Changes of air quality due to the revised Gothenburg Protocol: Improvement and challenge remain

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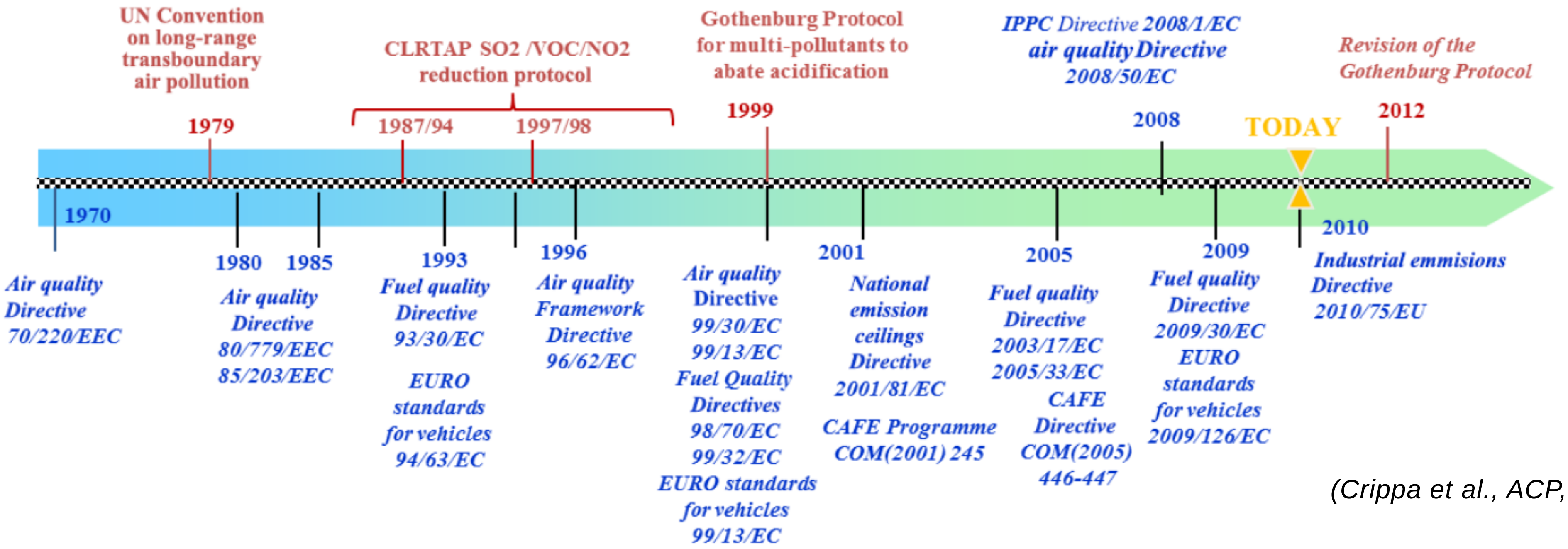
International efforts towards Clean Air



(Crippa et al., ACP, 2016)

The Gothenburg Protocol (1999)

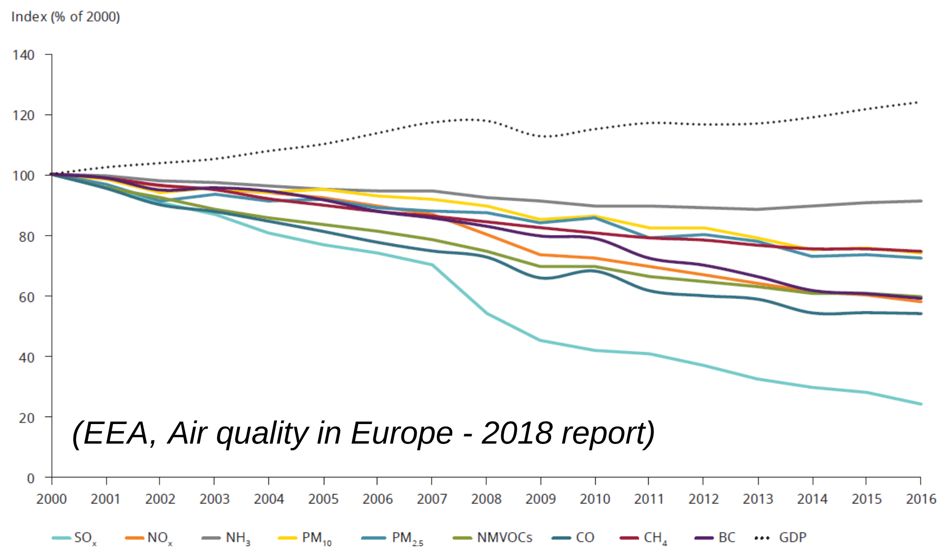
- a multi-pollutant protocol designed to reduce acidification, eutrophication and ground-level ozone by setting emissions ceilings for SO_2, NO_x, VOC and NH_3 to be met by 2010.

The revised Gothenburg Protocol (2012)

- More stringent emission reduction commitment for 2020
- A fifth pollutant PM2.5 is covered for the first time.
- EU reduction target: SO_2 - 59%, NO_x - 42%, NH_3 - 6%, VOC - 28%, $PM_{2.5}$ - 22%.

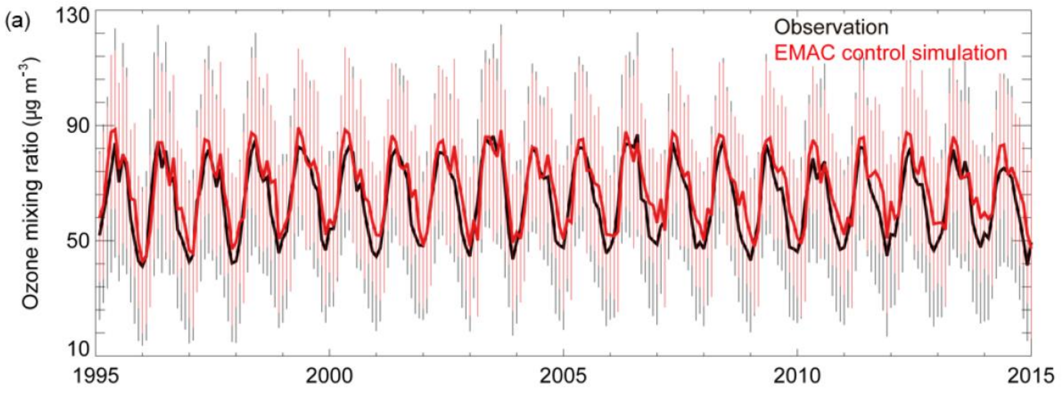
Reduced emissions ❓ Improved air quality

- *Significant reduction of emissions*



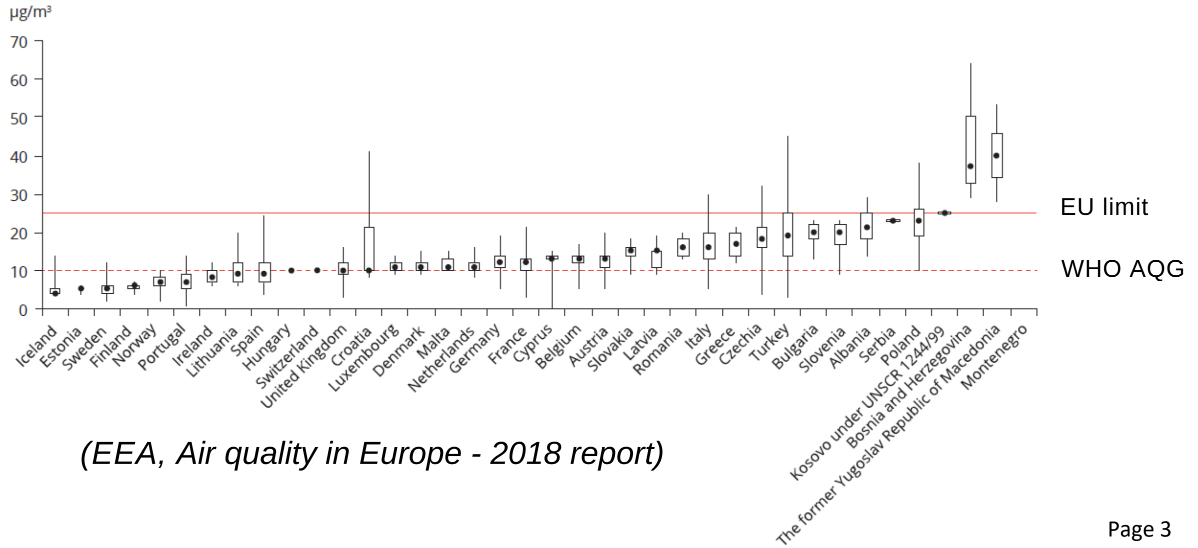
(EEA, Air quality in Europe - 2018 report)

- **Ozone**: No significant decrease



(Yan et al., ACP, 2018)

- **PM2.5**: 68% stations (in 32 of 37 countries) exceed the WHO AQG



(EEA, Air quality in Europe - 2018 report)

➢ ***What is the potential effects of the revised Gothenburg Protocol on air quality in Europe? – A modelling approach***

Method

- **CAMx version 6.50** *(Ramboll, 2018)*

Simulation periods	2010, 2020 (projection)
Model domain	17^{o} W - 39.8^{o} E, 32^{o} - 70^{o} N
Horizontal resolution	$0.4^{o} \times 0.25^{o}$
Vertical resolution	14 terrain-following layers (50 m – 8000 m)
Chemical mechanism	CB6r2
Aerosol scheme	SOAP2.1

- **Model Inputs** *(provided by EURODELTA-Trends project)*

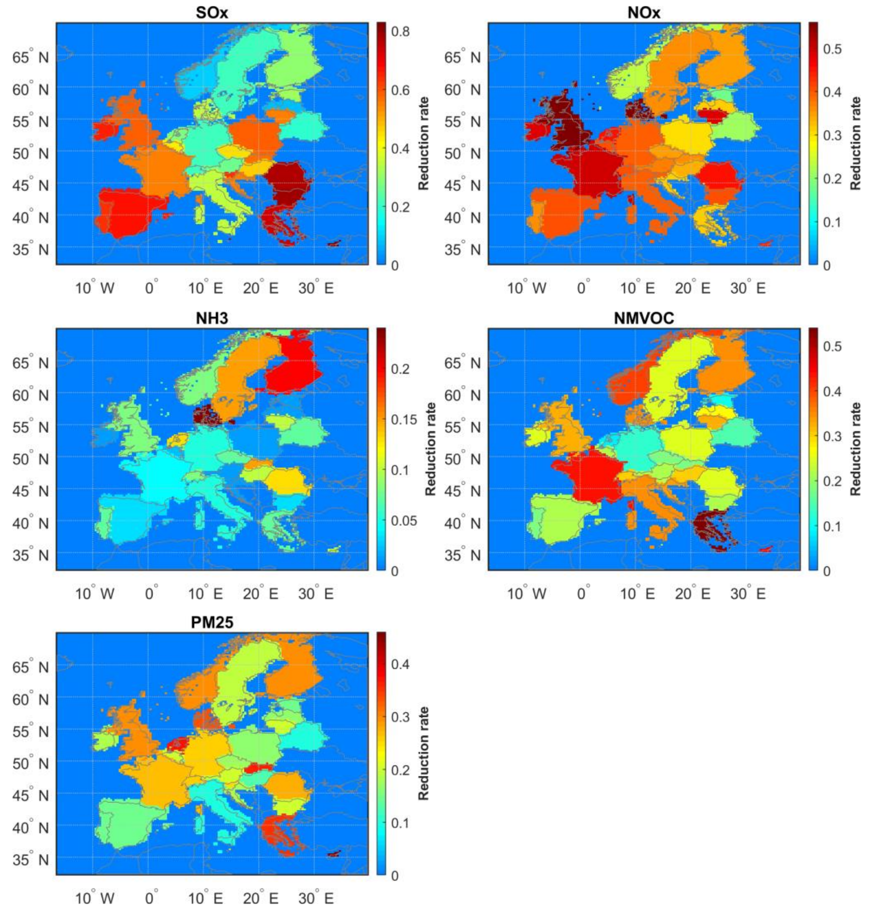
Meteorology	WRF version 3.3.1
Anthropogenic emissions	2010 and 2005 provided by EURODELTA-Trends
Biogenic emissions	MEGAN version 2.1
Boundary conditions	MOZART4/GEOS5
Ozone column density	TOMS by NASA
Photolysis rates	TUV rediation model version 4.8

- **Model evaluation**

European air quality database AirBase version 7

Projections of 2020 emissions:

✓ Reduced emissions based on the reference year (2005) emissions and the revised Gothenburg Protocol targets.



Model Evaluation (2010)

Comparison with AIRBASE observations

- Comparable performance with previous studies.
- O_3 and $PM_{2.5}$ meet the performance criteria given by *Boylan and Russell (2006)* and *EPA (2007)*:

  (O_3: MFB ≤ ±30%, MFE ≤ 45%; $PM_{2.5}$: MFB ≤ ±60%, MFE ≤ 75%)
- PM_{10} and $PM_{2.5}$ were underestimated in 2010, largely due to underprediction of SOA in winter for $PM_{2.5}$, and missing coarse species in emissions for PM_{10}.

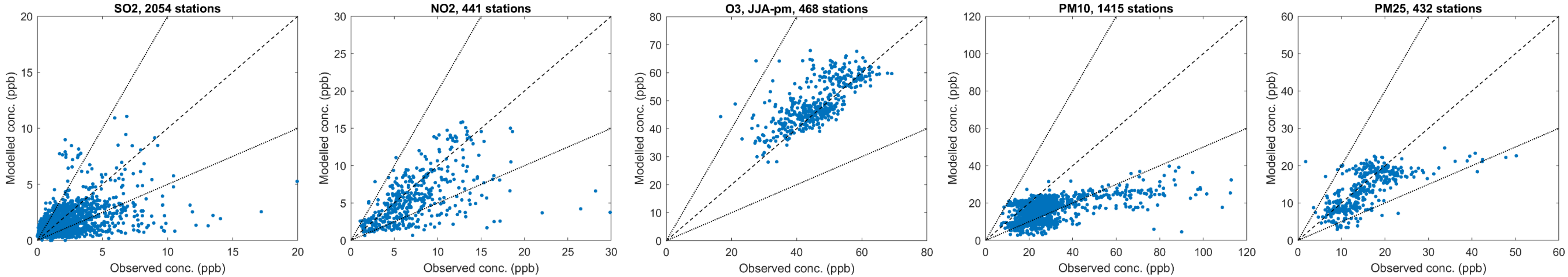


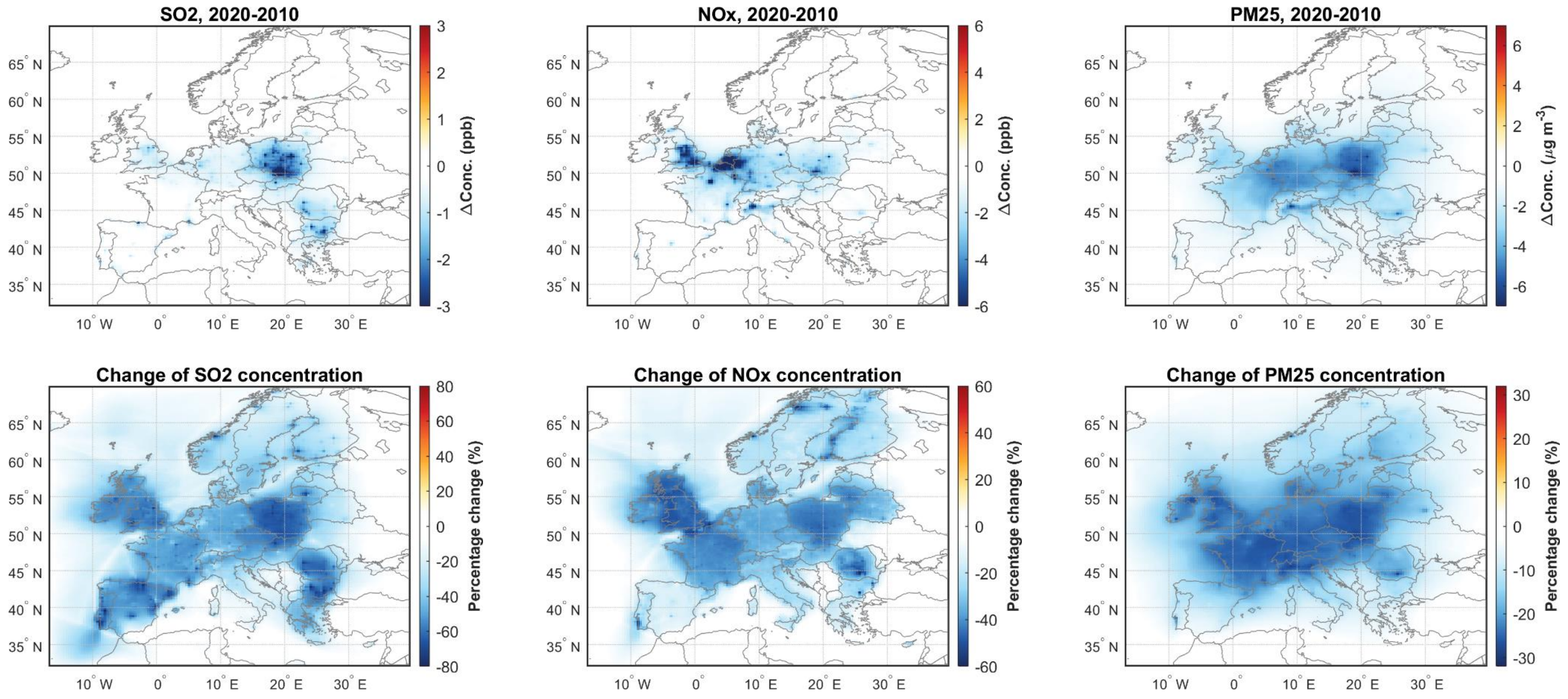
Table 1. Model performance evaluation for gaseous and particle species in 2010.

Species	Number of stations	Mean bias[a]		Mean error[a]		Root-mean-square error[a]		Mean fractional bias (%)		Mean fractional error (%)	
		JJA	DJF	JJA	DJF	JJA	DJF	JJA	DJF	JJA	DJF
SO_2	2054	-0.5	-0.7	0.9	1.7	1.4	4.7	-17	-4	67	61
O_3	468	3.1	5.3	5.1	7.2	7.1	9.4	7	19	11	26
NO_2	441	-1.1	-2.9	2.2	3.8	3.5	5.7	-23	-29	50	42
PM_{10}	1415	-12.5	**-16.0**	12.6	16.7	16.8	24.5	-67	-50	68	54
$PM_{2.5}$	432	-2.5	**-6.4**	3.6	8.0	4.5	15.2	-26	-22	37	34

[a] Units are ppb for gaseous species and μg m^{-3} for PM.

Changes in air quality between 2010 and 2020

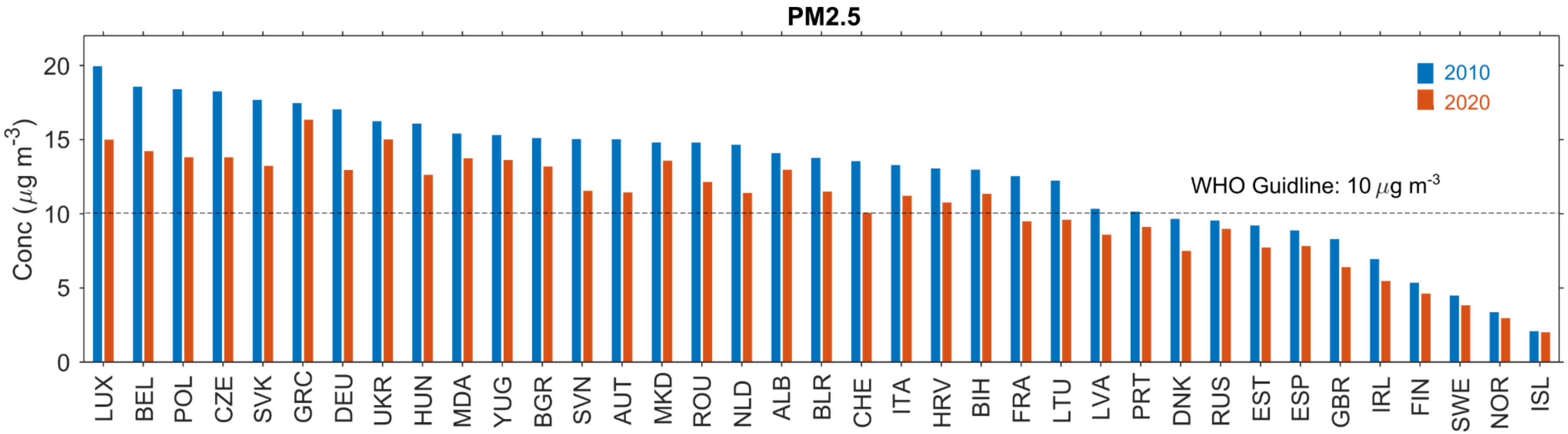
- Considerable **decrease** in **SO_2**, **NO_x** and **$PM_{2.5}$** concentrations
  - Domain average concentrations decrease by SO_2 29%, NO_x 28%, $PM_{2.5}$ 6%.
  - Highest country-level reduction rates: SO_2 62% (Poland), NO_x 44% (UK), $PM_{2.5}$ 26% (Switzerland).

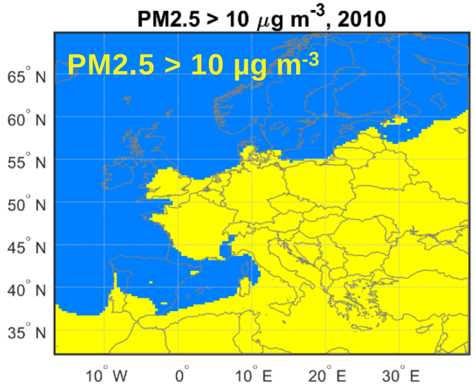


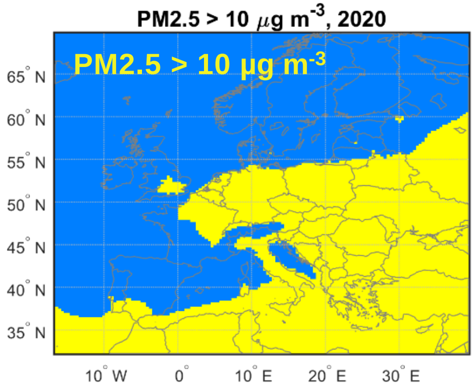
Changes in air quality between 2010 and 2020

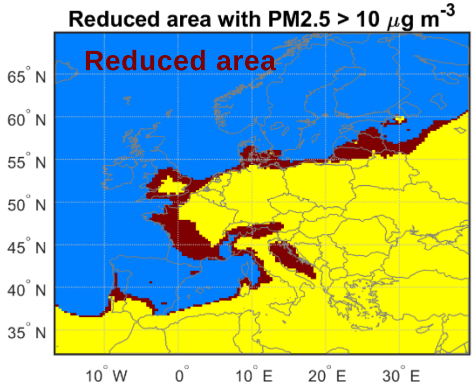
PM2.5 EU limit (25 µg m^{-3}) *vs.* WHO AQG (10 µg m^{-3})

- Countries meet WHO AQG increase from 10/42 to 14/42.
- Improvement only occurred in limited area (France, UK, Switzerland, the Baltic region)





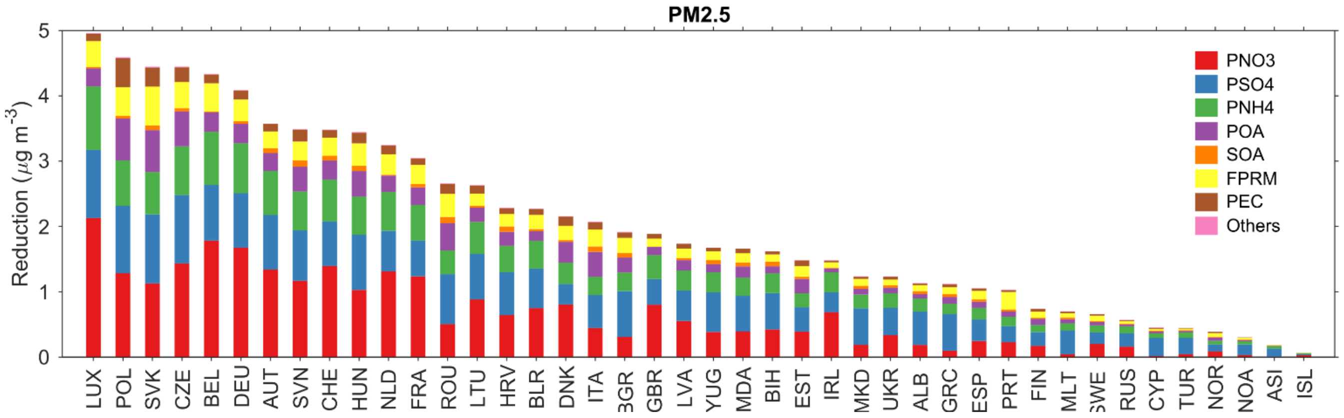


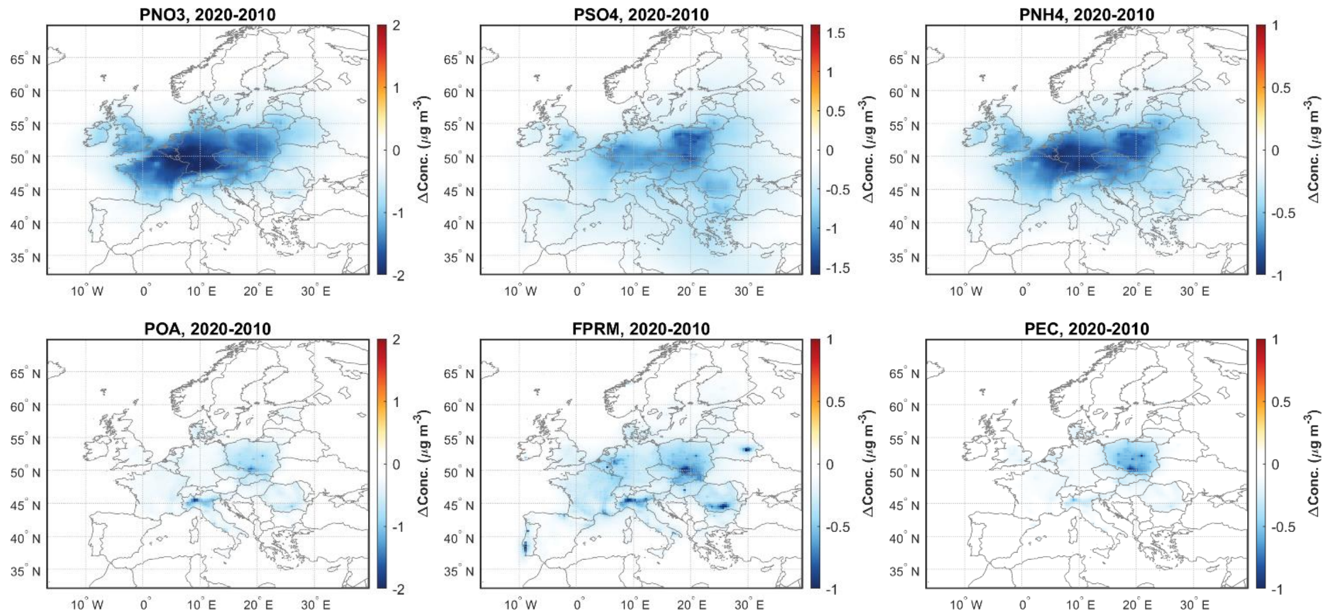


Changes in air quality between 2010 and 2020

- Changes in PM components

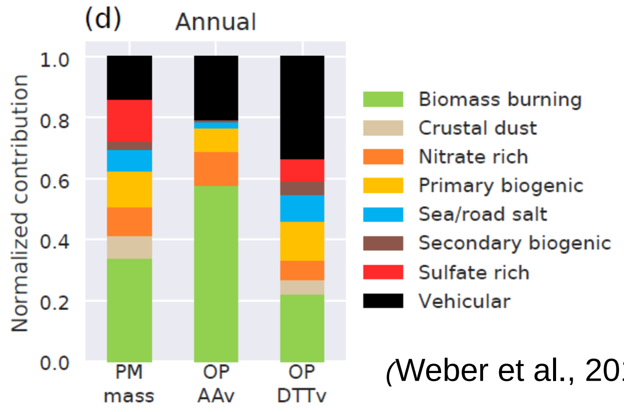
  - Reduced particulate NO_3^-, SO_4^{2-} and NH_4^+ contribute most to the reduction of $PM_{2.5}$ concentration, followed by the contributions from primary organic aerosol (POA), fine primary matter (FPRM) and elemental carbon (PEC)





- Reduced PM2.5 *vs.* Health Impact

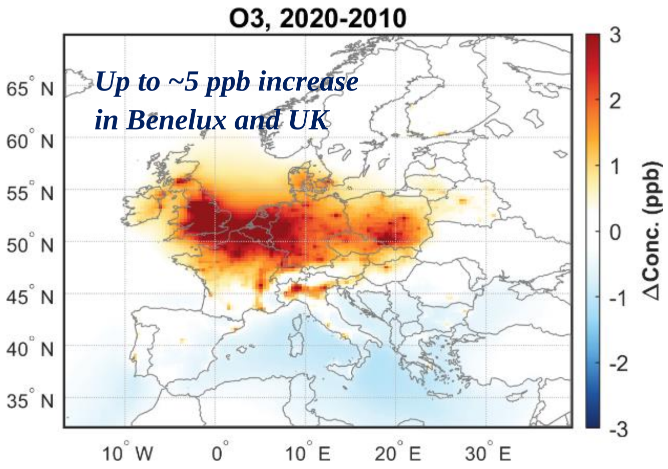
  - **Oxidative potential (OP)**, indicator of capacity to generate oxidative stress and impact human health
  - OP of inorganic aerosols are negligible compared with other PM components

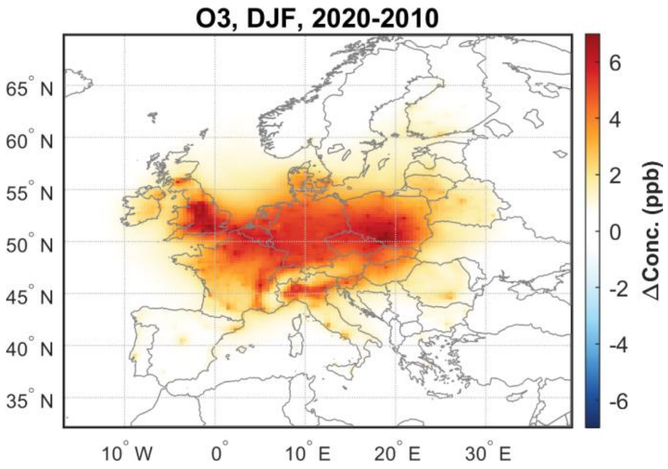


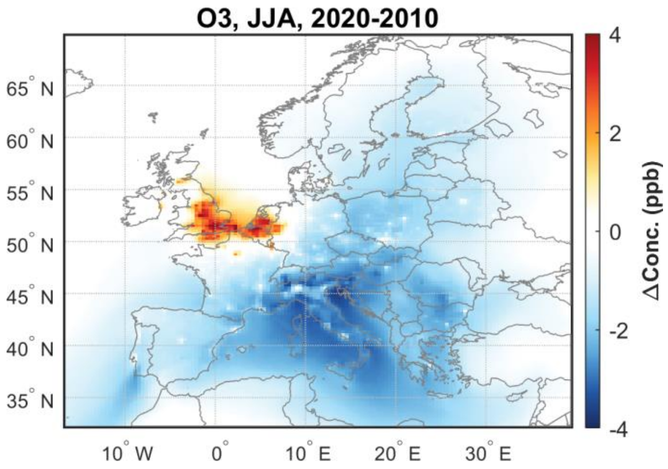
(Weber et al., 2018)

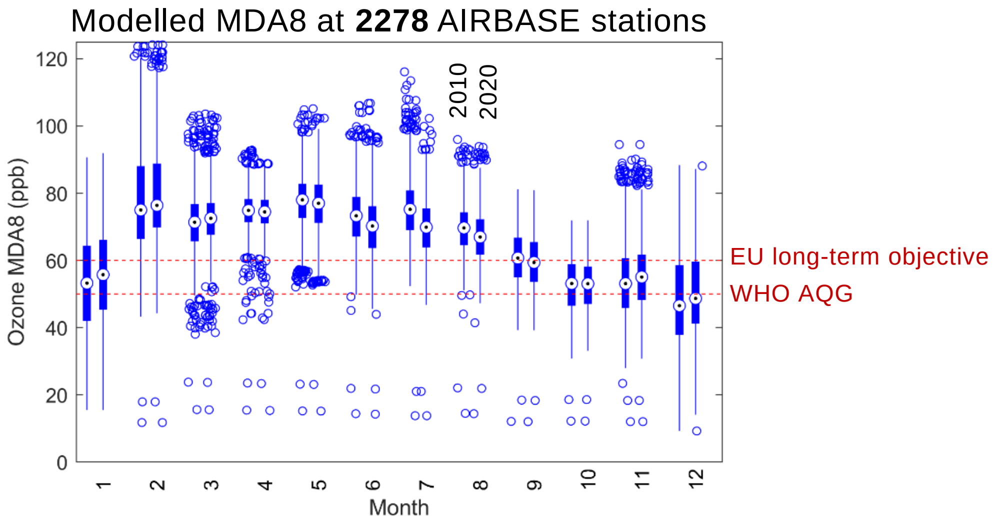
Changes in air quality between 2010 and 2020

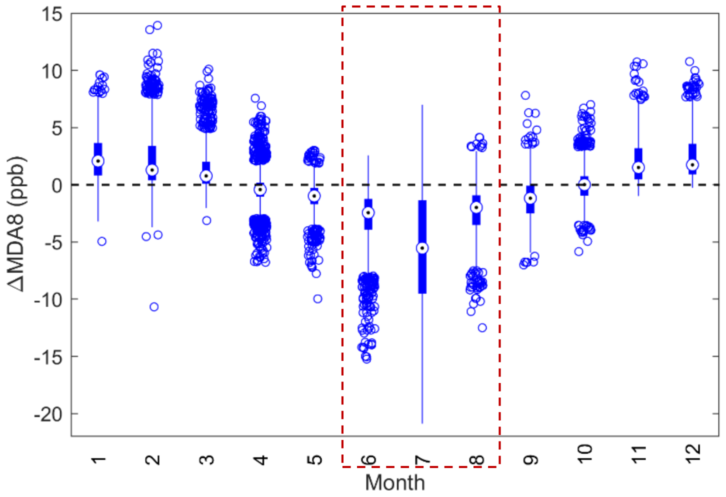
- **Generally increased** concentration of **O_3**
  - O_3 increase mostly occured in cold seasons (due to decreased titration with reduced NO_x), while summer O_3 decreased in most countries.
  - The maximum daily 8-hour mean ozone concentration decreased by ~4 ppb.





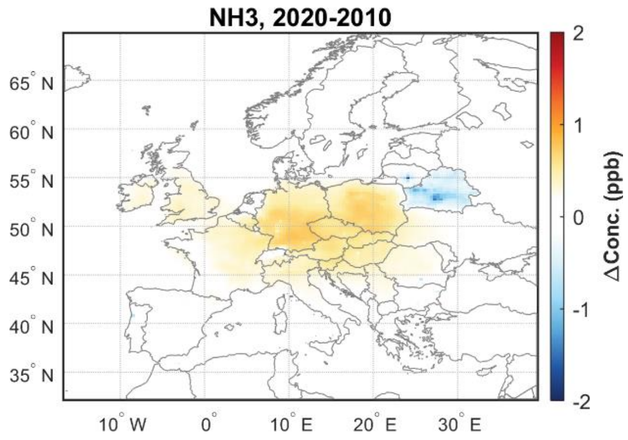


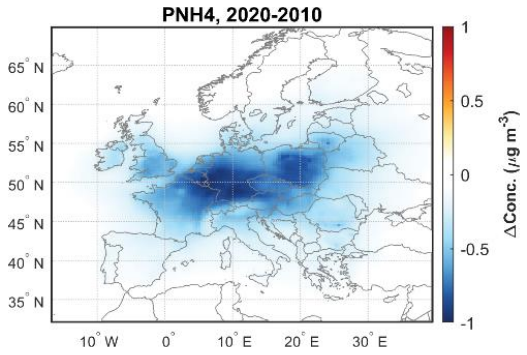


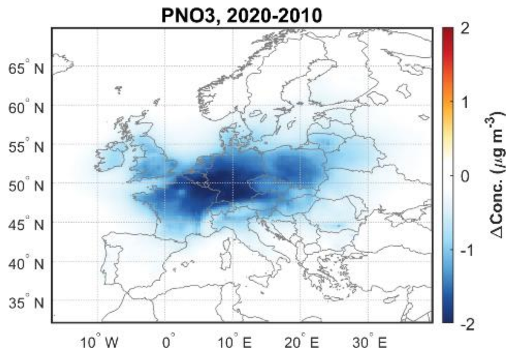


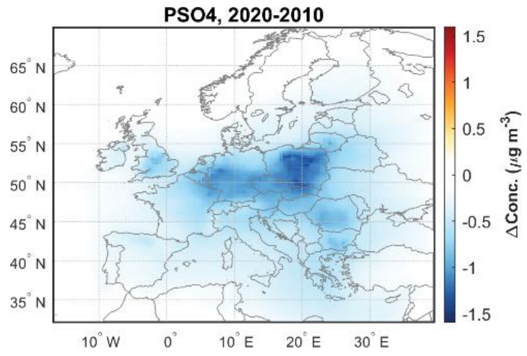
Changes in air quality between 2010 and 2020

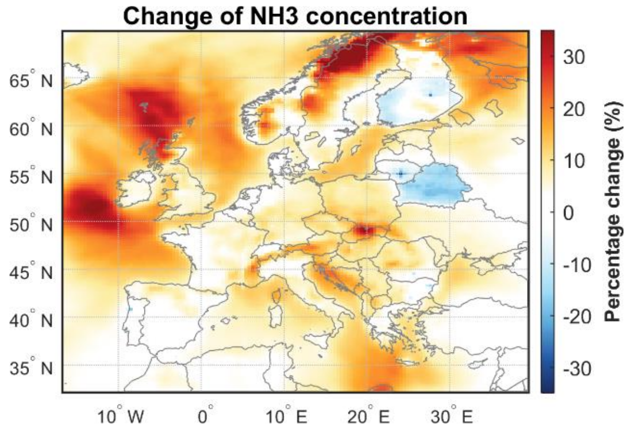
- **Generally** **increased** concentration of **NH_3**
  - Country-level average concentration of NH_3 increased by up to ~18% (Slovakia)
  - Reduced SO_2 and NO_x emissions lead to less NH_3 to particulate NH_4^+ conversion.

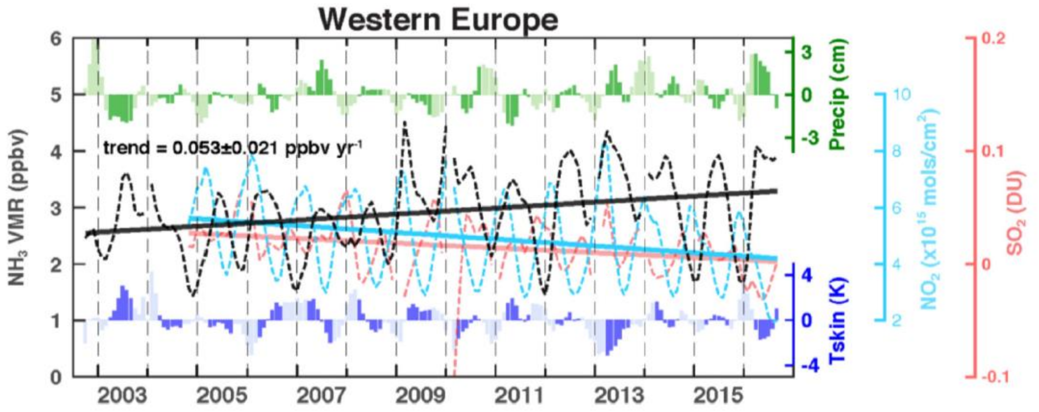












(Warner et al., 2017)

Conclusions

This study investigated the effects of the revised Gothenburg Protocol on the European air quality by modelling 2010 and 2020 using CAMx version 6.50.

- Reduced emissions lead to a significant decline in the concentrations of SO_2, NO_x and $PM_{2.5}$ in 2020.
- Annual average ozone increase due to decreased O_3 titration with NO_x, while peak ozone in summer decreases
- NH_3 levels slightly increase as reduced NO_x and SO_2 lead to a decrease in the formation of inorganic aerosols.

For future…

- ➢ Despite the predicted decrease in $PM_{2.5}$ levels, considerable population will still be exposed to high $PM_{2.5}$ exceeding the WHO air quality guidelines in 2020.
- ➢ Effects of the decreased $PM_{2.5}$ concentrations on reducing health impacts remain to be evaluated in the context of recent findings showing that different PM components and sources have distinct health impacts.

Acknowledgments

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Thank you for your attention!