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Bremen



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Institute of
Environmental Physics

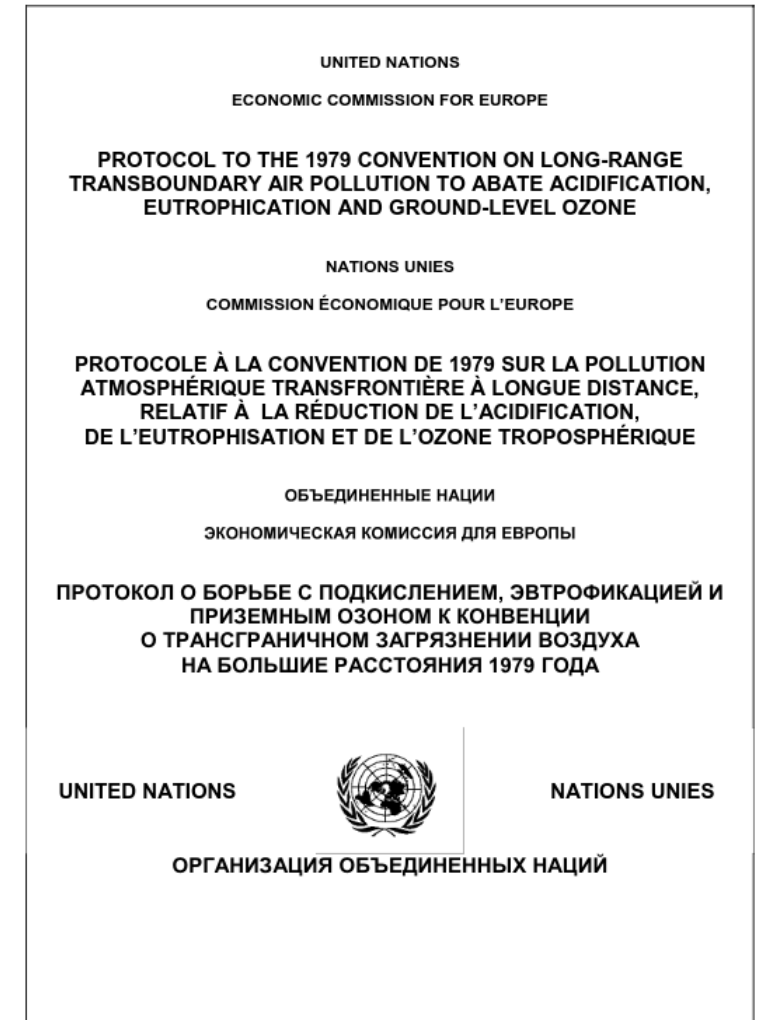
A first look into HTAP OPNS: Impacts of future emission scenarios on MDA8 Ozone

Bastian Grube
03.09.2026

HTAP Project



One of the Goals: Revision of
the Gothenburg Protocol
(Multi-effect Protocol)



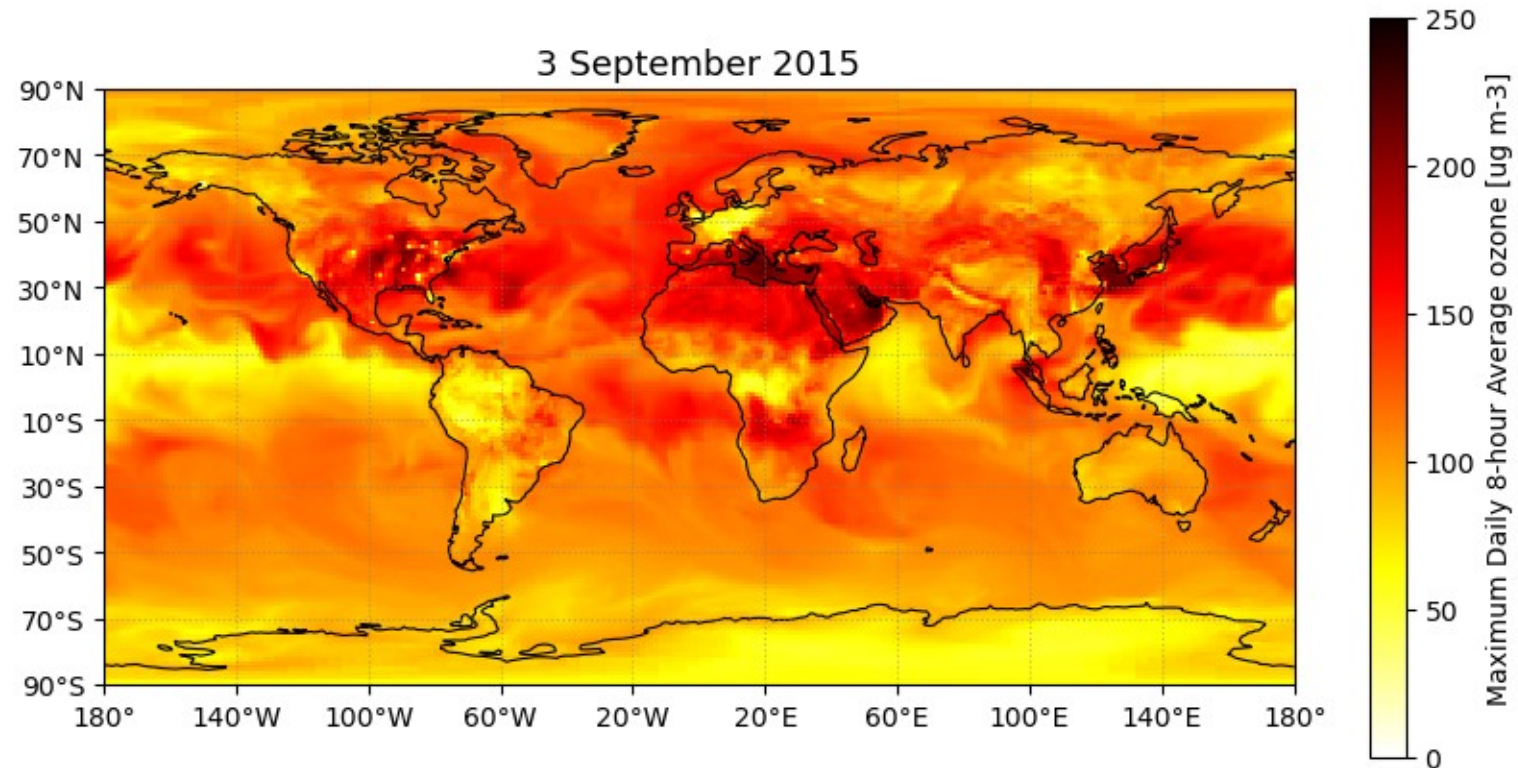
OPNS – The four horsemen of air pollution



Based on Viktor Vasnetsov "Four Horsemen of the Apocalypse", 1887

MDA8 ozone

Maximum daily 8-hour averaged ozone concentration



Experimental Setup

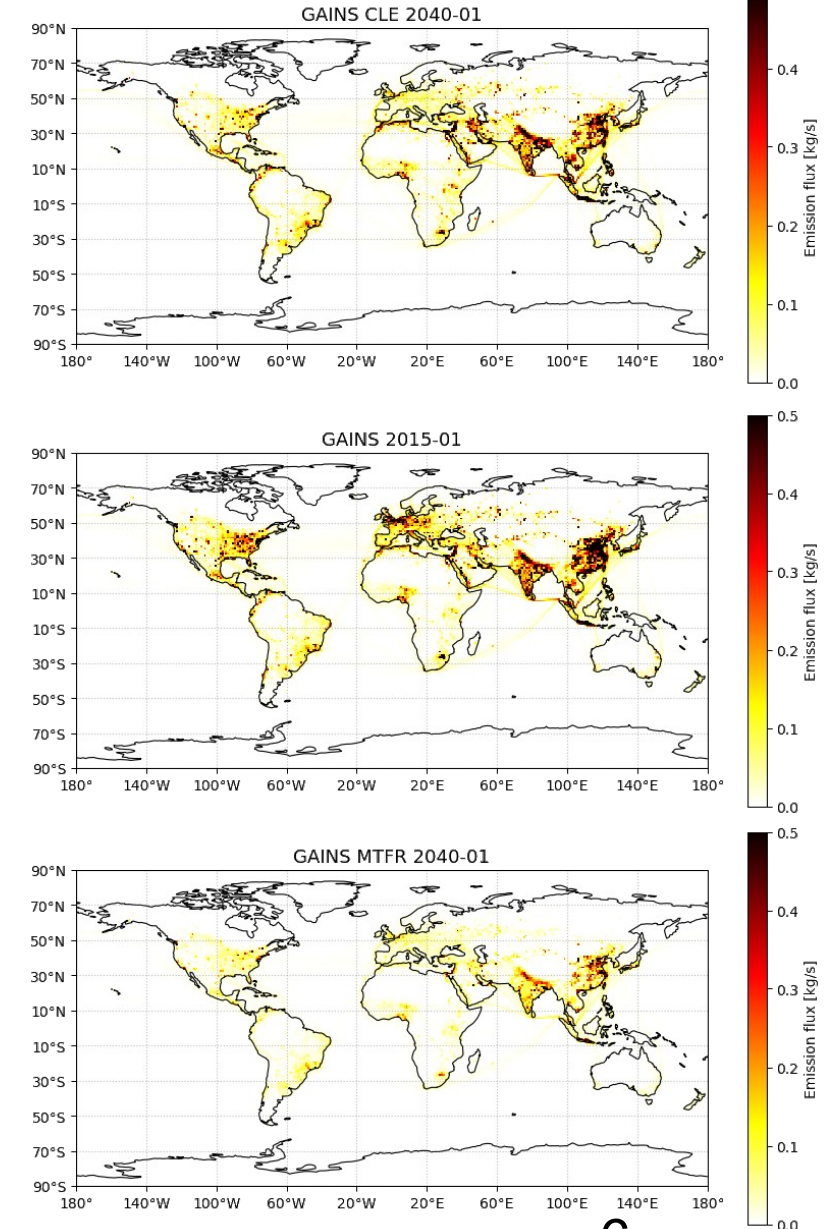
- **TM5-MP** with **HERMESv3** pre-processor

Sector	Emission inventory
Aviation	CMIP6 future (SSP 2-4.5)
Other anthropogenic	GAINS LRTAP v2.1
Biomass burning	GFAS4HTAP
Natural	MACC
Methane	None, fixed ppb

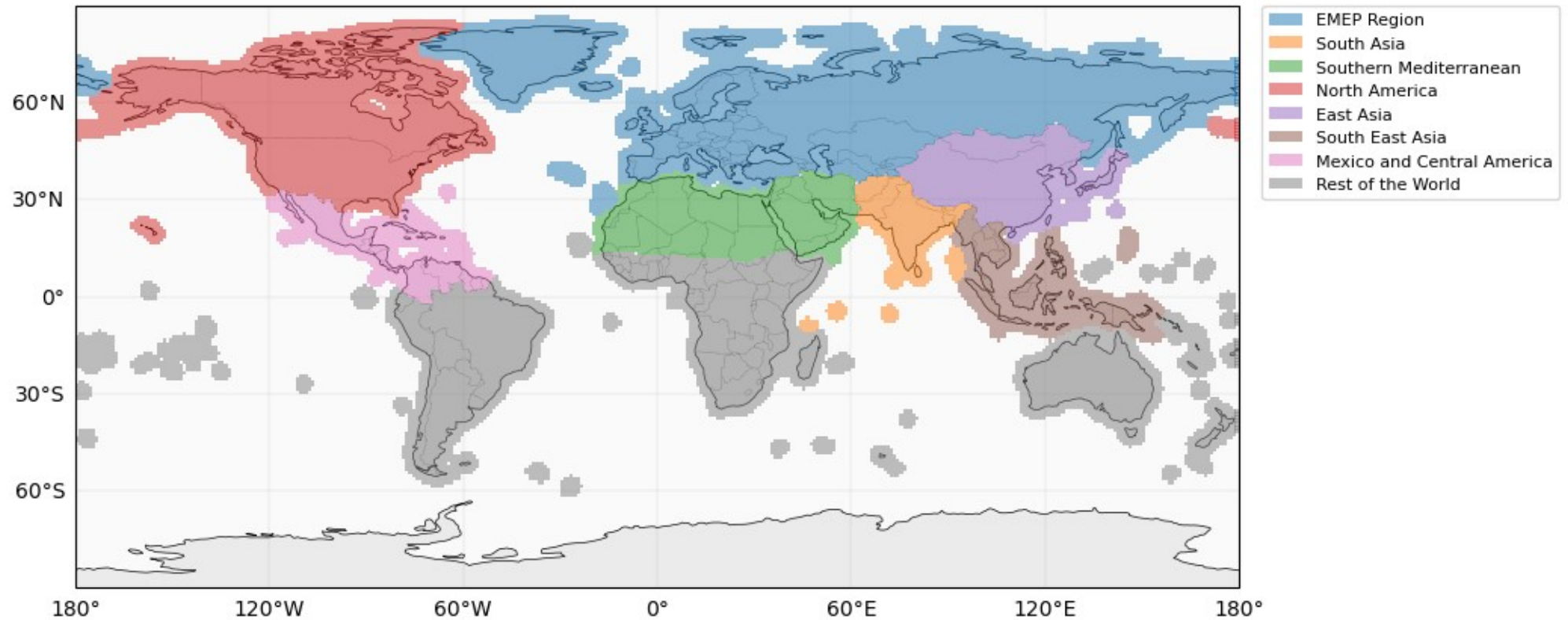
- Meteorology: ERA5 re-analysis (2015)
- 1°x1°, 34 layers
- MOGUNTIA chemistry

The scenarios

- **Hybrid scenarios:** Simulating 2015 but with future anthropogenic emissions (2040)
- **Baseline:** GAINS CLE 2040 (current legislation scenario)
- **Historical comparison:** GAINS 2015 anthropogenic emissions
- **“Best-case-scenario”:** GAINS MTFR (maximum technically feasible reduction)
- Several **perturbations** of CLE 2040 (reductions by 20%)

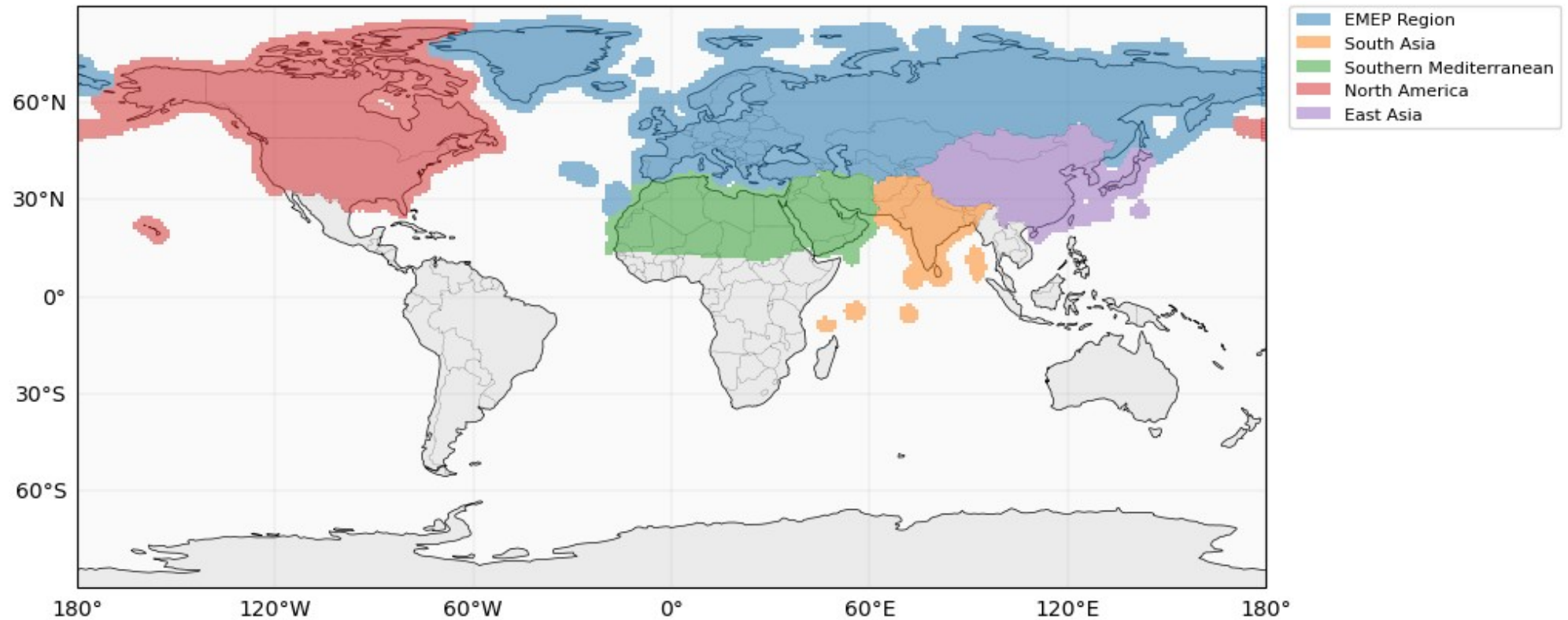


Regional perturbations



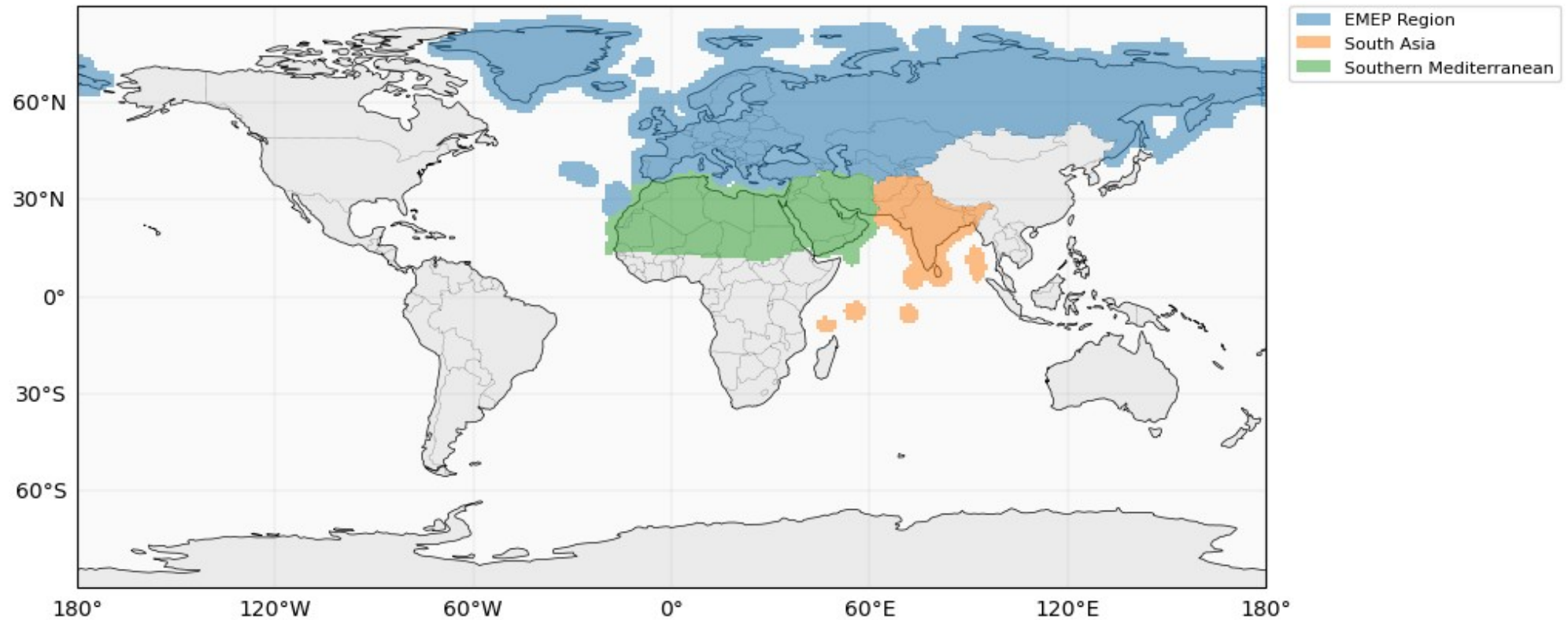
All regions

Regional perturbations



Regions where the perturbation runs are done.

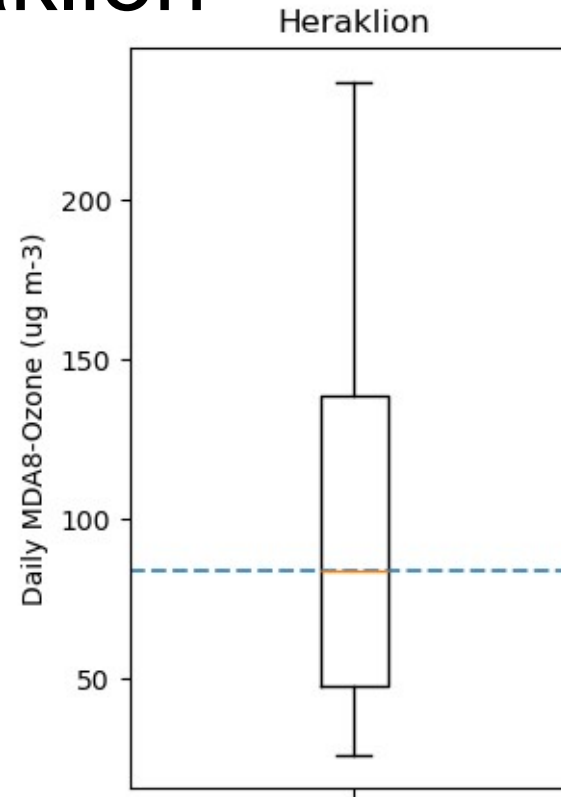
Regional perturbations



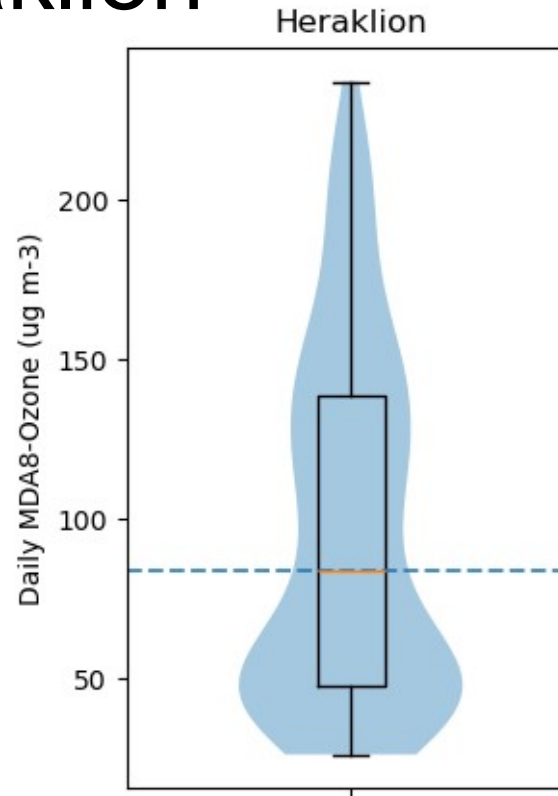
EMEP is very similar to North America and East Asia → only three left

Results

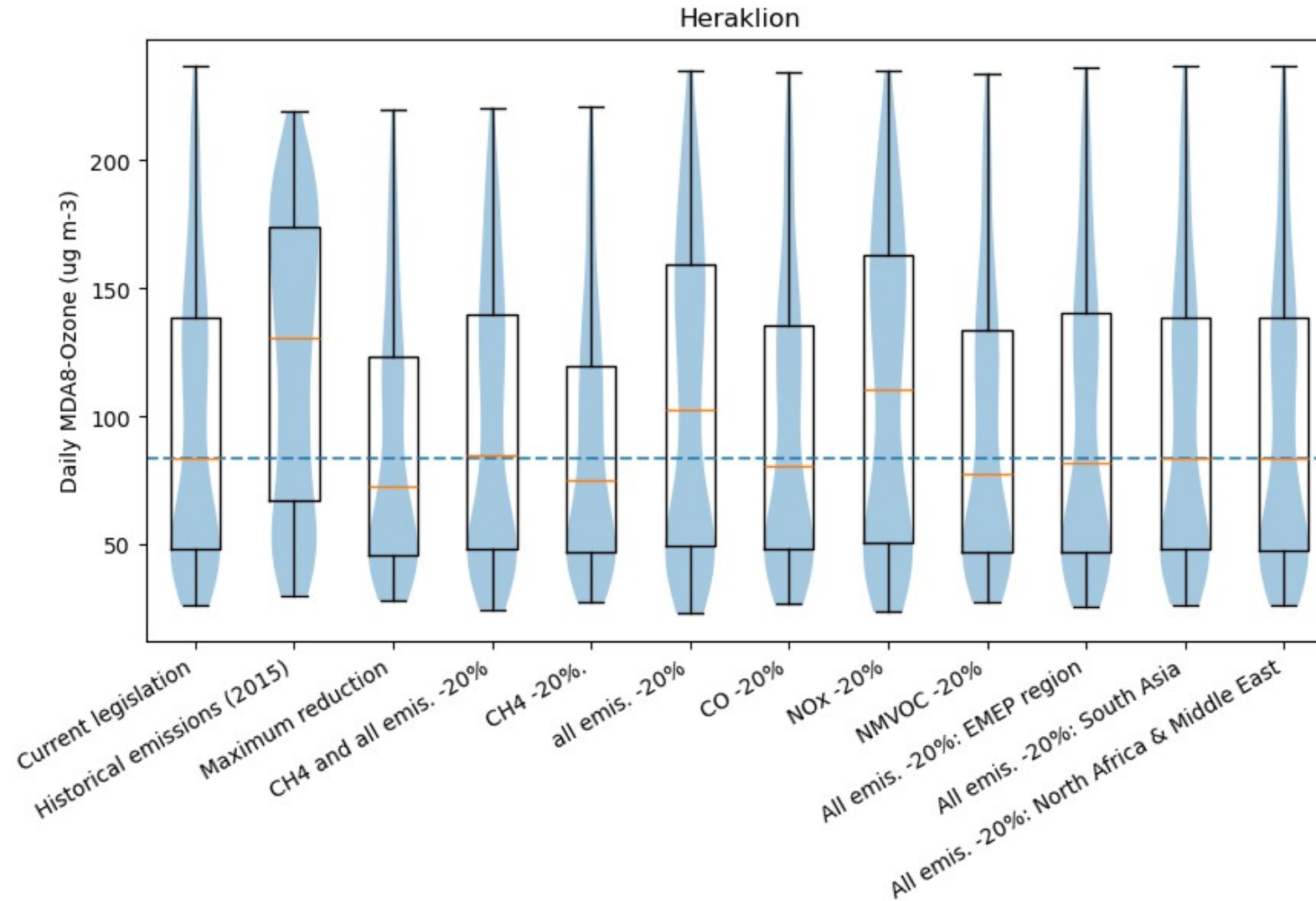
Ozone in Heraklion



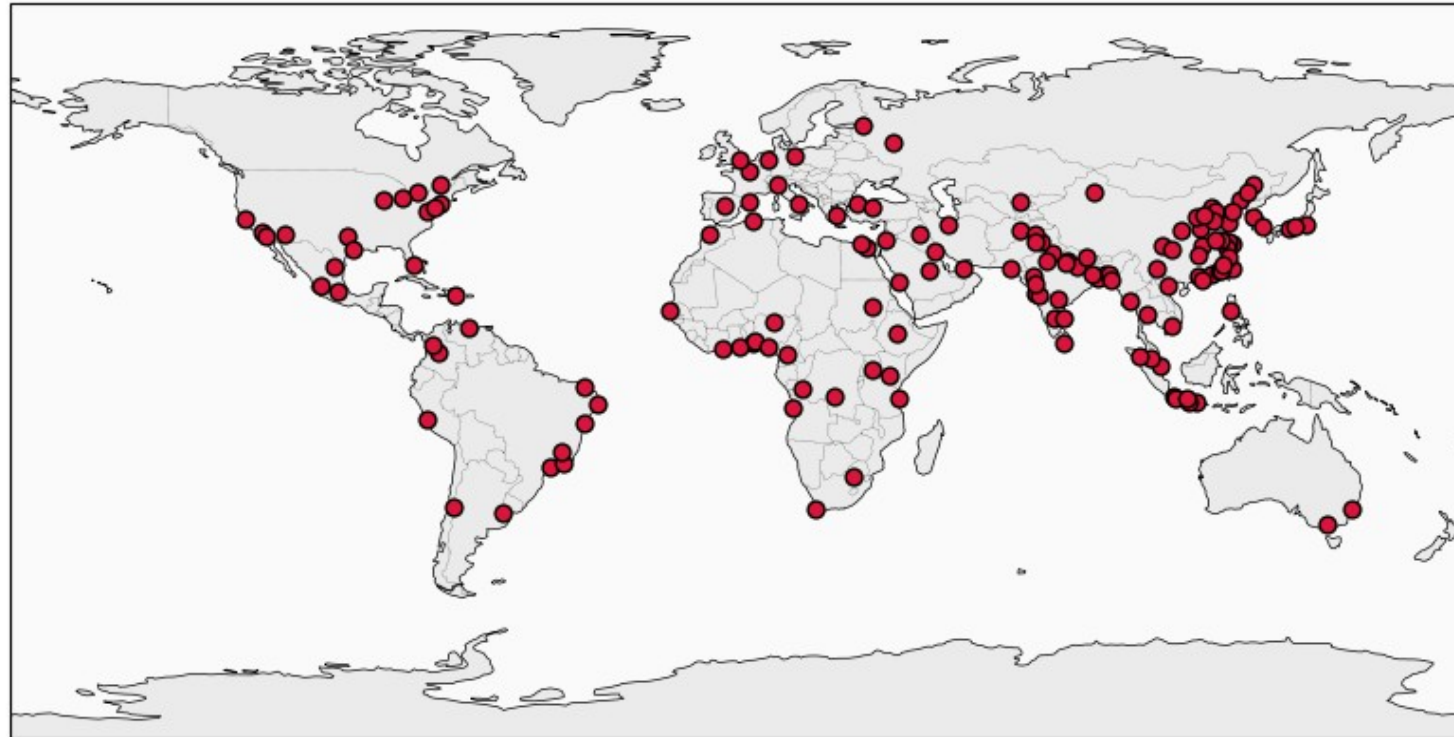
Ozone in Heraklion



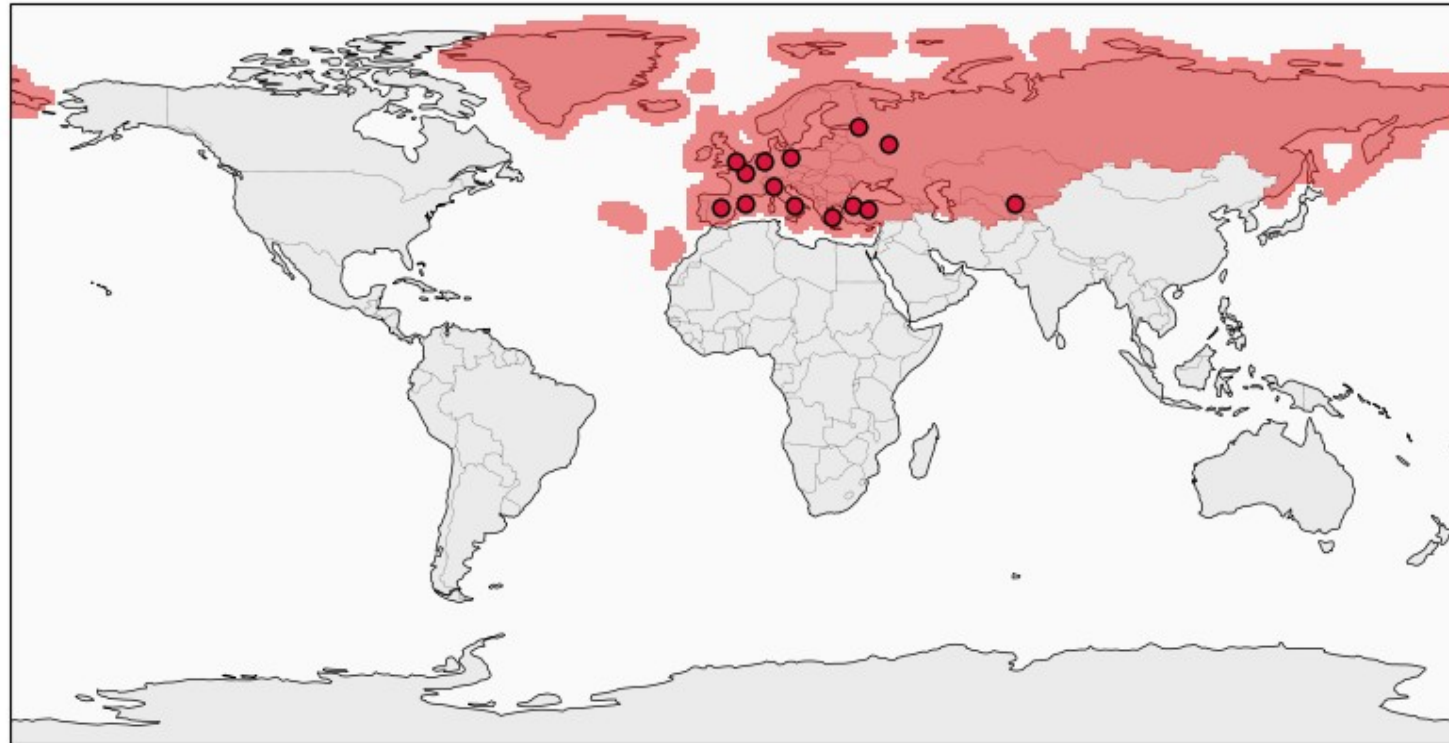
Ozone in Heraklion



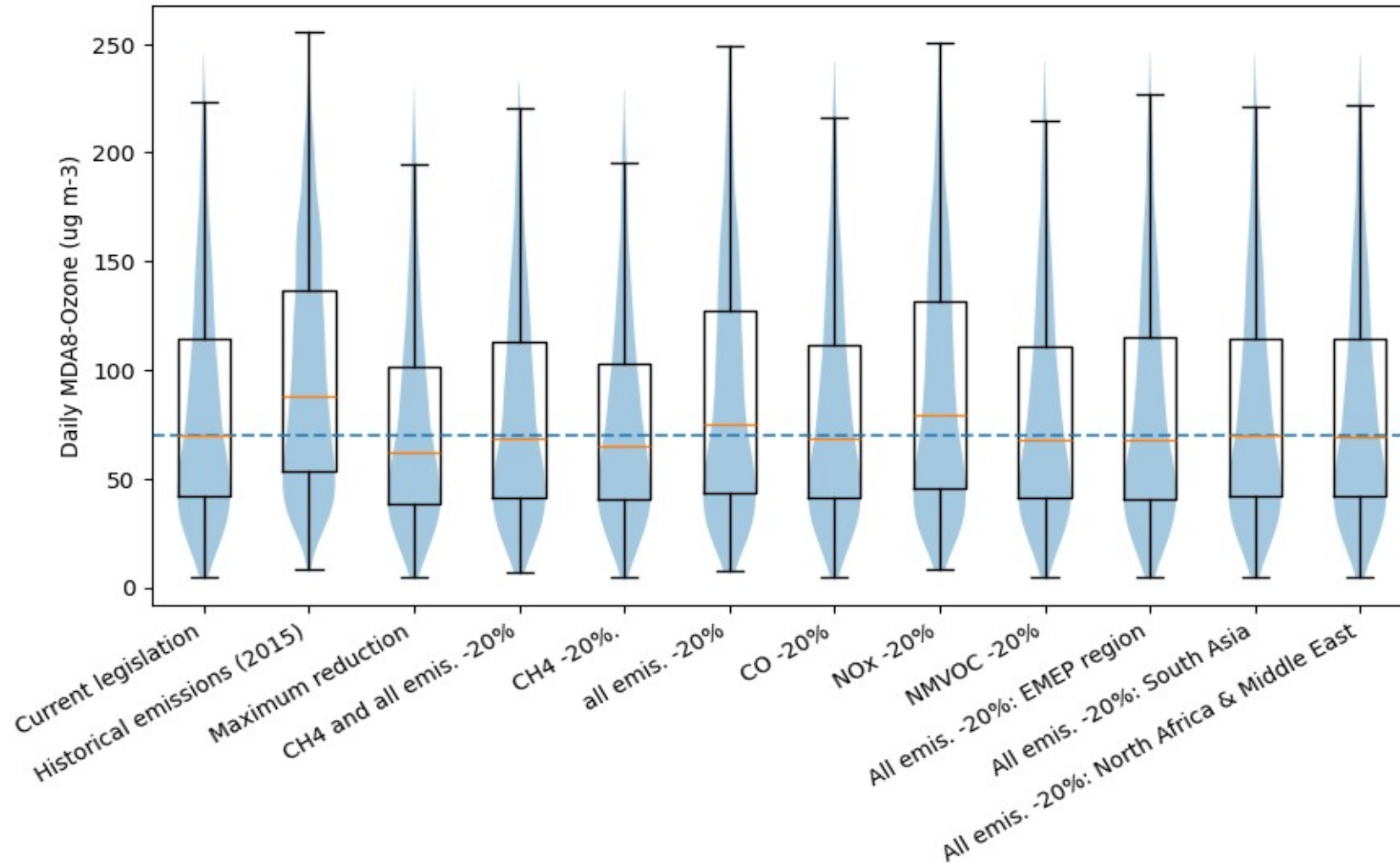
Largest 150 cities by population



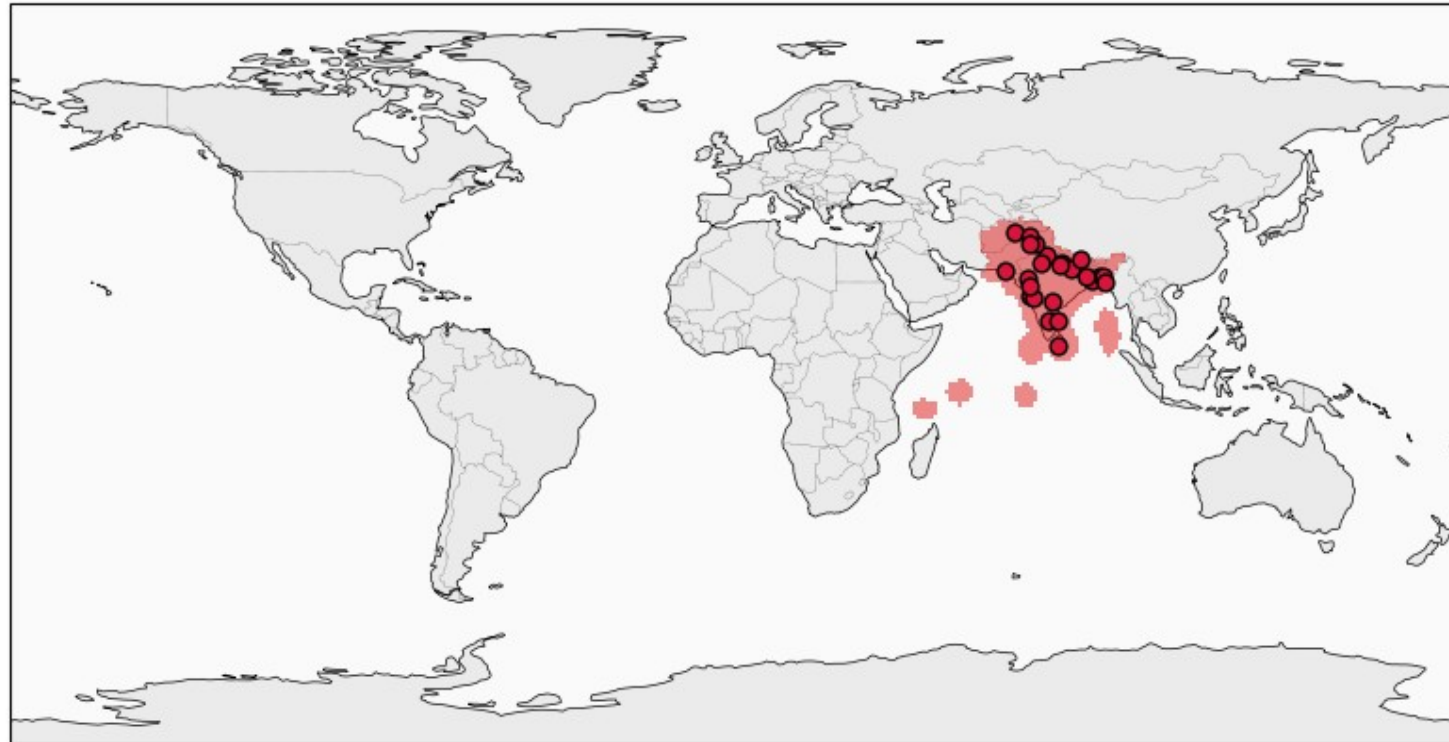
EMEP region



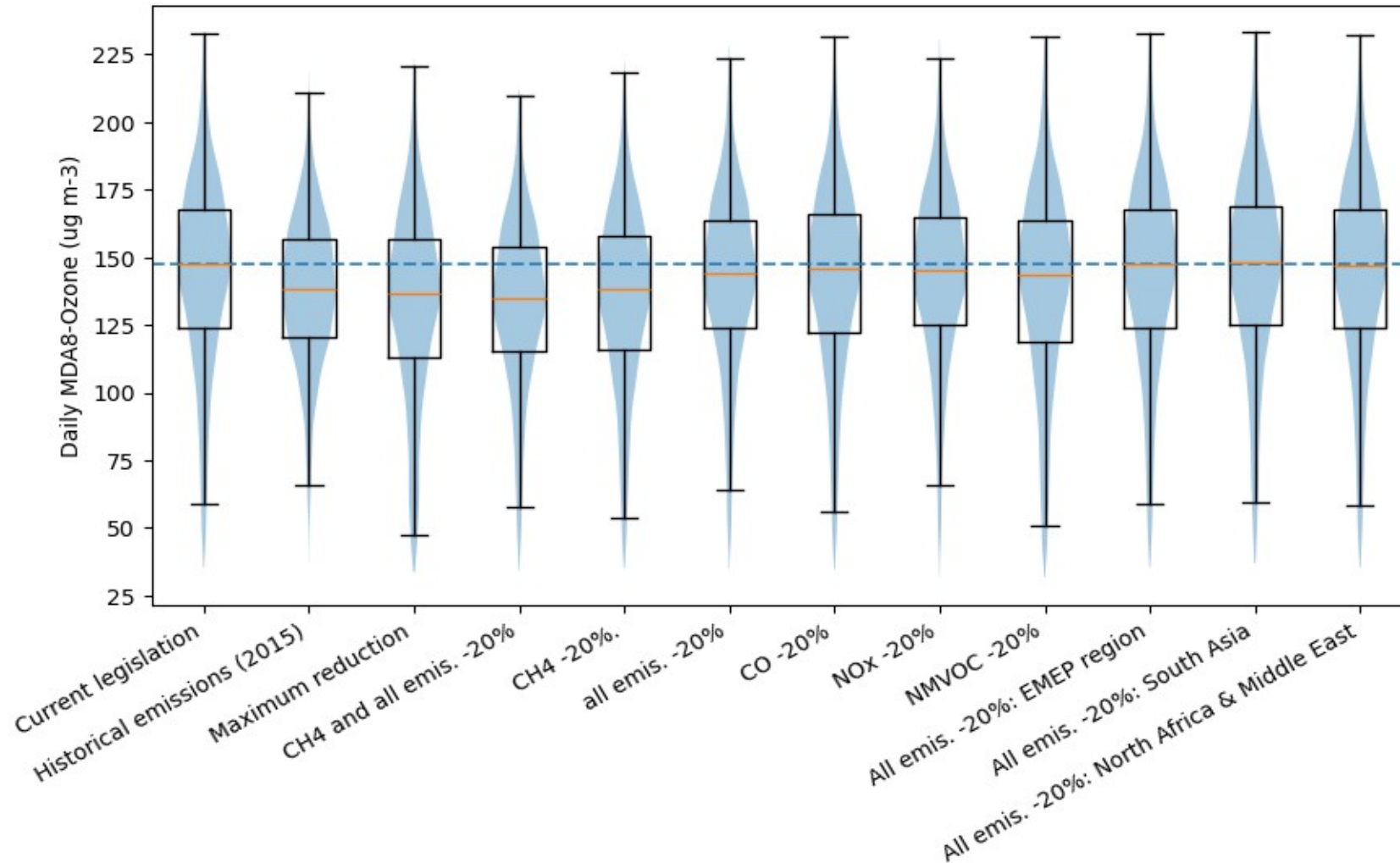
EMEP region



South Asia



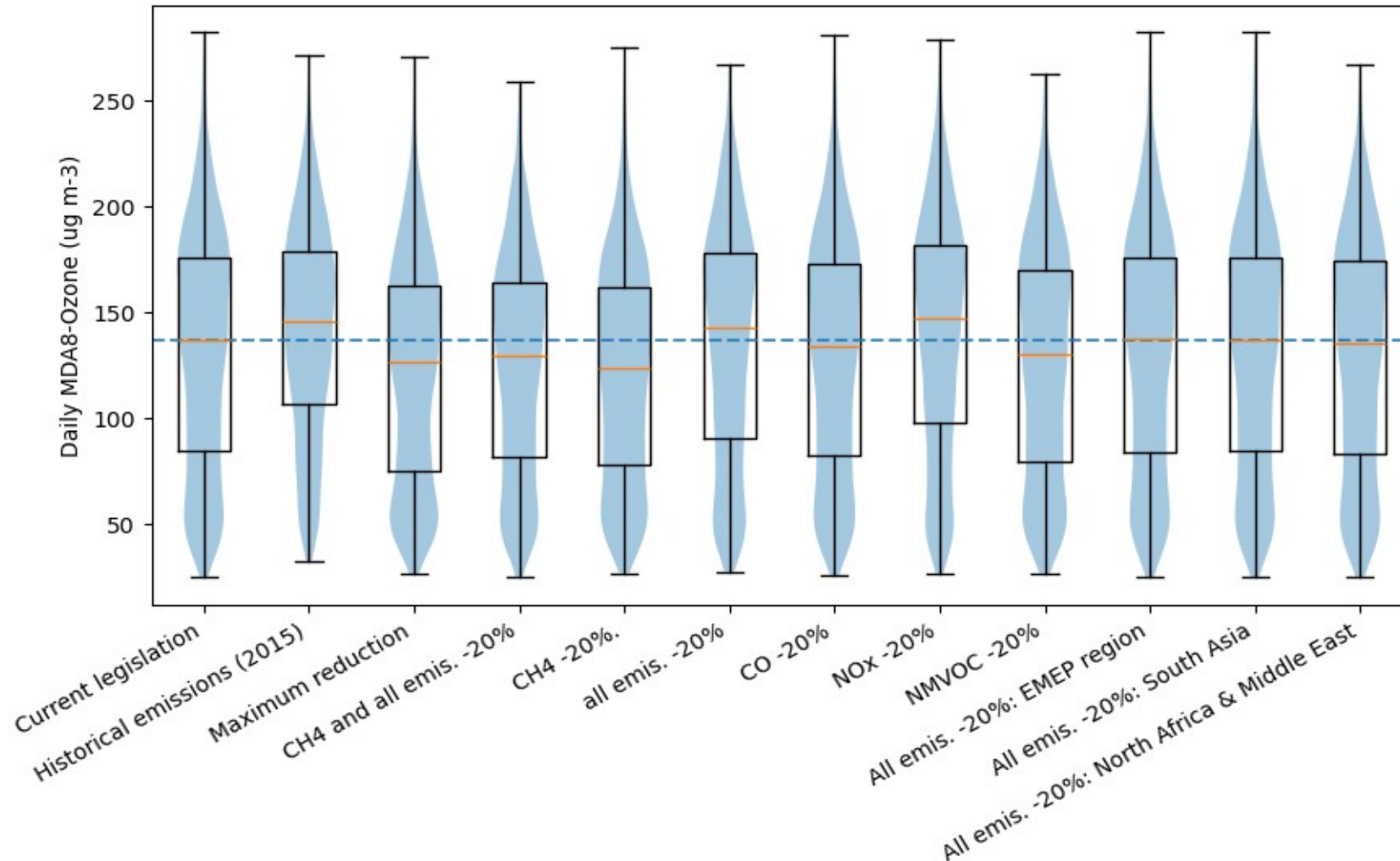
South Asia



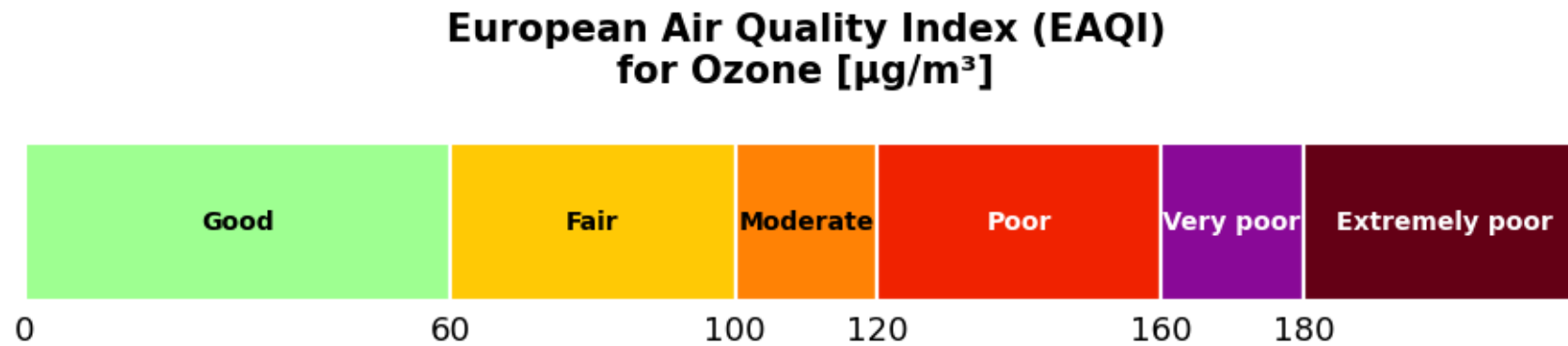
North Africa & Middle East



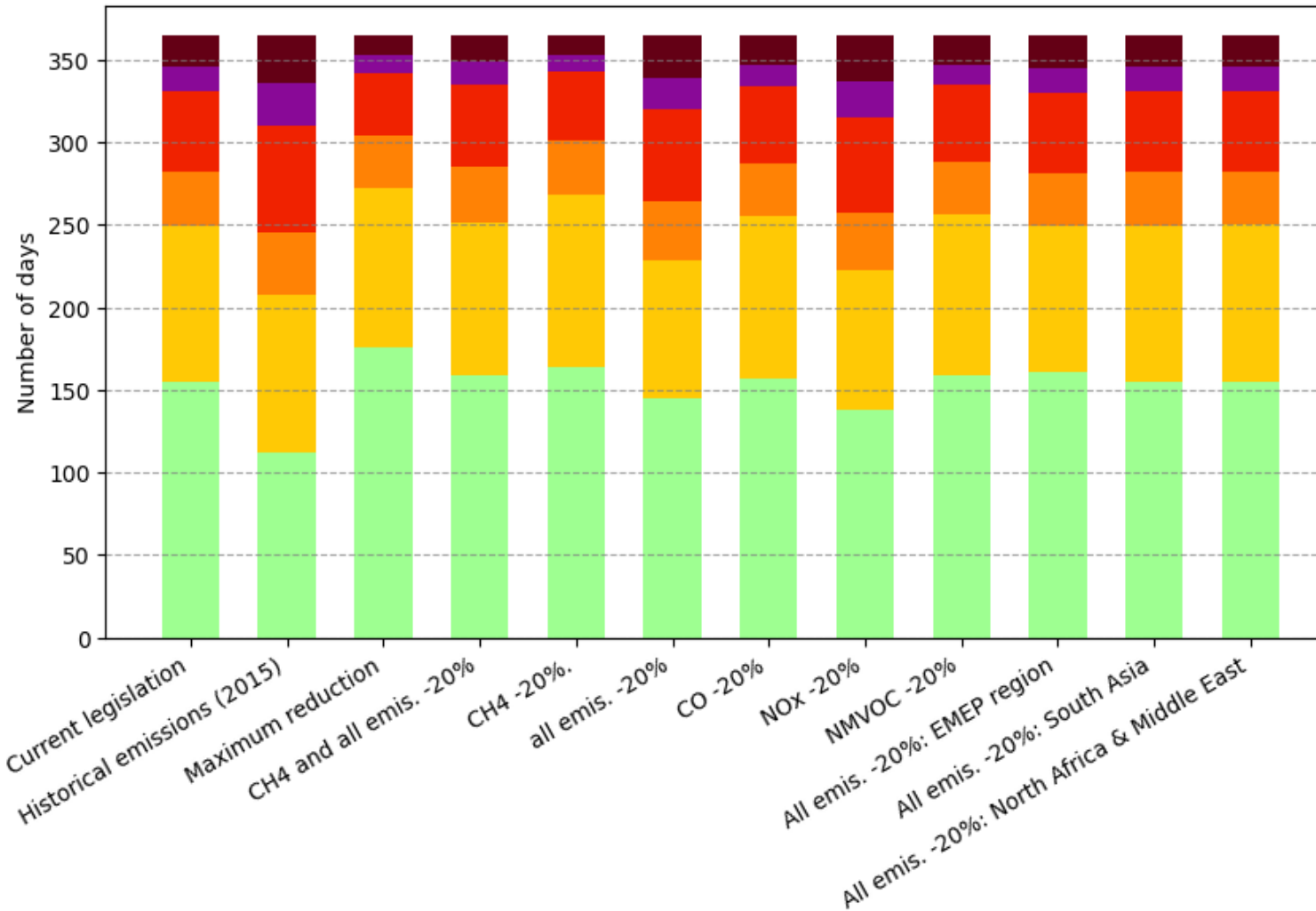
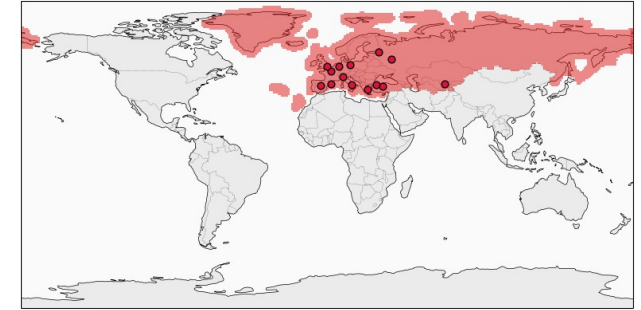
North Africa & Middle East



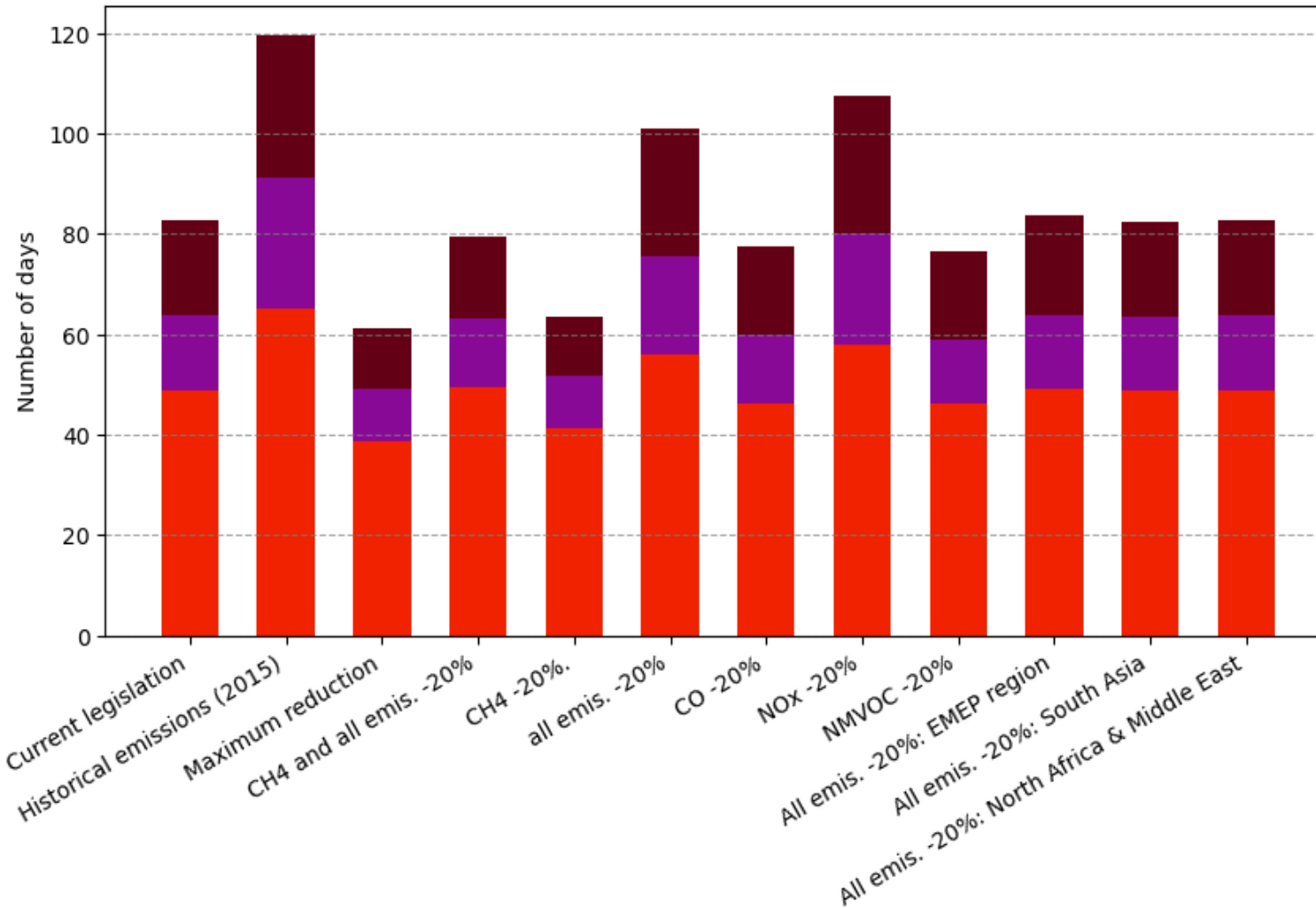
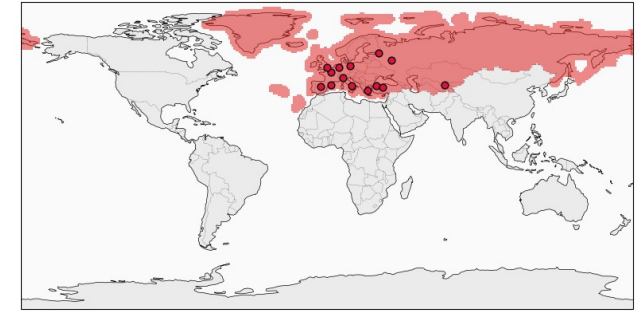
EAQI ozone levels



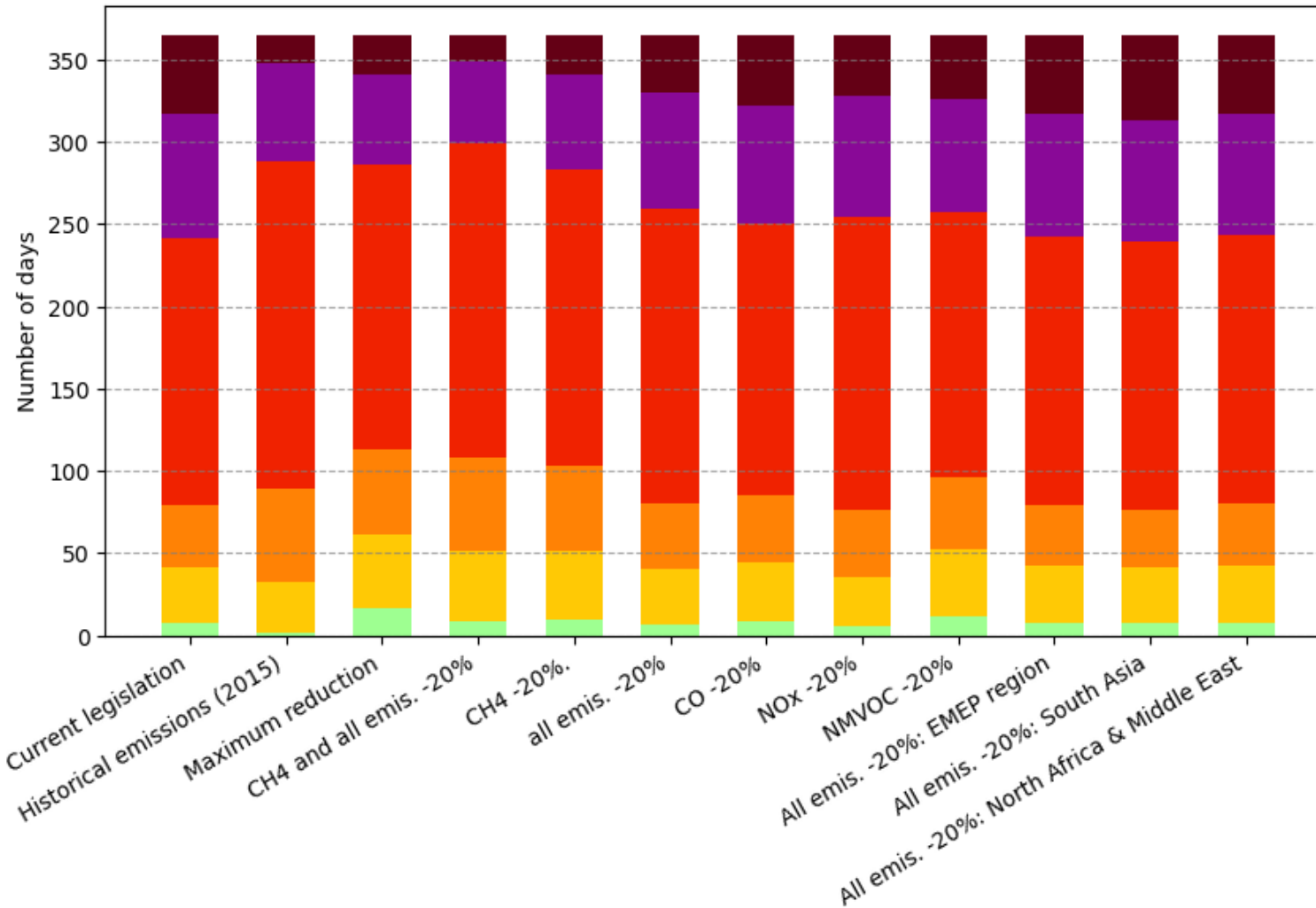
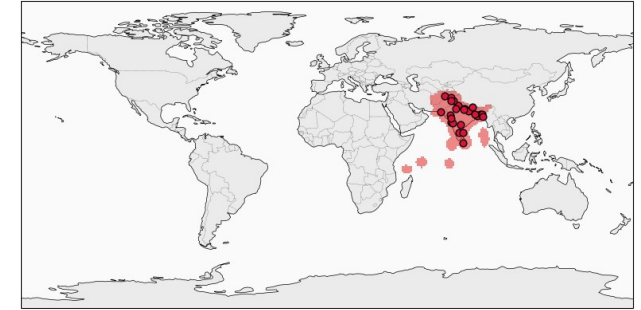
EAQI levels in the EMEP region



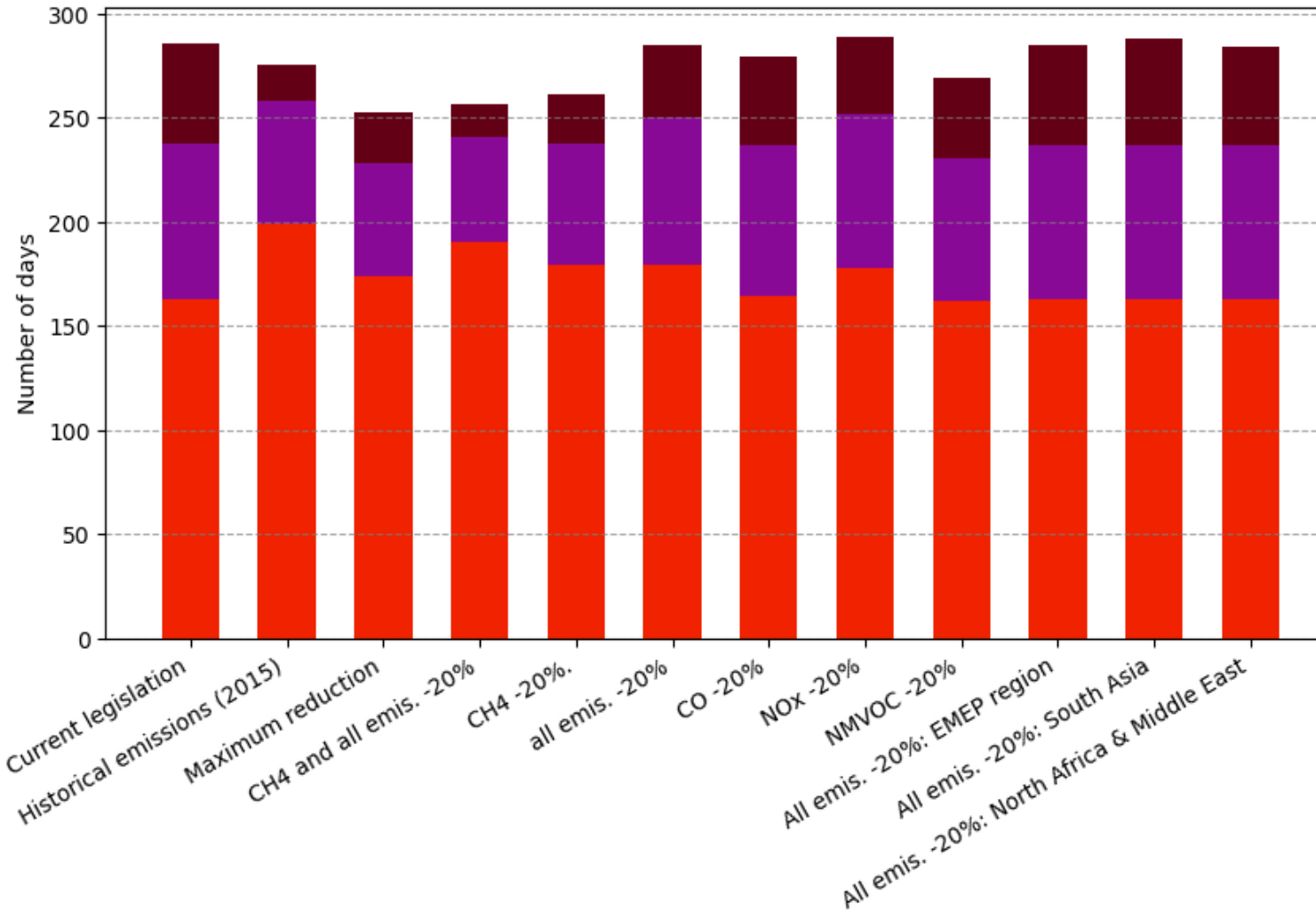
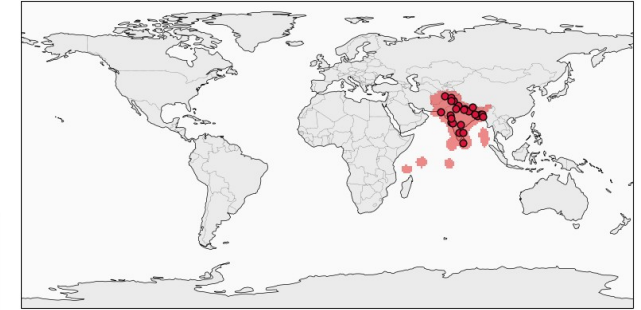
EAQI levels in the EMEP region



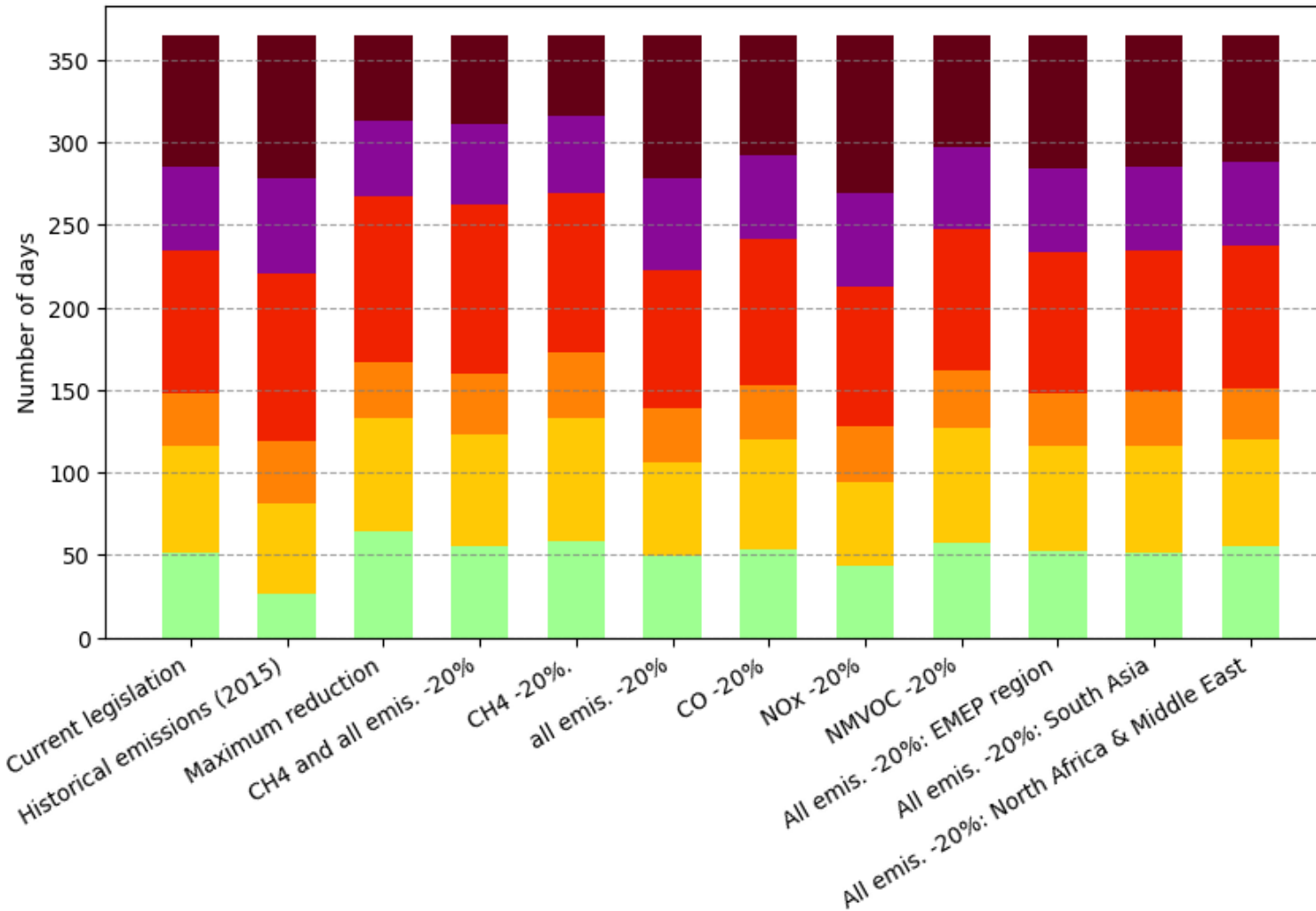
EAQI levels in South Asia



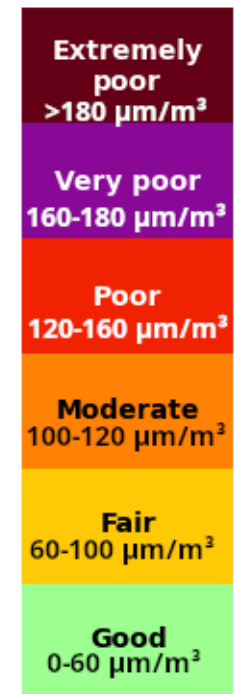
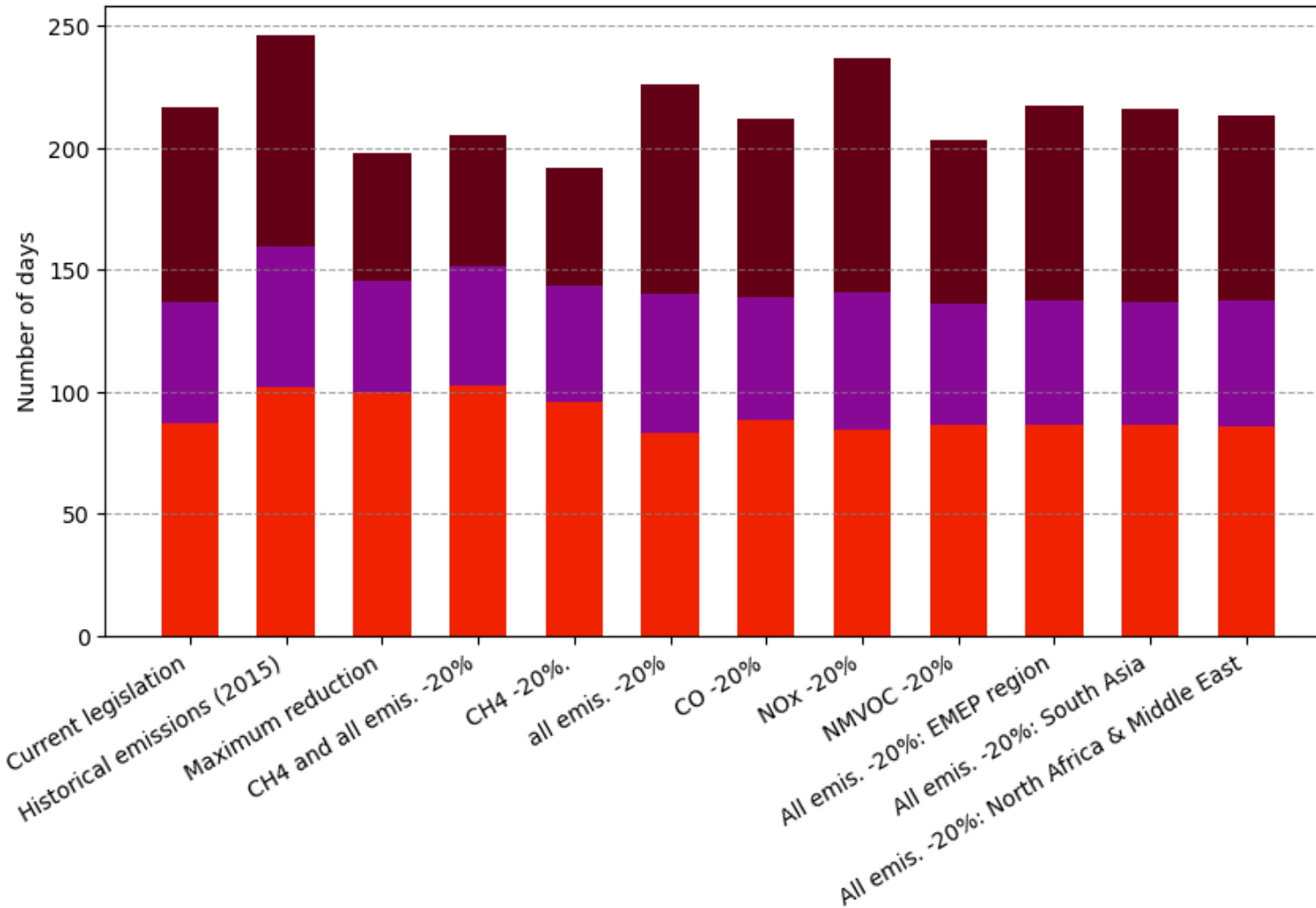
EAQI levels in South Asia



EAQI levels in North Africa & Middle East



EAQI levels in North Africa & Middle East



Conclusion

- Following **current legislation** could **reduce** O₃ levels in the future
- But: More reduction is possible and necessary
- Further reduction of **CH₄** and **NMVOCs** might **reduce** O₃
- Reducing **NO_x** emissions could **increase** O₃ depending on other emissions
- Regional emission reduction has very limited effect, even locally

Thank you!

Any questions?

Appendix

Appendix

Prescribed methane mixing ratios

Experiment	Methane [ppb]
Current Legislation	2119.33
Historic 2015	1834.21
Maximum reduction	1750.05
CH ₄ perturbations	1695.46
Other perturbations	2119.33

Appendix

Anthropogenic emissions (and methane mixing ratio)

Experiment	NO _x	CO	NM VOC	CH ₄
Current Legislation	34.03 Tg	322.6 Tg	78.2 Tg	2119.33 ppb
Historic 2015	+11.5 %	+42.2 %	+8.4 %	-13.5 %
Maximum reduction	- 53.7 %	- 57.8 %	-38.5 %	-17.4 %
Perturbations	0 % or -20 %	0 % or -20 %	0 % or -20 %	0 % or -20 %



Appendix

Priorities for HTAP3 Simulations

Base (CLE 2040 emissions)

Global Perturbations

Decrease CH4 Conc

Decrease CH4 Conc and all anthro emissions

Increase H2 conc

Decrease All anthro emissions

Decrease anthro NOX

Decrease anthro VOC

Decrease anthro CO

Global Scenario Runs

CLE 2015 emissions

MTFR (2040)

HILO (2040)

2015 meteorology / 2040 emissions

BASE (CLE2040)

1

CH4DEC

1

CH4ALL

1

H2INC

2

GLOALL

1

GLONOX

1

GLOVOC

1

GLOCO

1

CLE2015

1

MTFR2040

2

HILO2040

2

Highest Priority

Next Priority

Lower Priority

1 or 2

n

Regional Emissions Perturbation (2015 meteorology, 2040 CLE emissions)

N America

NAM

1

2

2

4

EMEP Domain

EMEP

1

2

2

4

EMEP West

EMEPW

3

4

4

4

EMEP East

EMEPE

3

4

4

4

East Asia

EAS

1

2

2

4

South Asia

SAS

1

2

2

4

South and East Mediterranean

SMD

1

2

2

4

Middle East

MDE

3

4

4

4

North Africa

NAF

3

4

4

4

SE Asia

SEA

3

4

4

4

Mex/C America/Caribbean

MCA

3

4

4

4

Rest of World (SAM+SAF+PAN)

ROW

3

4

4

4

South America

SAM

3

Southern Africa

SAF

3

Aust/NZ/Pacific

PAN

3

International Shipping

SHIP

1

Aviation (all vertical levels)

AVI

2

Fires (all fires)

FIRE

3

Table 2 Overview of the perturbation experiments in HTAP3-OPNS.

Appendix

AQ index	General population	Sensitive populations
Good	The air quality is good. Enjoy your usual outdoor activities.	The air quality is good. Enjoy your usual outdoor activities.
Fair	Enjoy your usual outdoor activities	Enjoy your usual outdoor activities
Moderate	Enjoy your usual outdoor activities	Consider reducing intense outdoor activities, if you experience symptoms.
Poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Consider reducing physical activities, particularly outdoors, especially if you experience symptoms.
Very poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Reduce physical activities, particularly outdoors, especially if you experience symptoms.
Extremely poor	Reduce physical activities outdoors.	Avoid physical activities outdoors.

<https://airindex.eea.europa.eu/AQI/index.html>

Appendix

