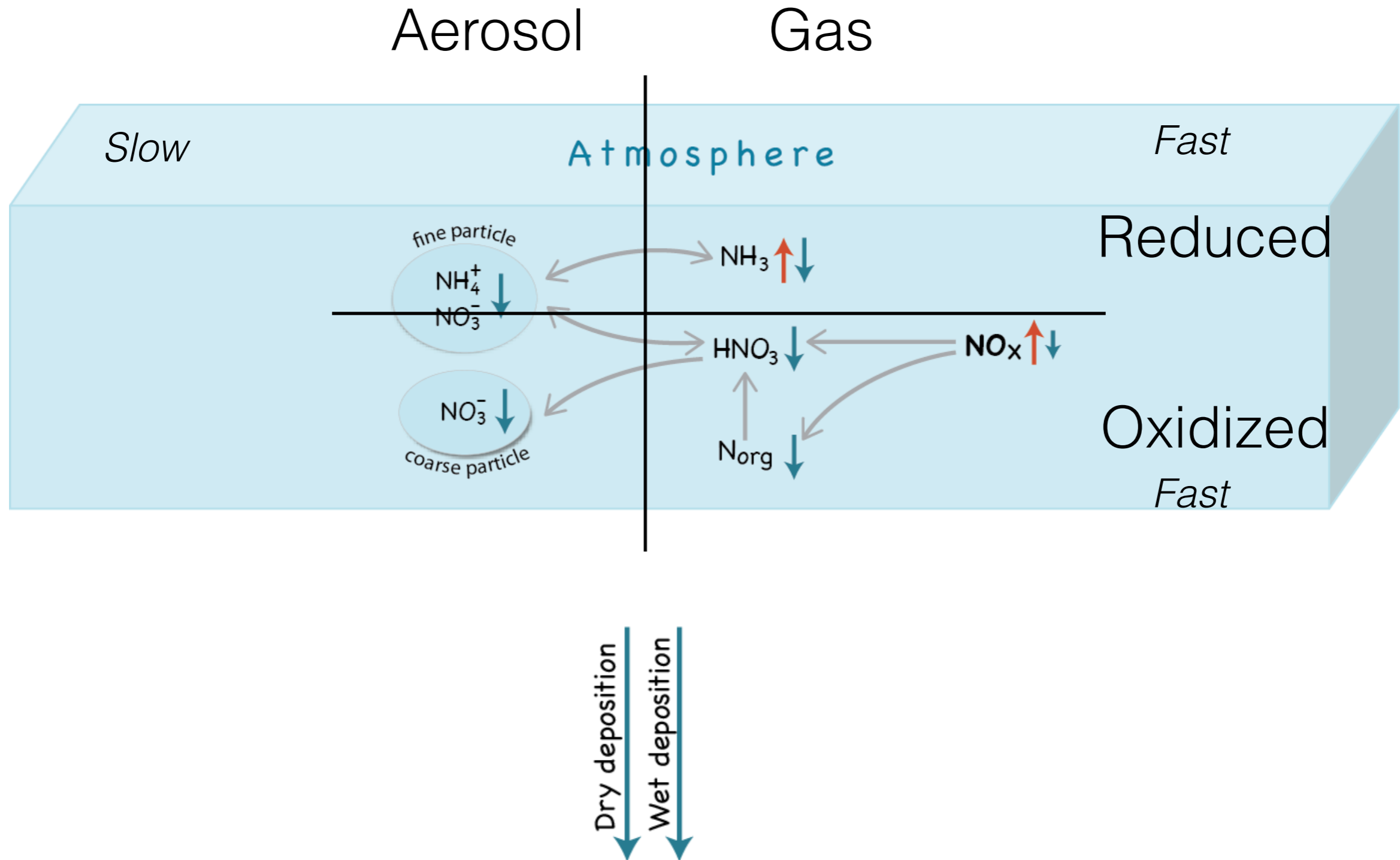
Global oceanic emission of ammonia: constraints from seawater and atmospheric observations

Fabien Paulot (NOAA GFDL, Princeton University)
Charles A Stock (NOAA GFDL)
Daniel J Jacob (Harvard University)
Tom G Bell (Plymouth Marine Lab)
Martin Johnson, Alex R Baker (University of East Anglia)
Ivan D Lima, Scott C Doney (WHOI)
W C Keene (University of Virginia)

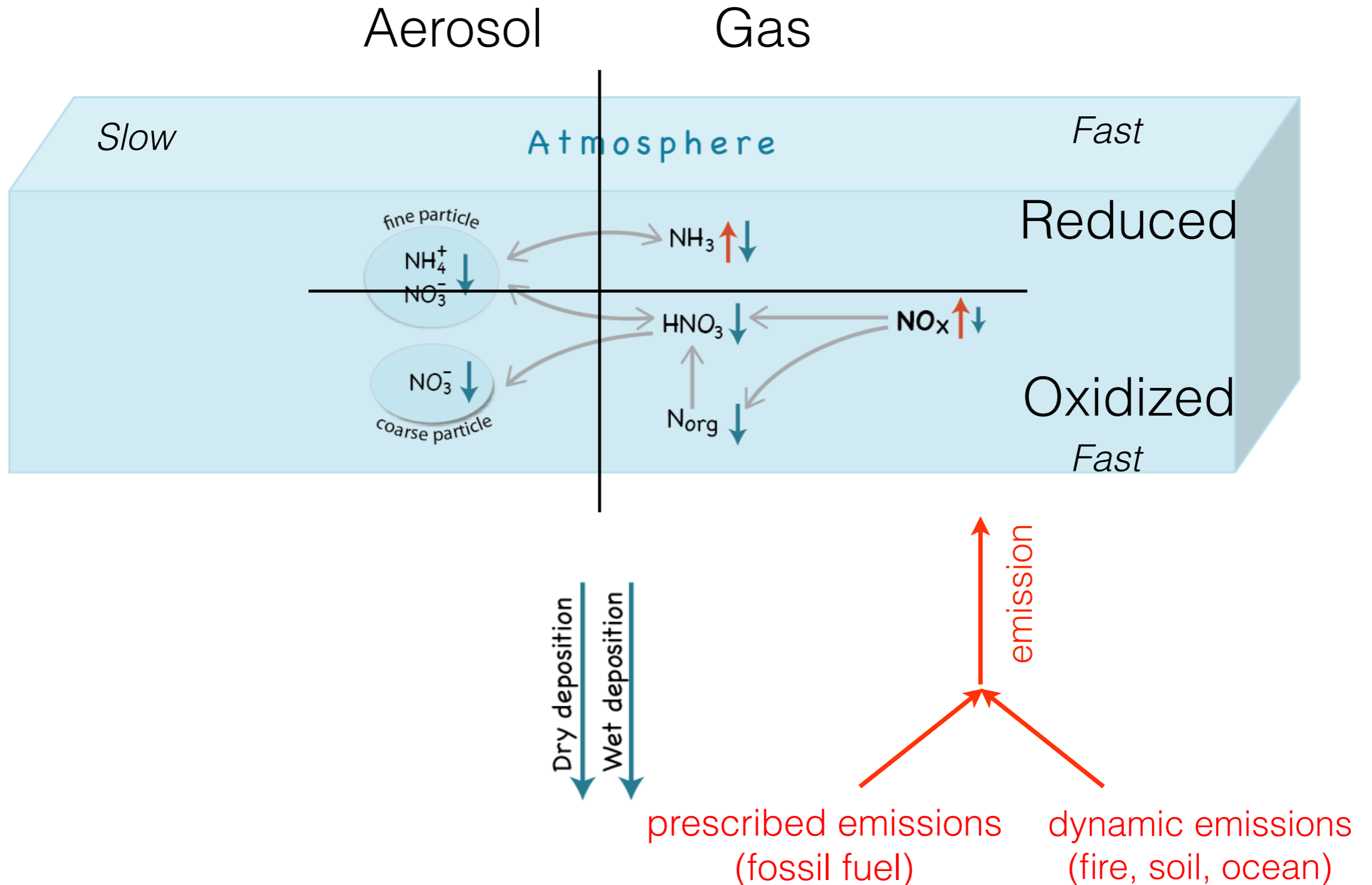
Representation of nitrogen in atmospheric chemistry models



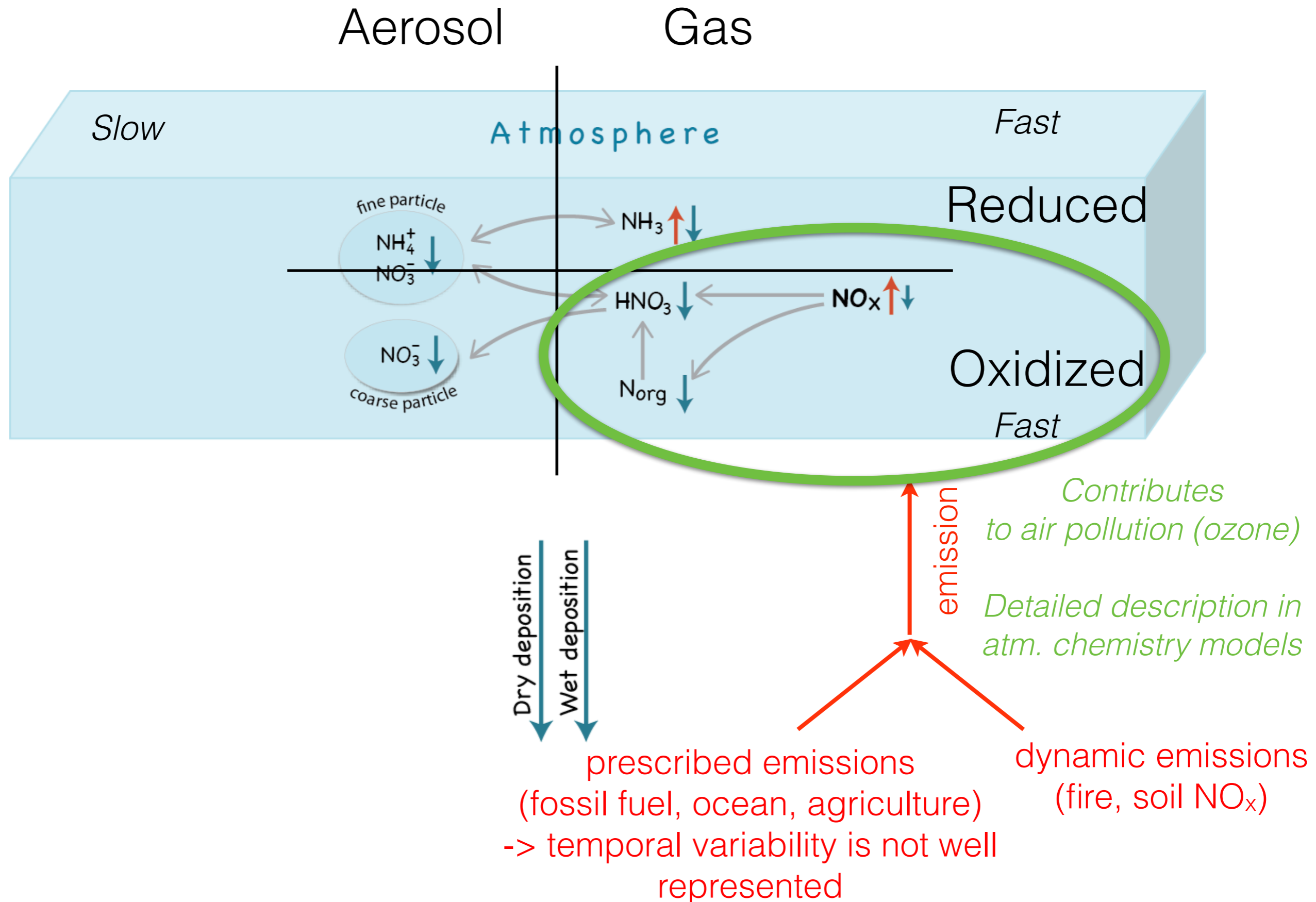
Representation of nitrogen in atmospheric chemistry models



Representation of nitrogen in atmospheric chemistry models

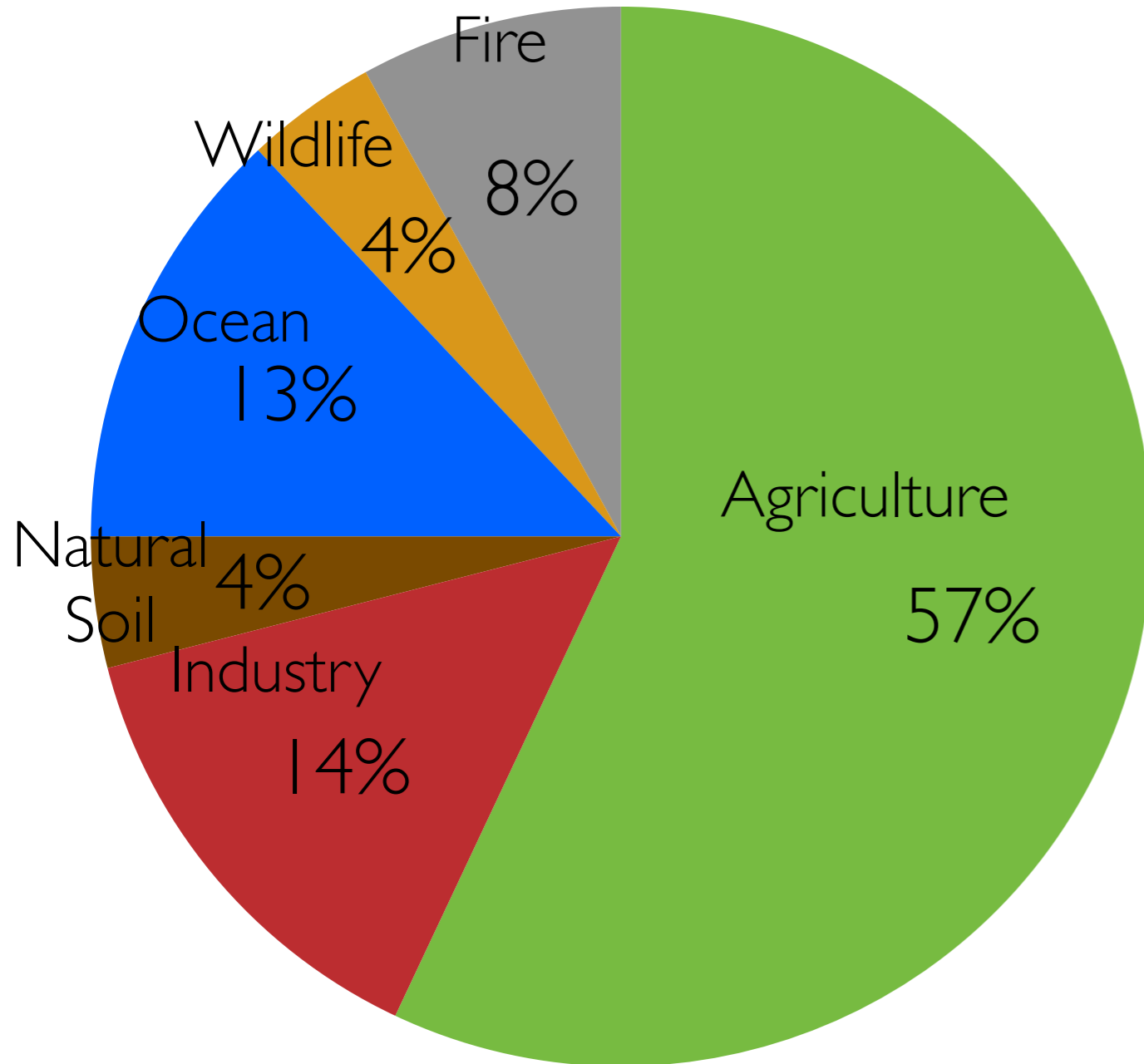


Representation of nitrogen in atmospheric chemistry models



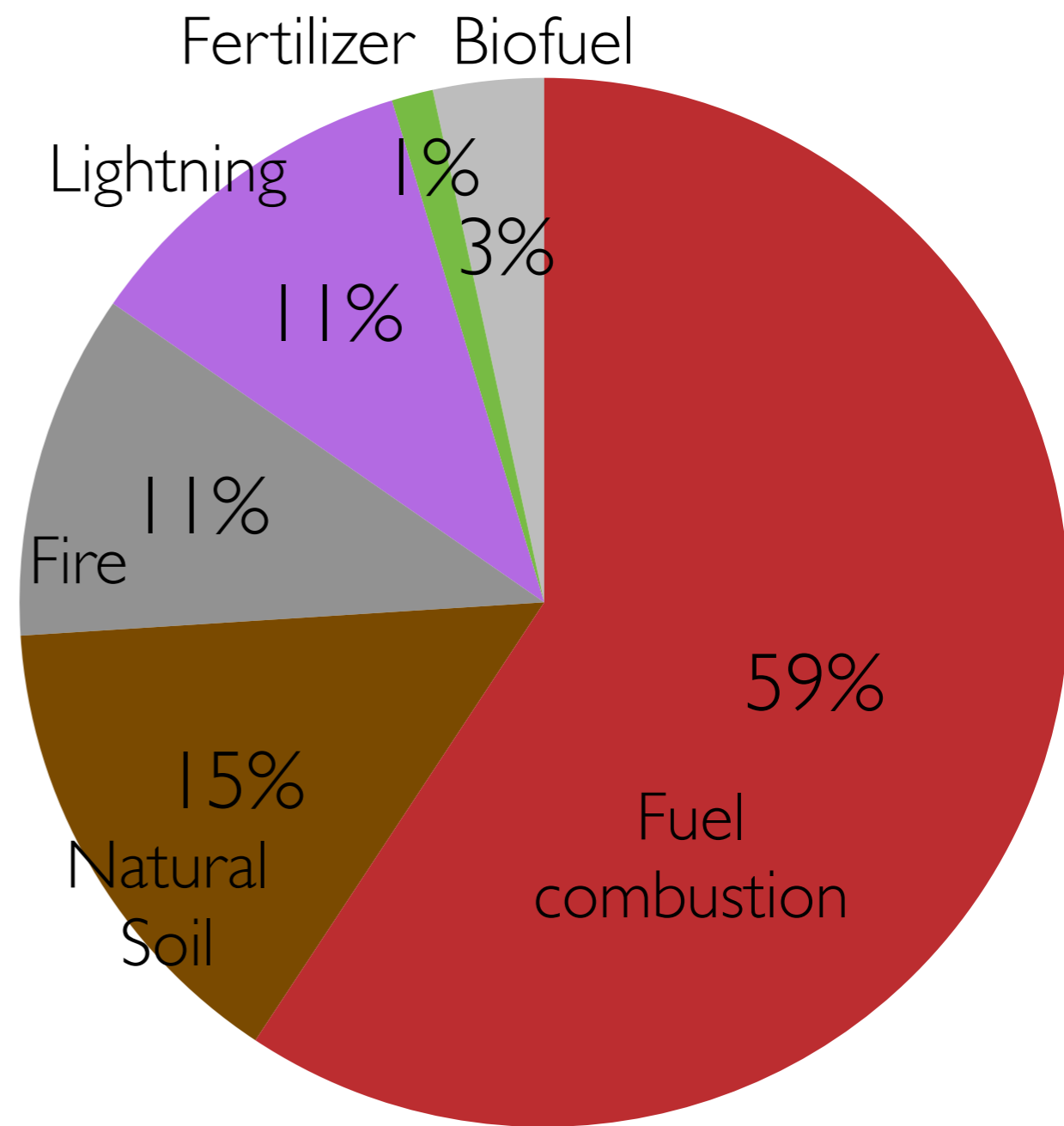
Global emissions of nitrogen

NH₃ sources (~65TgN/yr)



Present-day NH₃ emissions
(Sutton 2013)

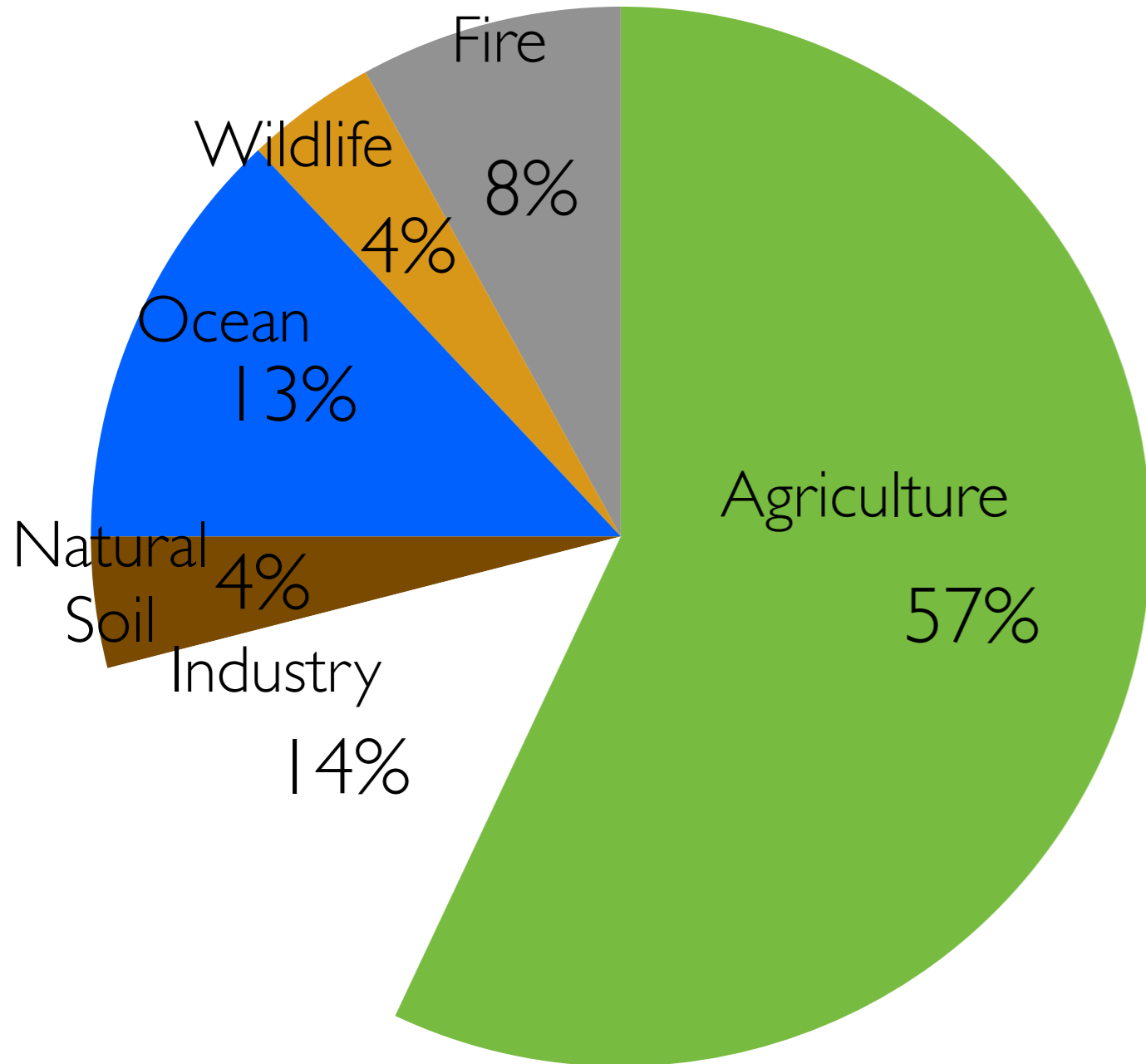
NO sources (~45TgN/yr)



Present-day NO emissions

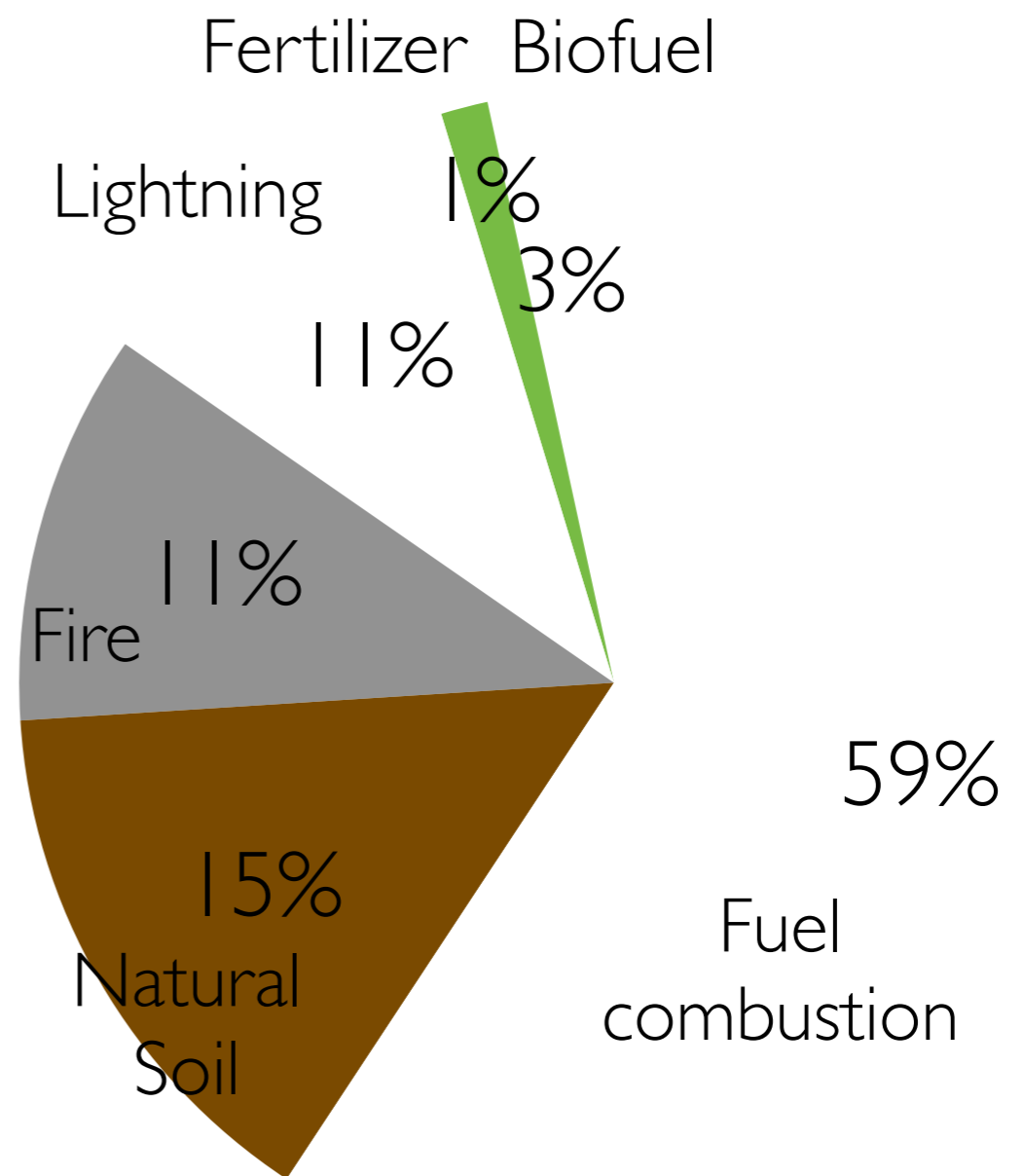
NH₃ sources are more uncertain than NO sources

NH₃ sources



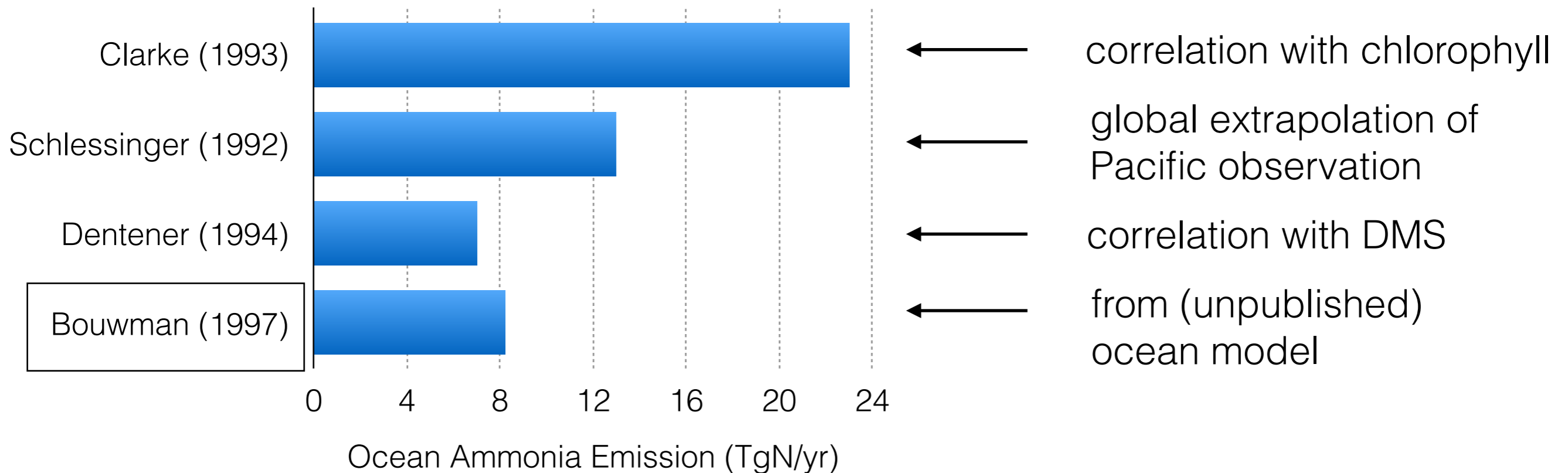
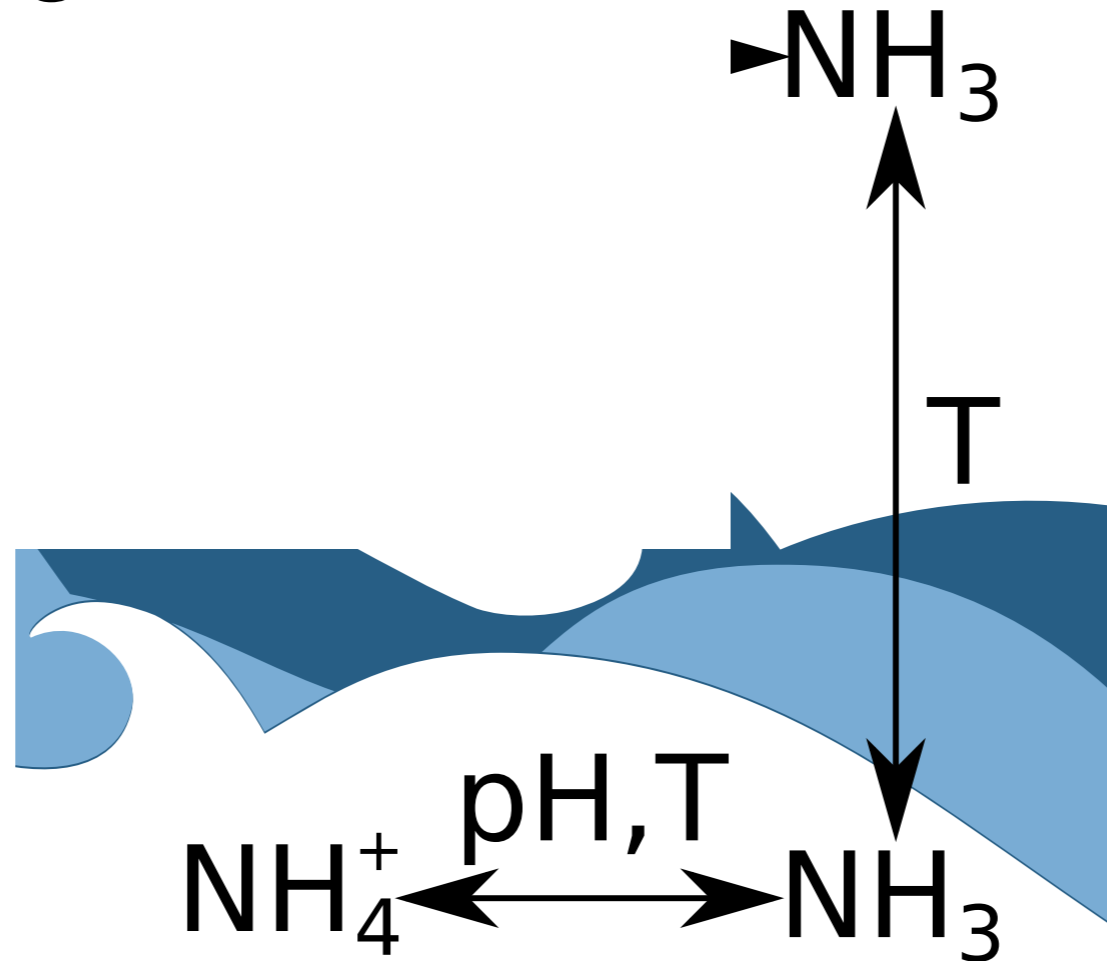
Present-day NH₃ emissions
(Sutton 2013)

NO sources

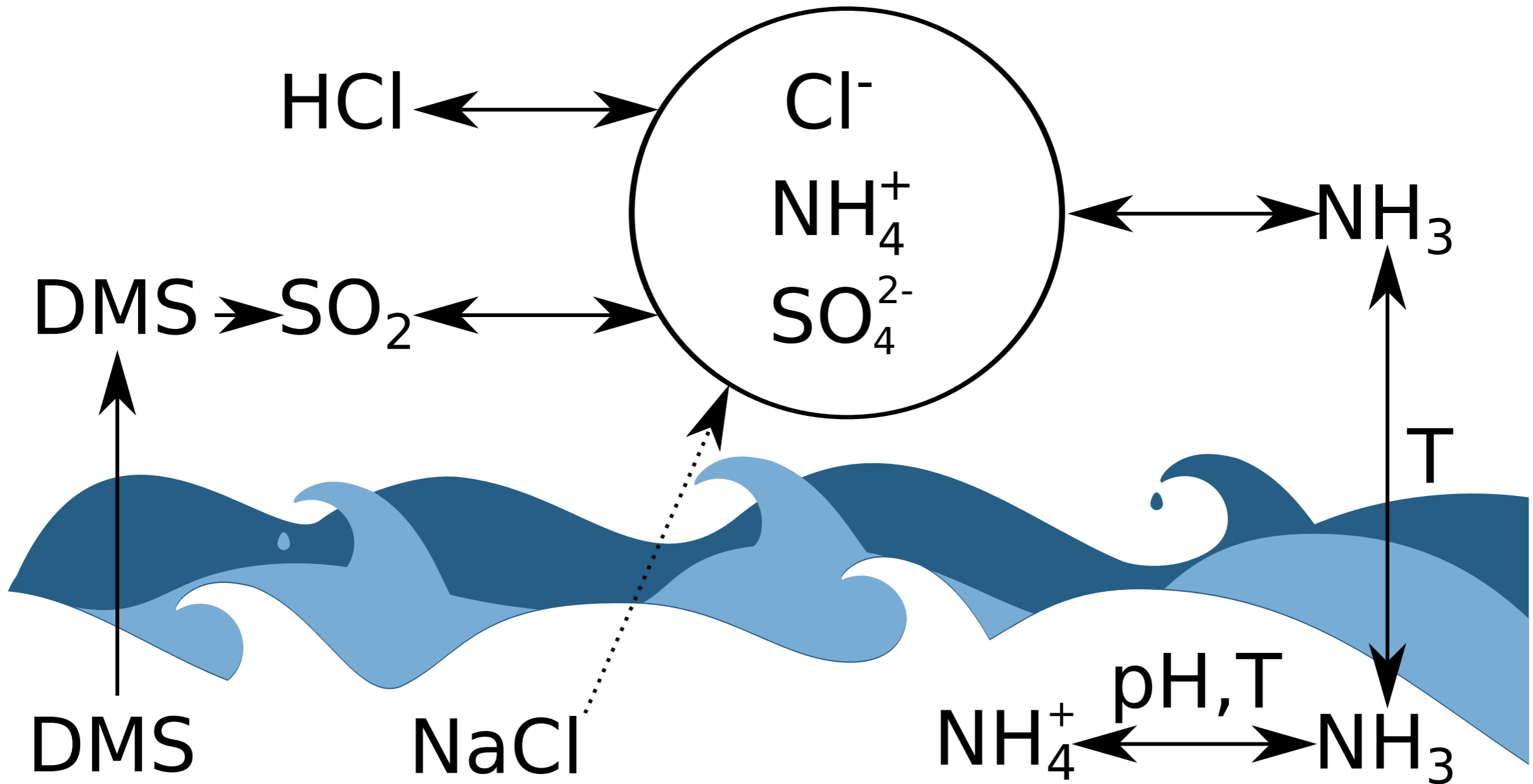


Present-day NO emissions

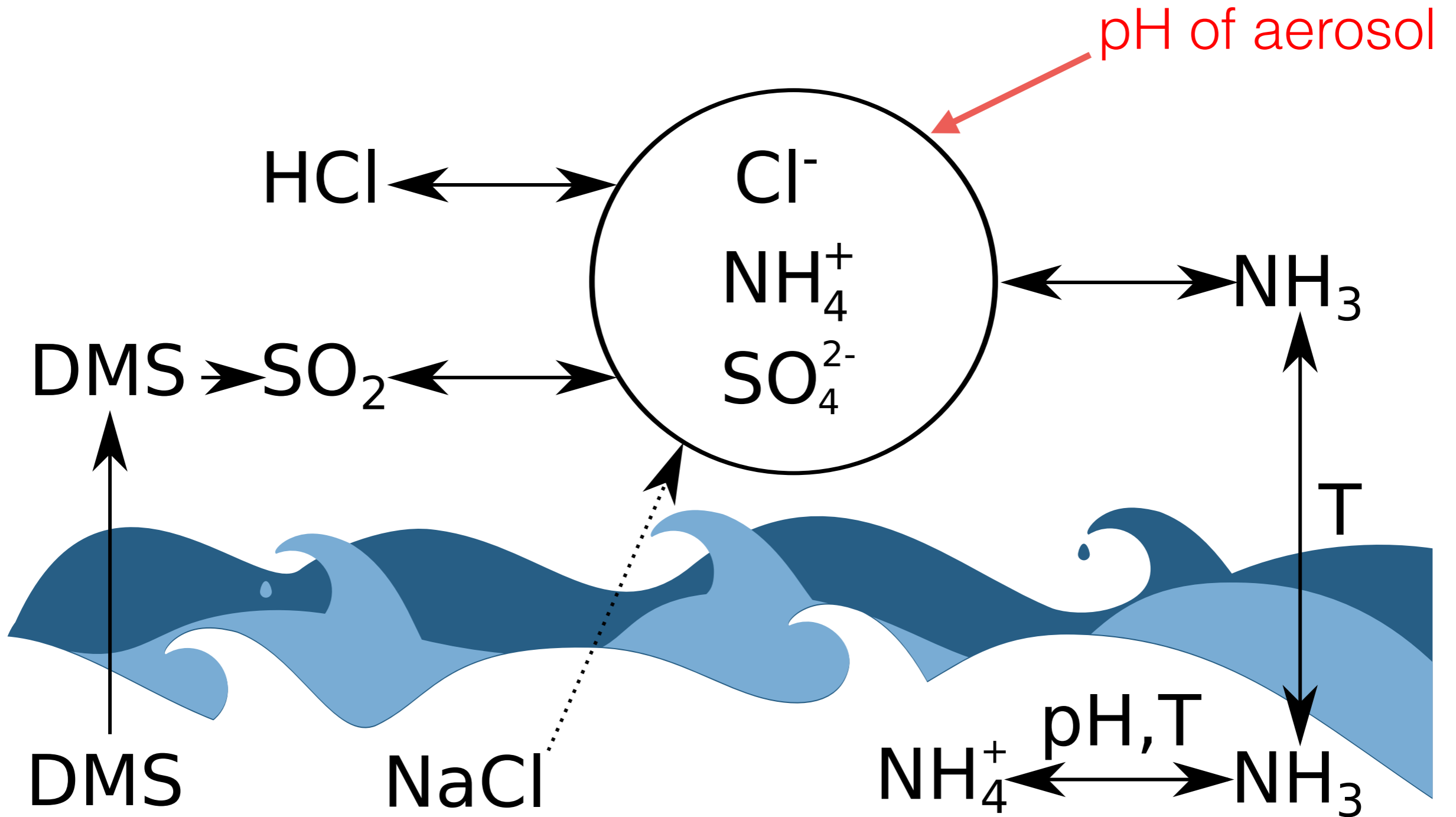
How large is the ocean NH₃ source?



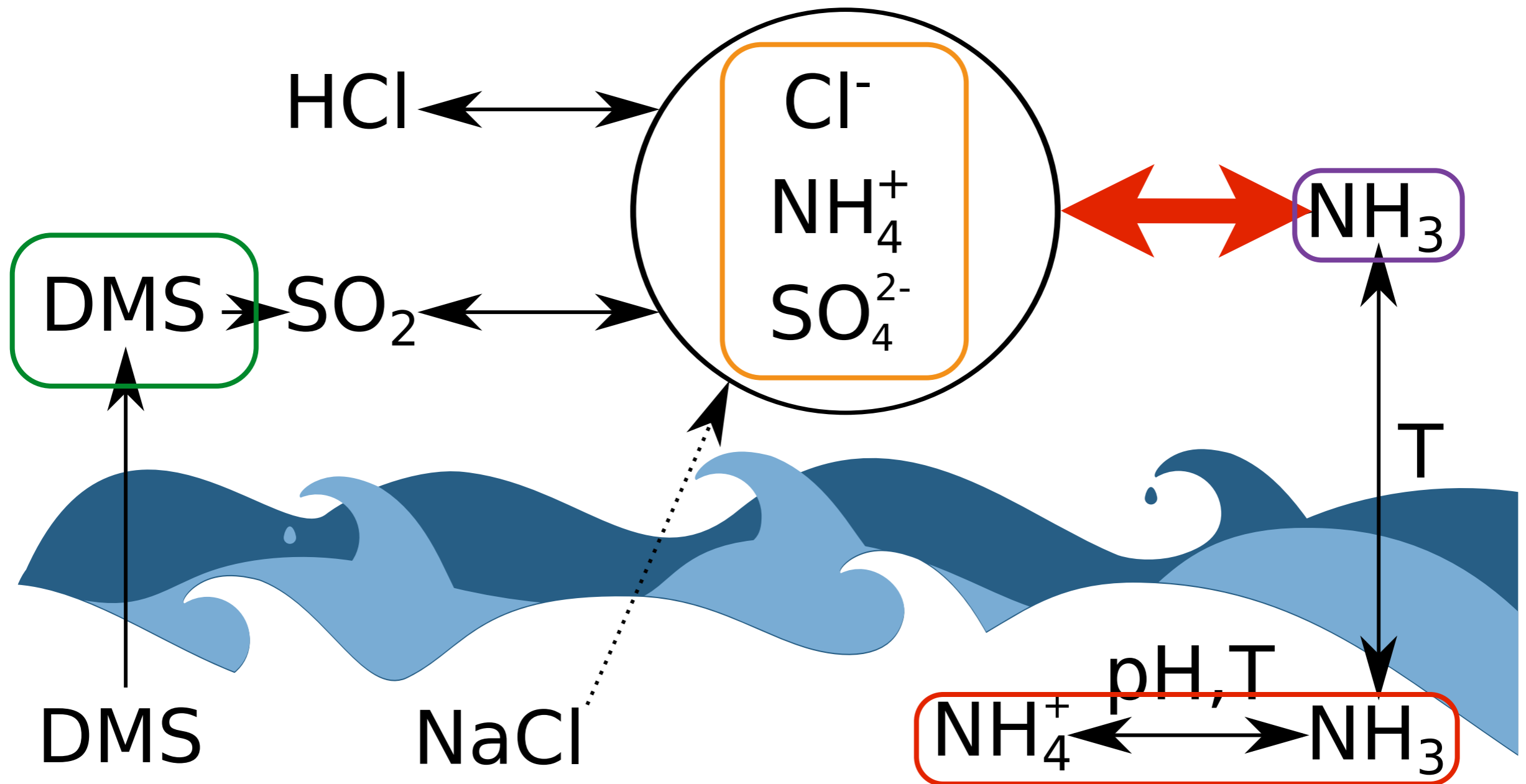
Fate of marine NH₃ is tied to other marine emissions



Fate of marine NH_3 is tied to other marine emissions



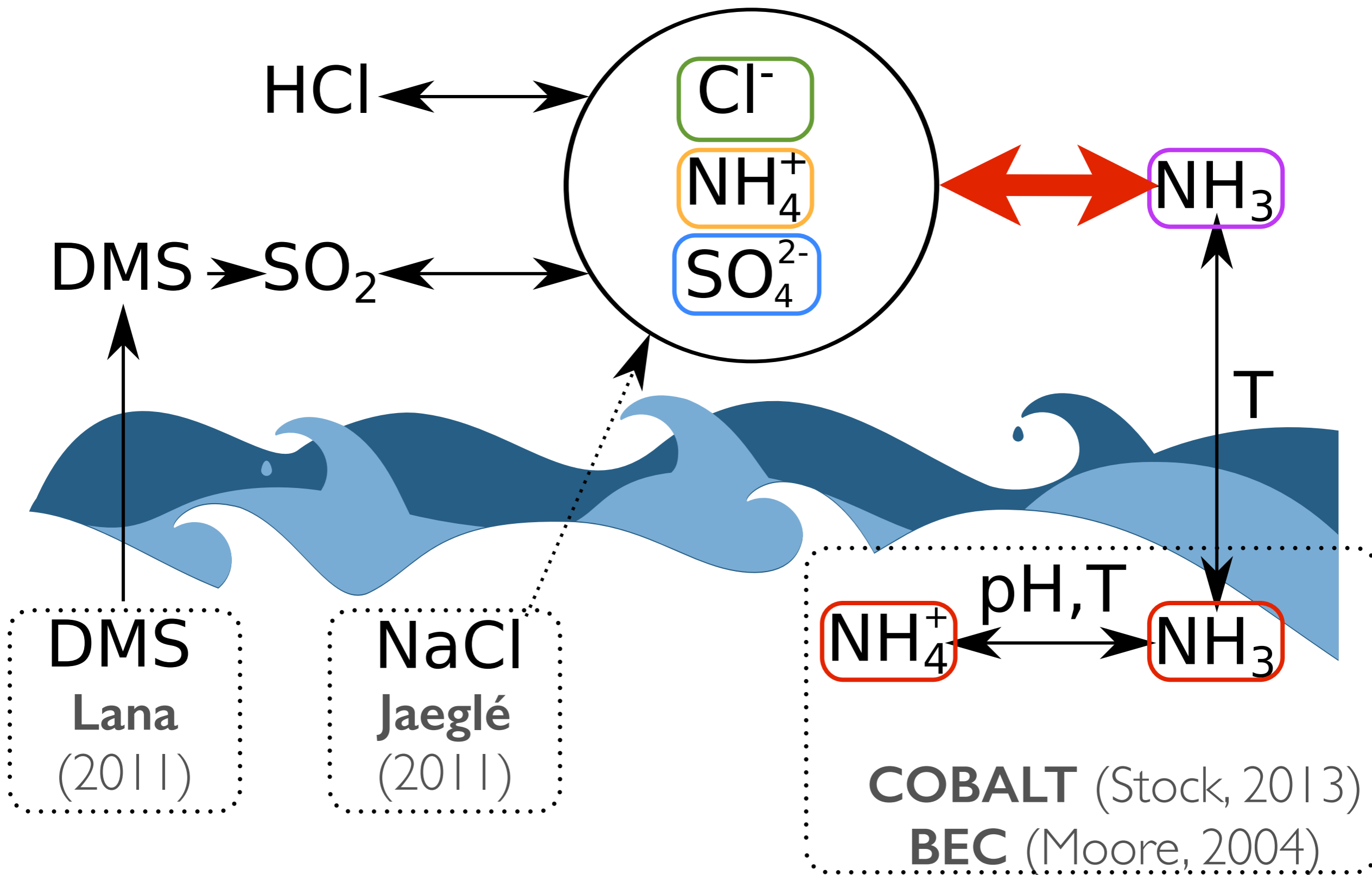
Fate of marine NH₃ is tied to other marine emissions



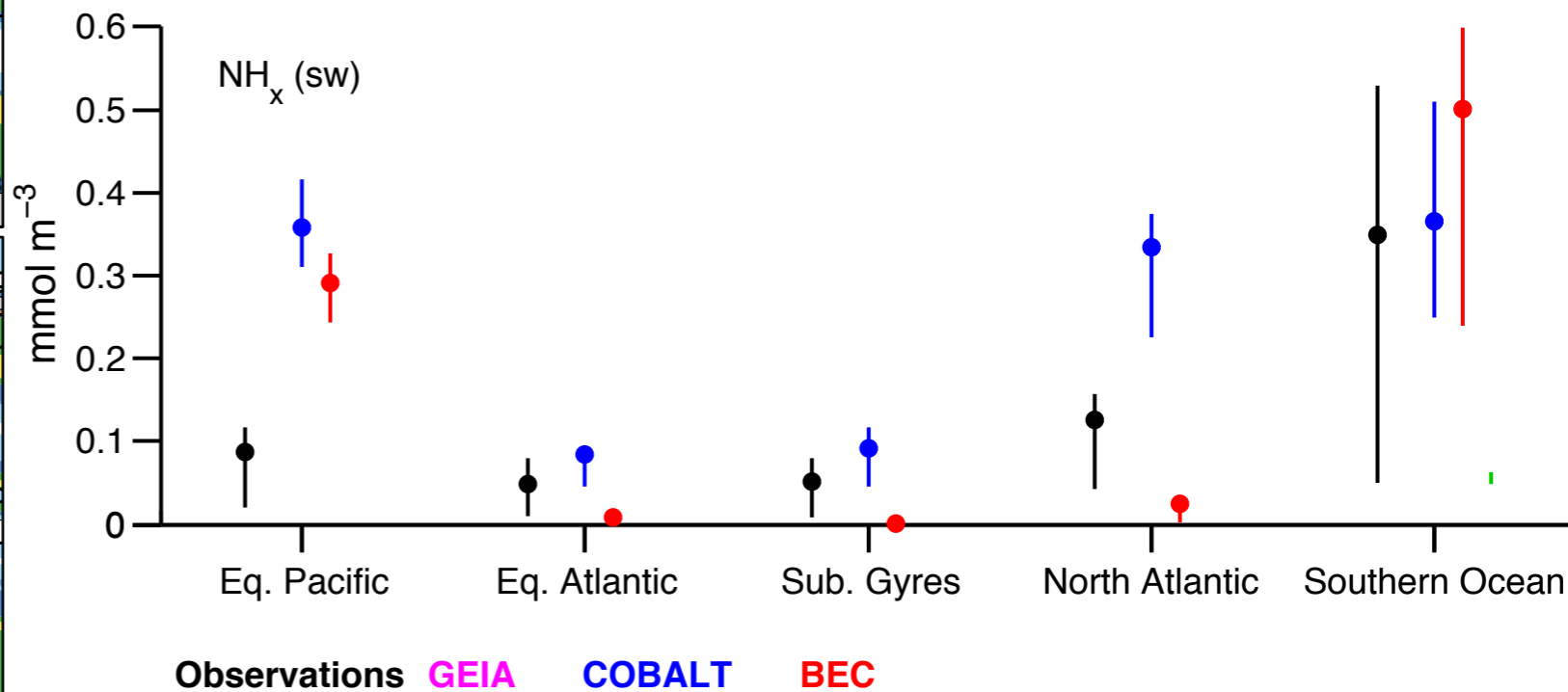
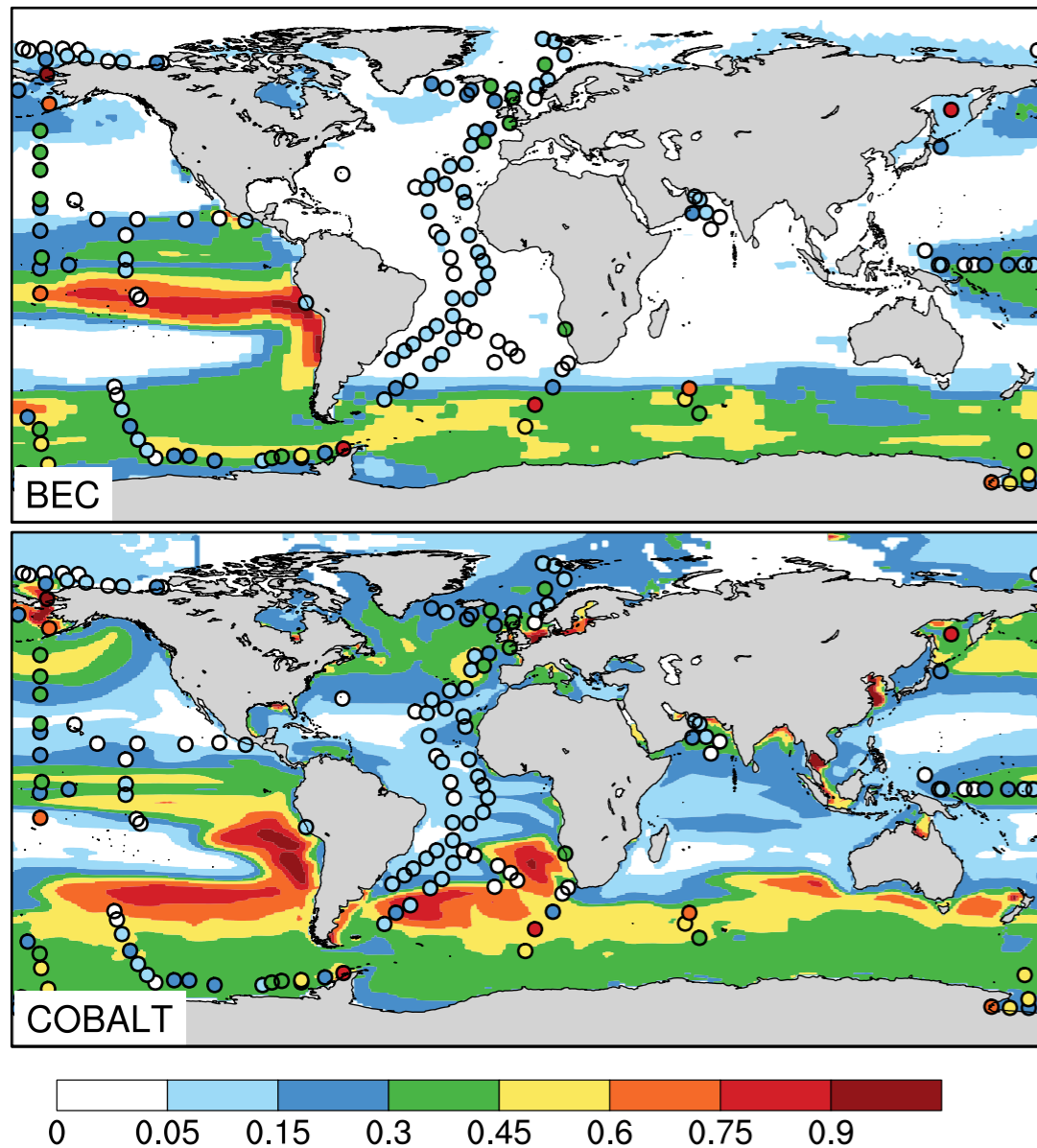
Modeling approach

GEOS-Chem

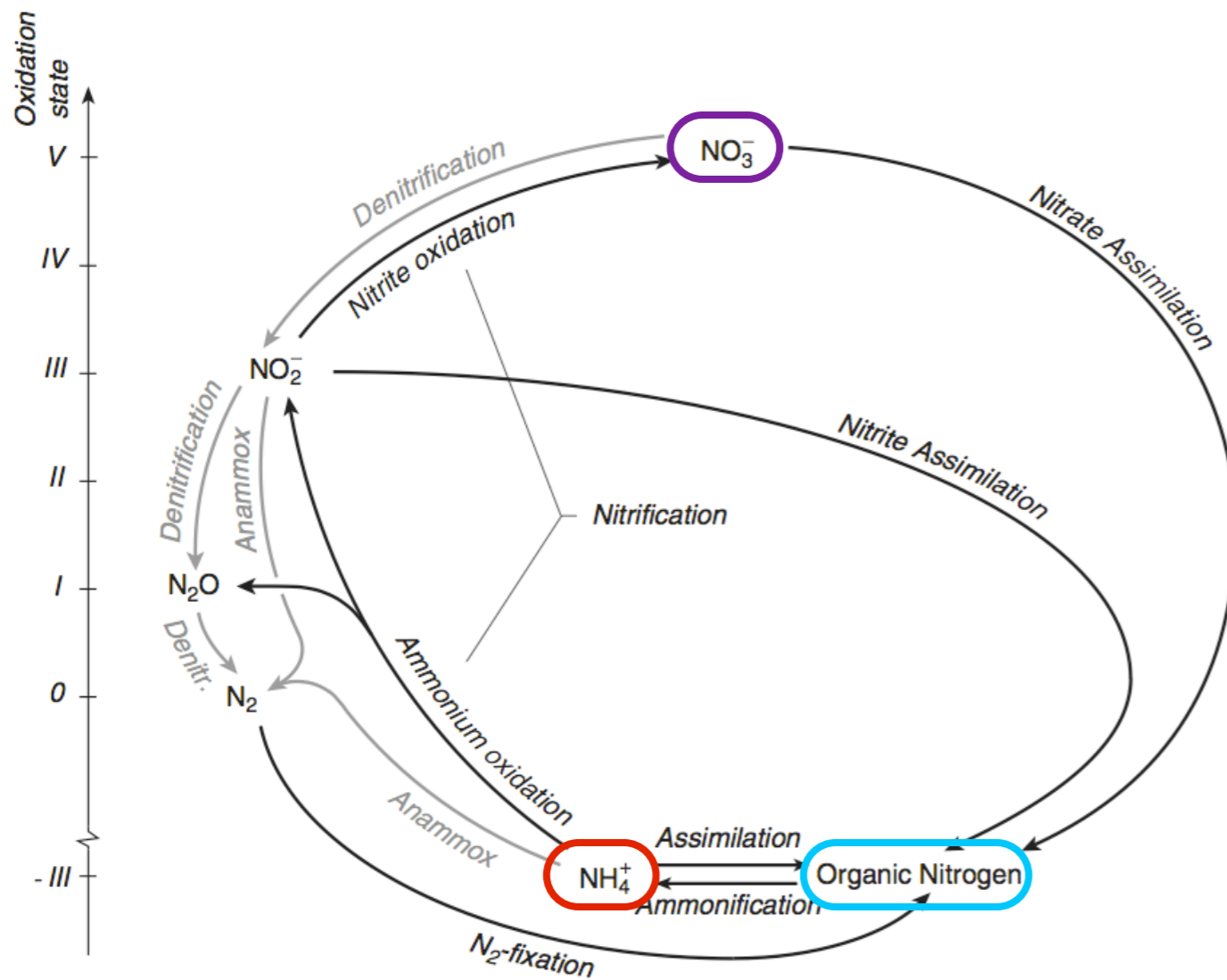
ISORROPIA



Simulated distribution of NH_x (sw)



A lot more observations will be available thanks to SOLAS!



Gruber (2008)

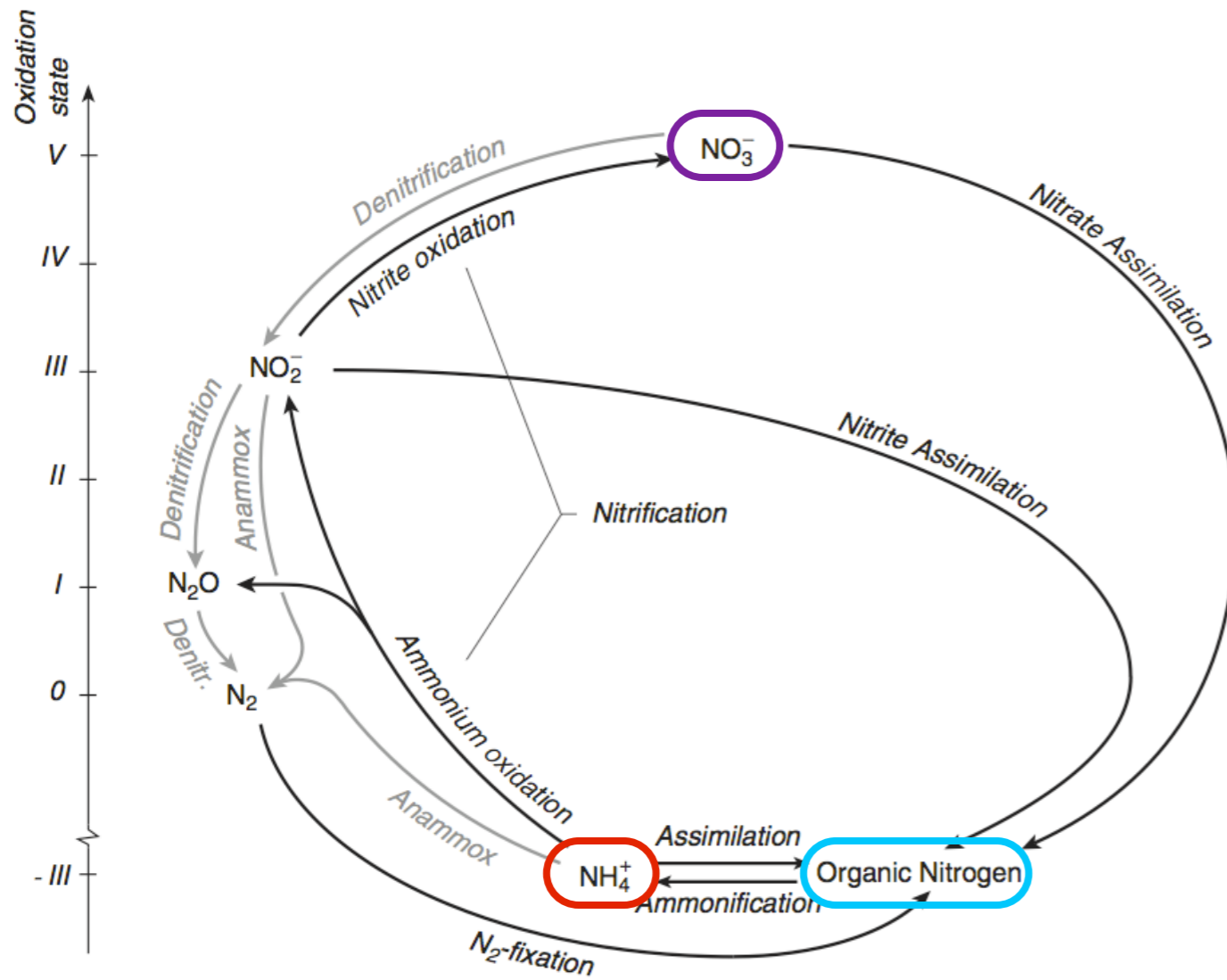
$$v_X = \frac{V_{max} [X]}{[X] + \kappa_X}$$

uptake rate of nutrient X

affinity of phytoplankton for X

	Small phytoplankton		Large phytoplankton		Obs 0.01-0.6 mmol/m ³
	BEC	COBALT	BEC	COBALT	
Ammonium	0.005	0.1	0.08	0.1	
Nitrate	0.5	0.5	2.5	2.5	

in mmol/m³



Gruber (2008)

$$v_X = \frac{V_{max} [X]}{[X] + \kappa_X}$$

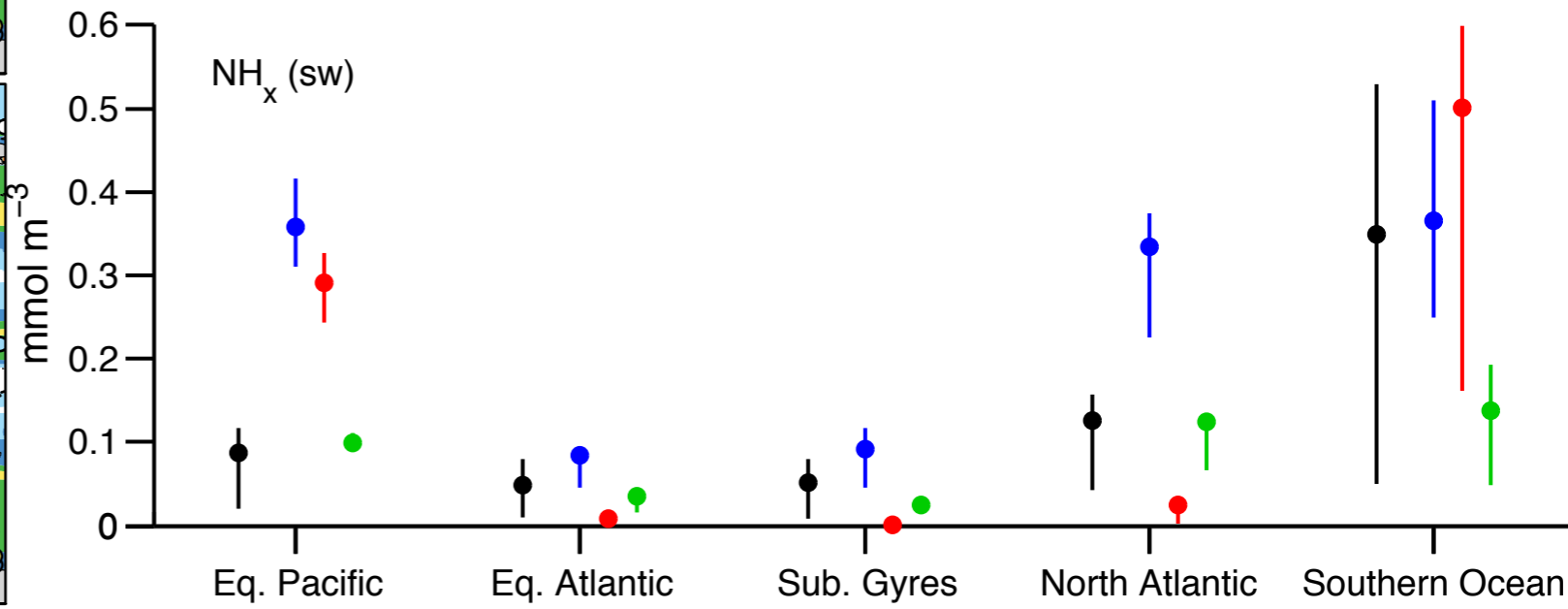
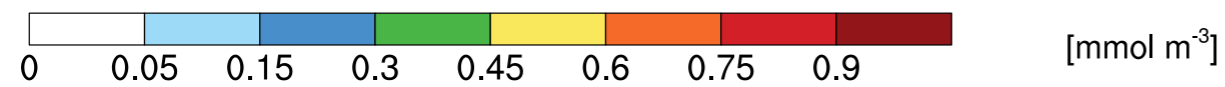
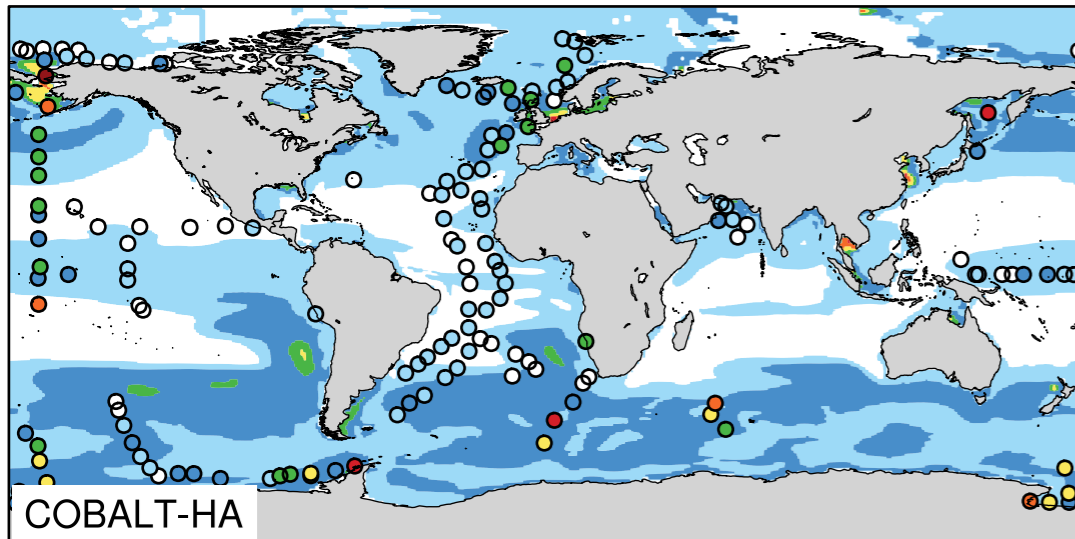
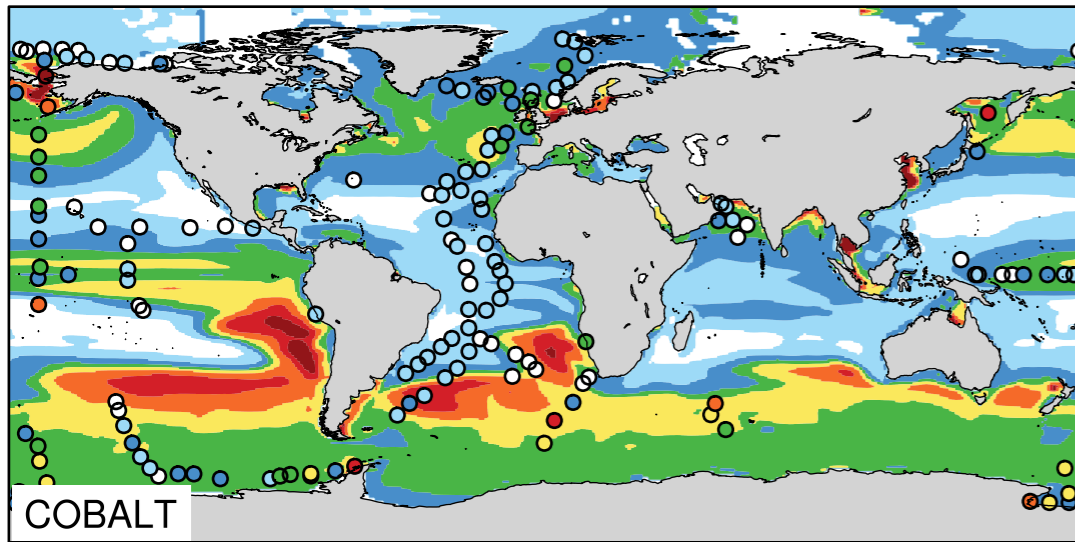
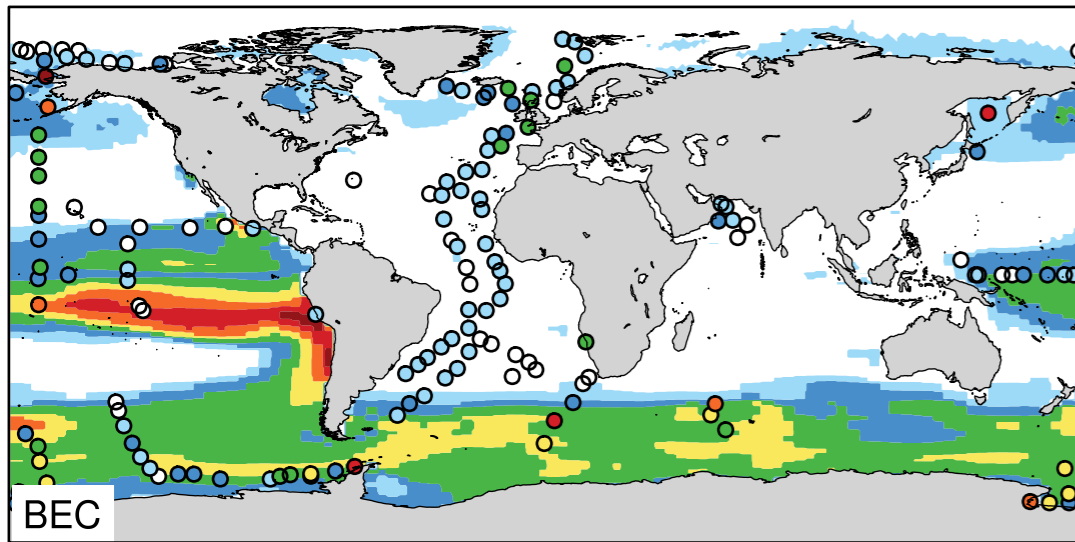
uptake rate of nutrient X

affinity of phytoplankton for X

	Small phytoplankton			Large phytoplankton		
	BEC	COBALT	COBALT-HA	BEC	COBALT	COBALT-HA
Ammonium	0.005	0.1	0.02	0.08	0.5	0.1
Nitrate	0.5	0.5	0.5	2.5	2.5	2.5

in mmol/m³

Simulated distribution of NH_x (sw)

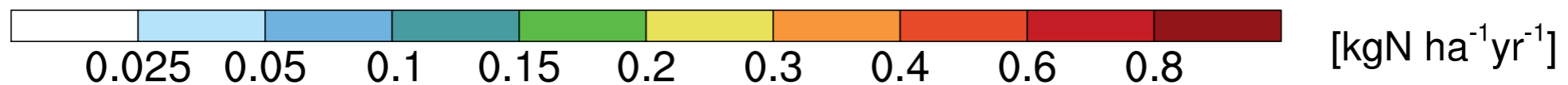
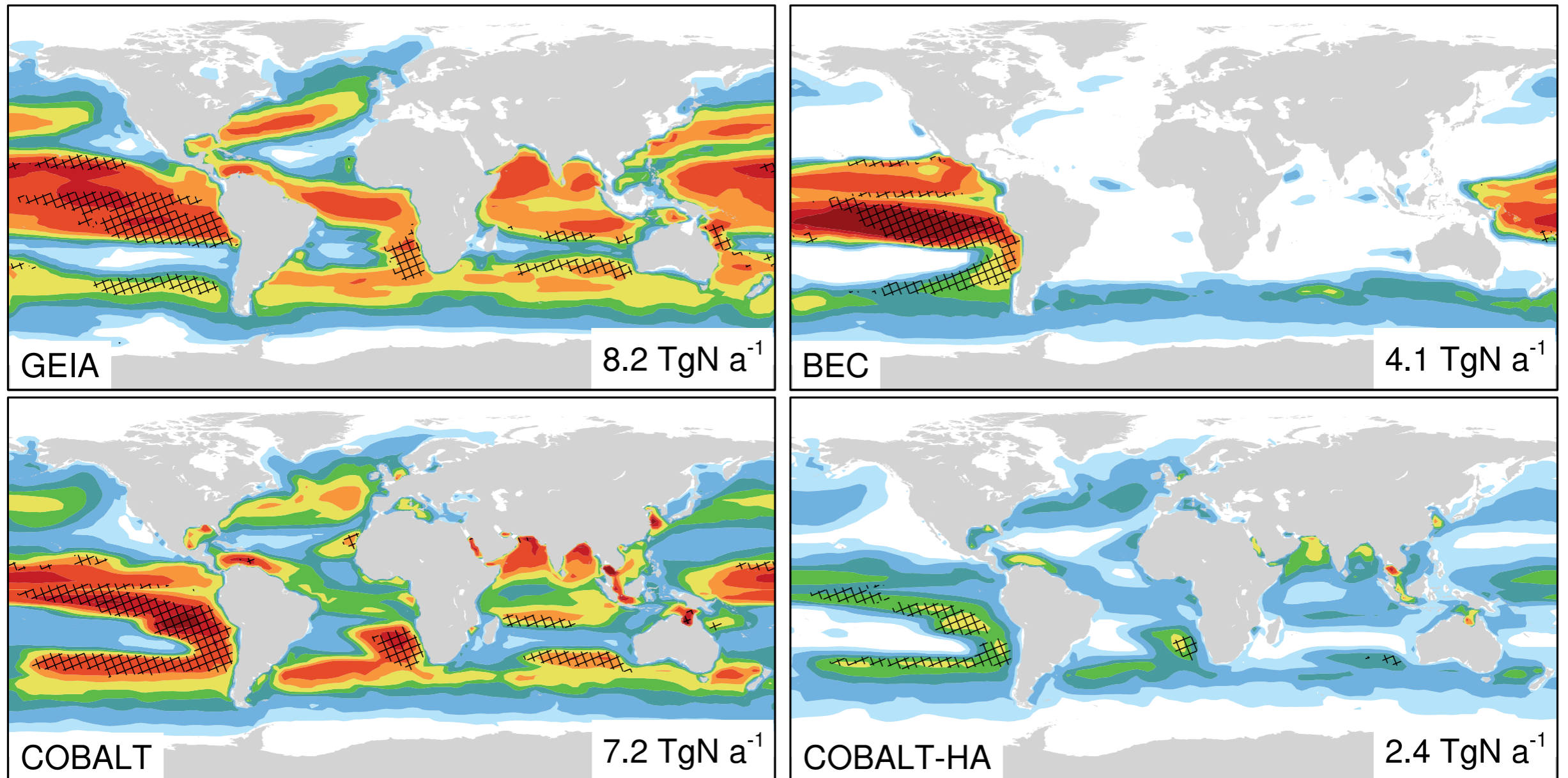


Observations GEIA COBALT BEC COBALT-HA

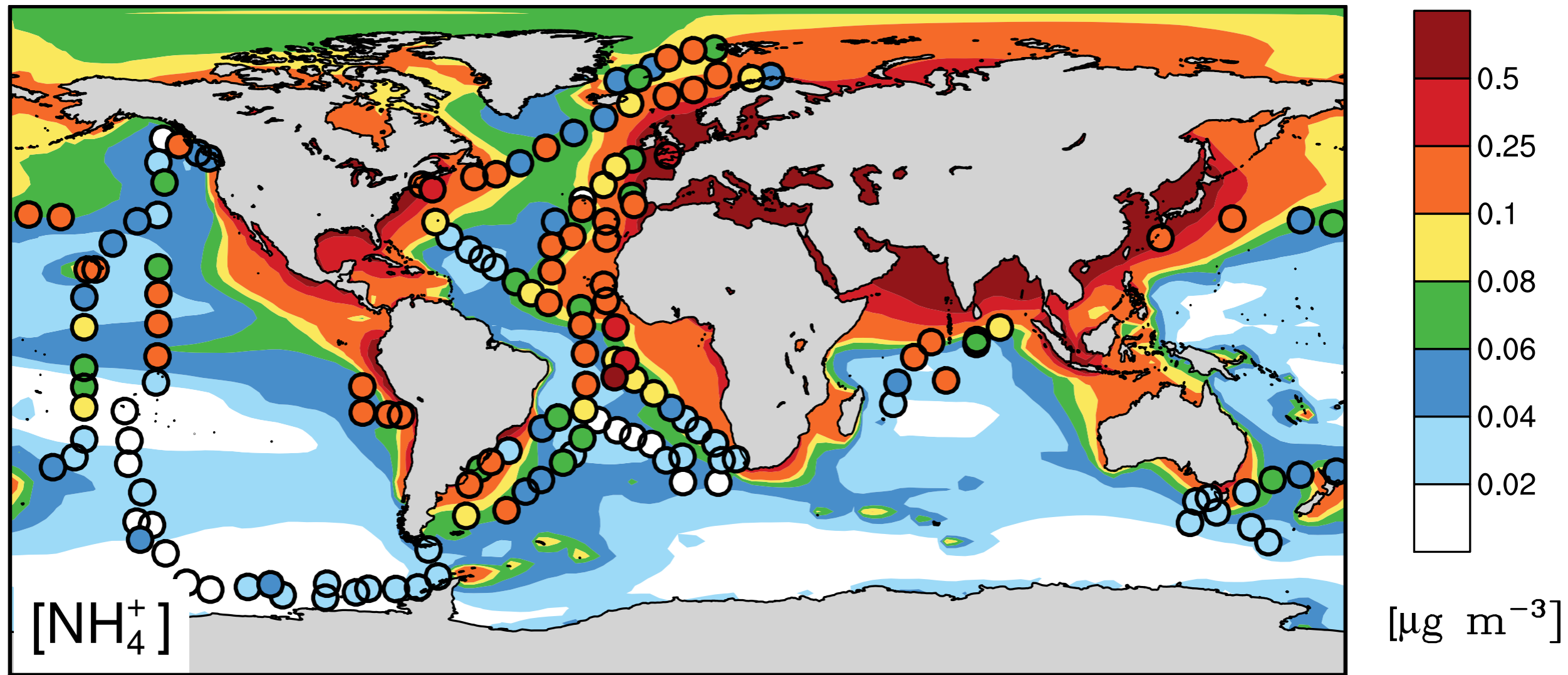
Simulated gross NH₃ emissions

$$F = -K ([\text{NH}_3] - H^*[\text{NH}_x(\text{sw})])$$

Hatches show regions where the ocean is a net source of NH_x to the atmosphere



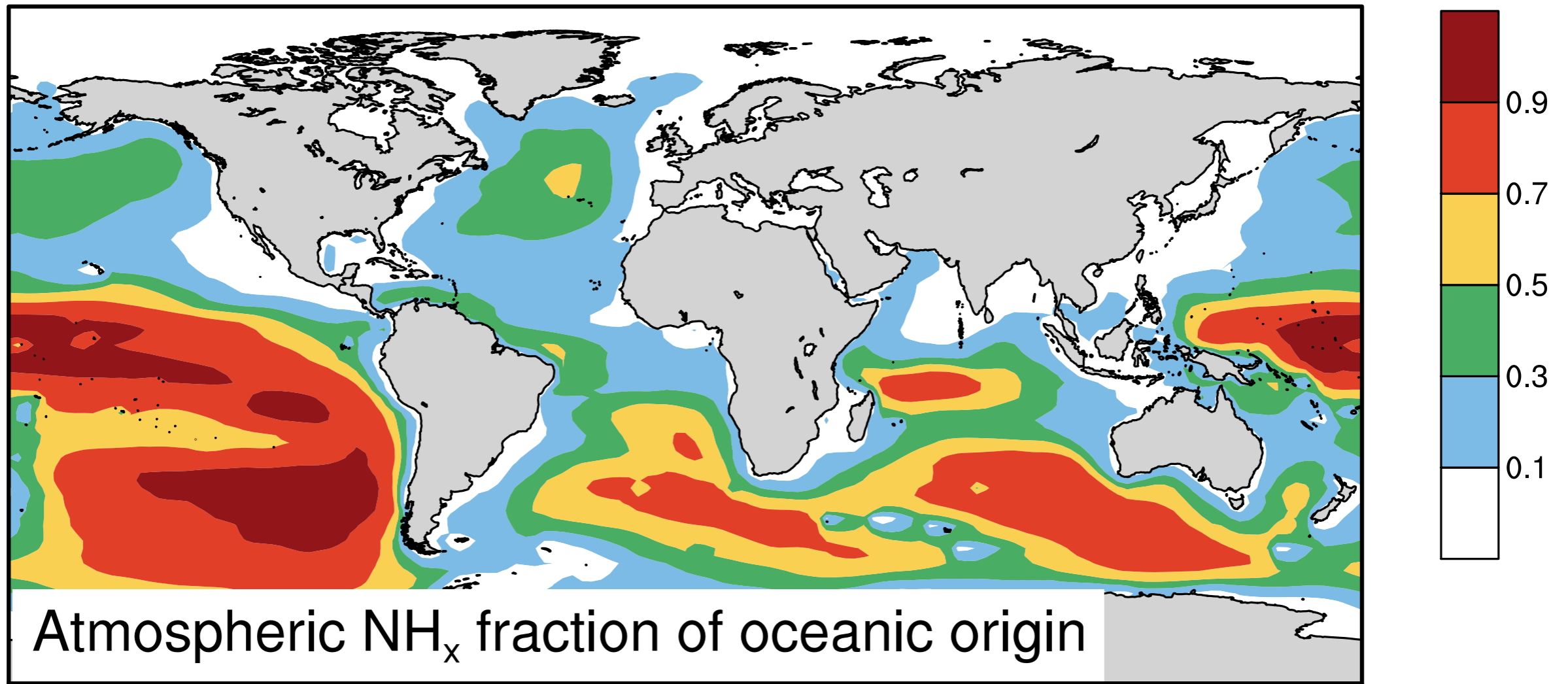
Evaluation against atmospheric observations



COBALT-HA

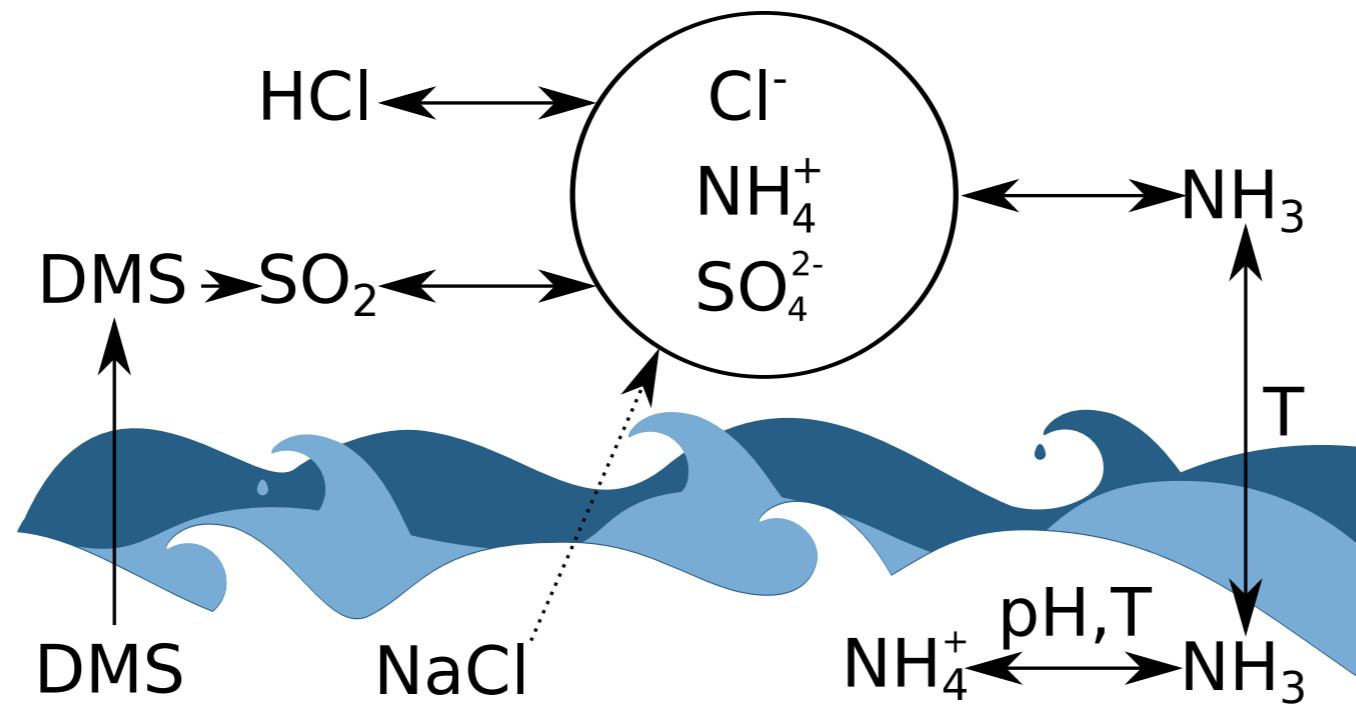
Challenges with atmospheric NH₄

Very large impact of continental sources of NH₃



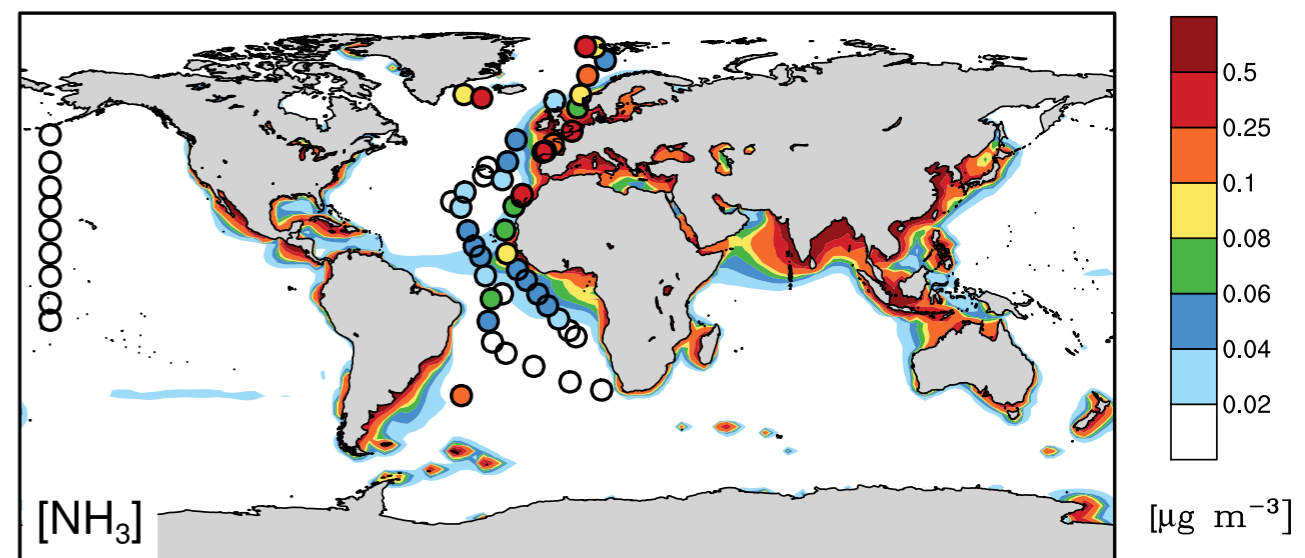
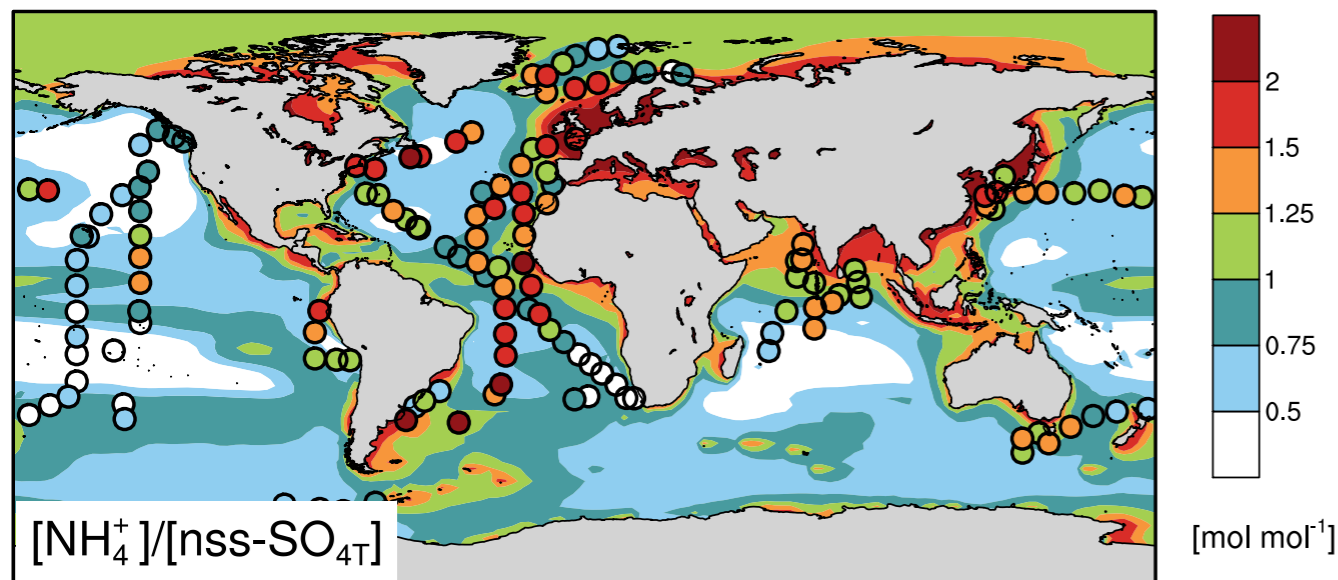
Challenges with atmospheric NH_4

How do we ascertain the partitioning between NH_4 and NH_3 is right

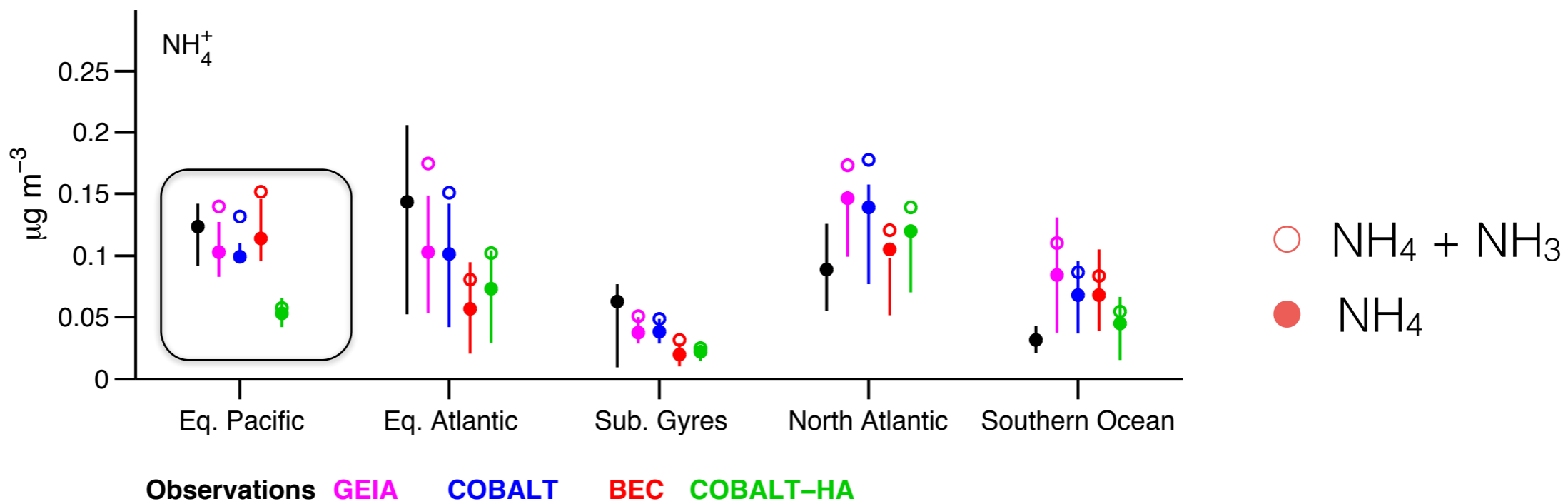
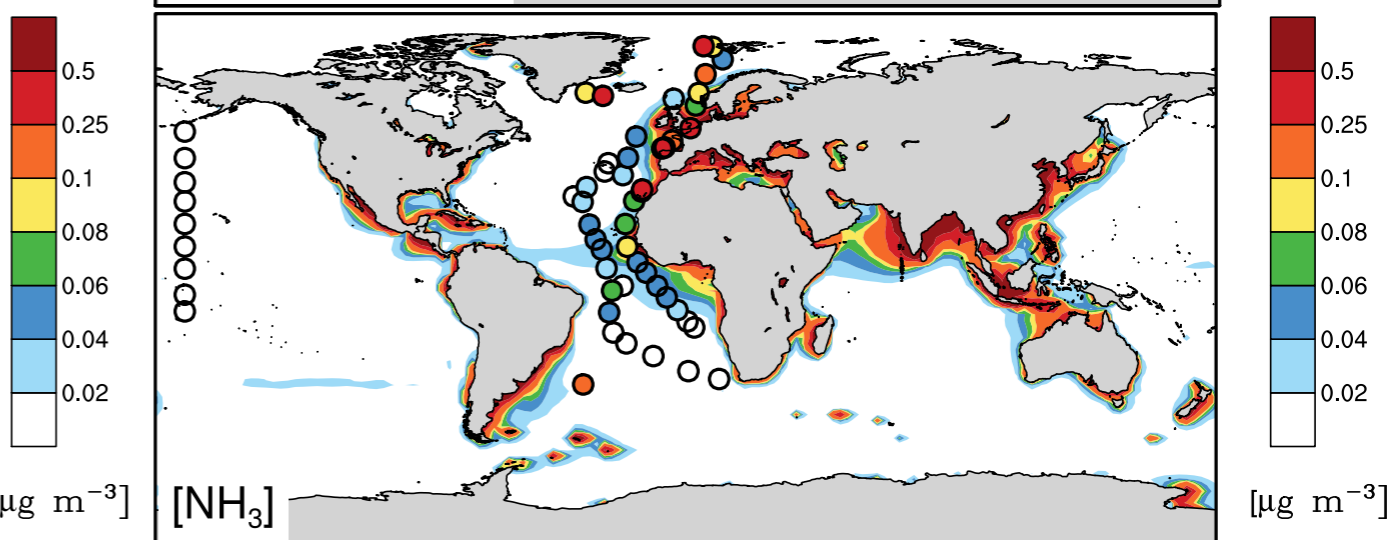
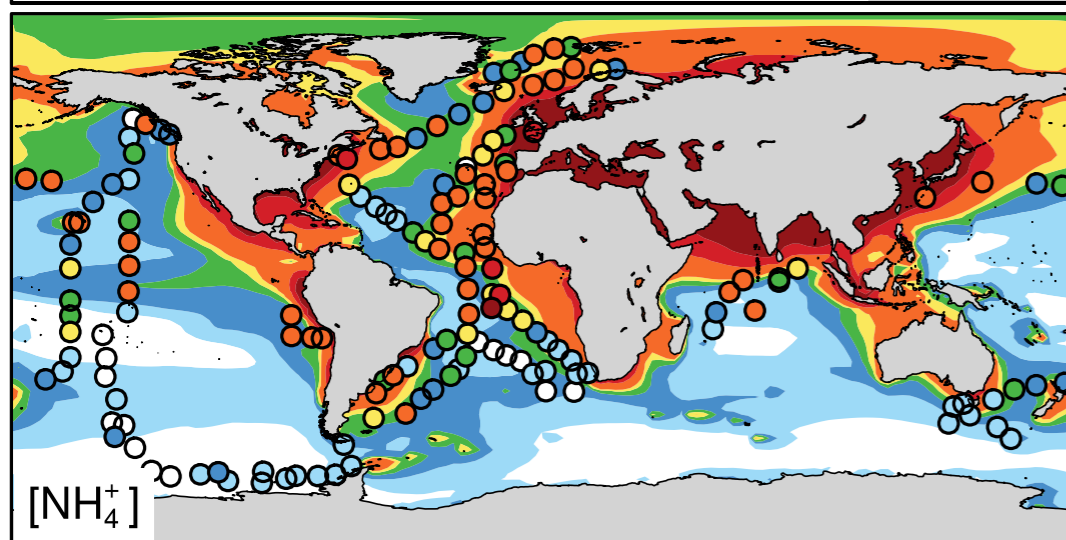
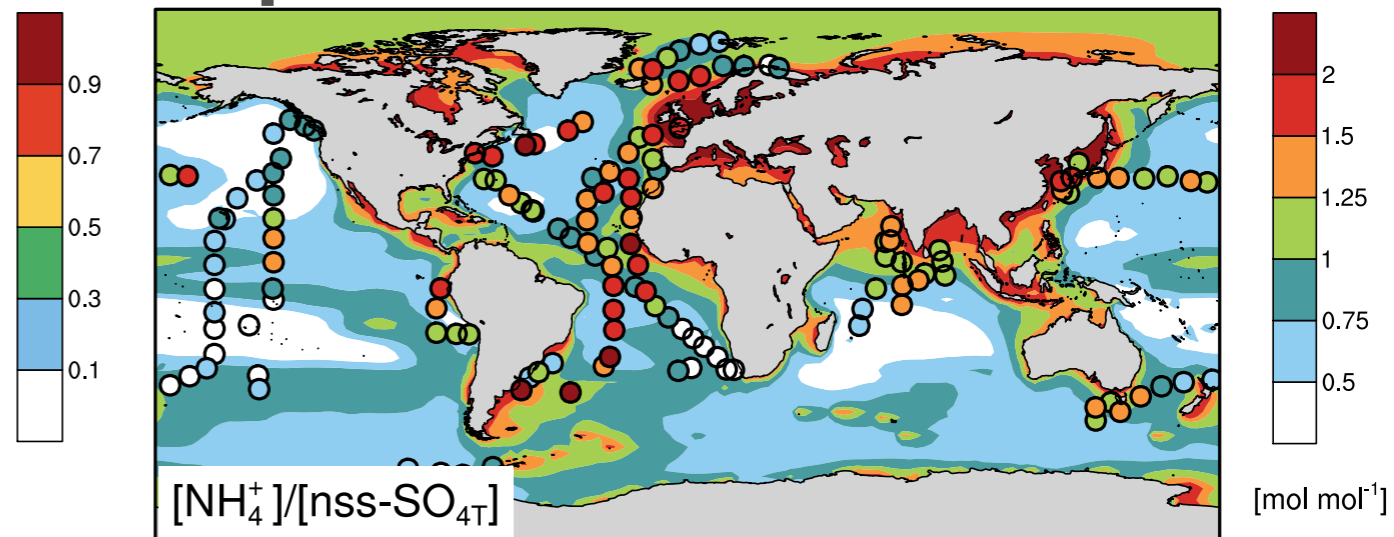
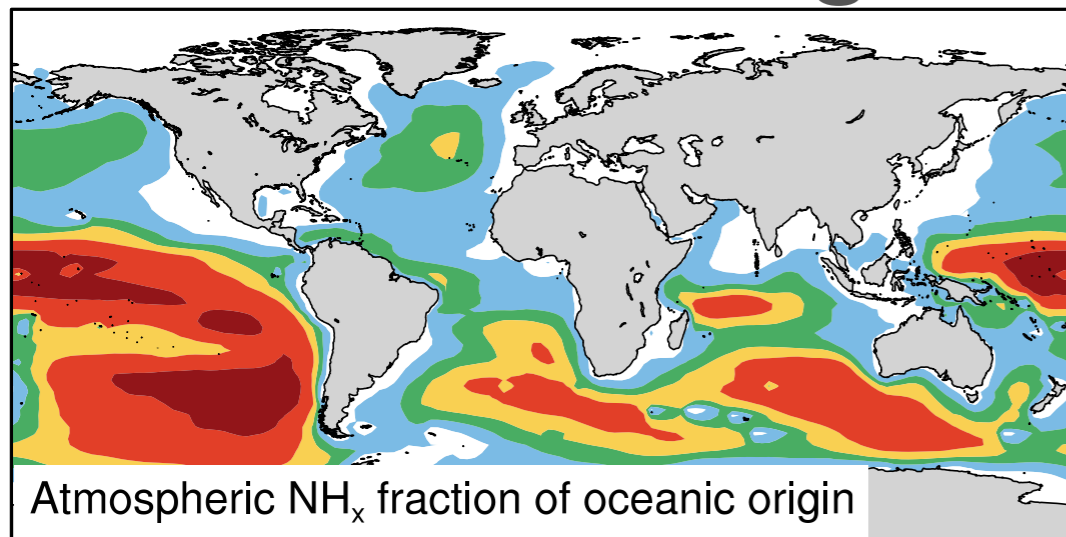


Degree of mixing between SO_4 and seasalt is uncertain

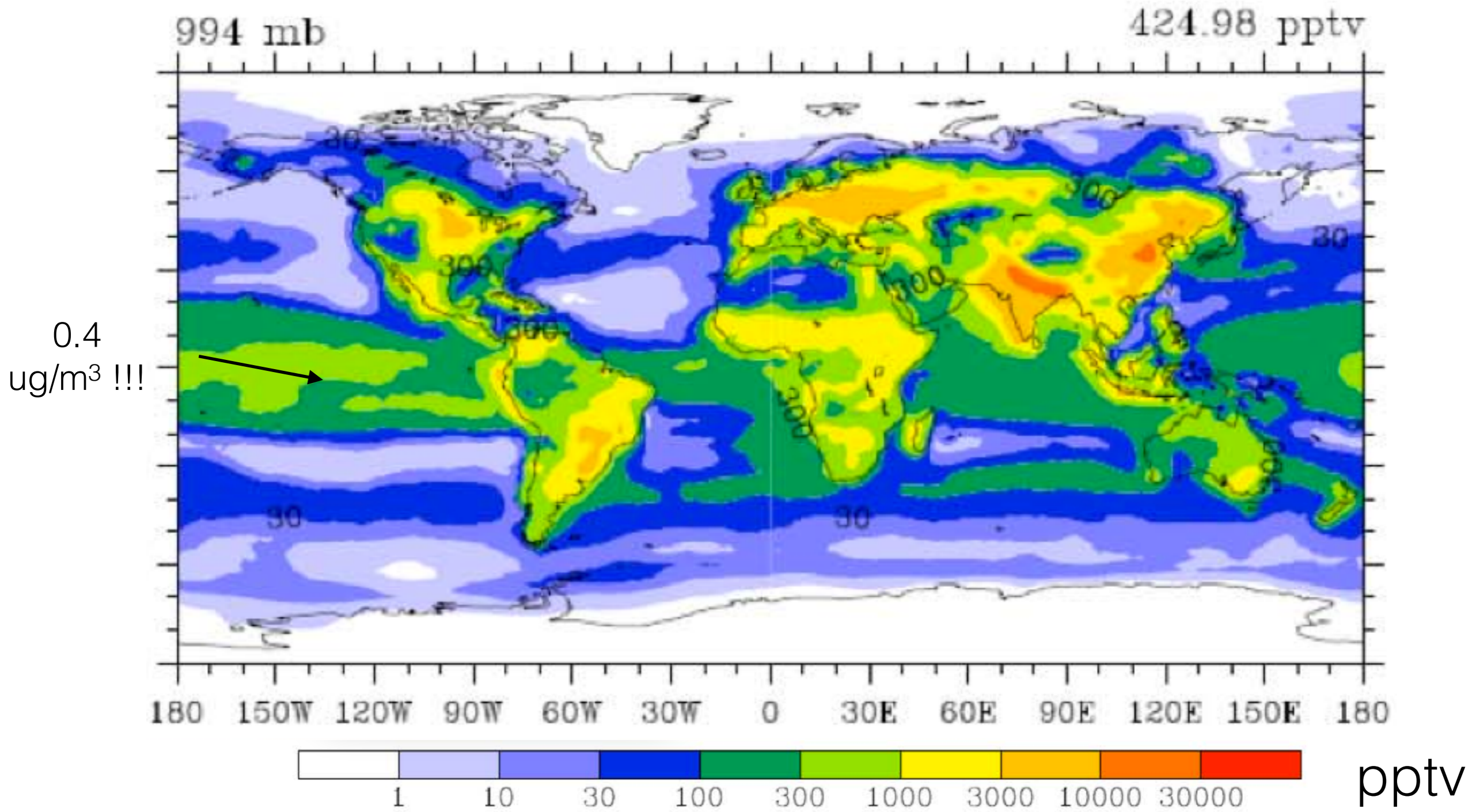
NH_3 measurements are sparse



Evaluation against atmospheric observations



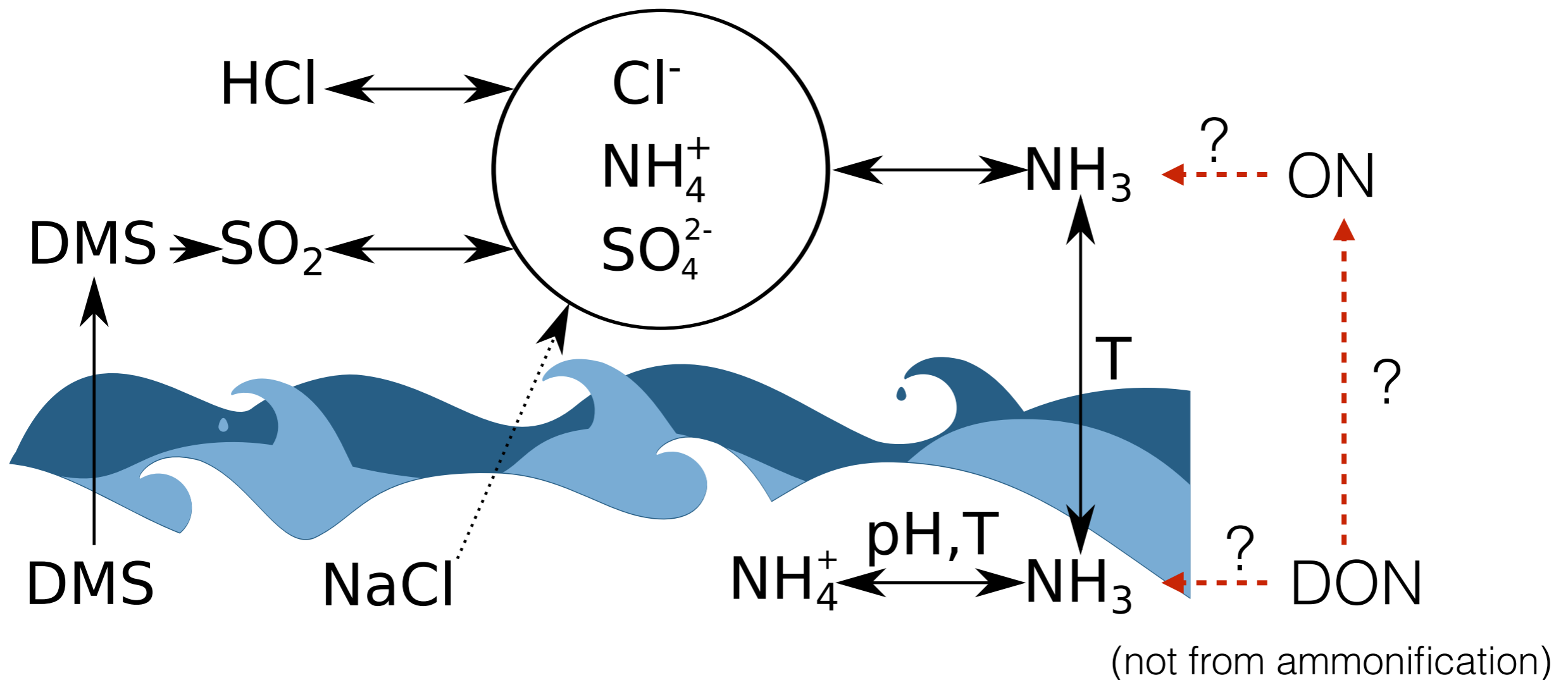
NH₃ concentrations at the surface (Joyce Penner group - GAEA ocean emissions)



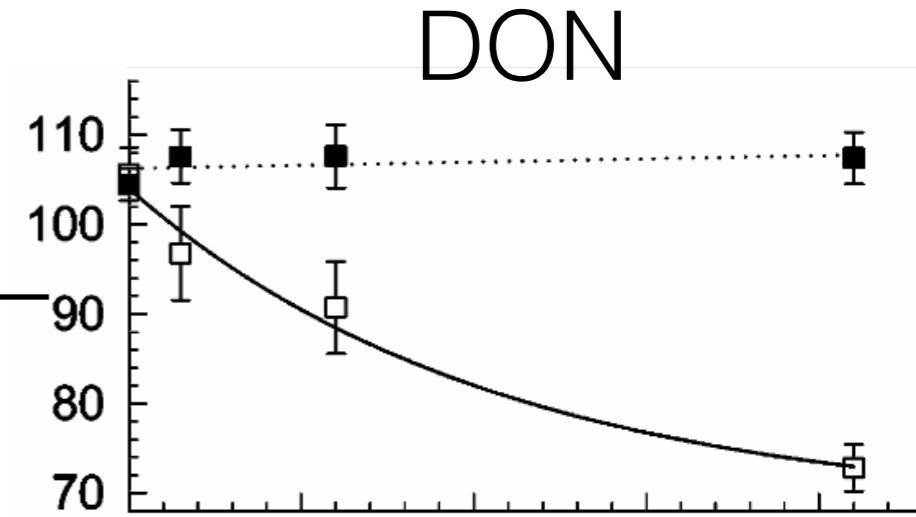
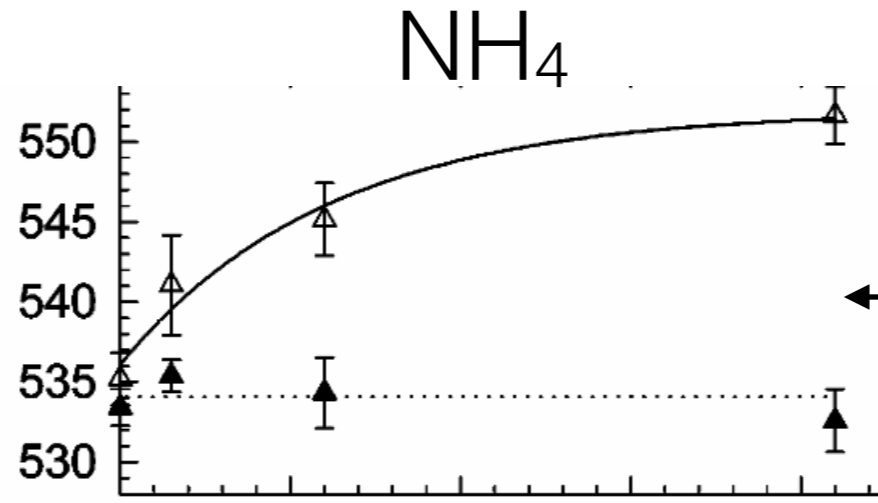
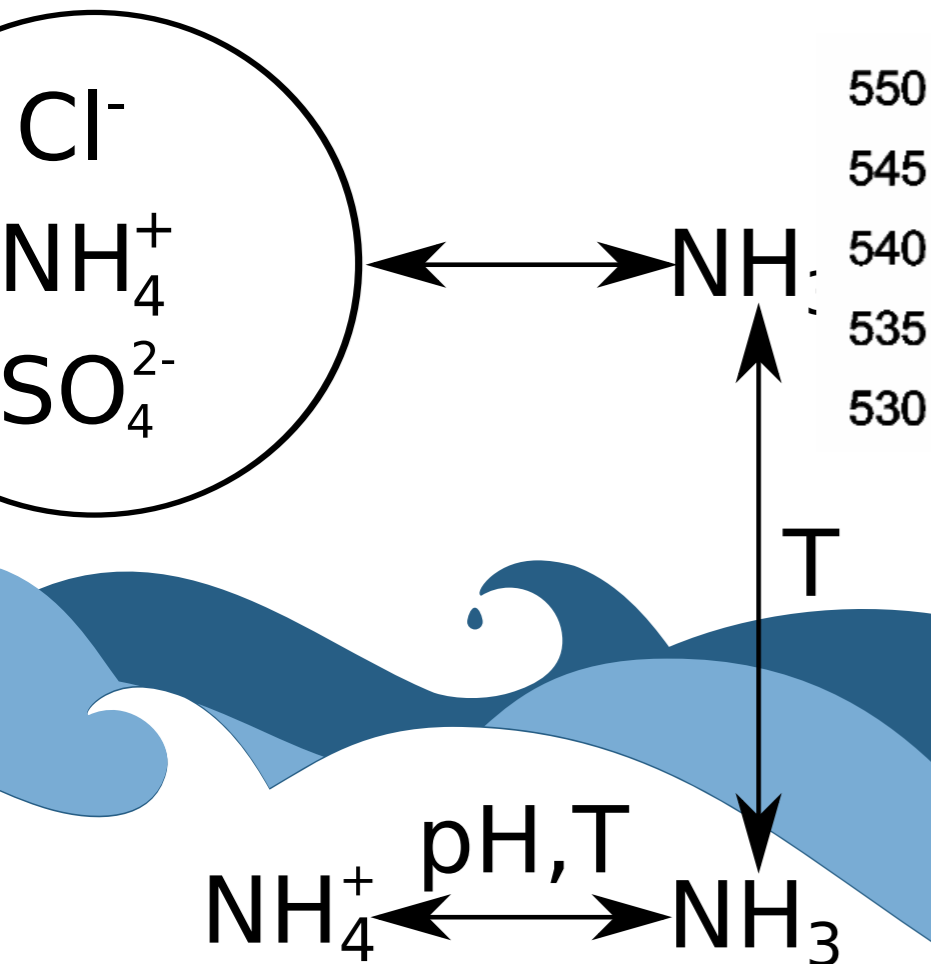
Xu et al. 2012

Apparent inconsistency between seawater and atmospheric observations in the equatorial Pacific

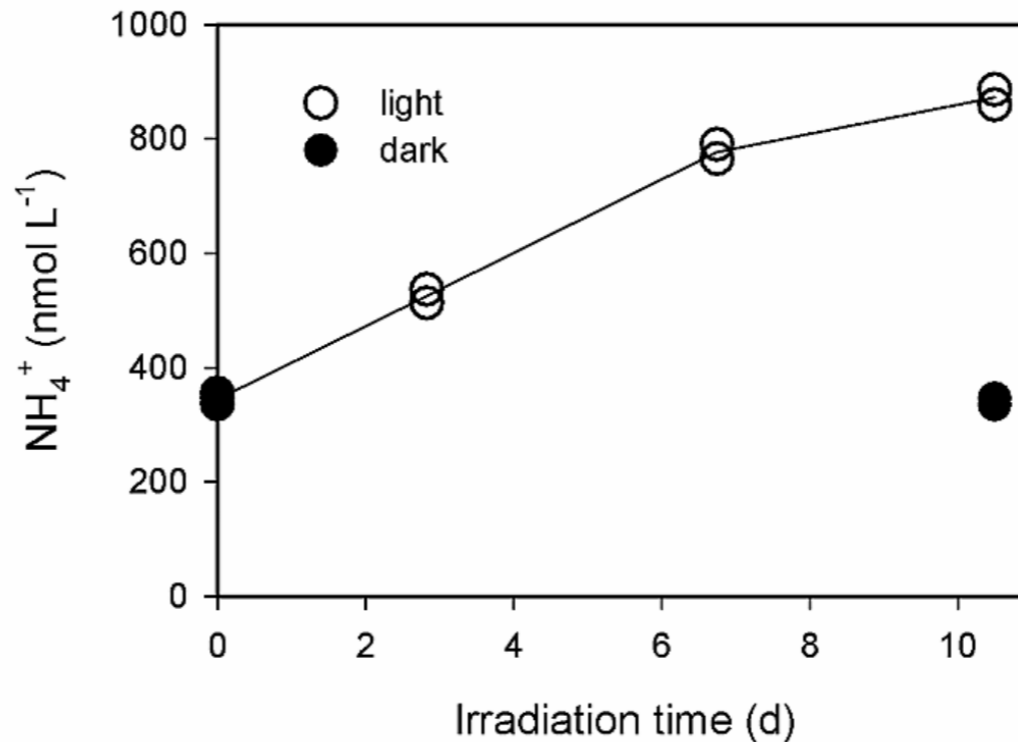
- Inconsistent sampling between atmosphere and seawater (space/time)
- Underestimate of the ocean/atmosphere exchange
- Other marine source of NH_3



Apparent inconsistency between atmospheric and seawater NHx



Zhang 2003

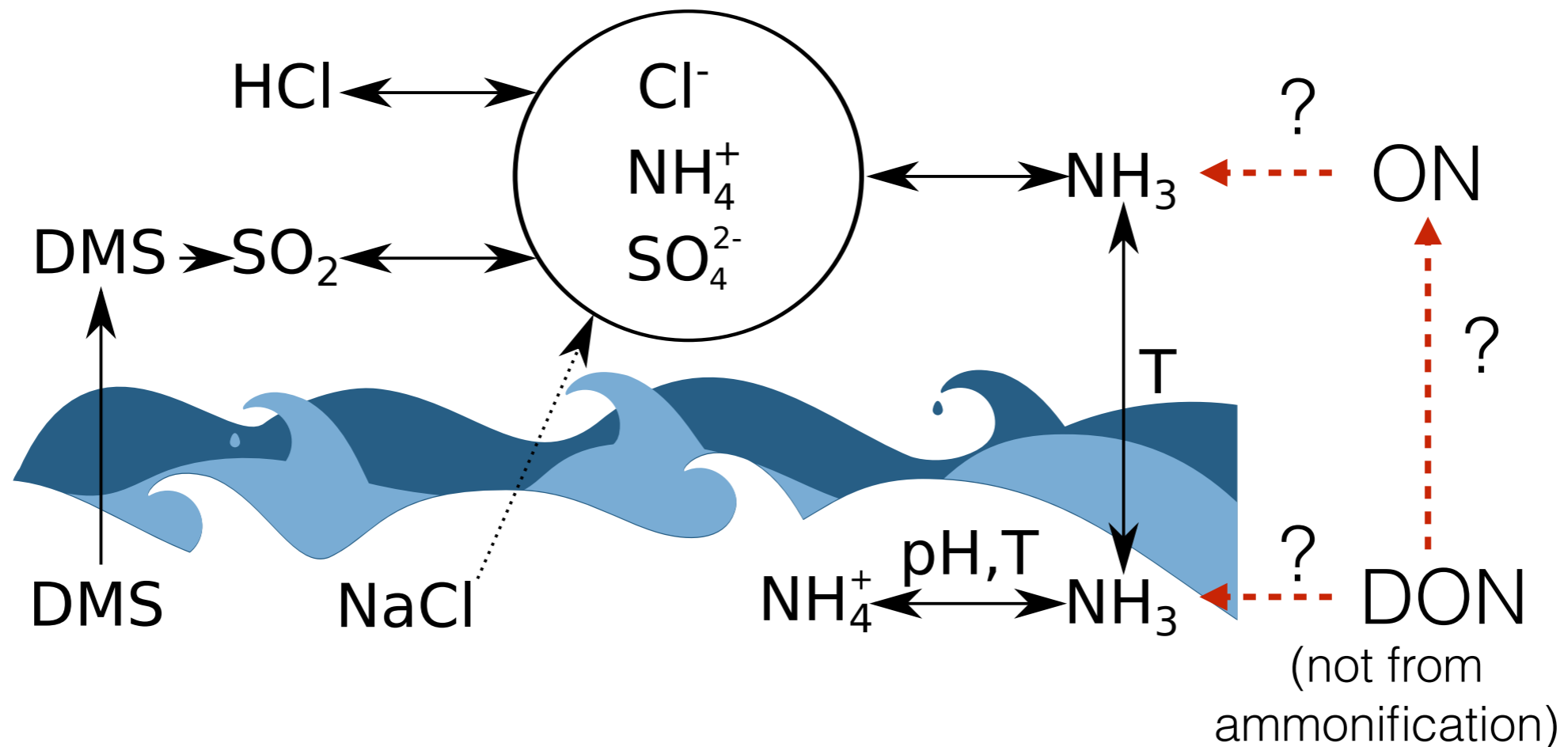


Xie 2012

Summary

1. NH_x (sw) high bias in COBALT can be reduced by increasing the affinity of plankton for NH_x
2. Resulting ocean NH_3 emissions are lower than in the widely used GEIA inventory (2-5 TgN/yr)
3. Ocean and atmospheric observations cannot be reconciled in Equatorial regions

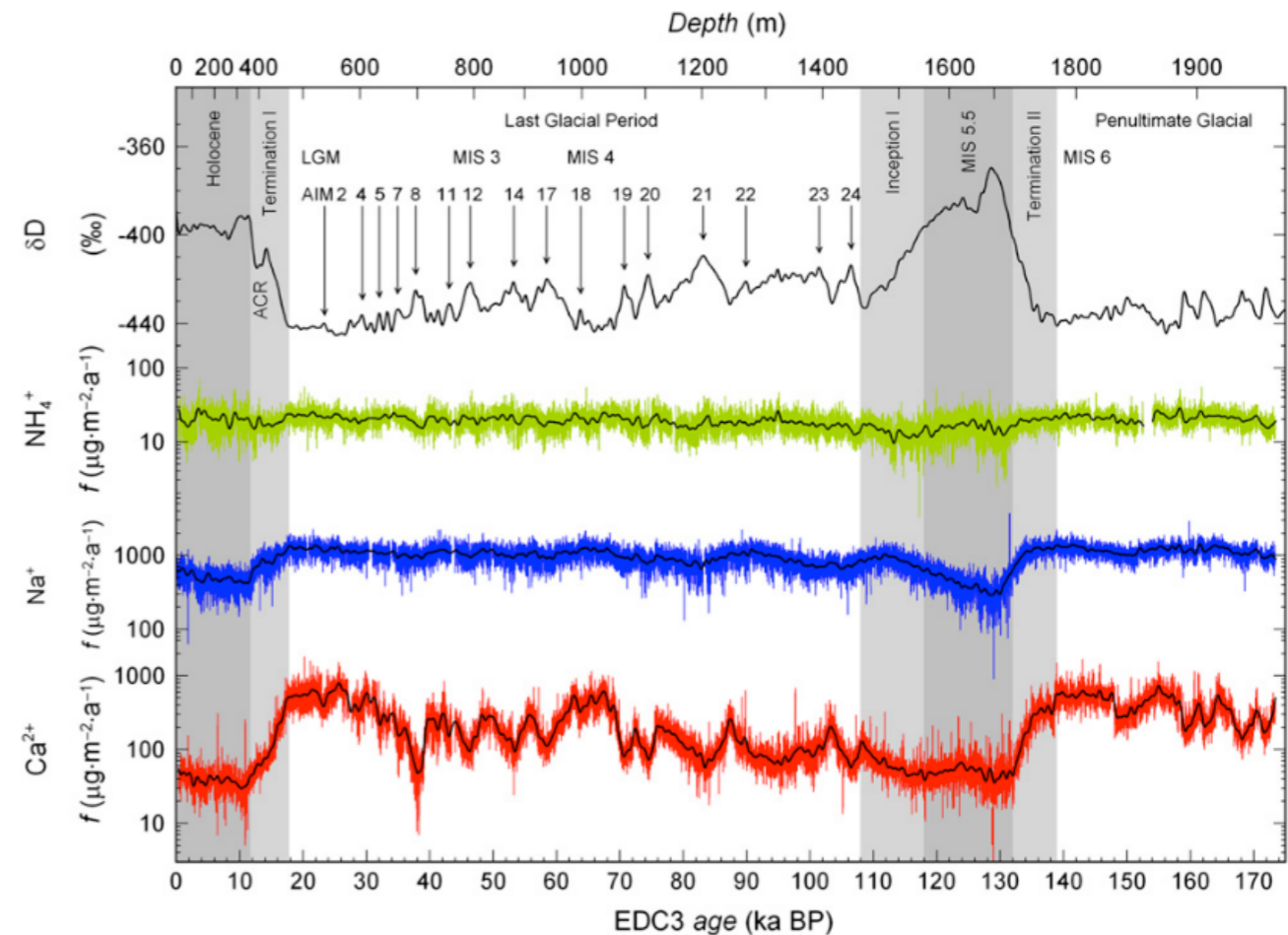
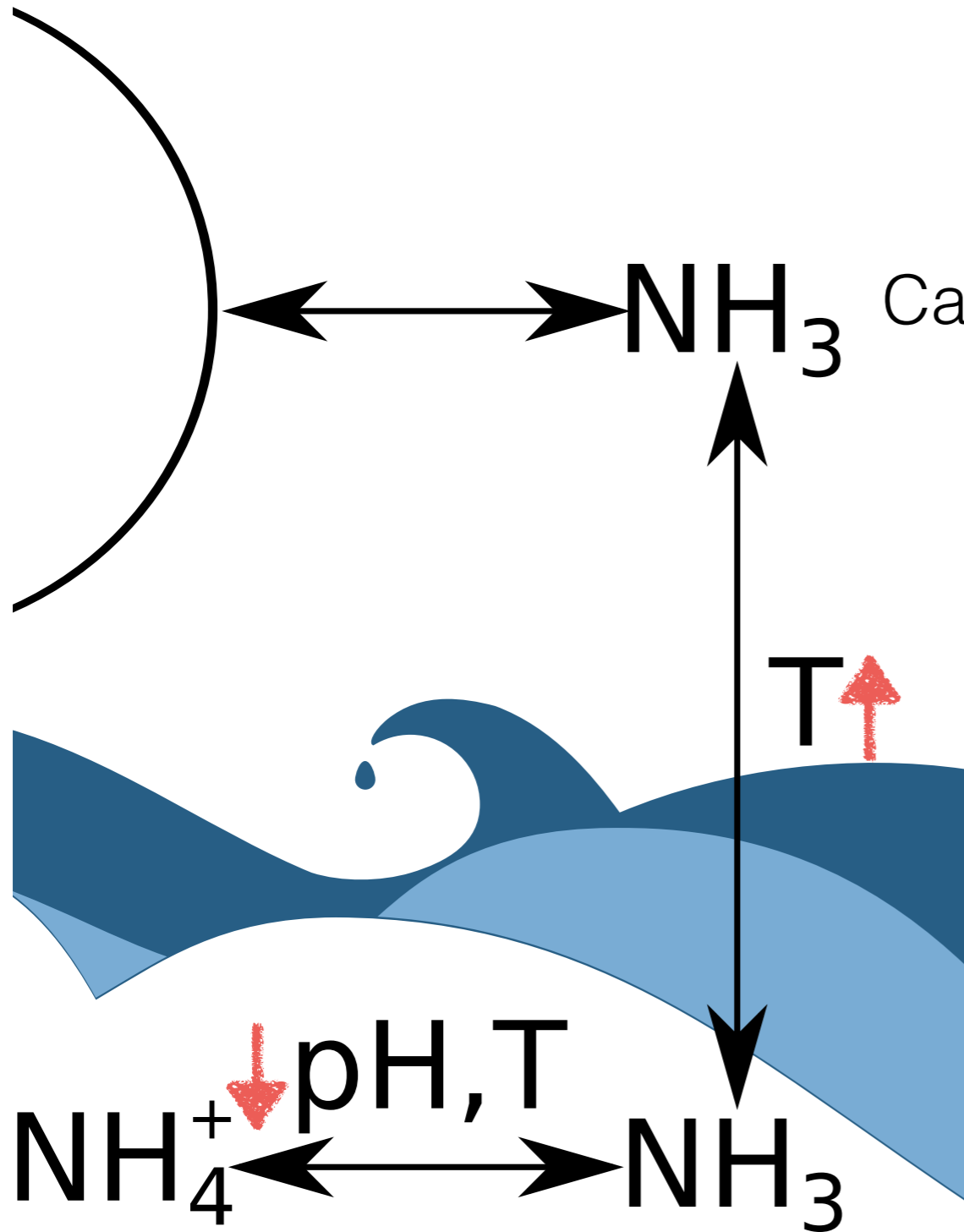
Need for “complete” observations of the NH_3 system (in Eq. Pacific!)



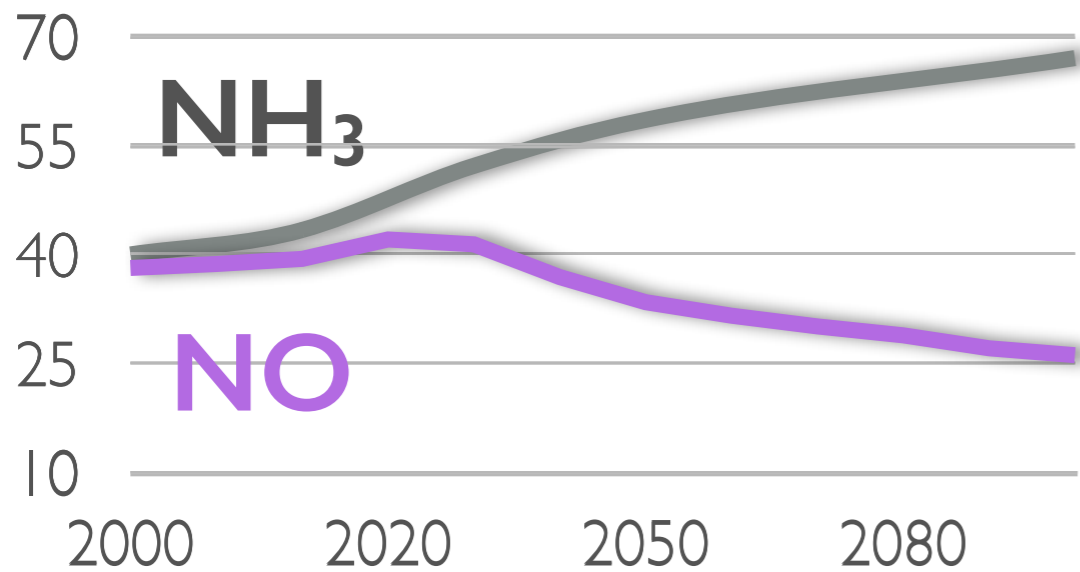
Past and future ocean NH₃?

How are NH₃ emissions going to respond to changes in temperature and pH (physical/biological response)

Can NH₄ in ice core tell us anything about the past ocean?

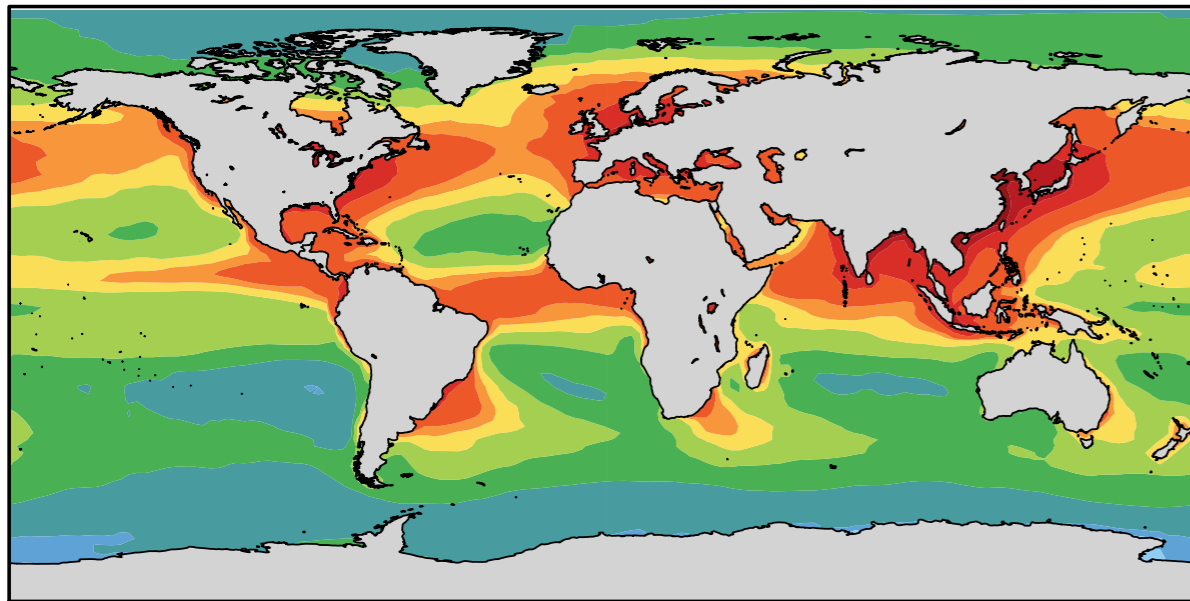


Will rising NH₃ emissions lead to greater N deposition to the ocean?

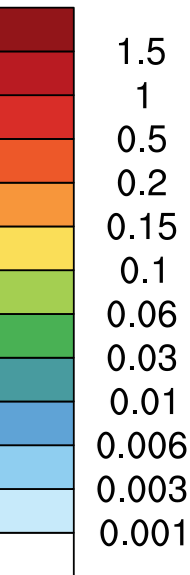
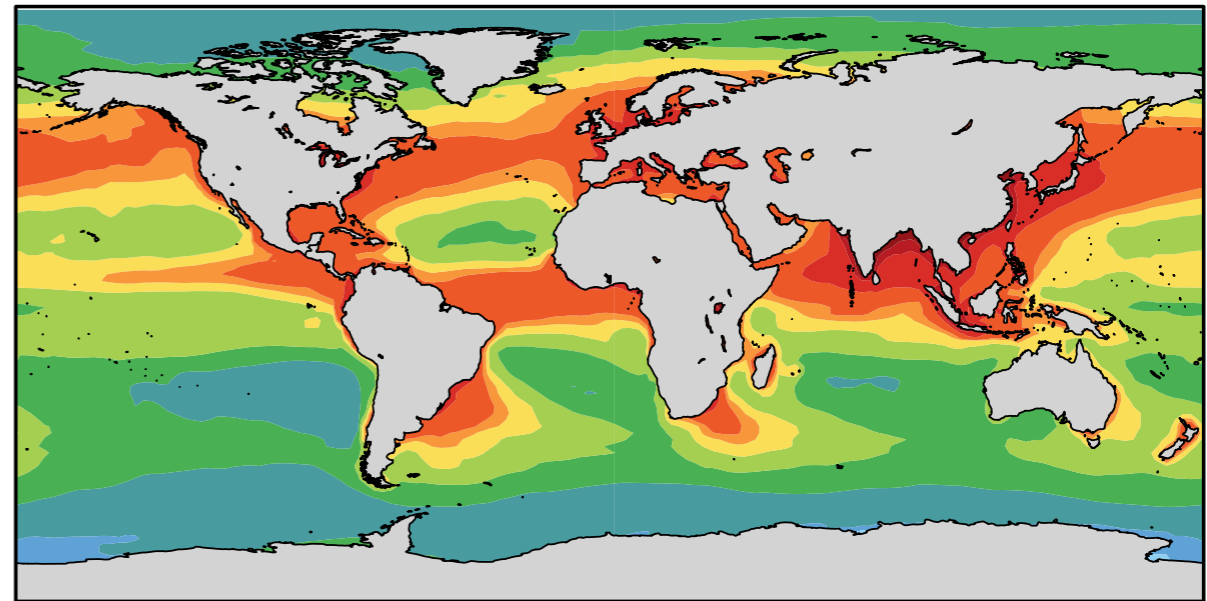


SO₂ emissions are declining rapidly
-> more NH₃ will be in gas-phase
shorter lifetime

~2010



~2050: NH₃ (+40%), NO (-15%), SO₂ (-40%)



Ocean N deposition increases by 5%!
Increasing role of rivers ?

gN/m²/year

Ongoing transition in atmospheric reactive nitrogen

