Major changes in forest carbon and nitrogen cycling caused by declining sulphur deposition

Filip Oulehle, Chris Evans, Henning Meesenburg, Jakub Hruska, Pavel Kram, Jiri Kopacek, Bridget Emmett, Jack Cosby, Dick Wright

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

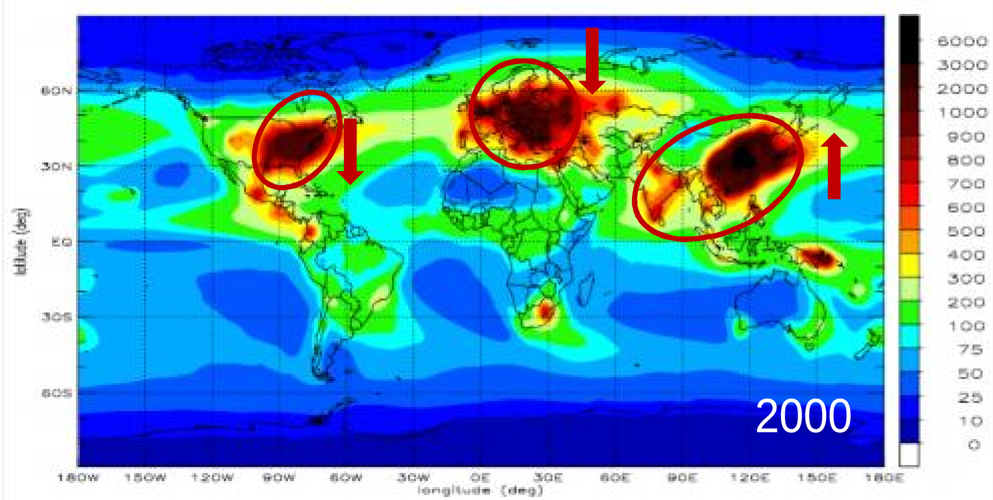
CZECH GEOLOGICAL SURVEY

Five things that I am going to talk about:

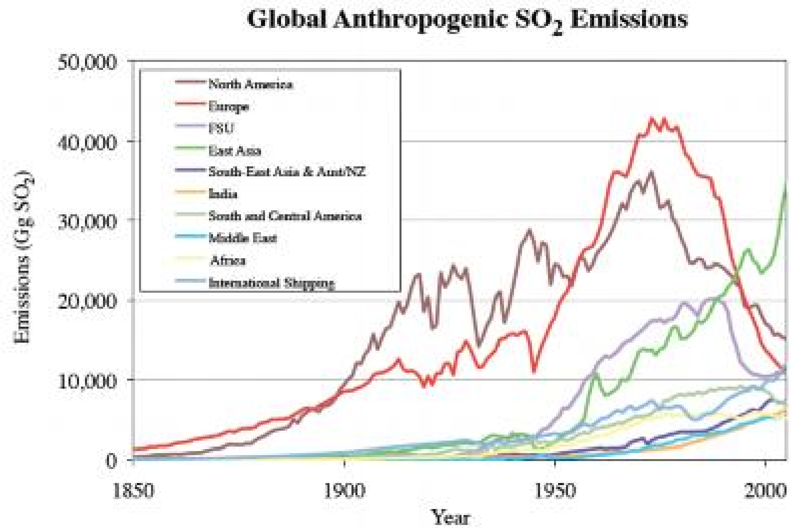
- Global extent of acid deposition (namely S)
- Effects of acid deposition on DOC
- Effects of acid deposition on forest soil carbon accumulation
- Effects of acid deposition on forest productivity
- Coupled C and N dynamics in MAGIC model

Global extent of sulphur and nitrogen deposition

Total S deposition (mg m^{-2} yr^{-1})

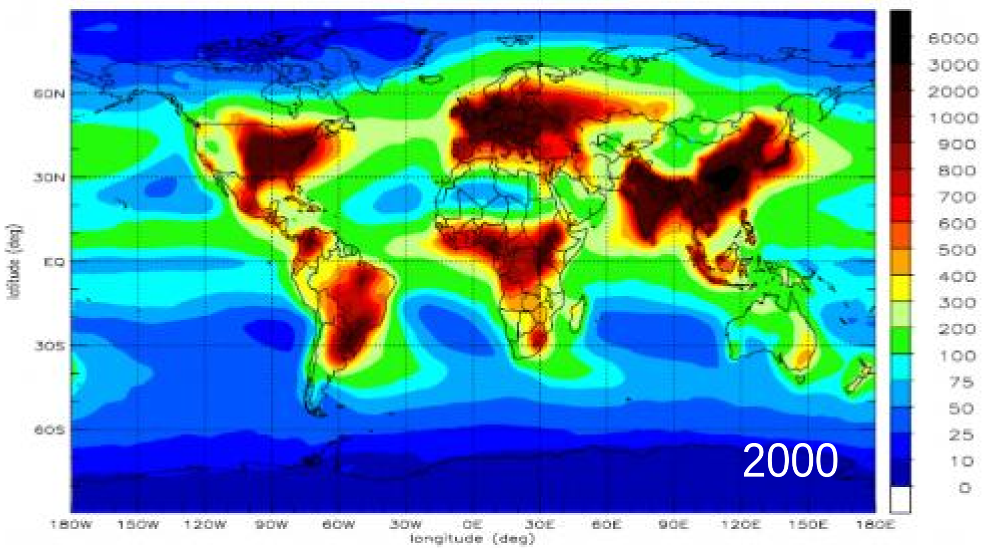


Simulation of future (2030) S deposition using CLE (Current Legislation scenario)

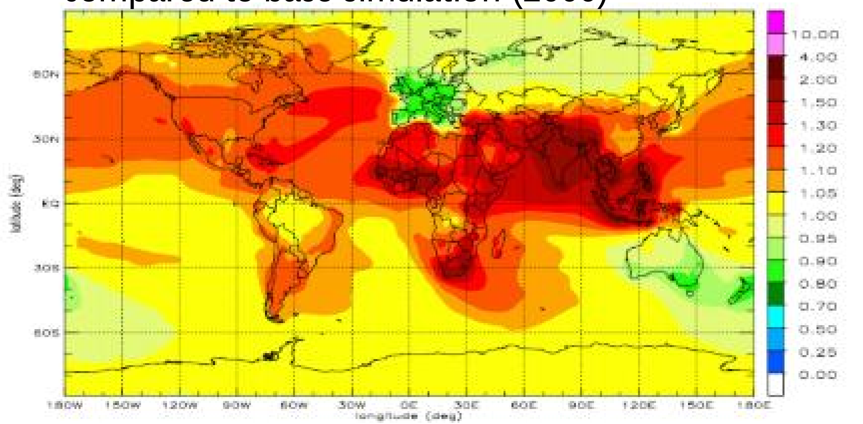


Smith S.J. et al., 2011, ATMOSPHERIC CHEMISTRY AND PHYSICS, 11, 1101–1116

Total N deposition (mg m^{-2} yr^{-1})



Ratio of total N deposition for scenario CLE (2030) compared to base simulation (2000)



Dentener F. et al., 2006, GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 20, GB4003

Effects of acid deposition on DOC

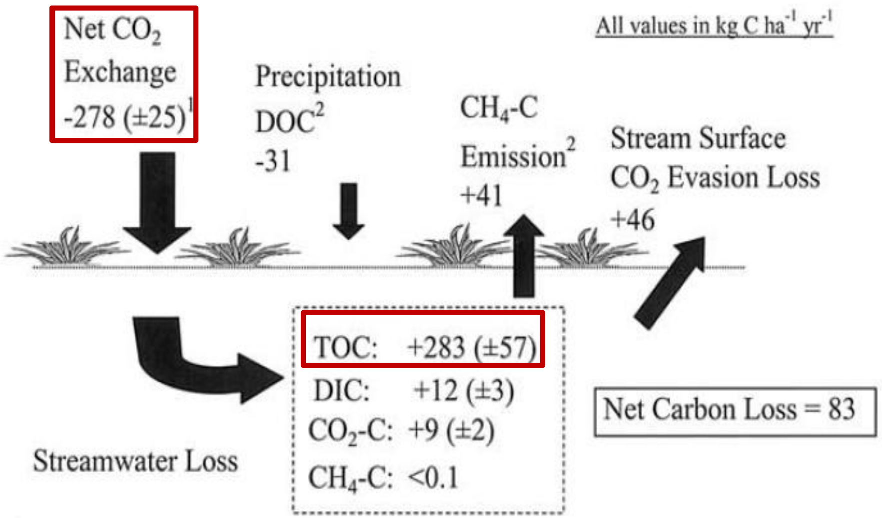
Why DOC (Dissolved Organic Carbon)?

• Northern peatlands store about 39% of the global terrestrial C pool

• Stream DOC may reflect changes in catchment C cycling

• Global estimates of both annual riverine organic C transport and soil C sequestration rates are comparable, suggesting that riverine losses of organic C may regulate future changes in soil C storage

Estimated annual carbon budget for the Auchencorth catchment in Scotland

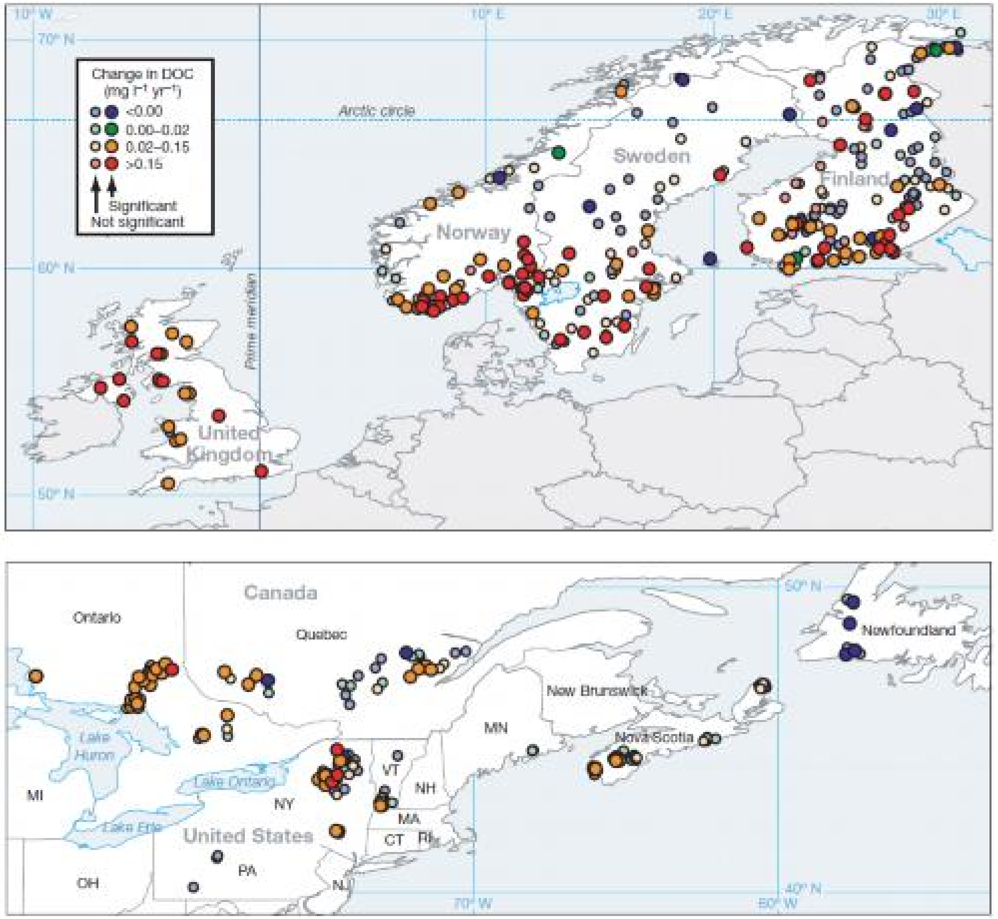


Billett M.F. et al., 2004, GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 18, GB1024

Effects of acid deposition on DOC

DOC has increased:

- In much of Europe and North America
- In lakes and streams
- In forests and moorlands
- In waterlogged and aerated soils
- At high and low flows



Monteith D. T. et al., 2007, NATURE, VOL. 450, 537-540

Effects of acid deposition on DOC

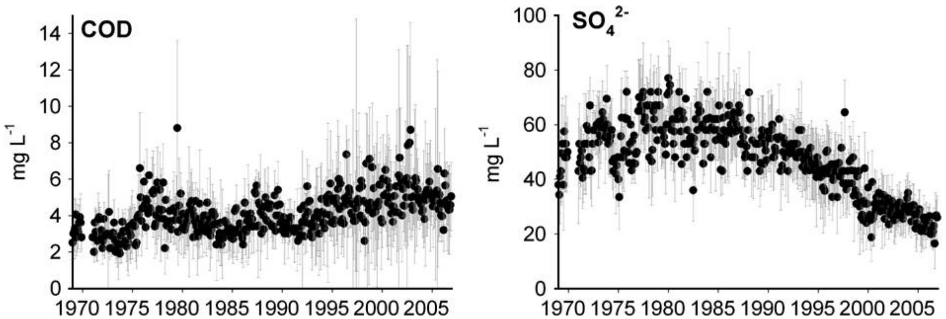
Strong evidence of a relationship between acid deposition and organic matter solubility

Solubility of DOC is dependent on:

- Acidity
- Ionic strength
- Aluminium concentration

Decomposition of organic matter (which produces DOC) also affected by pH, …and N

Temporal coherence between SO_4 declines and DOC increases in Central European catchments



Oulehle F. and Hruska J., 2009, ENVIRONMENTAL POLLUTION 157: 3433-3439

Results from acidity manipulation experiment in UK

Acid treatment – H_2SO_4
Alkaline treatment - NaOH + $MgCl_2$

Consistent, positive DOC response to pH change at all sites, which can be described by a simple, general relationship, such that a 1 unit increase in soil solution pH is sufficient to more than double DOC concentrations.

Conclusions

- Declining S deposition appears able to explain a large part of observed DOC trends.

- Therefore, rising DOC in well studied areas (Europe, USA) should not be misconstrued as evidence of rising DOC in unmonitored waters globally.
  - threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO_2 concentration may have been overstated in those areas.

- Past acid conditions may have reduced decomposition rates, allowing a pool of relatively labile organic matter to accumulate, from which DOC is generated as acidity decreases.

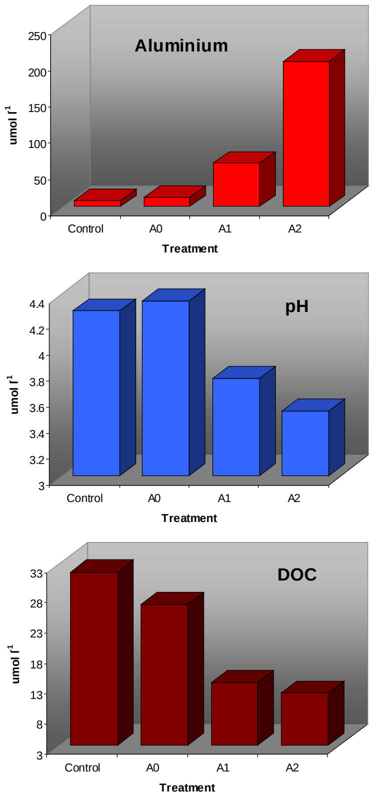
Effects of acid deposition on soil C accumulation

Experimental evidence:

- Suppression of litter decomposition under simulated acid (S) deposition (e.g. Pennanen et al., 1998; Persson et al., 1989)

- Adverse effect of aluminium on C availability for microorganisms (e.g. Scheel et al., 2007)

- pH effect on microbial enzyme activity (e.g. Sinsabaugh, 2010)

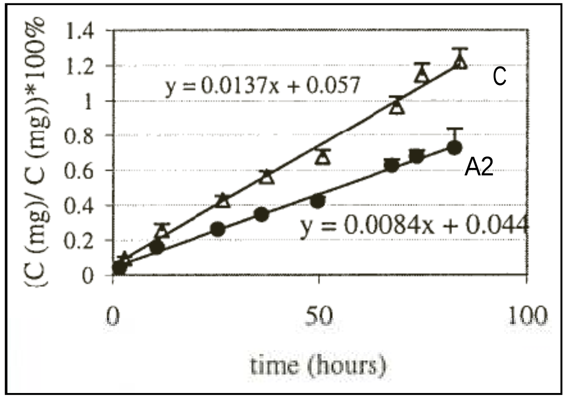


Al addition (as $AlCl_3$):

effects on soil water chemistry

Al addition:

effects on soil respiration



Mulder J. et al., 2001, WATER, AIR AND SOIL POLLUTION 130: 989-994

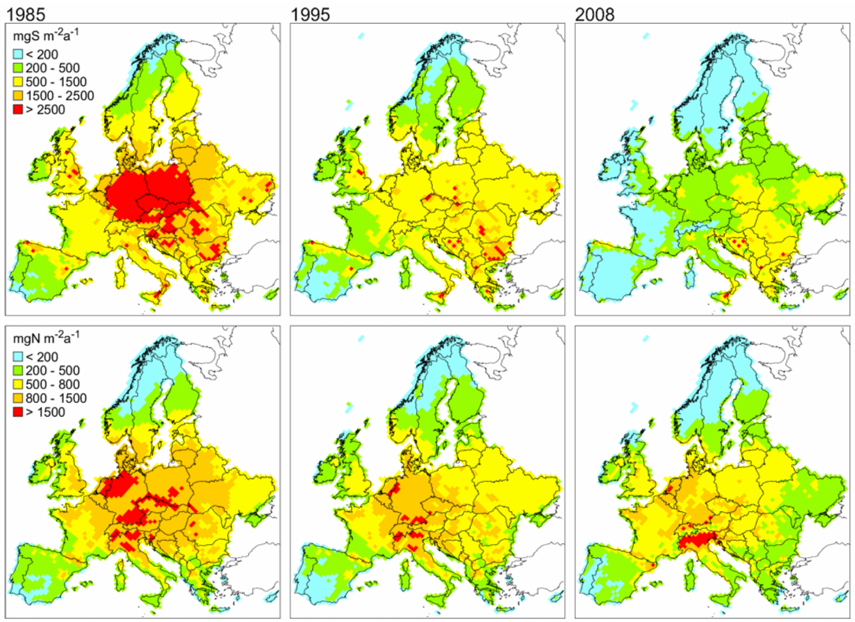
Effects of acid deposition on soil C accumulation

Long-term evidence:

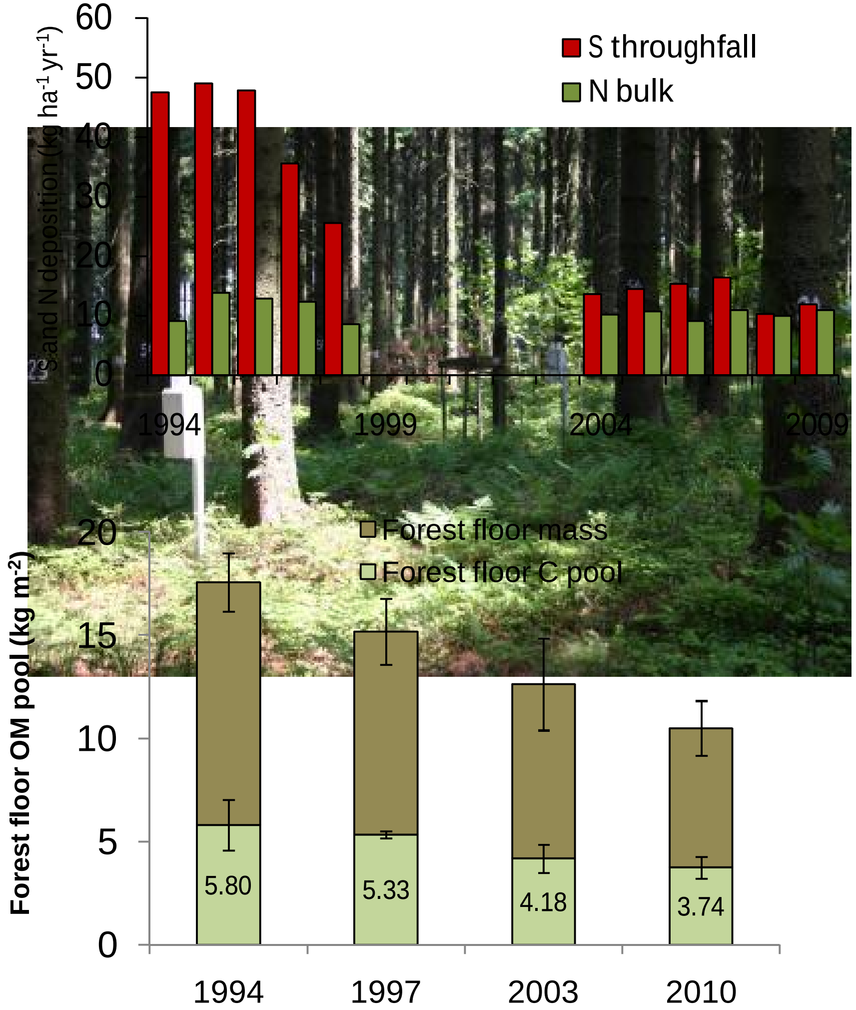
- Across Czech forest catchments (n=14), S bulk deposition explained 32% variability in soil C/N ratio and 50% variability in forest floor depth (Oulehle et al., 2008)

Nacetin spruce forest research plot:

Wet deposition of sulphur (top) and nitrogen (bottom) in Europe based on the EMEP model

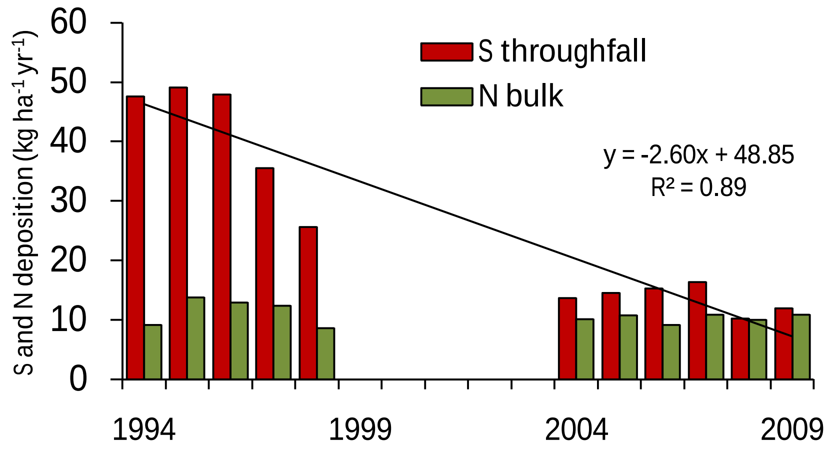


Source www.emep.int



Oulehle F, Evans C.D., Hofmeister J et al., 2011, GLOBAL CHANGE BIOLOGY (accepted)

Effects of acid deposition on soil C accumulation

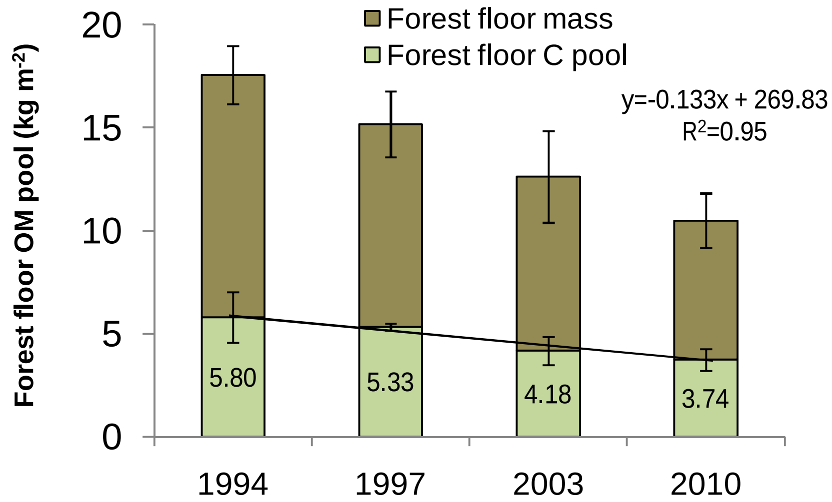


Nacetin spruce forest research plot:

-Forest floor C pool reduced by 47% since 1994

-Total S deposition reduced by 77% since 1994

$$dC/dS = 509$$

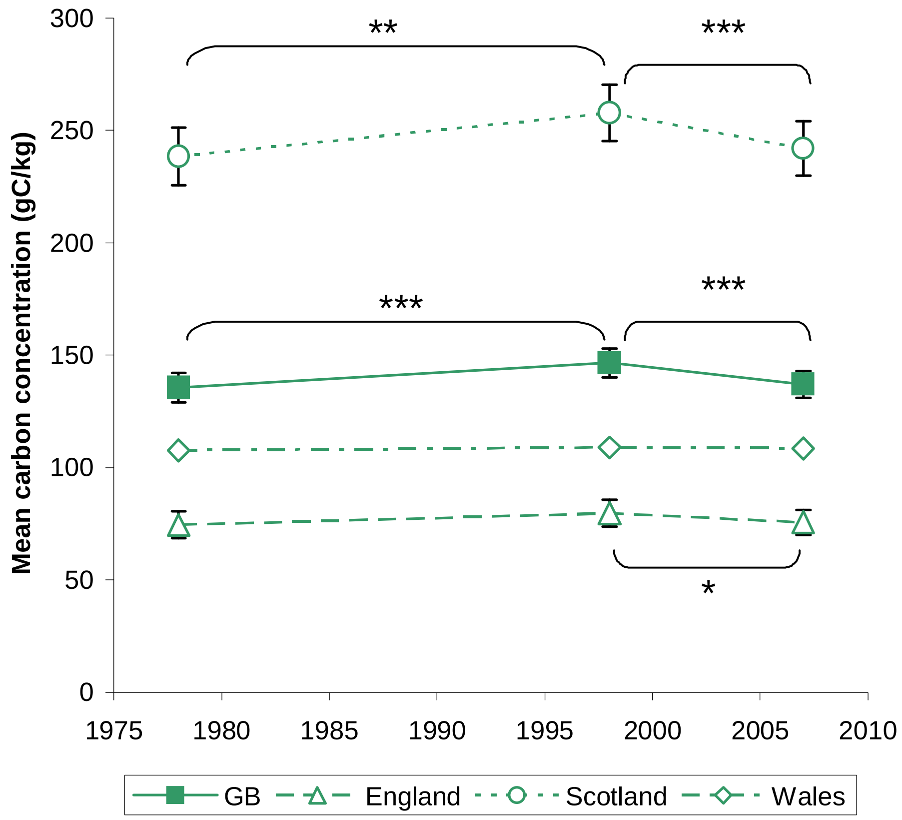


Oulehle F, Evans C.D., Hofmeister J et al., 2011, GLOBAL CHANGE BIOLOGY (accepted)

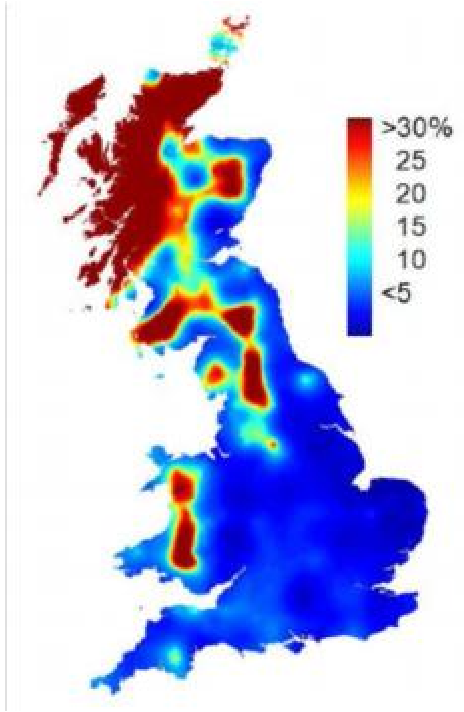
Effects of acid deposition on soil C accumulation

GB's countryside survey (http://www.countrysidesurvey.org.uk/)

Change in GB topsoil carbon concentration
(Countryside Survey results; Emmett et al. 2010)



Top soil C concentration



Best predictor of spatial and temporal changes in topsoil C concentrations was change in soil pH (soil C loss where soil pH has increased)

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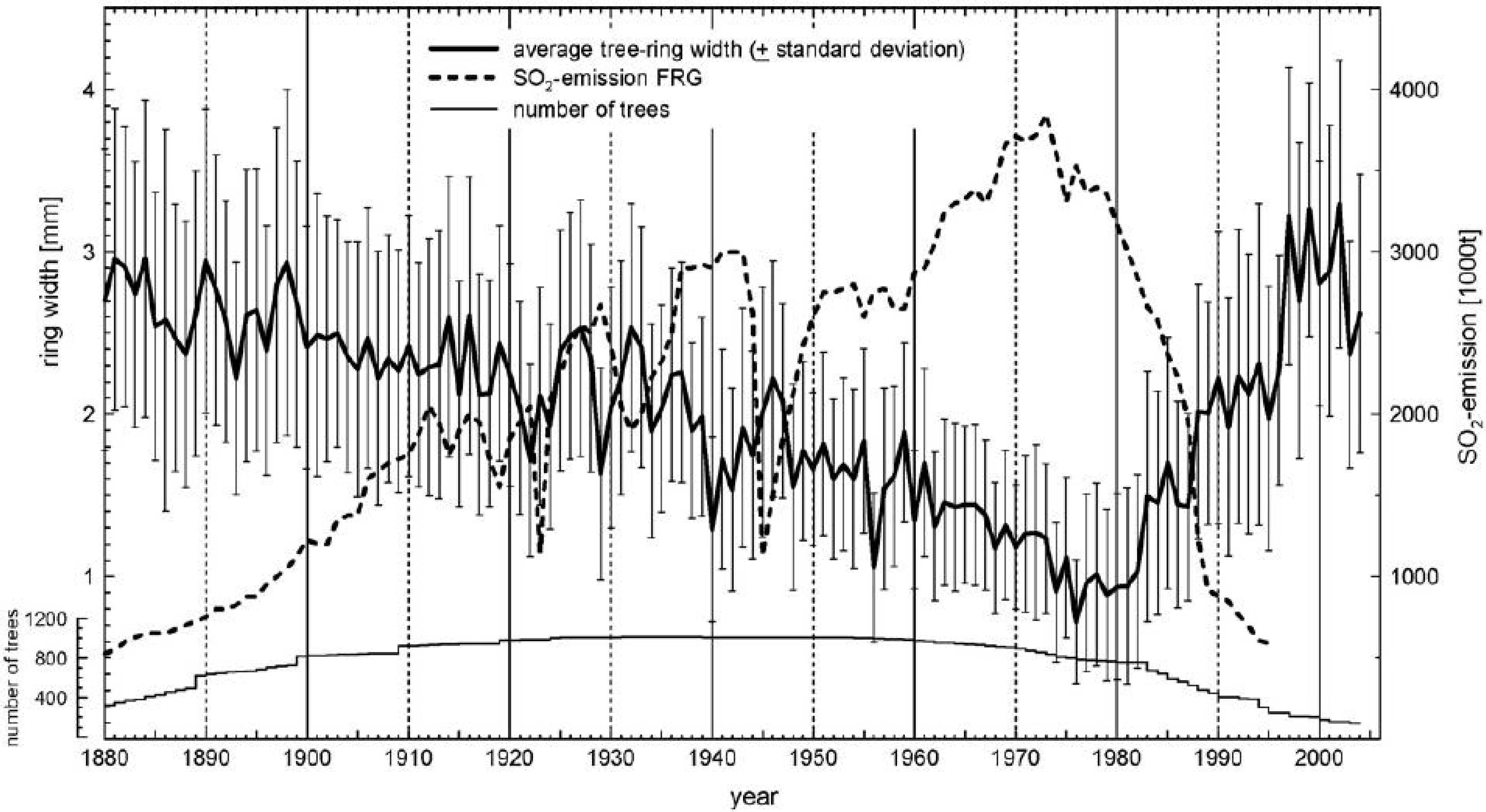
- threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO_2 concentration may have been overstated in those areas.

• Past acid conditions may have reduced decomposition rates, allowing a pool of relatively labile organic matter to accumulate, from which DOC is generated as acidity decreases.

• It appears that past acidification caused the suppression of decomposition leading to the accumulation of a large pool of organic matter on the forest floor. The alleviation of this acidification pressure over the last two decades appears to have triggered the remobilisation of the soil C pool.

Effects of acid deposition on forest productivity

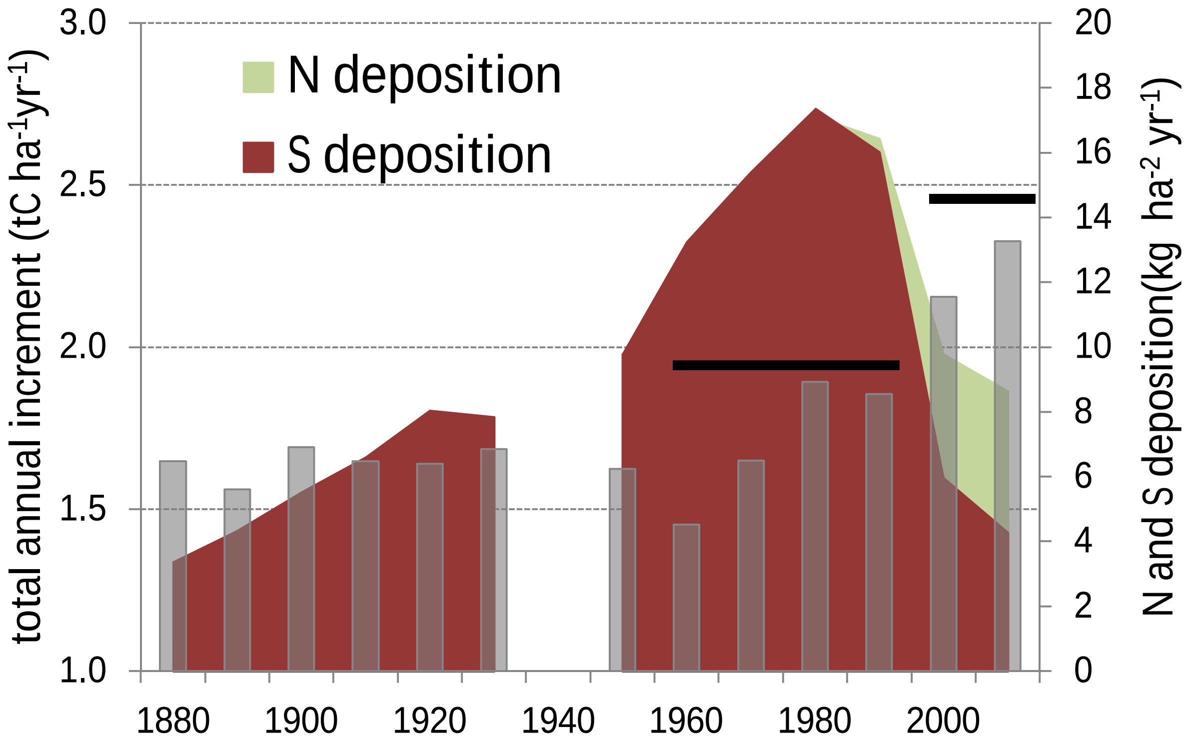
Growth depression under high acid deposition, and subsequent recovery following deposition reductions



Elling et al., 2009, FOREST ECOLOGY AND MANAGEMENT 257: 1175-1187

Effects of acid deposition on forest productivity

Results from Czech national forest inventories



$dC/dN_{(1960-2010)}=34$

20-40 – de Vries et al., 2008
25 – Nadelhoffer et al., 1999
25-37 – Högberg et al., 2006
19 – Solberg et al., 2009

BUT

$dC/dN_{(1960-1990)}=10$
$dC/dN_{(2000-2010)}=154$

- Annual above-ground carbon increment increased by 30% since 1950s

- In the European NITREX series of experiments, a 50% increase in tree growth was observed following experimental reduction of N and S inputs in N-saturated site (Emmett et al., 1998).

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• Growth reduction of conifer forests in Central Europe has been observed between the 1960s and 1980s.

• During recent decades a distinct increasing growth trends were observed. This trend might only be explained if climate, fertilization by N-deposition, and the strong reduction of SO_2 pollution are taken into account.

Modelling C and N dynamics using new version of MAGIC model

MAGIC (Model for Acidification of Groundwater In Catchments)

-Developed to predict the long-term effects of acidic deposition on surface water chemistry

-Model simulates soil and surface water chemistry in response to changes in drivers such as deposition of S and N, land use practices, climate…

- As sulphate concentrations have decreased, in response to the decreased S deposition, nitrate (NO_3) has become increasingly important. In acid soils much of the NO_3 leached from soil is accompanied by the acid cations H+ and inorganic aluminium (Ali)

-In the early versions of MAGIC retention of N was calculated empirically as a fraction of N deposited from input-output budgets

-Later on fraction N retained was described as a function of the N richness of the ecosystem (soil C/N ratio in this case)

-Alternative formulation of N retention in new version of MAGIC is based directly on the microbial processes which determine the balance of N mineralization and immobilization

Soil Solution Carbon & Nitrogen Fluxes

fC1 = organic and inorganic C in runoff
fC2 = inorganic C exchange with the atmosphere

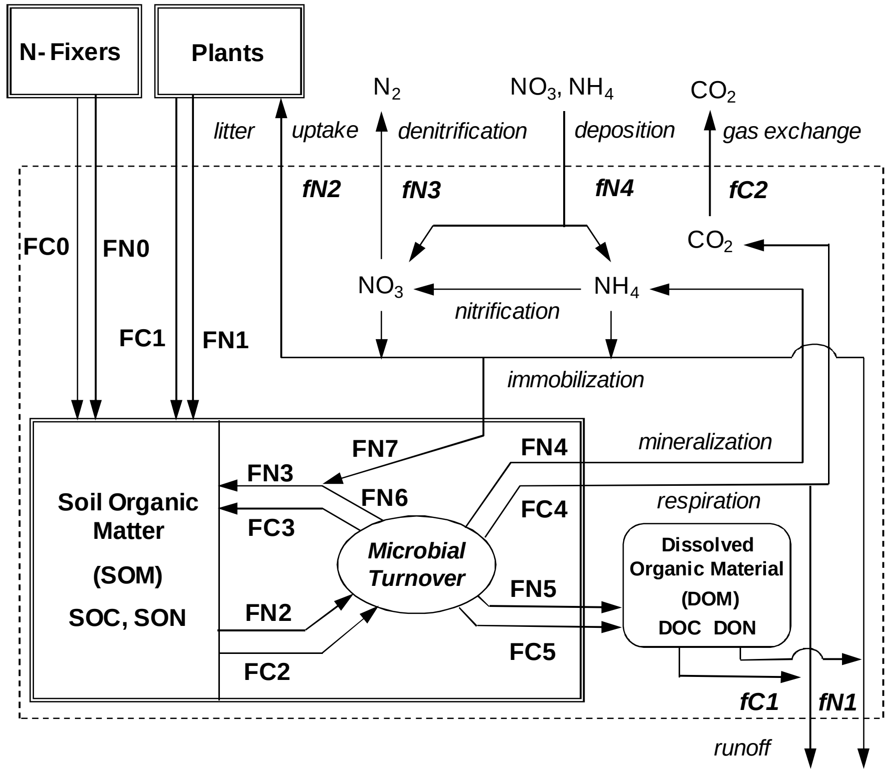
f*N1* = organic and inorganic N in runoff
fN2 = inorganic N uptake by plants
fN3 = denitrification of inorganic N
fN4 = atmospheric deposition of inorganic N

Soil Organic Matter Carbon fluxes

FC0 = organic C from N-fixers
FC1 = organic C from plant litter
FC2 = organic C processed in SOM turnover
FC3 = C in new microbial biomass (new SOM)
FC4 = SOM C respired (CO2 in soil solution)
FC5 = SOM C solubilized (DOC in soil solution)

Soil Organic Matter Nitrogen fluxes

FN0 = organic N from N-fixers
FN1 = organic N from plant litter
FN2 = organic N processed in SOM turnover
FN3 = N in new microbial biomass (new SOM)
FN4 = SOM N mineralized (NH4 in soil solution)
FN5 = SOM N solubilized (DON in soil solution)
FN6 = organic N from SOM used by microbes
FN7 = inorganic N immobilization by microbes

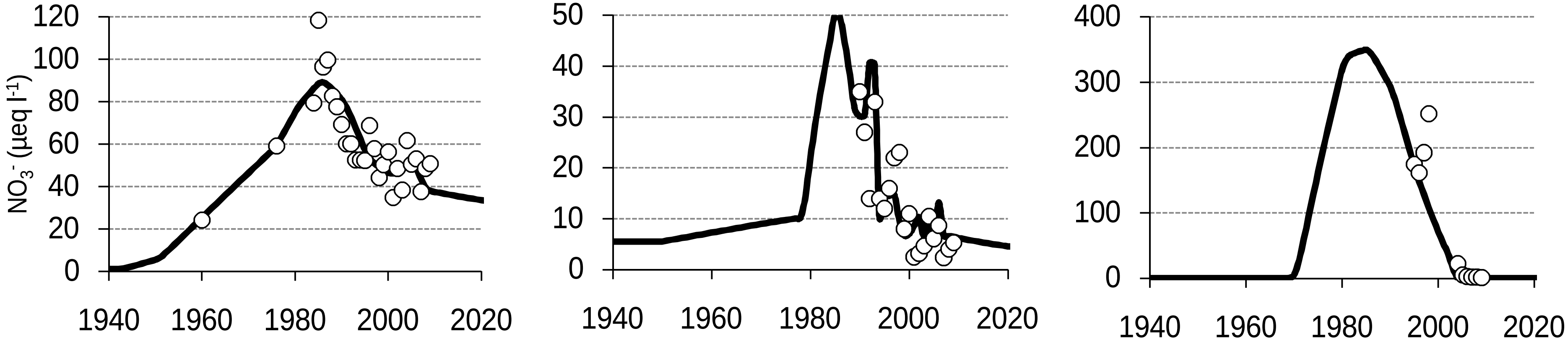


-Inorganic N enters the model as deposition (wet and dry)

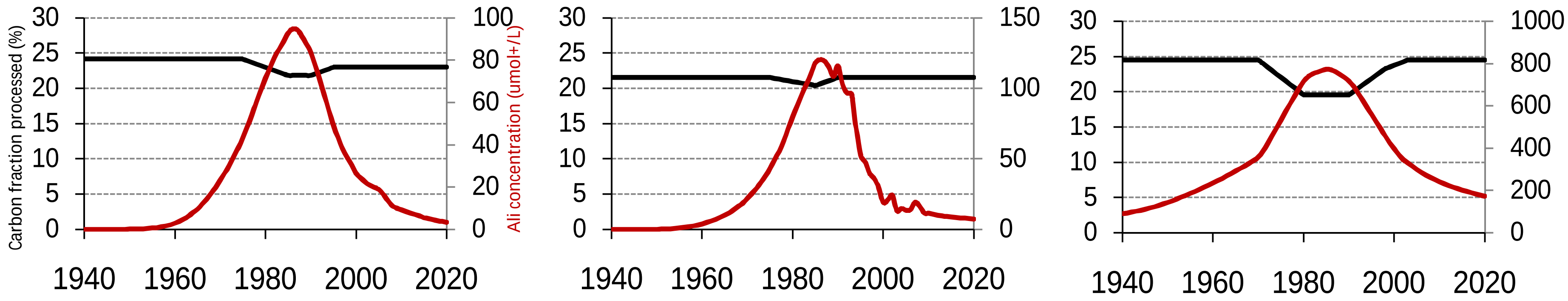
- Time series of plant litter and N fixation (FC1 and FC2) are external inputs to SOM. At each time step, decomposers process some of the C and N content of SOM (FC2 and FN2). A portion of this C and N turnover returns to the SOM as decomposer biomass (FC3 and FN3), while the remainder is lost from SOM as CO_2 and NH_4 (FC4 and FN4) or as DOC and DON (FC5 and FN5).

Modelling C and N dynamics using new version of MAGIC model

MAGIC application on three long-term monitoring sites in the Czech Republic



- Lake, stream and soil water chemistry (nitrate) from different catchments in the Czech Republic
- Constant carbon turnover
- Adjusted carbon turnover based on Ali concentration



Oulehle F., Cosby B.J., Wright R.F. et al., 2011, ENVIRONMENTALL POLLUTION (in prep)

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• Acidity changes in forest ecosystems might have a strong confounding influence on ecosystem sensitivity to eutrophication, with acidification accelerating N saturation (nitrate leaching), and recovery potentially resulting in reversion to N limitation (nitrate retention).

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• It appear… n leading to the accumulati… viation of this acidificatio… the remobilisation of the soil …

THANK YOU FOR YOUR ATTENTION

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