MODELLING THE CONTRIBUTION OF SO_2 AND NO_X EMISSIONS FROM INTERNATIONAL SHIPPING TO SULPHUR AND OXIDISED NITROGEN DEPOSITION IN THE UNITED KINGDOM

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Contents of Talk

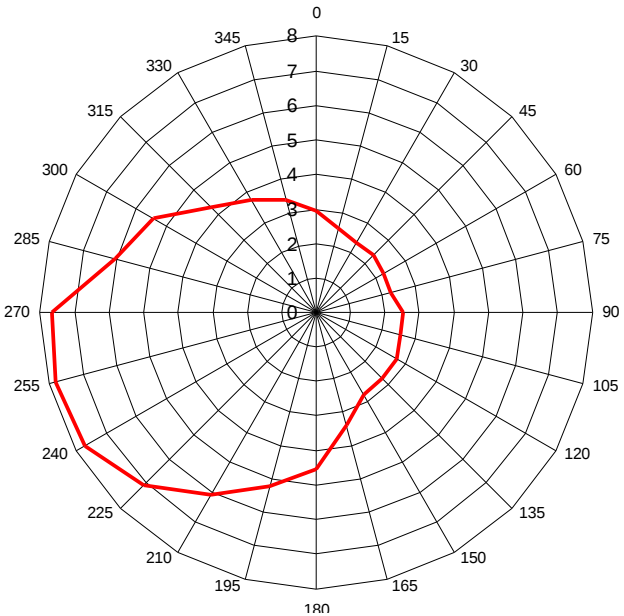
- FRAME model description
- UK Nitrogen and sulphur deposition maps for 2005
- Comparison with measurements
- Source attribution (UK, Europe, shipping)
- Contribution of shipping emissions to sulphur and nitrogen deposition in the UK

OVERVIEW OF THE FRAME MODEL

- 5 x 5 km^2 resolution over the British Isles.
- Input gas and aerosol concentrations at the edge of the model domain calculated with FRAME-Europe, using European emissions and run on the EMEP 50 km scale grid.
- Air column divided into 33 layers moving along straight-line trajectories in a Lagrangian framework with a 1^o angular resolution. Variable layer thickness from 1 m at the surface to 100 m at 2500 m.
- Emissions gridded separately by SNAP sector for SO_2 and NO_x and by agricultural sector for NH_3 and injected into vertical model layers which depend on the sector.
- Vertical diffusion in the air column is calculated using K-theory eddy diffusivity and solved with the Finite Volume Method.
- Wet deposition is calculated using a diurnally varying scavenging coefficient and a ‘constant drizzle’ approximation driven by an annual rainfall map.
- Five land classes: forest, moorland, grassland, arable, urban & water. Vegetation specific canopy resistance parameterisation is employed to calculate dry deposition of SO_2, NO_x and NH_3.
- Chemistry includes gas phase and aqueous phase reactions of oxidised sulphur and oxidised nitrogen and conversion of NH_3 to ammonium sulphate and ammonium nitrate aerosol.

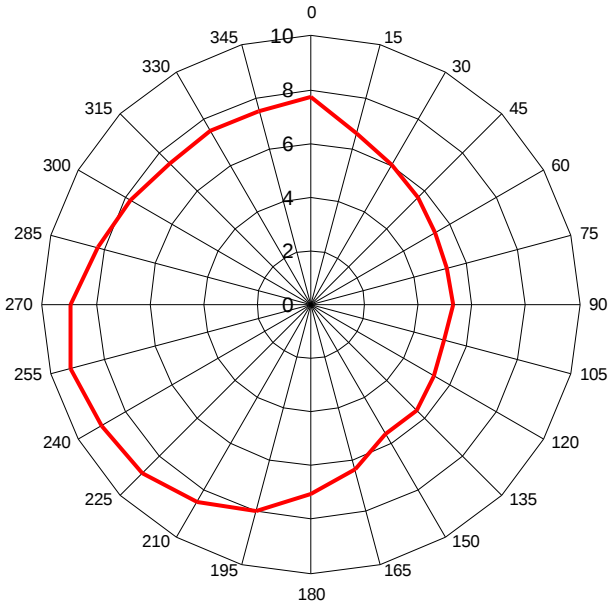
Meteorological Inputs

Wind Frequency Rose

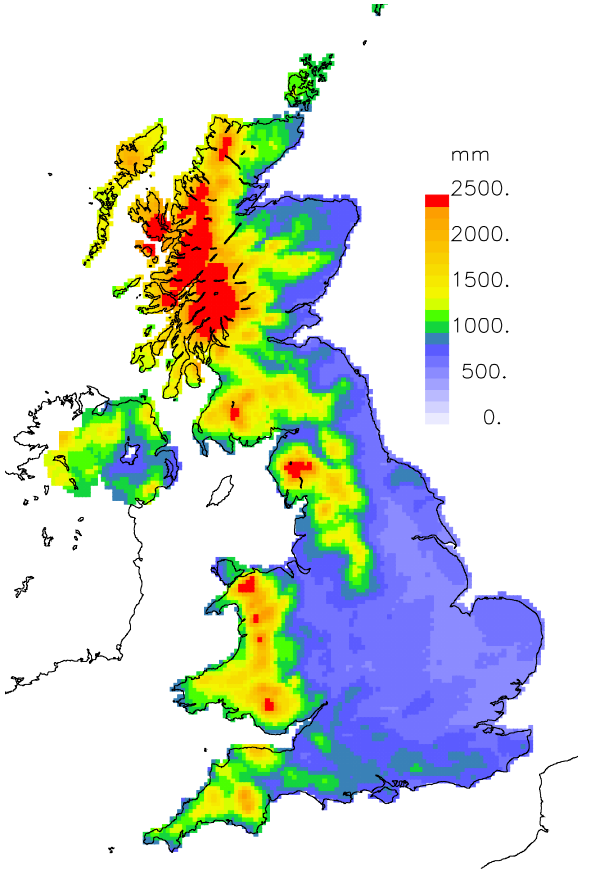


Wind Speed Rose

Calculated from analysis of 10 000 radiosondes
1991-2000 from 4 stations in the British Isles



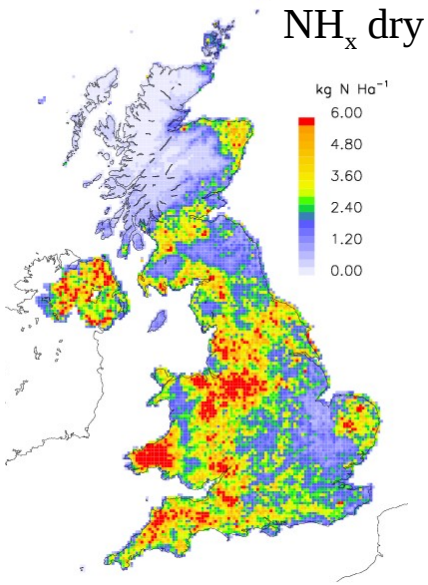
Annual precipitation map



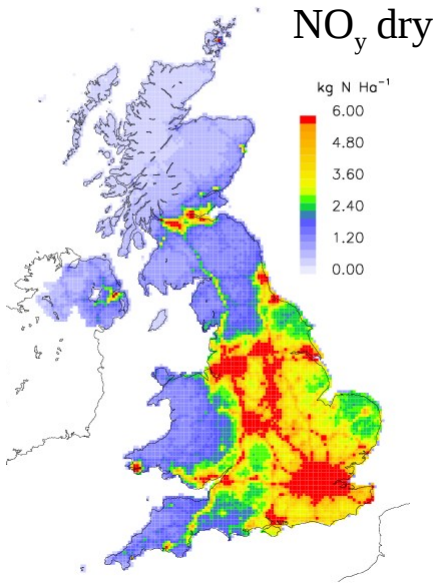
A.J. Dore, M. Vieno, N. Fournier, K.J. Weston & M.A. Sutton (2006) Development of a New Wind Rose for the British Isles Using Radiosonde Data and application to An Atmospheric Transport Model *Q.J.Roy.Met.Soc*. **132**, 2769-2784

2005 Deposition of N and S (kg N/S ha^{-1})

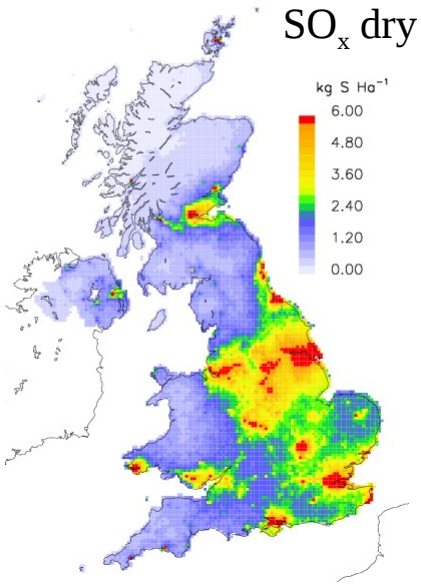
NH_x dry



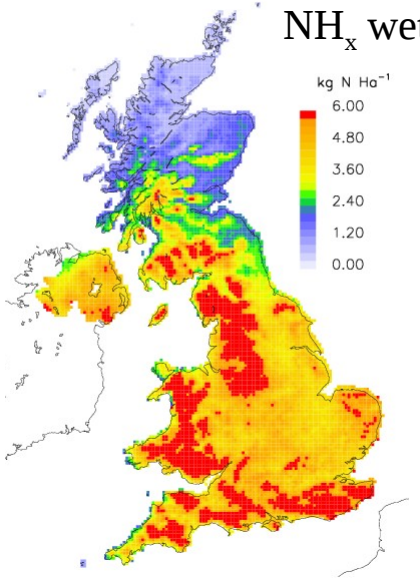
NO_y dry



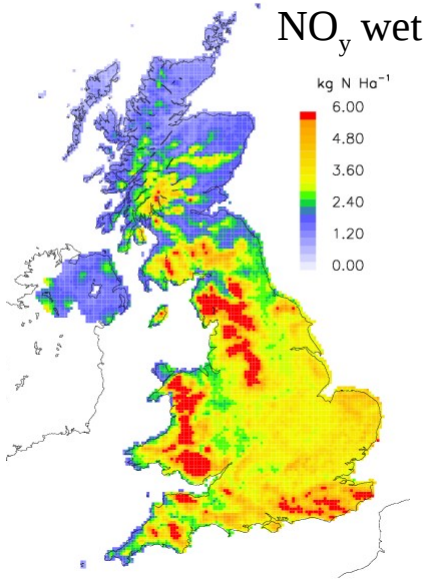
SO_x dry



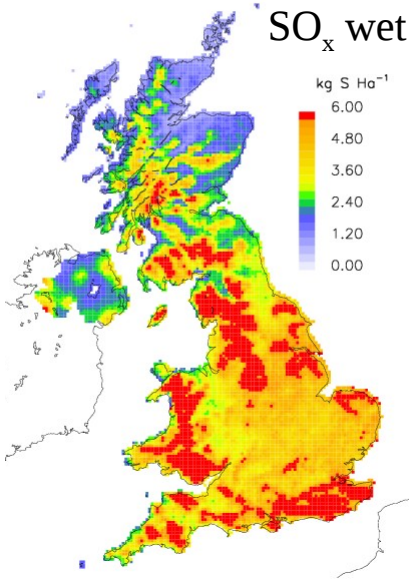
NH_x wet



NO_y wet



SO_x wet



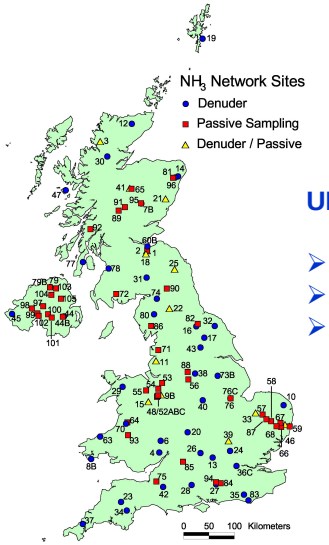
Comparison with measurements

	m	c	R^2
SO_2 gas concentration	1.18	+0.03	0.95
NO_2 gas concentration	1.15	-0.37	0.94
NH_3 gas concentration	0.90	+0.87	0.49
SO_4^{--} aerosol concentration	1.36	-0.09	0.92
NO_3^- aerosol concentration	1.27	-0.14	0.96
NH_4^+ aerosol concentration	0.98	-0.04	0.97
HNO_3 concentration	0.54	+0.24	0.67
SO_4^- wet deposition	1.07	+0.08	0.68
NO_3^{--} wet deposition	0.89	+0.11	0.68
NH_4^+ wet deposition	0.90	+0.17	0.70

Comparison of model (y) with measurements (x) of annual average concentrations (µg m^{-3}) and wet deposition (kg N/S Ha^{-1}) from the national monitoring networks.

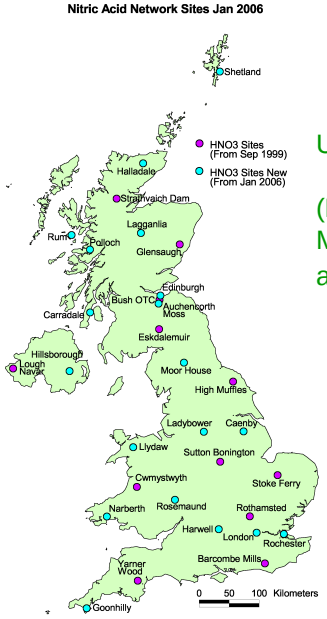
$$y_{(modelled)} = m * x_{(measured)} + c$$

R^2 is the correlation coefficient



UK National Ammonia Monitoring

- **94 sites with monthly measurements**
- **57 sites with DELTA samplers**
- **49 sites with ALPHA samplers**

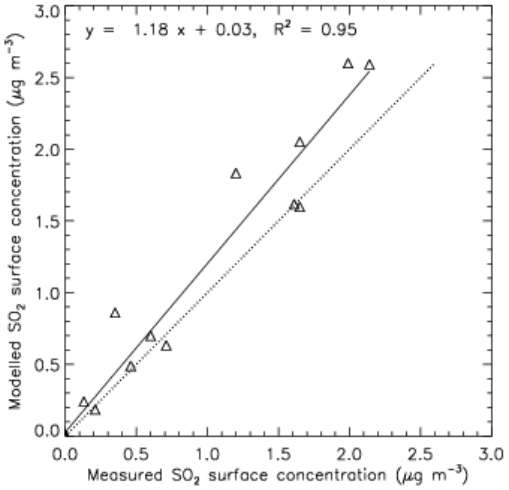


UK Nitric acid **DELTA** sampler monitoring network

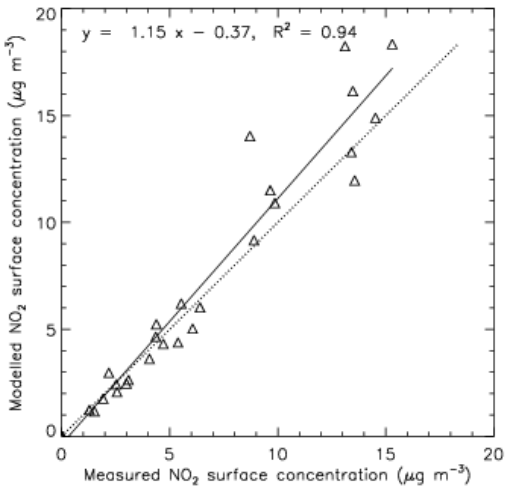
(**DE**nuder for **L**ong **T**erm **A**tmospheric sampling)
Measurements include HNO_3, NH_3 & SO_2 gas and NO_3^-, NH_4^+ & SO_4^{--} aerosol chemistry

Correlation of model with measurements

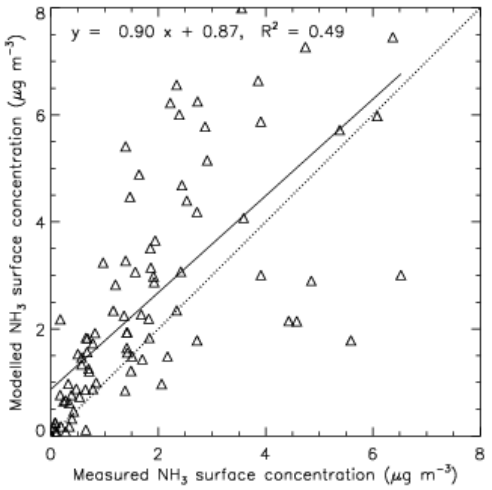
SO_2 concentration



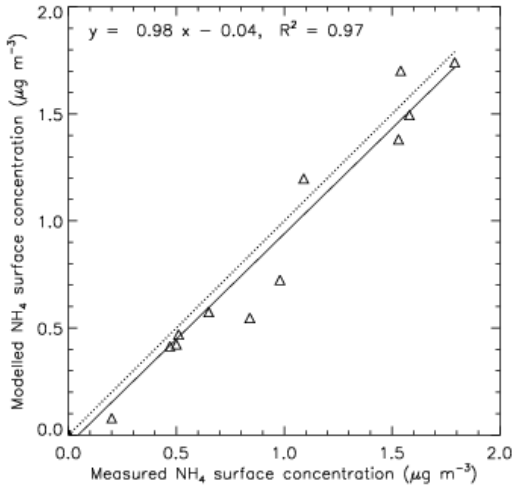
NO_2 concentration



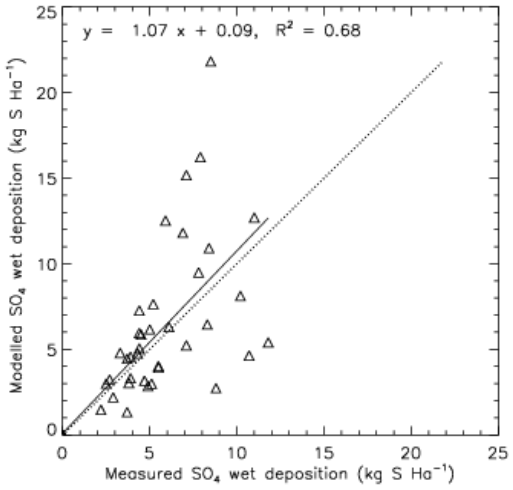
NH_3 concentration



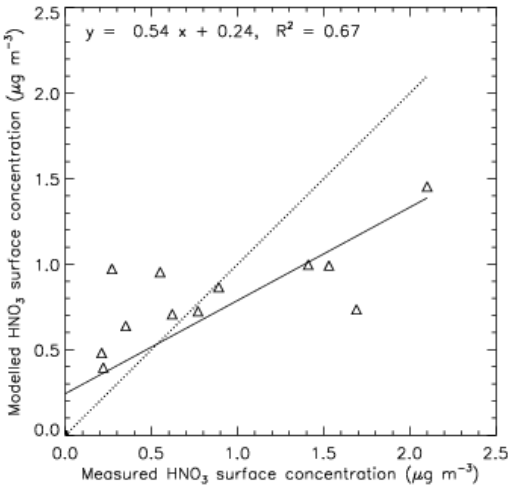
NH_4^+ aerosol concentration



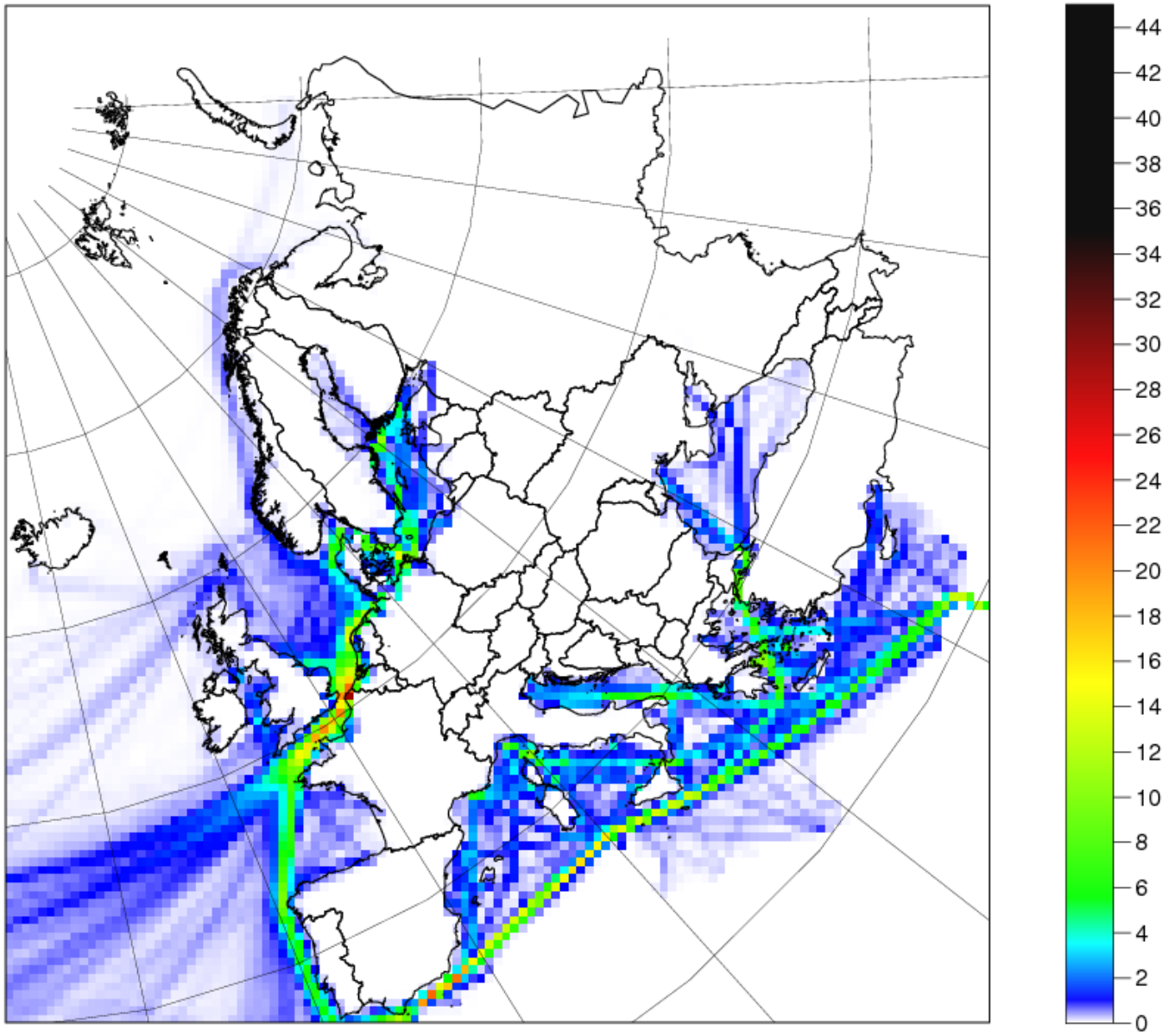
SO_4^- wet deposition



HNO_3 concentration



FRAME-Europe 2005 SO_2 shipping emissions (Kg S Ha^{-1})



Emissions of SO_2 & NO_x from international shipping

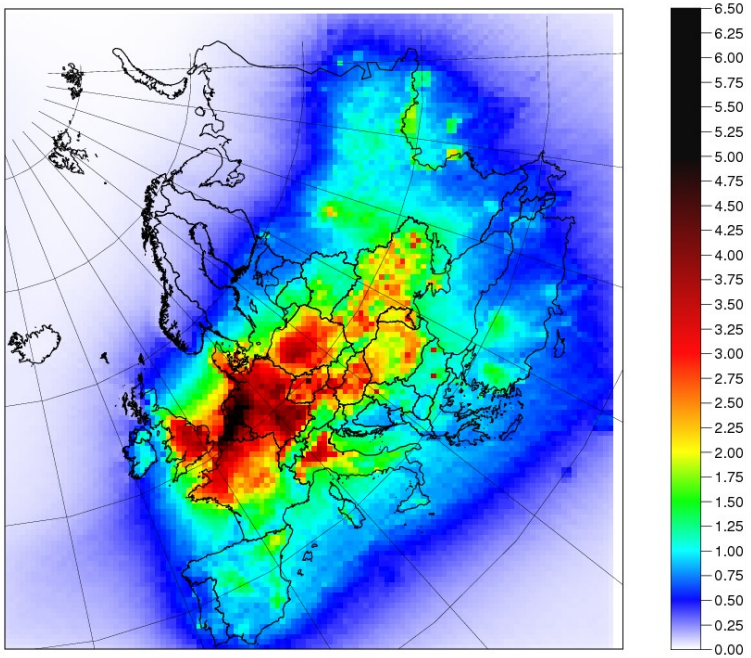
- Large uncertainties in the magnitude and location of SO_2 and NO_x emissions from international shipping (global estimates range from 3.2[(1)] to 4.7[(2)] Tg S-SO_2 $year^{-1}$)
- Global emissions are INCREASING at a rate of 1.5 - 2.5% $year^{-1}$.
- UN International Maritime Organisation agreement to restrict emissions of SO_2 from international shipping. This includes a sulphur cap of 0.5% for bunker fuel from 2020.
- Shipping emissions are difficult to control due to their international mobility.
- Emissions are currently available on the EMEP 50 km grid. High emissions in port areas overlap land squares in a 5 km resolution model. Regridding from 'land' to 'sea' results in further uncertainties.

[(1)] Endresen, Ø., E. Sørgård, J. K. Sundet, S. B. Dalsøren, I. S. A. Isaksen, T. F. Berglen, and G. Gravir (2003), Emission from international sea transportation and environmental impact, J. Geophys. Res., 108(D17), 4560, doi:10.1029/2002JD002898.

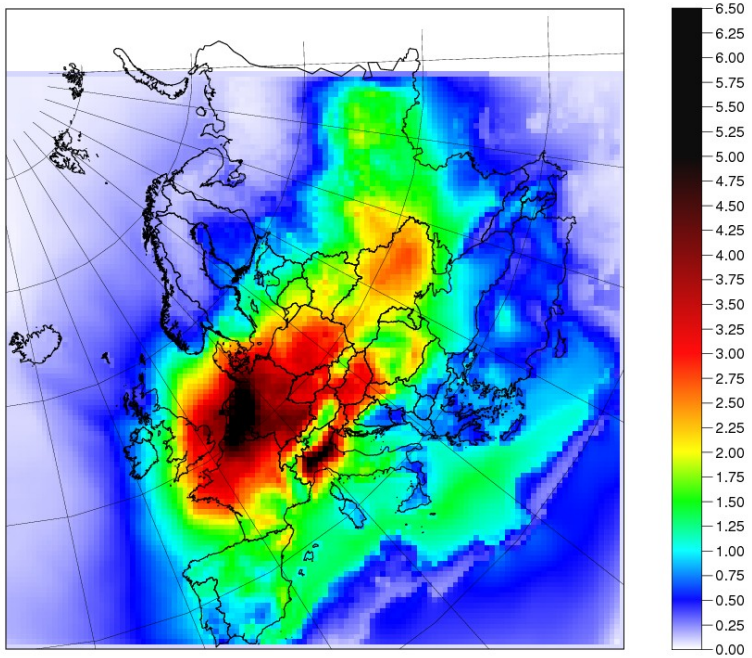
[(2)] Corbett, J. J., and H. W. Köhler (2003), Updated emissions from ocean shipping, J. Geophys. Res., 108(D20), 4650, doi: 10.1029/2003JD003751.

2005 NO_3^- aerosol concentration (μg m^{-3})

FRAME-Europe



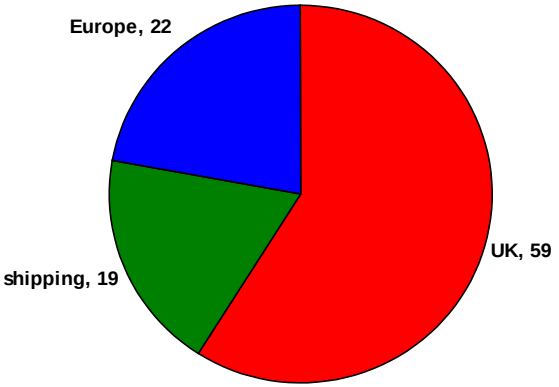
EMEP



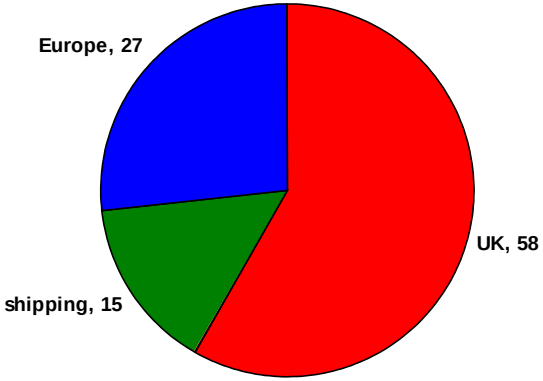
EMEP data provided by Hilde Fagerli, Met.No.

Source-attribution for deposition in the UK for the year 2005

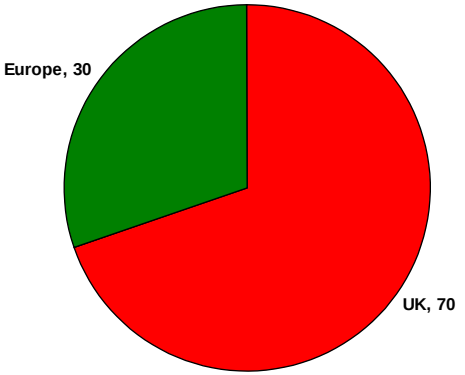
FRAME SO_x deposition



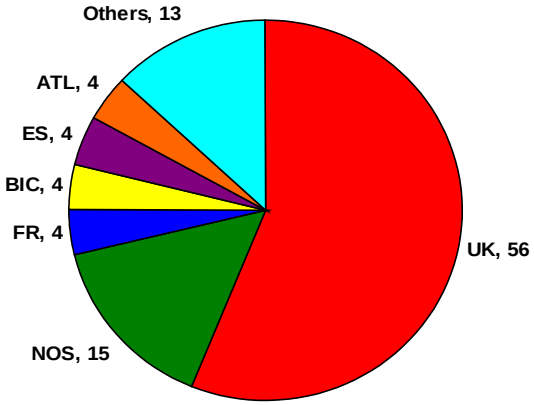
FRAME NO_y deposition



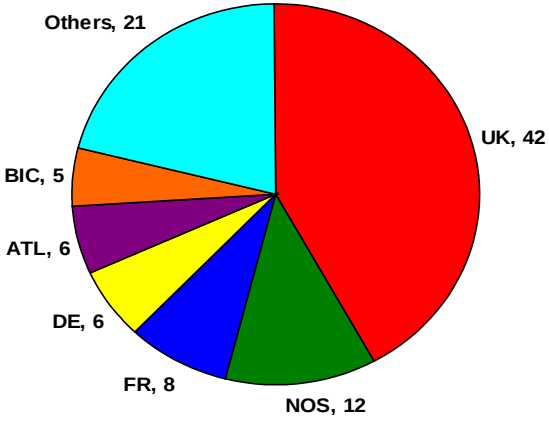
FRAME NH_x deposition



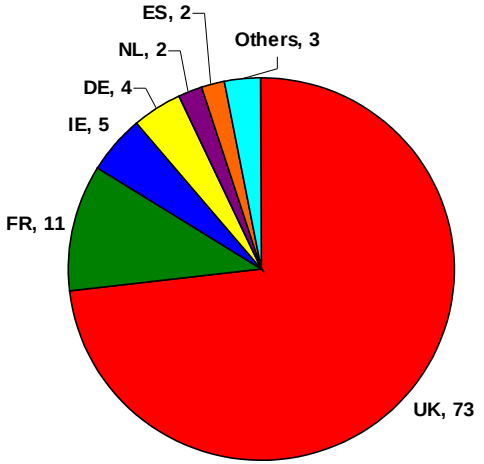
EMEP SO_x deposition



EMEP NO_y deposition



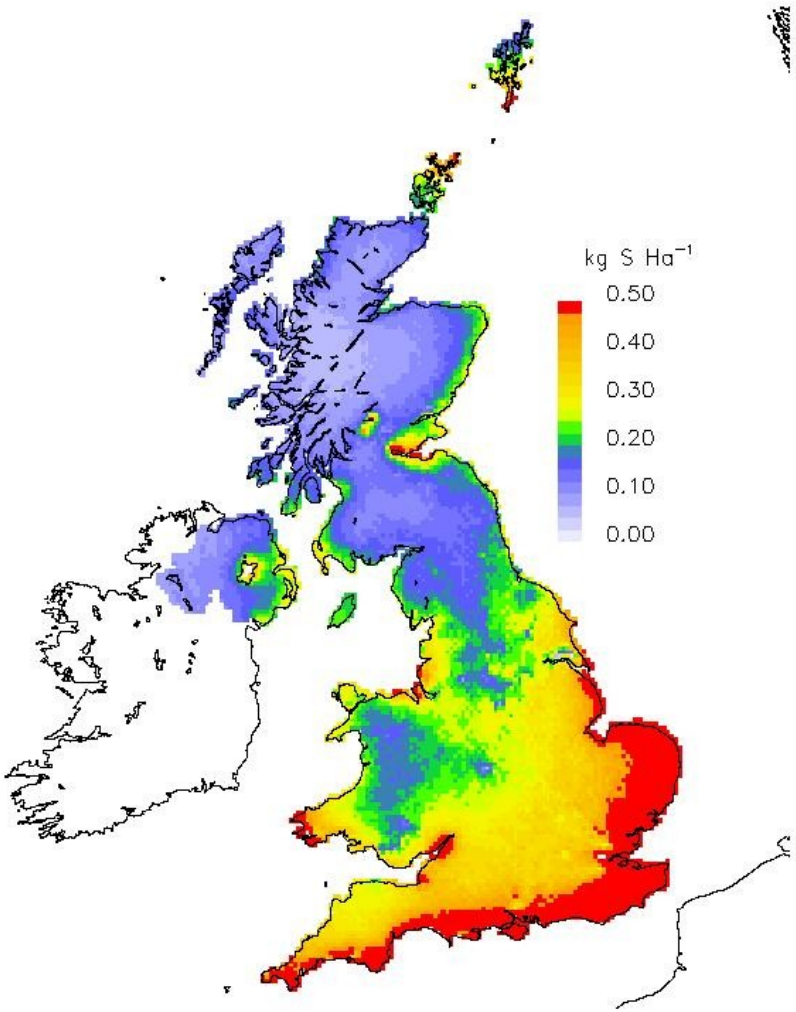
EMEP NH_x deposition



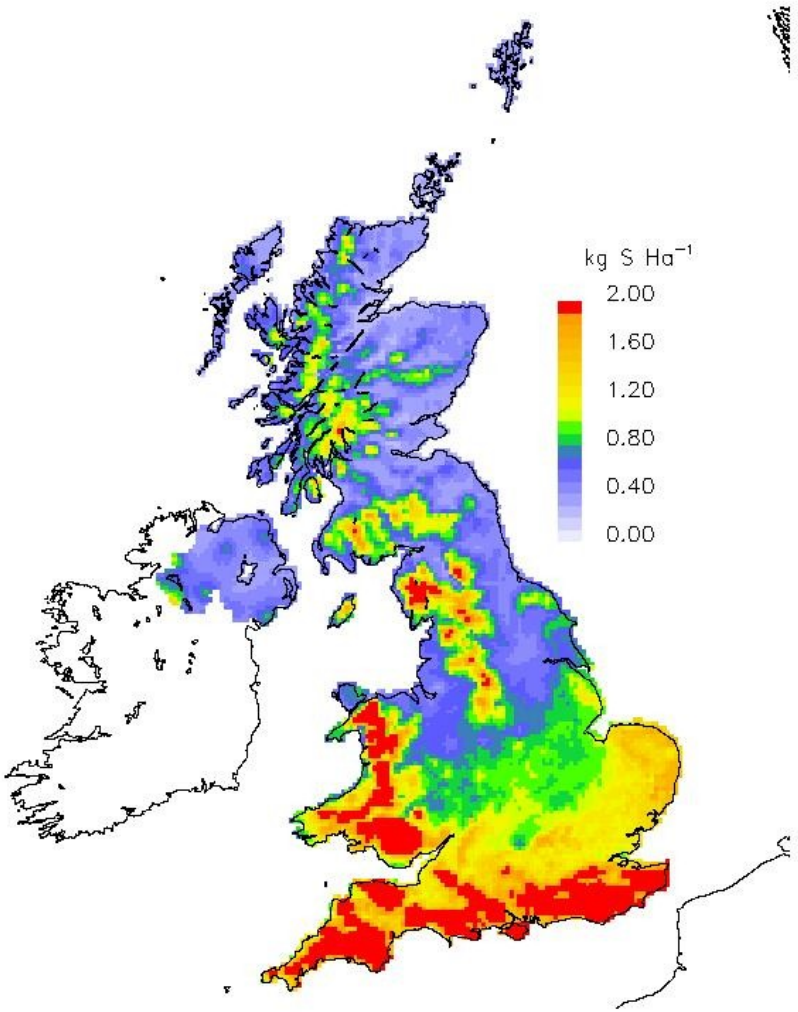
EMEP data from 2005 UK country report

Influence of international shipping emissions on sulphur deposition

2005 Dry deposition (kg S Ha^{-1})



2005 Wet deposition (kg S Ha^{-1})



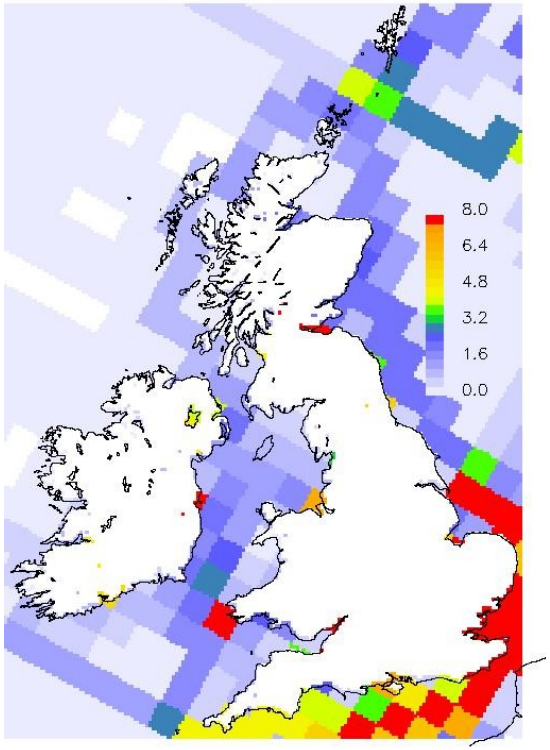
Sulphur and Nitrogen Deposition Budgets to the United Kingdom

for 2005, 2020 Business As Usual scenario and 2020 with IMO agreement on shipping emissions

	2005		2020 BAU		2020 IMO	
	SO_x	NO_y	SO_x	NO_y	SO_x	NO_y
Dry deposition (Gg S/N)	60	71	38	44	26	44
Wet deposition (Gg S/N)	125	104	84	71	59	71
Total deposition (Gg S/N)	185	175	122	115	85	115
% contribution to total dep from shipping emissions	**19**	**15**	**37**	**20**	**9**	**20**

Dore, A.J., M. Vieno, Y.S. Tang, U. Dragosits, A. Dosio, K.J. Weston and M.A. Sutton (2007) Modelling the atmospheric transport and deposition of sulphur and nitrogen over the United Kingdom and assessment of the influence of SO_2 emissions from international shipping. *Atmos.Env.* **41**, 2355-2367.

Conclusion



- The FRAME model was applied to estimate S and N deposition in the UK. The model was able to reproduce measurements of gas & aerosol measurements & wet deposition.

- Emissions of SO_2 and NO_x from international shipping make a major contribution to S and N deposition in the UK (and to acidification / eutrophication).

- There is considerable uncertainty in the global distribution and magnitude of emissions from international shipping

- Global emissions of SO_2 and NOx from international shipping are increasing by 1.5% - 2.5% $year^{-1}$.

- Future work will focus on incorporation of new fine (5km) resolution emissions maps into the model to more effectively model the transport of pollutants from ships in coastal areas.

Thank you for your attention