
The title 'Aerosol Trends' is centered on the slide. The word 'Aerosol' is in a smaller, light blue font, and 'Trends' is in a larger, bold white font. A white horizontal line is positioned above the text. A stylized blue line graph with an upward trend is positioned behind the word 'Aerosol'.

Aerosol Trends

Do AeroCom phase III models reproduce the
observed trends over the last two decades?

A. Mortier, J. Gliss, M. Schulz
Norwegian Meteorological Institute - Metno

- 1. Trends Web Interface**
- 2. Regional Observed Trends**
- 2. Observed Trends Representativeness**
- 3. Model Trends Evaluation**

work in progress

1. Trends Interface

Trends computation

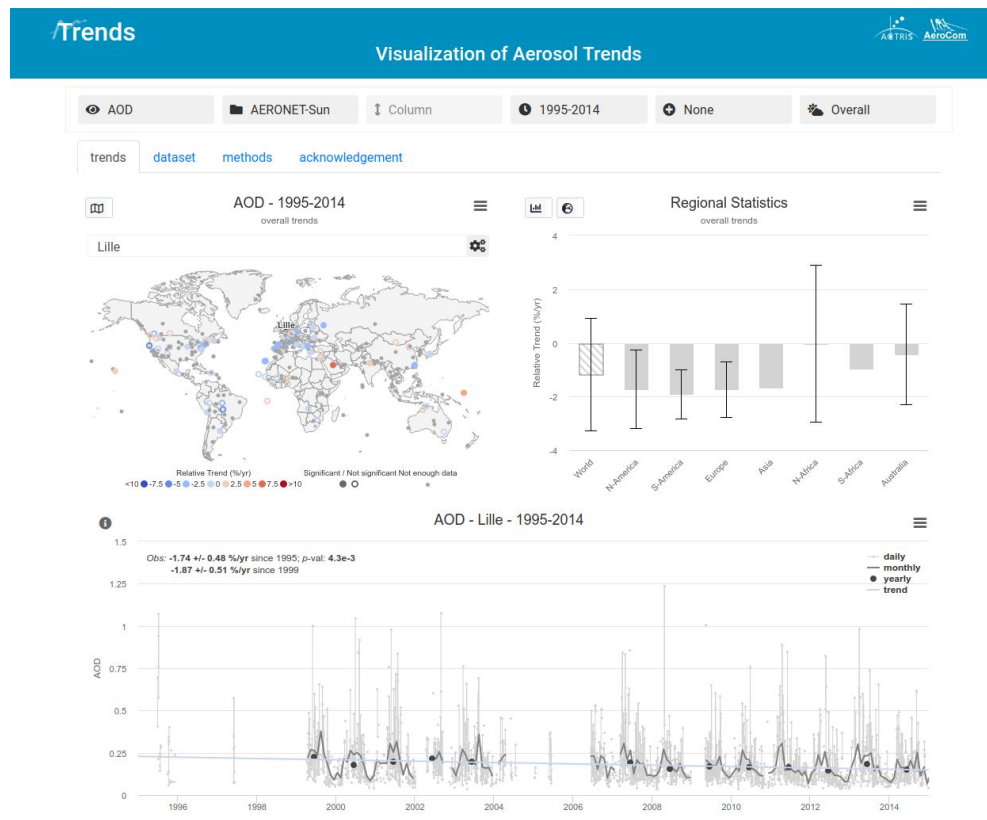
Computed from yearly averaged values: no seasonal cycles → no need for prewhitening

- 1 year if 4 seasons
- 1 season if 1 month
- 1 month if 5 days

Relative trends as compared to the value of the regression line at the first date of the studied period

Slope computation

Mann-Kendall + Theil-Sen slope



<https://aerocom-trends.met.no>

1. Trends Interface

Trends computation

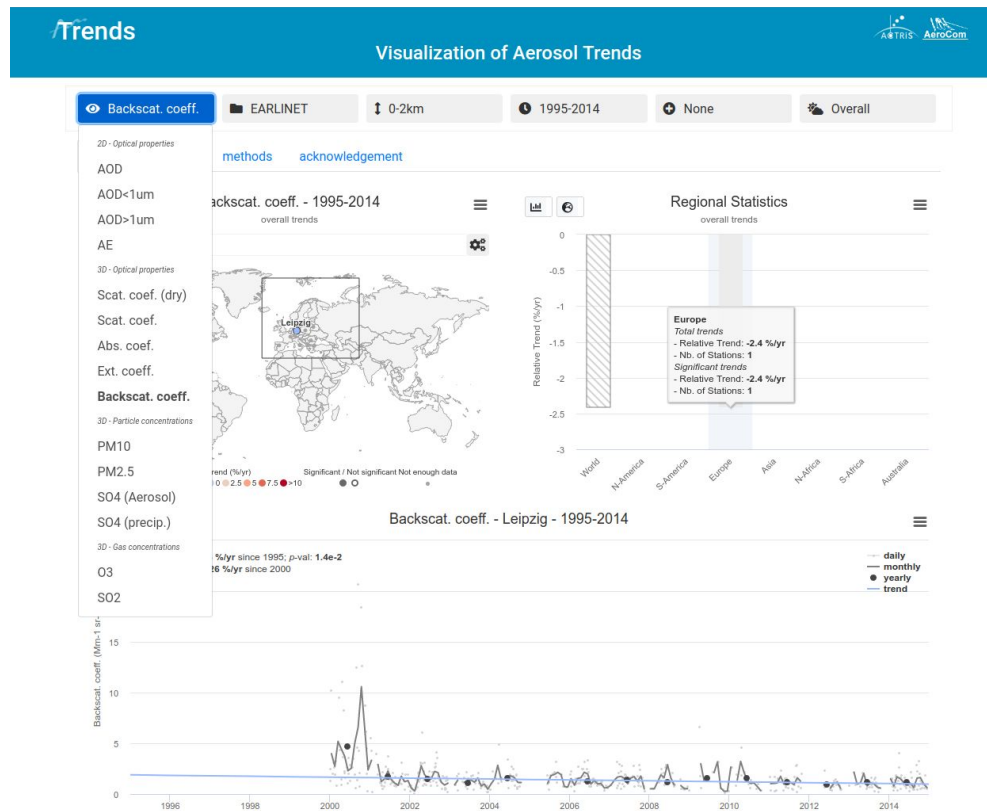
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- *1 year if 4 seasons*
- *1 season if 1 month*
- *1 month if 5 days*

Relative trends as compared to the value of the regression line at the first date of the studied period

Slope computation

Mann-Kendall + Theil-Sen slope



<https://aerocom-trends.met.no>

**What are the
observed regional
trends?**

2. Regional Observed Trends

Methodology

- **From individual station trend to regional trends → Regional Time Series**
(!) Regions definition. Use of standard AeroCOM regions
- **Piecewise linear fit**
Allow for one break point in the time series

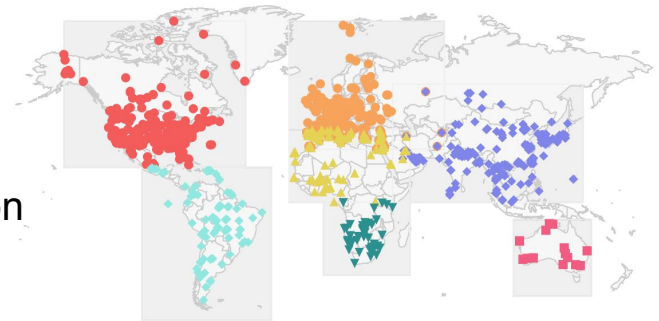
Datasets

- AERONET: AOD, AE, AOD<1 μ m, AOD>1 μ m
- EBAS: PM2.5, PM10
- GAW/TAD/EANET (Aas *et al.*, 2019): SO₄ concentration
- ...?

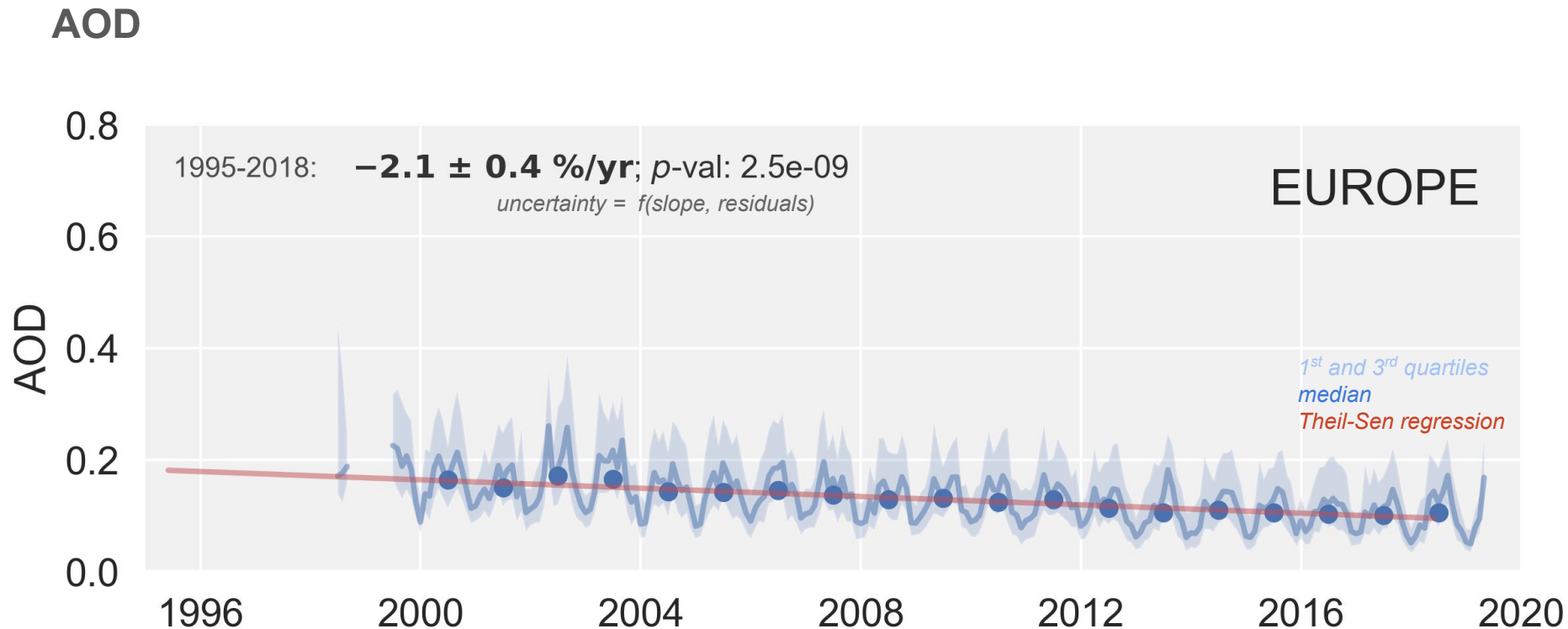
Period

1995-2018

AERONET-Sun stations



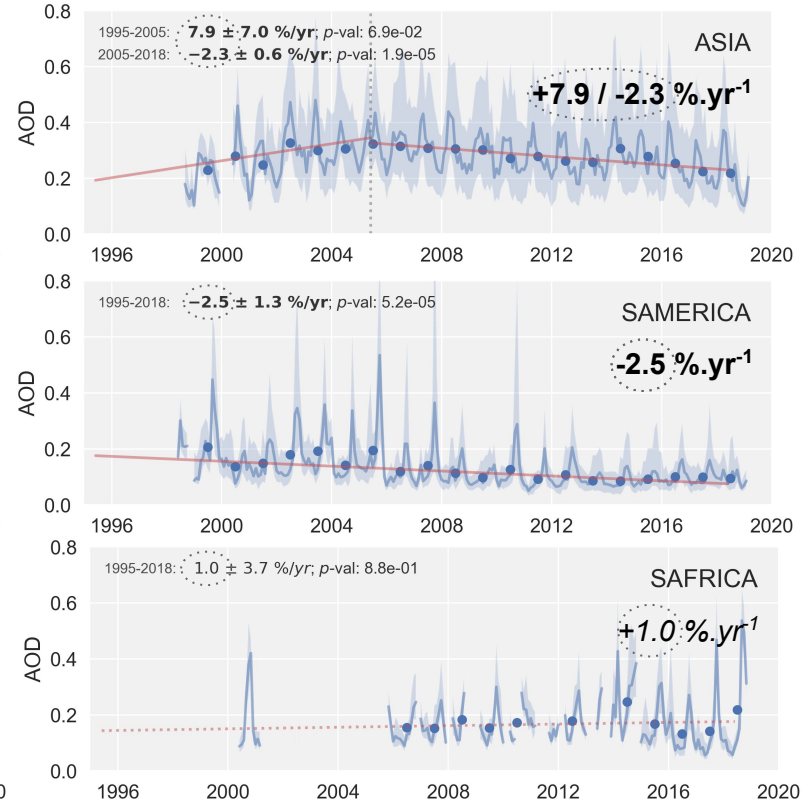
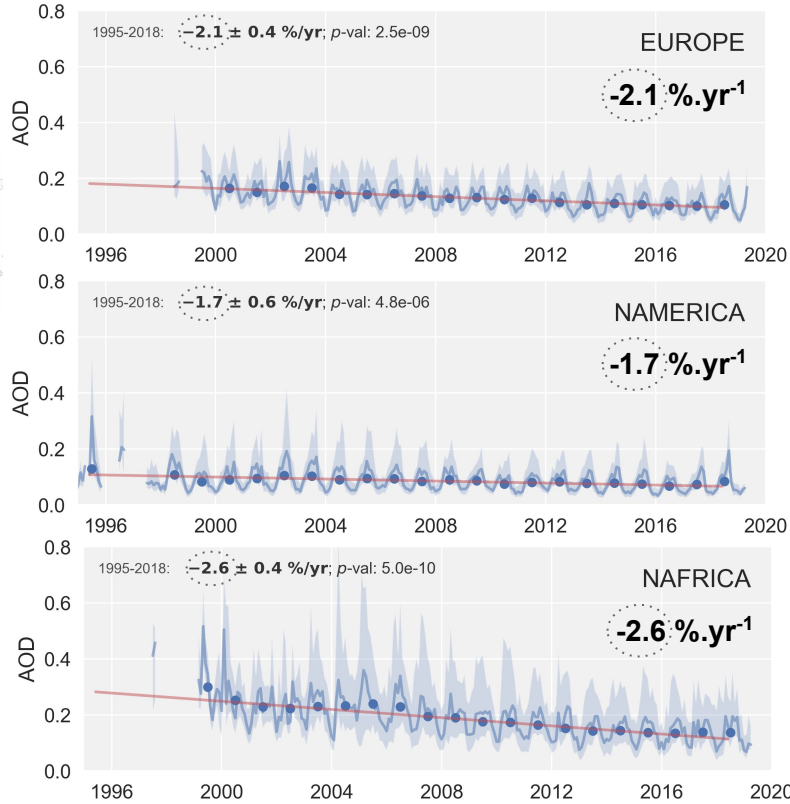
2. Regional Observed Trends



2. Regional Observed Trends

AOD

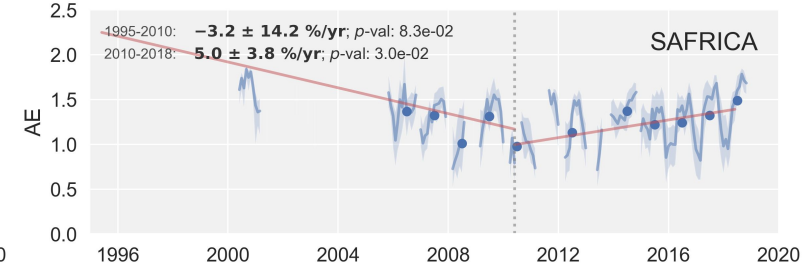
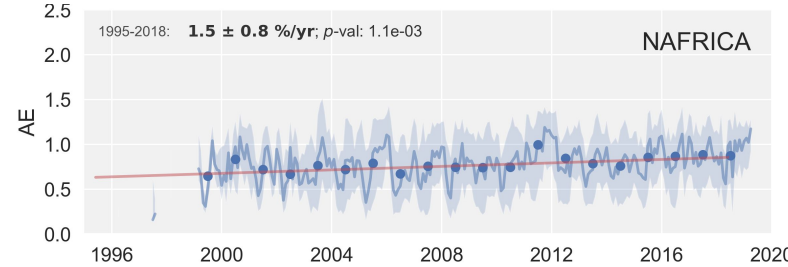
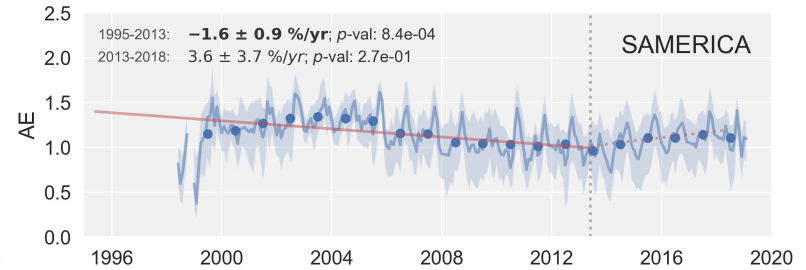
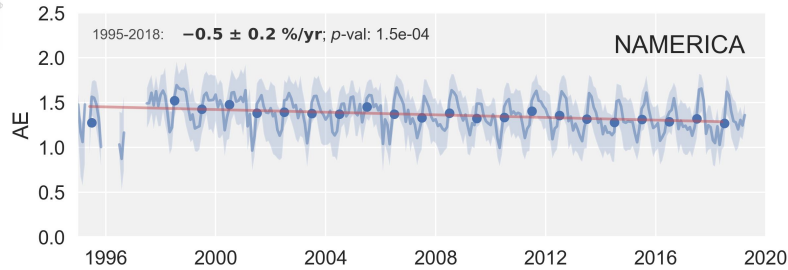
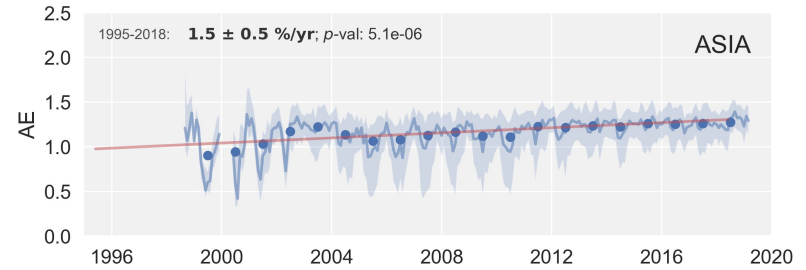
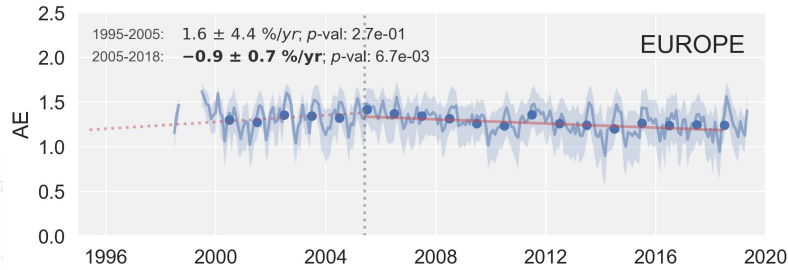
AERONET



2. Regional Observed Trends

AE

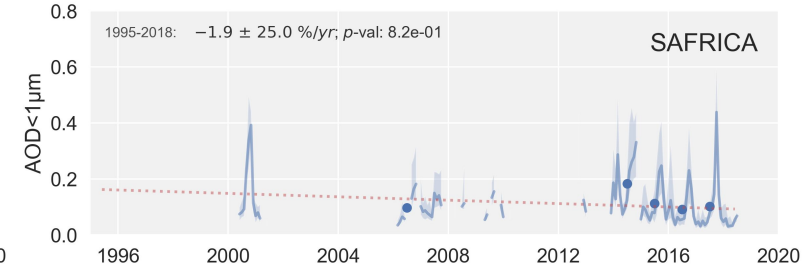
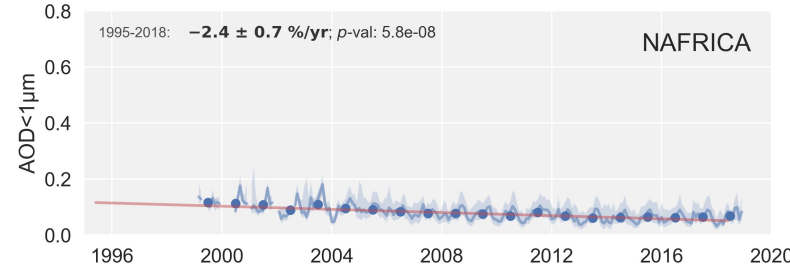
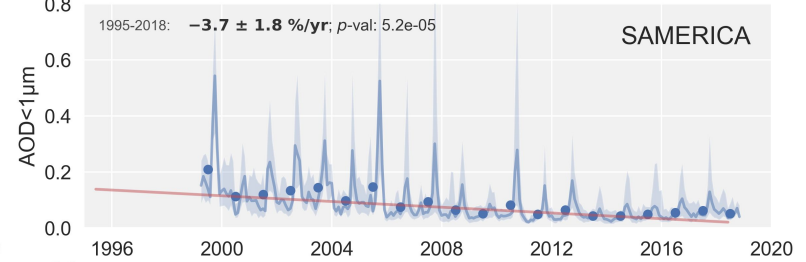
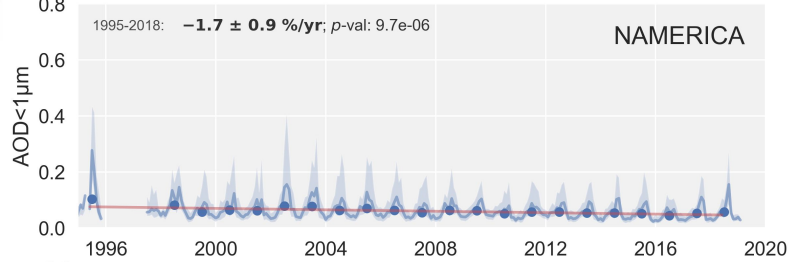
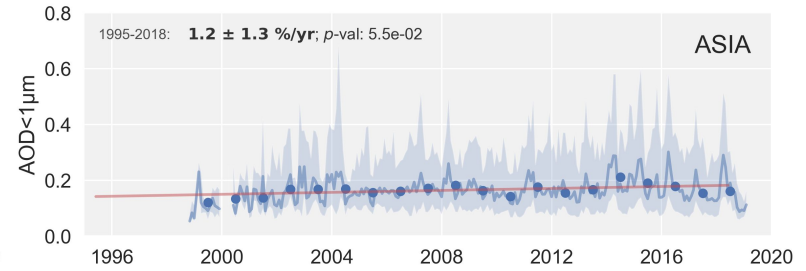
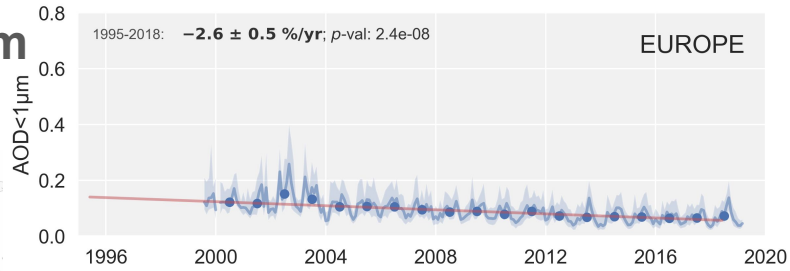
AERONET



2. Regional Observed Trends

AOD < 1 μm

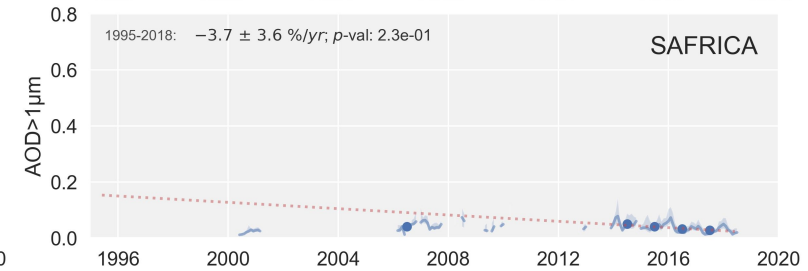
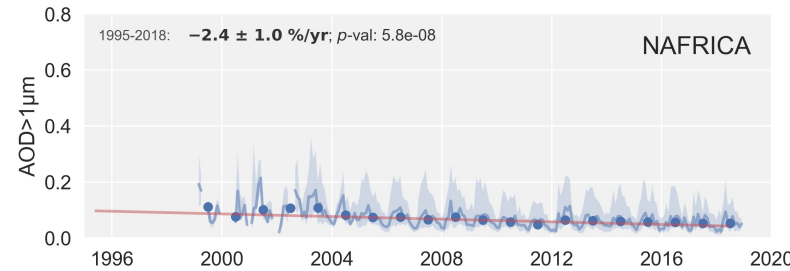
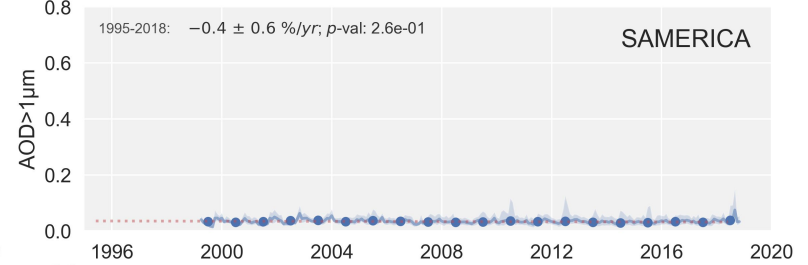
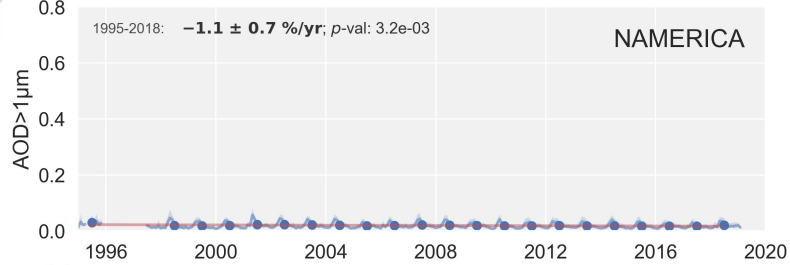
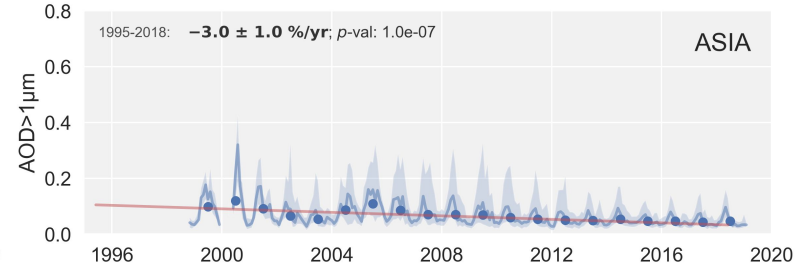
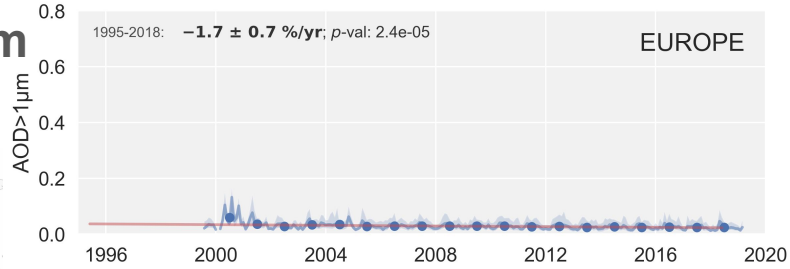
AERONET



2. Regional Observed Trends

AOD > 1 μ m

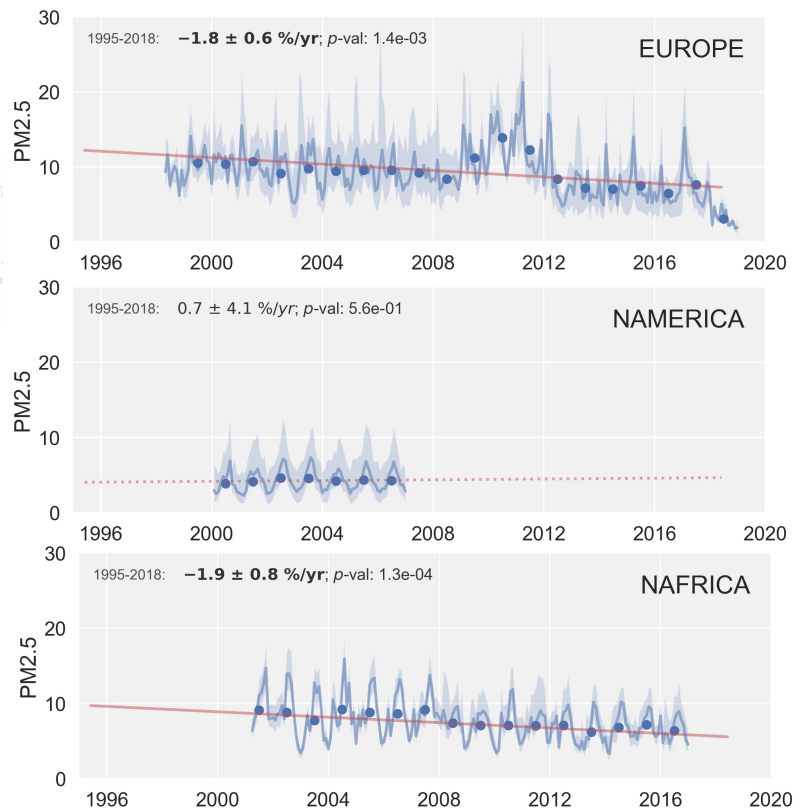
AERONET



2. Regional Observed Trends

PM2.5

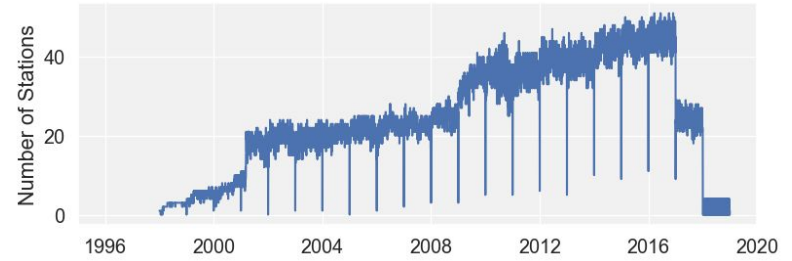
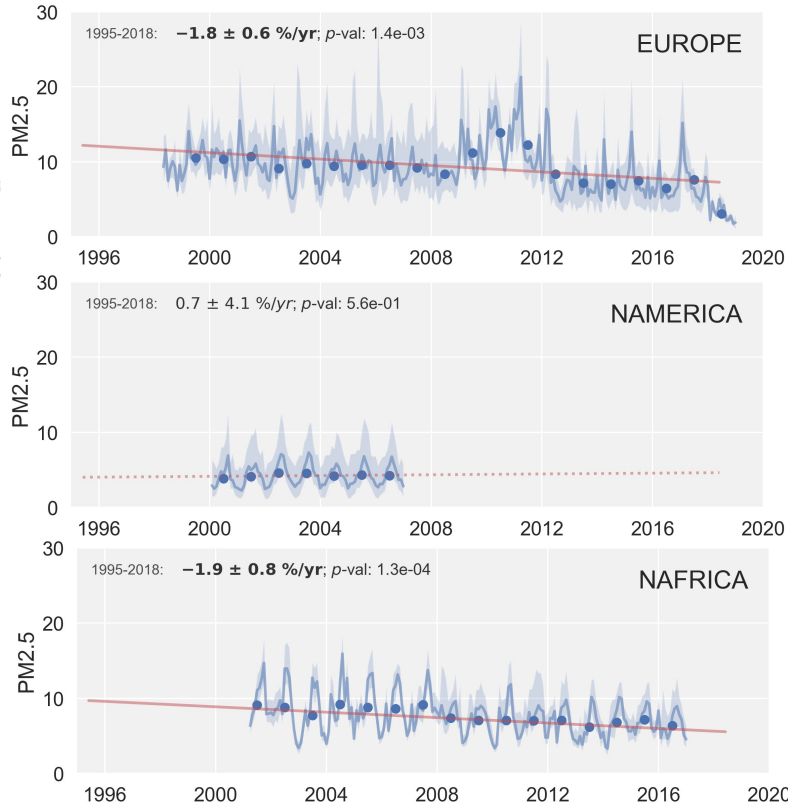
EBAS



2. Regional Observed Trends

PM2.5

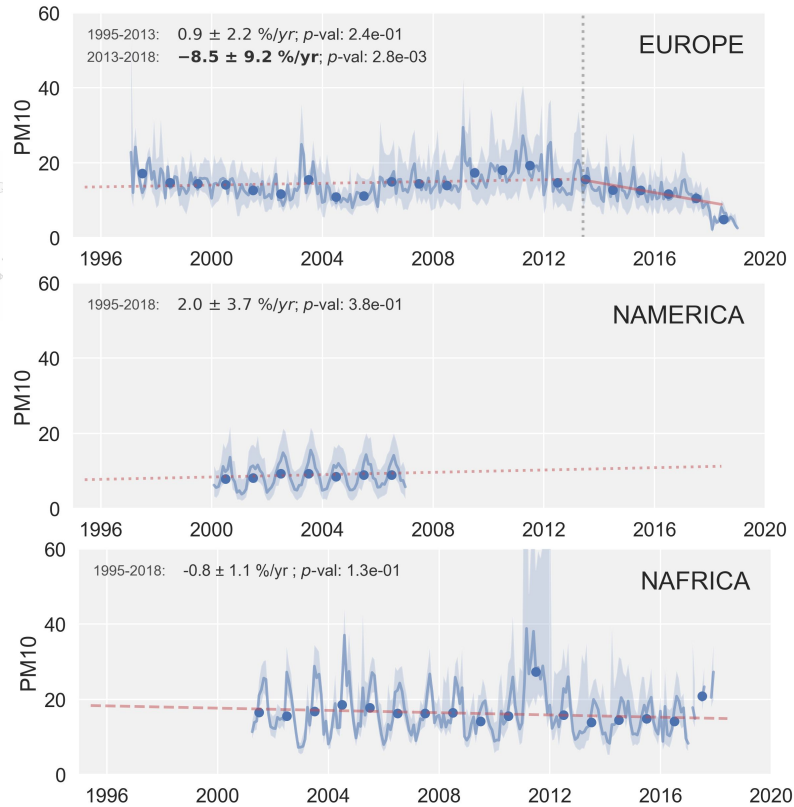
EBAS



2. Regional Observed Trends

PM10

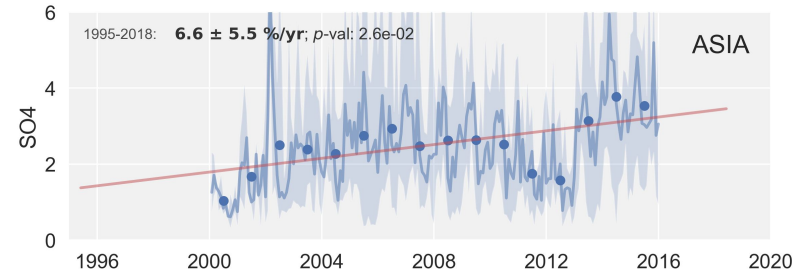
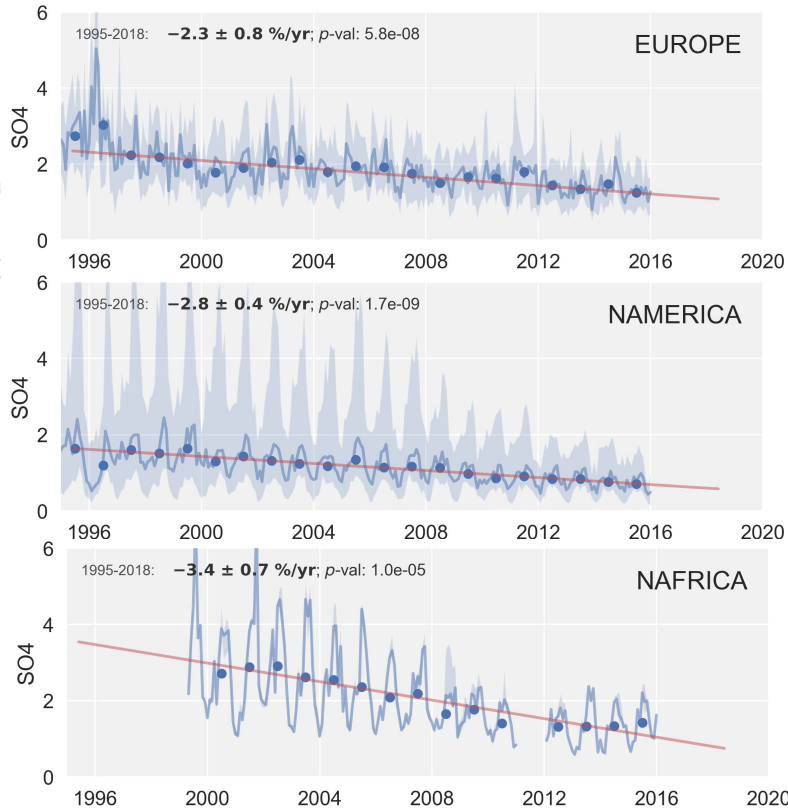
EBAS



2. Regional Observed Trends

SO₄ conc.

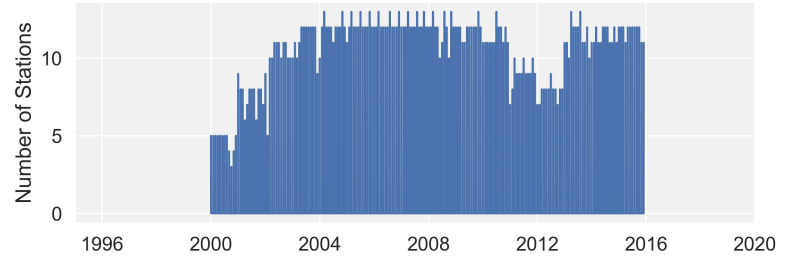
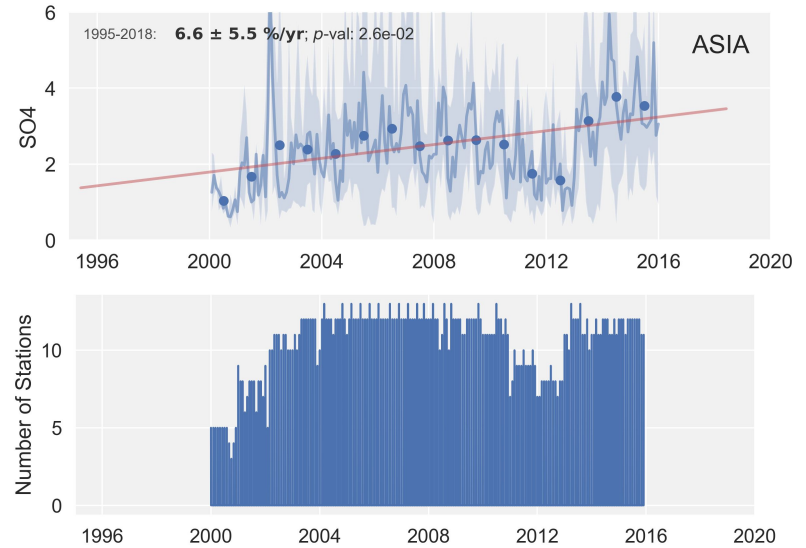
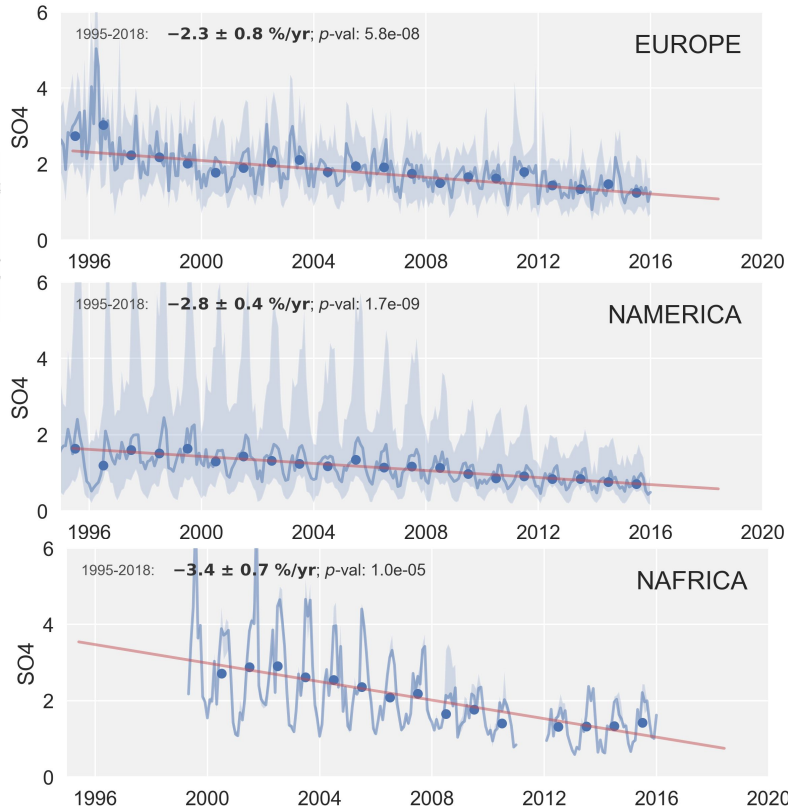
Aas et. al, 2019



2. Regional Observed Trends

SO₄ conc.

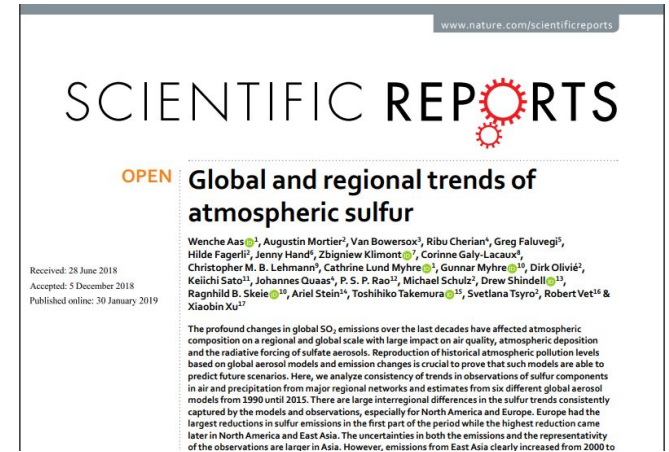
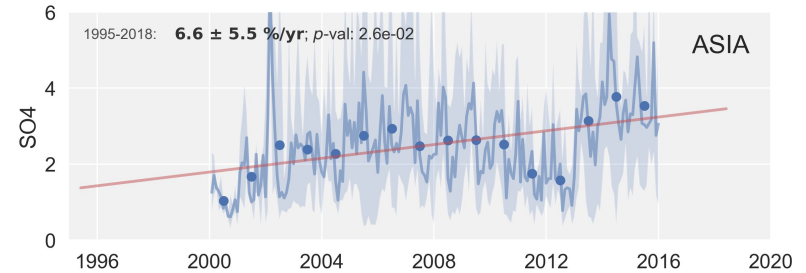
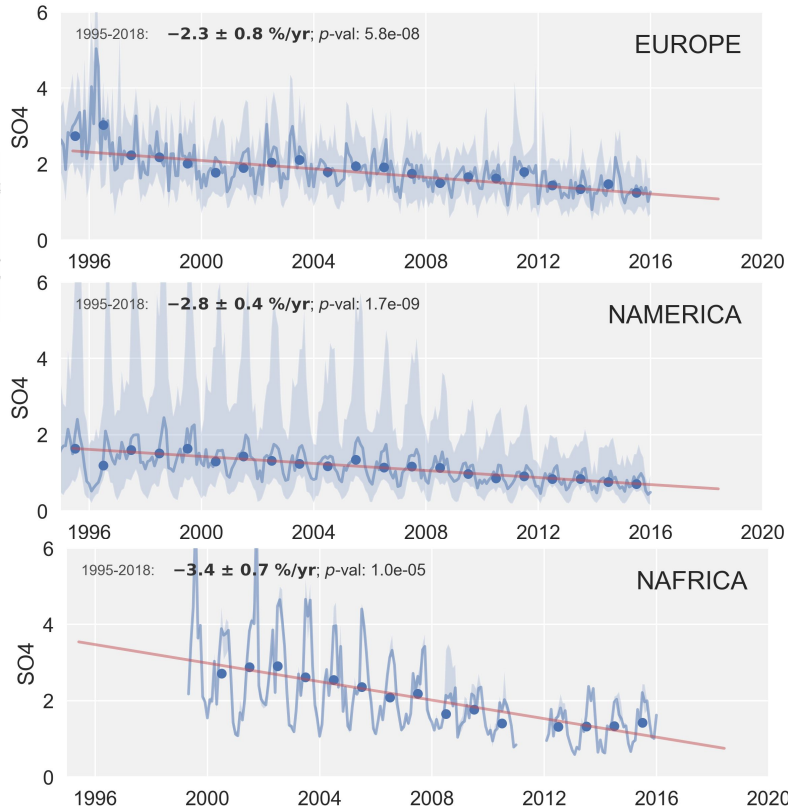
Aas et. al, 2019



2. Regional Observed Trends

SO₄ conc.

Aas et al, 2019



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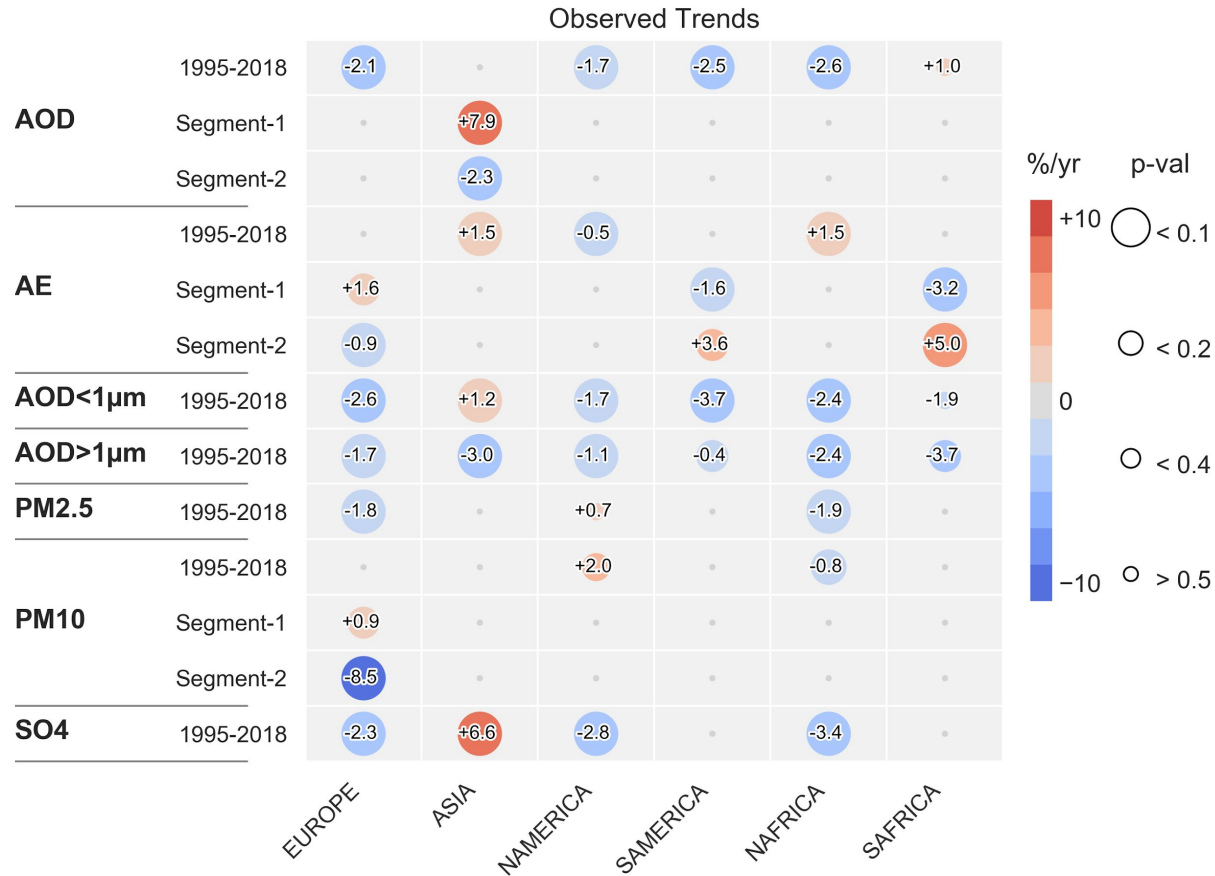
OPEN **Global and regional trends of atmospheric sulfur**

Wenche Aas¹, Augustin Mortier², Van Bowersox³, Ribu Cherian⁴, Greg Faluvegi⁵, Hilde Fagerli⁶, Jenny Hand⁷, Zbigniew Klimont⁸, Corinne Galy-Lacaux⁴, Christopher M. B. Lehmann⁹, Cathrine Lund Myhre¹⁰, Gunnar Myhre¹¹, Dirk Olivie², Keiichi Sato¹², Johannes Quaas¹, P. S. P. Rao¹³, Michael Schulz¹, Drew Shindell¹³, Ragnhild B. Skeie¹⁴, Ariel Stein¹⁵, Toshihiko Takemura¹⁶, Svetlana Tsyro¹, Robert Vet¹⁶ & Xiaobin Xu¹⁷

Received: 28 June 2018
Accepted: 5 December 2018
Published online: 30 January 2019

The profound changes in global SO₂ emissions over the last decades have affected atmospheric composition on a regional and global scale with large impact on air quality, atmospheric deposition and the radiative forcing of sulfate aerosols. Reproduction of historical atmospheric pollution levels based on global aerosol models and emission changes is crucial to prove that such models are able to predict future scenarios. Here, we analyze consistency of trends in observations of sulfur components in air and precipitation from major regional networks and estimates from six different global aerosol models from 1990 until 2015. There are large interregional differences in the sulfur trends consistently captured by the models and observations, especially for North America and Europe. Europe had the largest reductions in sulfur emissions in the first part of the period while the highest reduction came later in North America and East Asia. The uncertainties in both the emissions and the representativity of the observations are larger in Asia. However, emissions from East Asia clearly increased from 2000 to

2. Regional Observed Trends

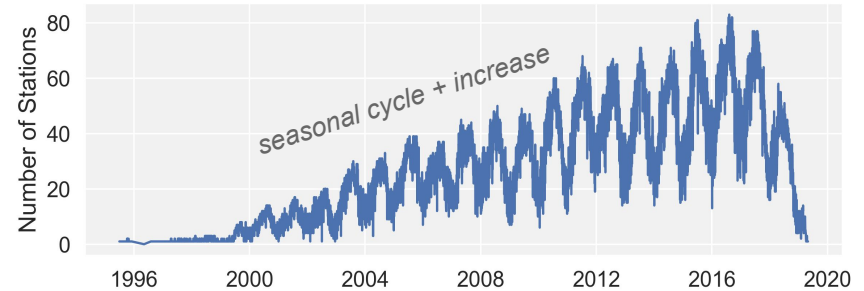


**How representative
are these trends?**

3. Assessment of Networks Representativeness

Experiments using model data

- Time Representativity
 - **Ref_{time}**
 - Colocated in Space
 - Colocated in Time
 - **Exp_{time}**
 - Colocated in Space
 - Full Time Series



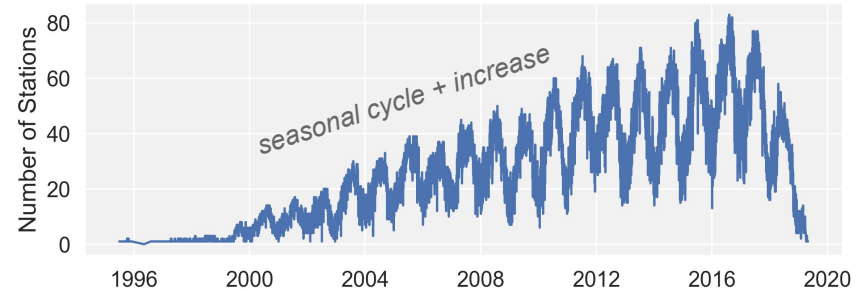
Number of stations used to compute the regional daily AOD time series in Europe.

3. Assessment of Networks Representativeness

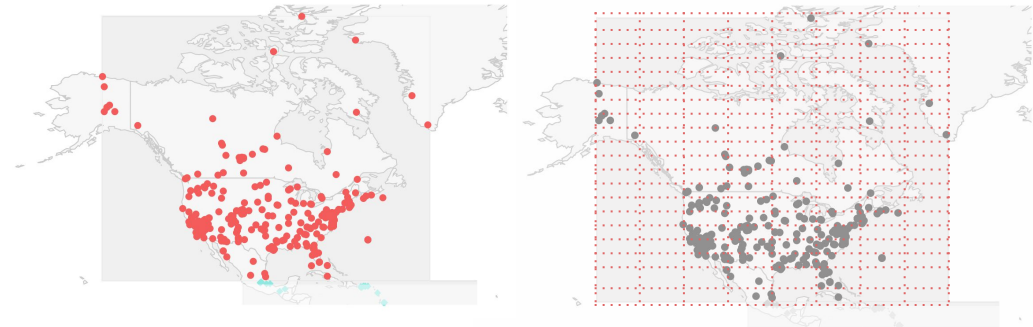
Experiments using model data

- Time Representativity
 - **Ref_{time}**
 - Colocated in Space
 - Colocated in Time
 - **Exp_{time}**
 - Colocated in Space
 - Full Time Series

- Space Representativity
 - **Ref_{space} (=Exp_{time})**
 - Colocated in Space
 - Full Time Series
 - **Exp_{space}**
 - All grid boxes in Region
 - Full Time Series



Number of stations used to compute the regional daily AOD time series in Europe.



3. Assessment of Networks Representativeness

AOD

Parameter	Model	Region	Segment	Trends (%/yr)		
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}
AOD	GFDL	EUROP	1995-2018	-1.6	-1.5	-0.5
			2003-2005			
		ASIA	2005-2018	-1.2	-0.7	0
			AUSTR	1995-2018	-2.4	-0.3	-0.1
		NAFRI	1995-2018	-1.7	-0.5	0.2
		SAFRI	1995-2018	0.6	0.5	0.4
		NAMER	1995-2018	-1.1	-1.9	-0.8
		SAMER	1995-2018	-1.9	-0.8	-0.2

3. Assessment of Networks Representativeness

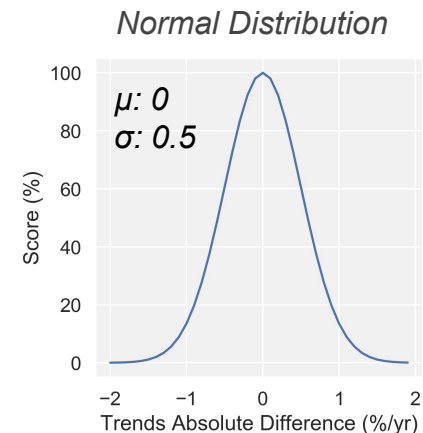
AOD

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)		
				Ref_{time}	$\frac{Exp_{time}}{Ref_{space}}$	Exp_{space}	Time exp.	Space exp.	Total
AOD	GFDL	EUROP	1995-2018	-1.6	-1.5	-0.5	0.1	1	0.55
			2003-2005						
		ASIA	2005-2018	-1.2	-0.7	0	0.5	0.7	0.6
			1995-2018	-2.4	-0.3	-0.1	2.1	0.2	1.15
		NAFRI	1995-2018	-1.7	-0.5	0.2	1.2	0.7	0.95
		SAFRI	1995-2018	0.6	0.5	0.4	0.1	0.1	0.1
		NAMER	1995-2018	-1.1	-1.9	-0.8	0.8	1.1	0.95
		SAMER	1995-2018	-1.9	-0.8	-0.2	1.1	0.6	0.85

3. Assessment of Networks Representativeness

AOD

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)		
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	Time exp.	Space exp.	Total
AOD	GFDL	EUROP	1995-2018	-1.6	-1.5	-0.5	0.1	1	0.55
			2003-2005						
		ASIA	2005-2018	-1.2	-0.7	0	0.5	0.7	0.6
		AUSTR	1995-2018	-2.4	-0.3	-0.1	2.1	0.2	1.15
		NAFRI	1995-2018	-1.7	-0.5	0.2	1.2	0.7	0.95
		SAFRI	1995-2018	0.6	0.5	0.4	0.1	0.1	0.1
		NAMER	1995-2018	-1.1	-1.9	-0.8	0.8	1.1	0.95
SAMER	1995-2018	-1.9	-0.8	-0.2	1.1	0.6	0.85		



3. Assessment of Networks Representativeness

AOD

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			Overall
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	Time exp.	Space exp.	Total	Time	Space	Total	
AOD	GFDL	EUROP	1995-2018	-1.6	-1.5	-0.5	0.1	1	0.55	78	11	44	30
			2003-2005										
		ASIA	2005-2018	-1.2	-0.7	0	0.5	0.7	0.6	48	30	39	
			AUSTR	1995-2018	-2.4	-0.3	-0.1	2.1	0.2	1.15	0	74		6
		NAFRI	1995-2018	-1.7	-0.5	0.2	1.2	0.7	0.95	4	30	13	
		SAFRI	1995-2018	0.6	0.5	0.4	0.1	0.1	0.1	78	78	78	
		NAMER	1995-2018	-1.1	-1.9	-0.8	0.8	1.1	0.95	22	7	13	
		SAMER	1995-2018	-1.9	-0.8	-0.2	1.1	0.6	0.85	7	39	19	
								34	33				

3. Assessment of Networks Representativeness

AE

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			Overall
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	Time exp.	Space exp.	Total	Time	Space	Total	
AE	GFDL	EUROP	1995-2005	-0.4	-0.3	-0.2	0.1	0.1	0.1	78	78	78	48
			2005-2014	-0.4	-0.3	-0.1	0.1	0.2	0.15	78	74	76	
		ASIA	1995-2018	1.2	0.2	0.1	1	0.1	0.55	11	78	44	
		AUSTR	1995-2011	0.8	-0.1	0	0.9	0.1	0.5	16	78	48	
			2011-2014	-5.4	-0.9	-0.7	4.5	0.2	2.35	0	74	0	
		NAFRI	1995-2018	-0.7	-0.2	0	0.5	0.2	0.35	48	74	62	
		SAFRI	1995-2010	-1.3	-0.2	-0.1	1.1	0.1	0.6	7	78	39	
			2010-2014	5.1	-0.2	-0.2	5.3	0	2.65	0	80	0	
		NAMER	1995-2018	0.3	0.3	0.1	0	0.2	0.1	80	74	78	
		SAMER	1995-2013	-0.7	0	-0.1	0.7	0.1	0.4	30	78	58	
			2013-2014							35	77		

3. Assessment of Networks Representativeness

PM2.5

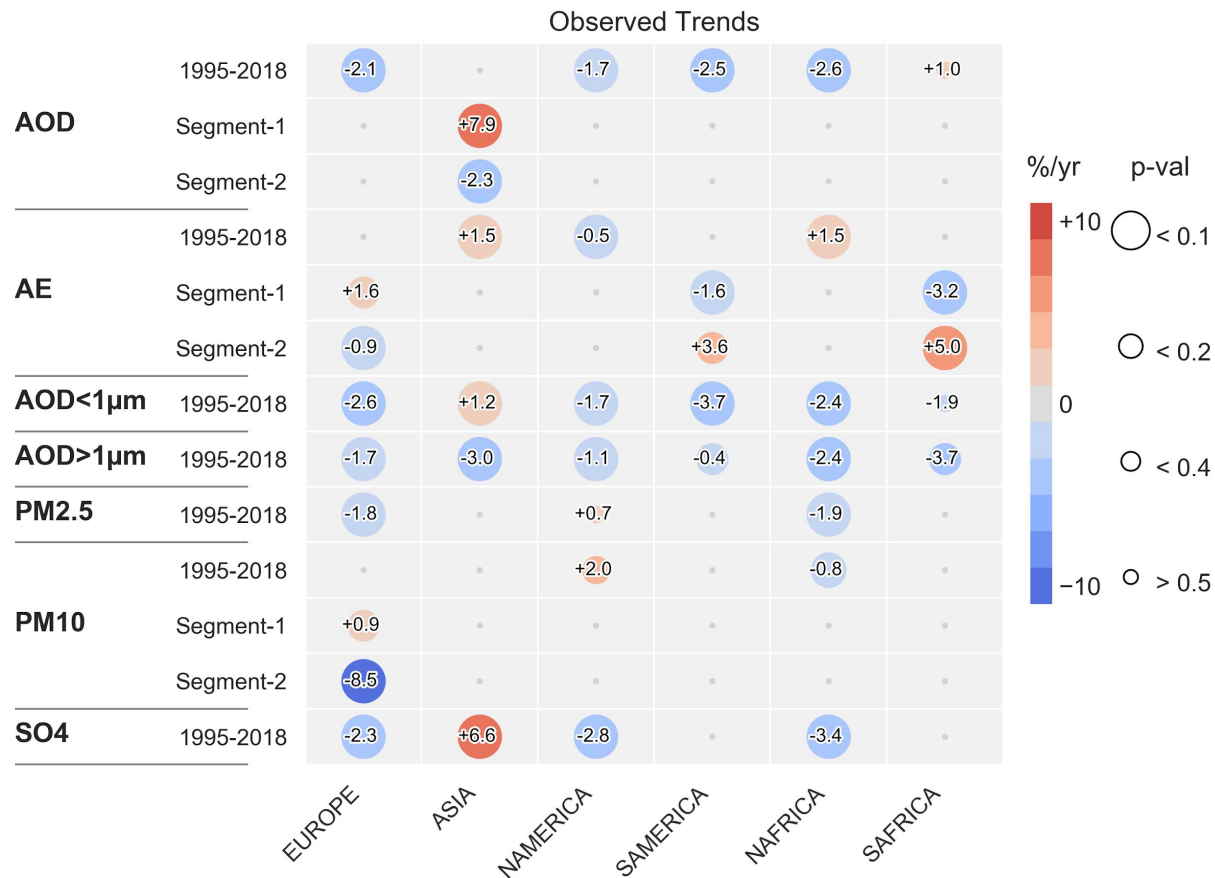
Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	Time exp.	Space exp.	Total	Time	Space	Total	Overall
PM2.5	ECMWF	EUROP	1995-2018	-2.2	-1.9	-0.4	0.3	1.5	0.9	67	1	16	18
		ASIA	1995-2019										
		AUSTR	1995-2020										
		NAFRI	1995-2021	-2.4	-2	0.1	0.4	2.1	1.25	58	0	4	
		SAFRI	1995-2022										
		NAMER	1995-2023	-1.7	-1.8	-0.6	0.1	1.2	0.65	78	4	34	
		SAMER	1995-2024							68	2		

3. Assessment of Networks Representativeness

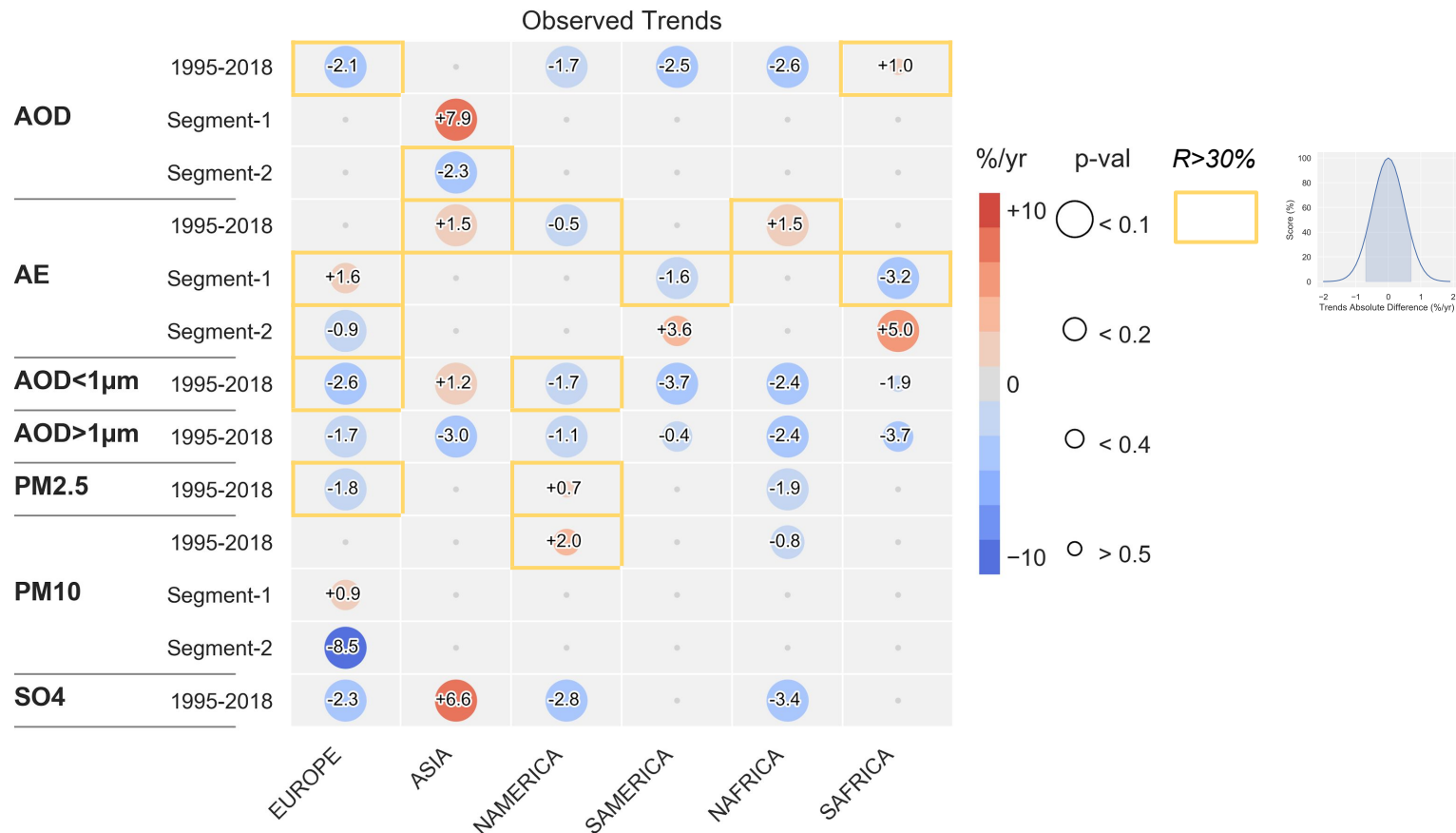
PM10

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			Overall
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	$Time\ exp.$	$Space\ exp.$	$Total$	Time	Space	Total	
PM10	ECMWF	EUROP	1995-2013	-2.5	-2.3	0	0.2	2.3	1.25	74	0	4	13
			2013-2018	-3.4	-1.7	-0.7	1.7	1	1.35	0	11	2	
		ASIA	1995-2018										
		AUSTR	1995-2018										
		NAFRI	1995-2018	-1.5	-1.8	0.1	0.3	1.9	1.1	67	0	7	
		SAFRI	1995-2018										
		NAMER	1995-2018	-1.8	-1.8	-0.6	0	1.2	0.6	80	4	39	
		SAMER	1995-2018							55	4		

3. Assessment of Networks Representativeness



3. Assessment of Networks Representativeness



**Do the models
reproduce the
observed trends?**

4. Model Trends Evaluation

Methodology

- Colocation in **time** (model to obs.) and **space** (closest grid box from obs. stations)
- If **break-point** found in **obs.** dataset, use it to **split** the **model** time-series

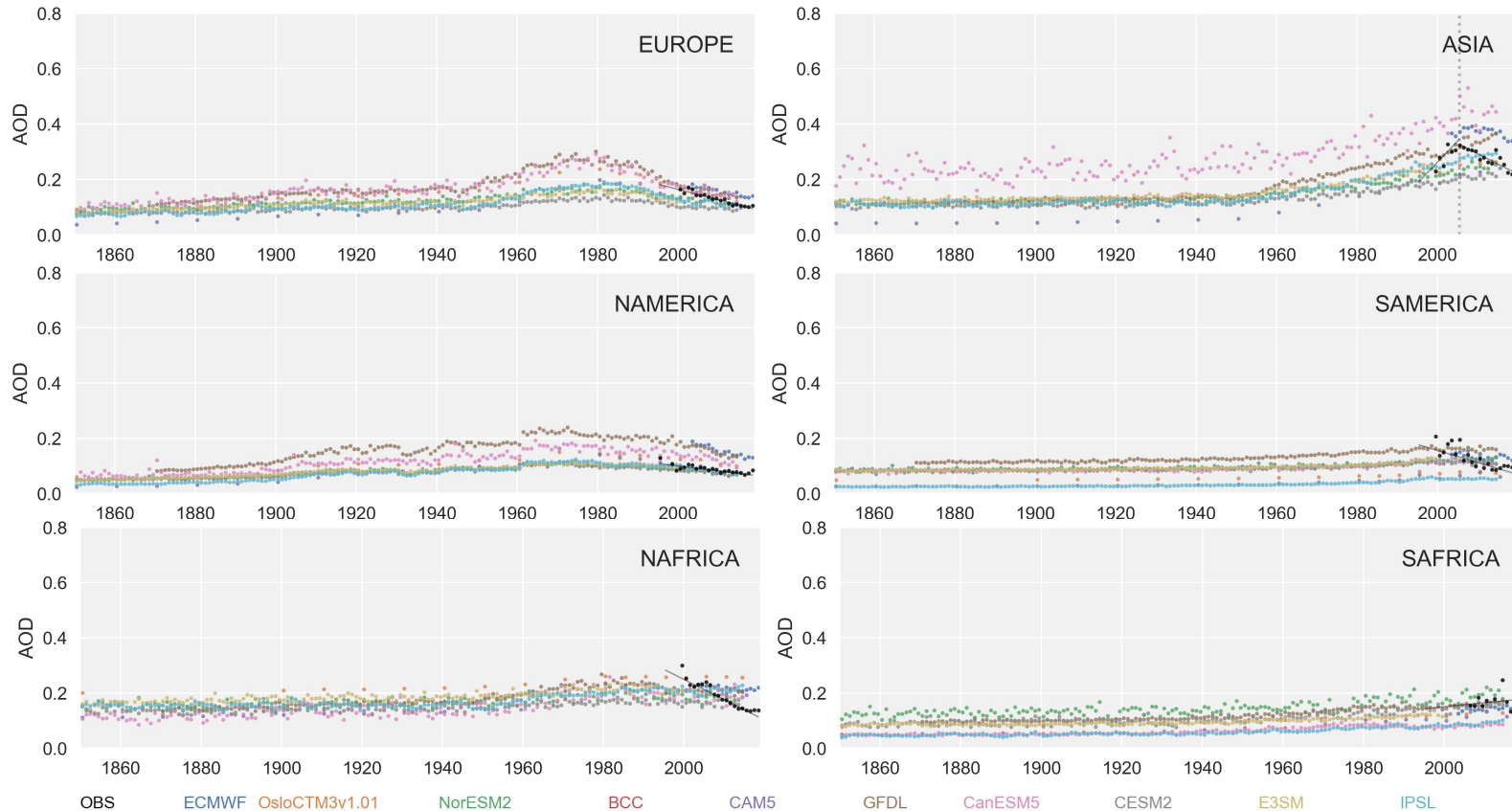
Models

- ECMWF_CAMS_REAN
- OsloCTM3v1.01-met2010_AP3-HIST
- NorESM2-LM_historical
- BCC-CUACE_HIST
- CAM5-ATRAS_AP3-HIST
- GFDL-AM4-amip_HIST
- CanESM5_historical
- CESM2_historical
- E3SM-1-0_historical
- IPSL-CM6A-LR_historical

4. Model Trends Evaluation

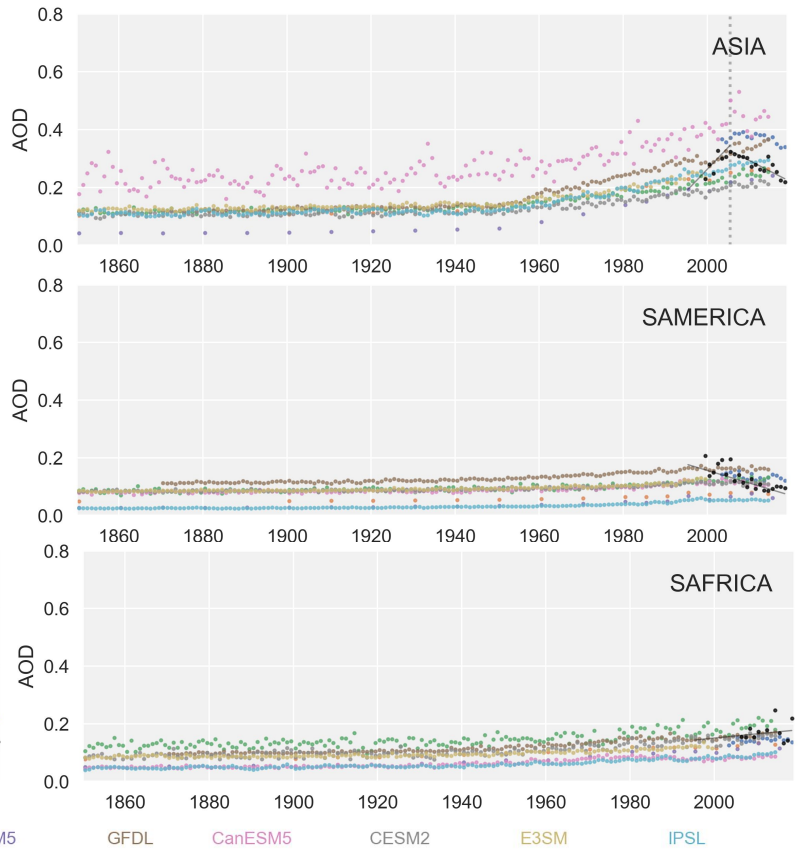
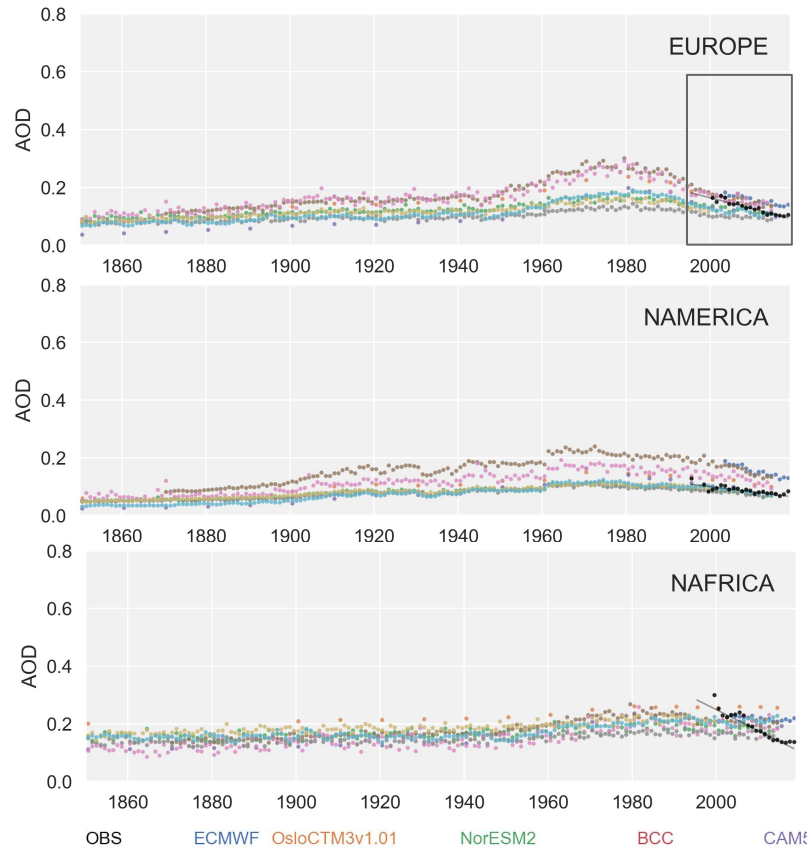
AOD

Without time collocation

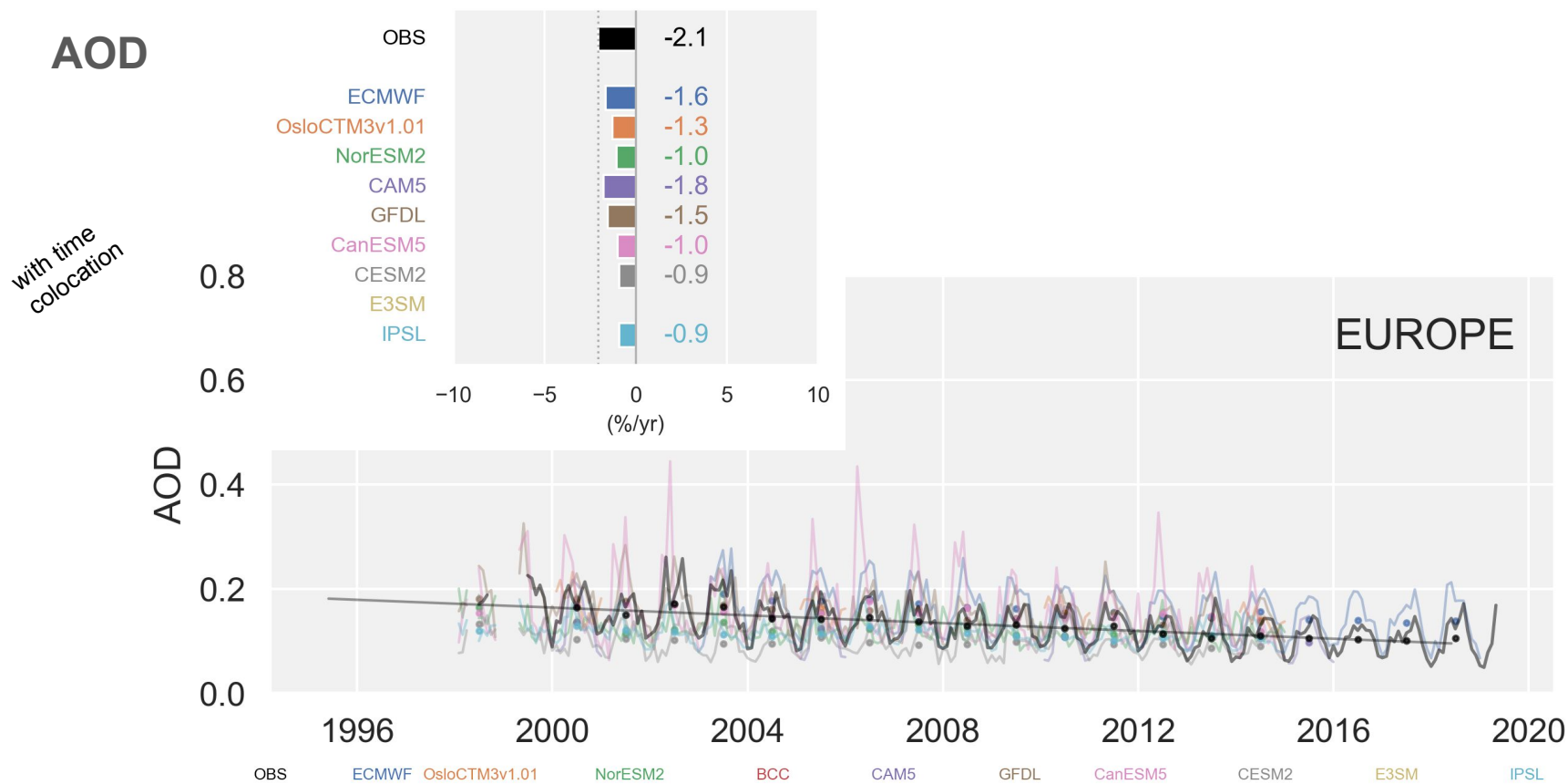


4. Model Trends Evaluation

AOD
Without time collocation



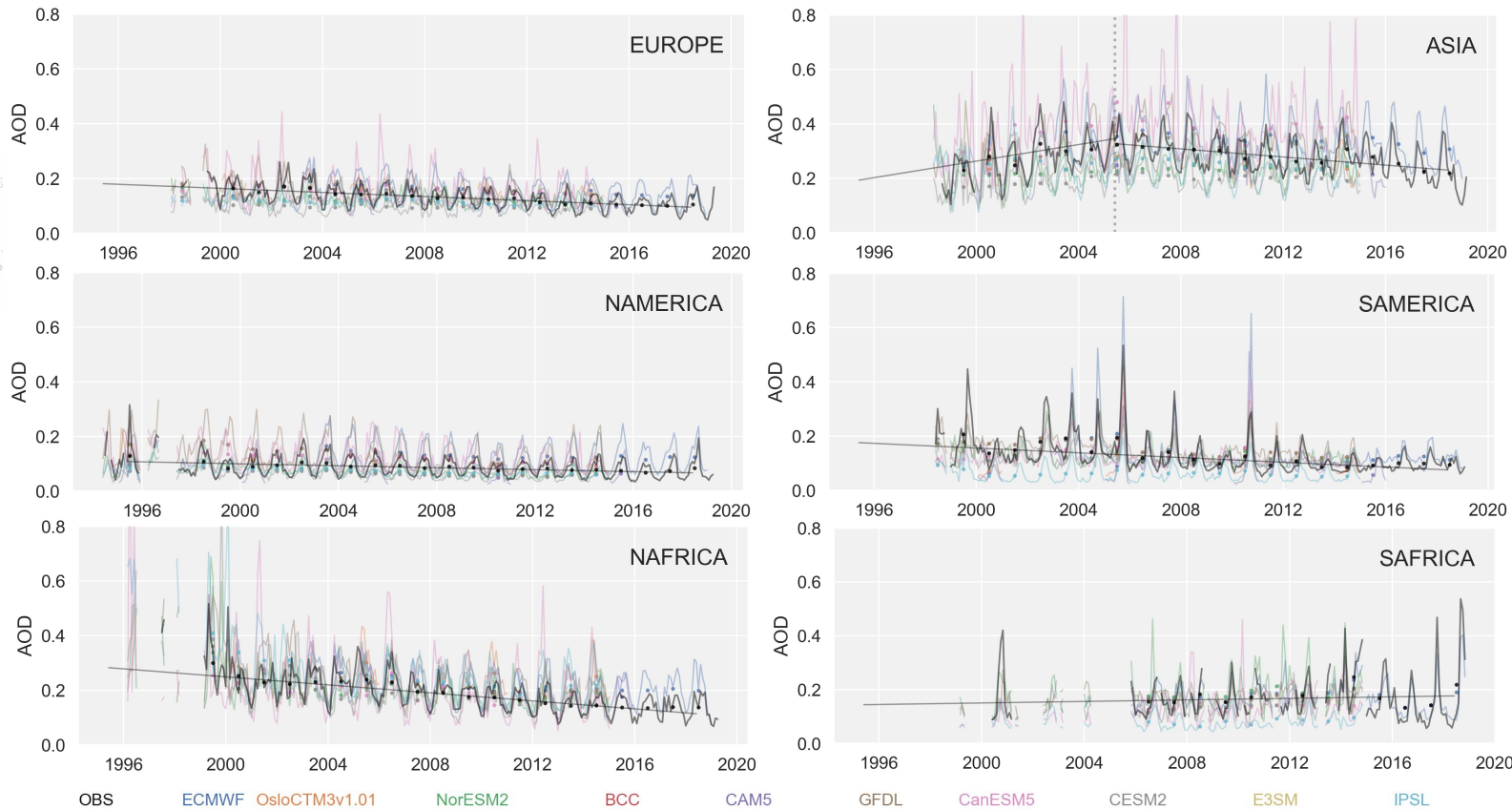
4. Model Trends Evaluation



4. Model Trends Evaluation

AOD

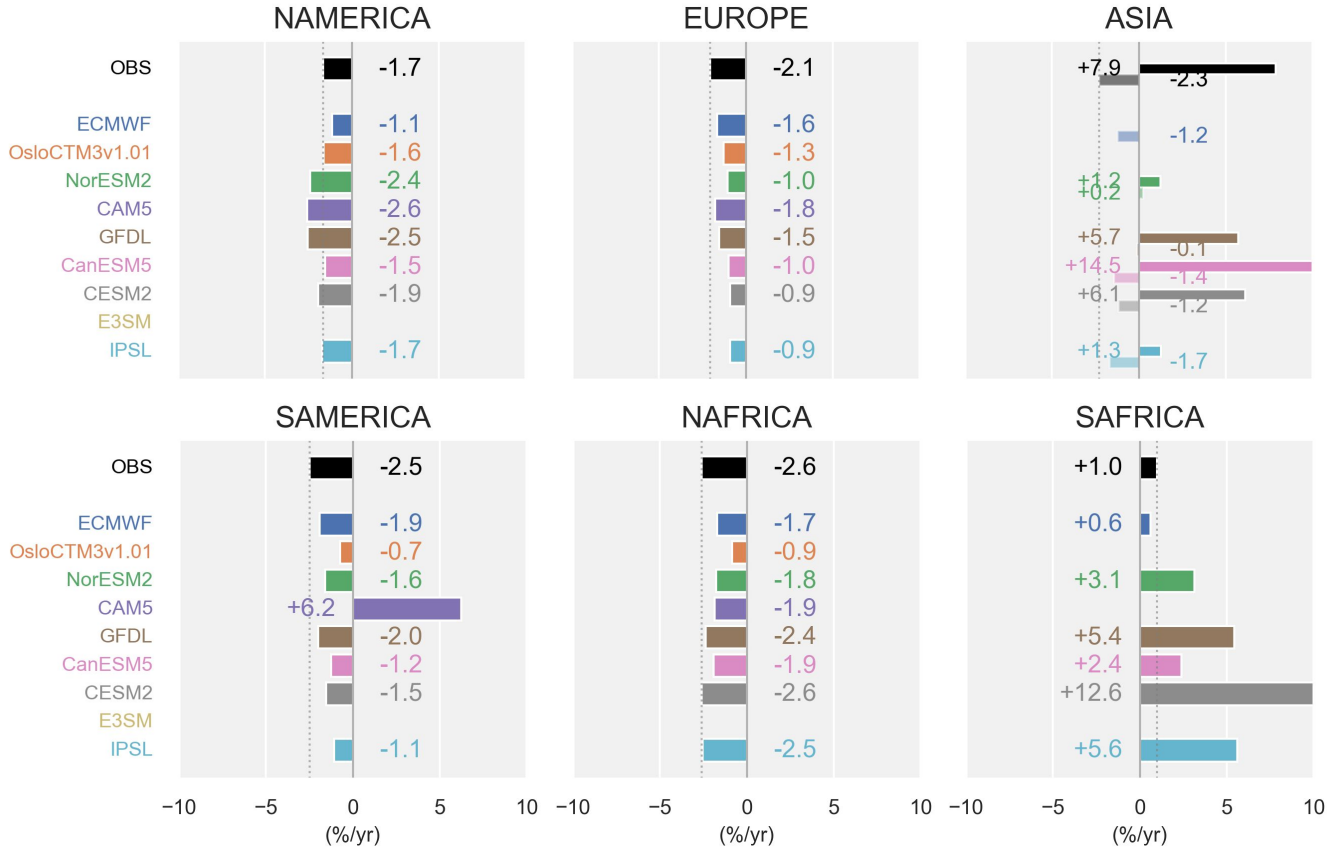
AERONET



4. Model Trends Evaluation

AOD

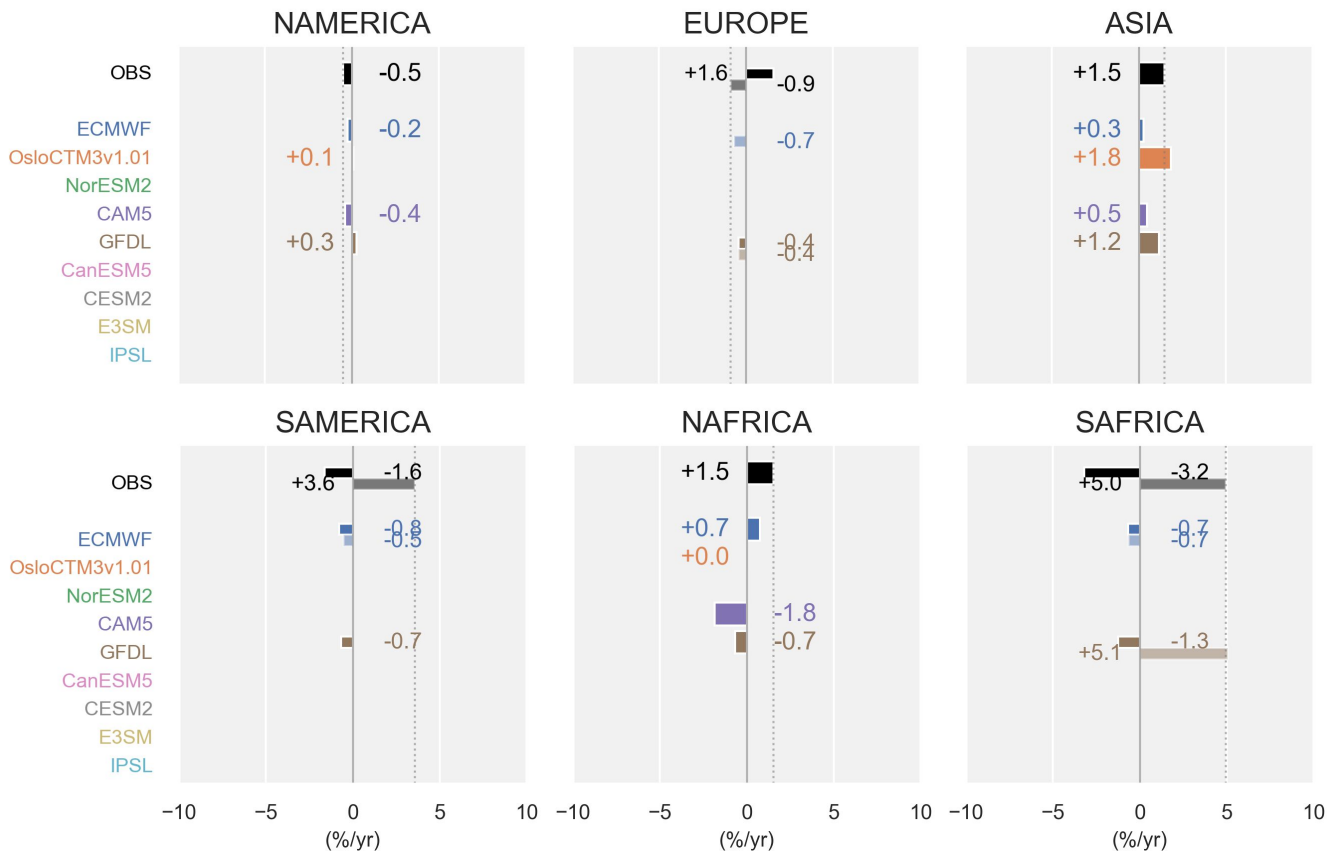
AERONET



4. Model Trends Evaluation

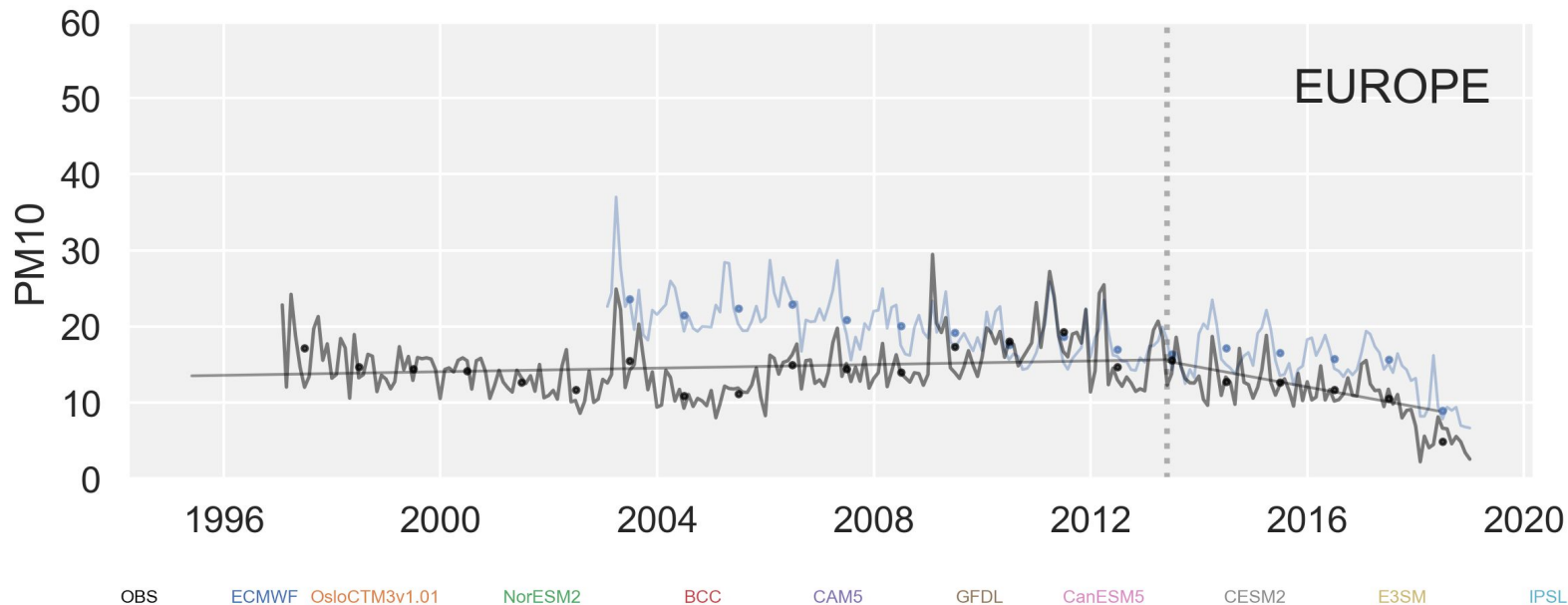
AE

AERONET



4. Model Trends Evaluation

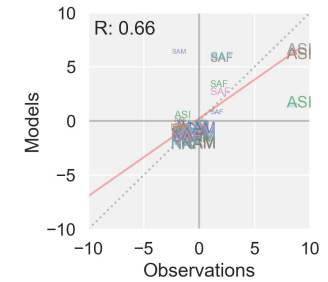
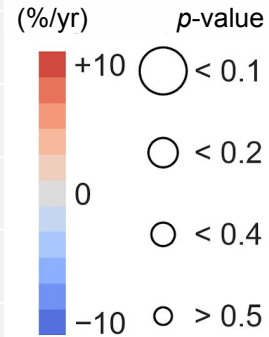
PM10



4. Model Trends Evaluation

AOD

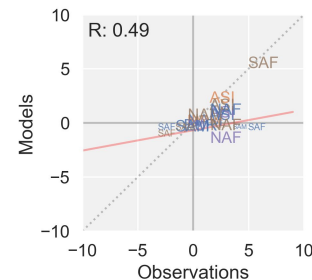
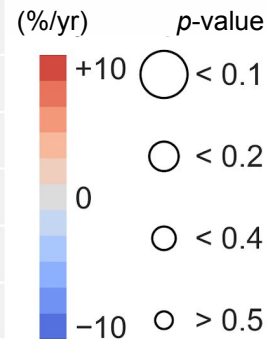
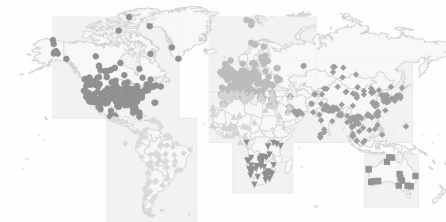
		AOD								
		OBS	ECMWF	OsloCTM3v1.01	NotESM2	CAM5	GFDL	CanESM5	CESM2	IPSL
EUROPE	1995-2018	-2.1	-1.6	-1.3	-1.0	-1.8	-1.6	-1.0	-0.9	-0.9
ASIA	1995-2005	+7.9	.	.	+1.2	.	+5.7	+14.5	+6.1	+1.3
	2005-2018	-2.3	-1.2	.	+0.2	.	-0.1	-1.4	-1.2	-1.7
NAMERICA	1995-2018	-1.7	-1.1	-1.6	-2.4	-2.6	-2.5	-1.5	-1.9	-1.7
SAMERICA	1995-2018	-2.5	-1.9	-0.7	-1.6	+6.2	-2.0	-1.2	-1.5	-1.1
NAFRICA	1995-2018	-2.6	-1.7	-0.9	-1.8	-1.9	-2.4	-1.9	-2.6	-2.5
SAFRICA	1995-2018	+1.0	+0.6	.	+3.1	.	+5.4	+2.4	+12.7	+5.6



4. Model Trends Evaluation

AE

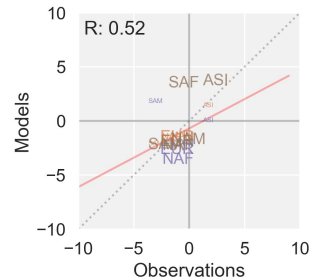
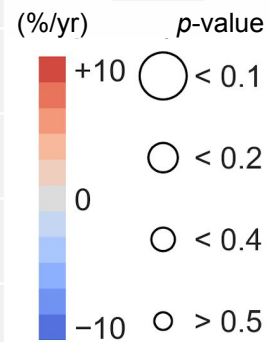
		AE								
		OBS	ECMWF	OsloCTM3v1.01	NorESM2	CAM5	GFDL	CanESM5	CESM2	IPSL
EUROPE	1995-2005	+1.6	.	.	.	.	-0.4	.	.	.
	2005-2018	-0.9	-0.7	.	.	.	-0.4	.	.	.
ASIA	1995-2018	+1.5	+0.3	+1.8	.	+0.5	+1.2	.	.	.
NAMERICA	1995-2018	-0.5	-0.2	+0.1	.	-0.4	+0.3	.	.	.
SAMERICA	1995-2013	-1.6	-0.8	.	.	.	-0.7	.	.	.
	2013-2018	+3.6	-0.5	.	.	.	.	.	.	.
NAFRICA	1995-2018	+1.5	+0.8	+0.0	.	-1.9	-0.7	.	.	.
SAFRICA	1995-2010	-3.2	-0.7	.	.	.	-1.3	.	.	.
	2010-2018	+5.0	-0.7	.	.	.	+5.1	.	.	.



4. Model Trends Evaluation

AOD < 1μm

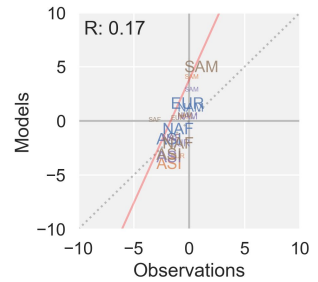
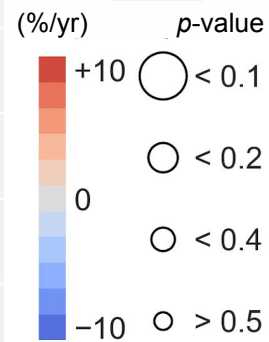
		AOD < 1μm								
Region	Period	OBS	ECMWF	OsloCTM3v1.01	NorESM2	CAM5	GFDL	CanESM5	CESM2	IPSL
EUROPE	1995-2018	-2.6	•	-1.9	•	-3.0	-2.3	•	•	•
ASIA	1995-2018	+1.2	•	+1.3	•	-0.1	+3.3	•	•	•
NAMERICA	1995-2018	-1.7	•	-1.7	•	-2.4	-2.1	•	•	•
SAMERICA	1995-2018	-3.7	•	-2.3	•	+1.7	-2.6	•	•	•
NAFRICA	1995-2018	-2.4	•	-1.8	•	-4.0	-2.7	•	•	•
SAFRICA	1995-2018	-1.9	•	•	•	•	+3.1	•	•	•



4. Model Trends Evaluation

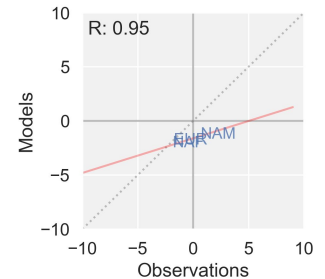
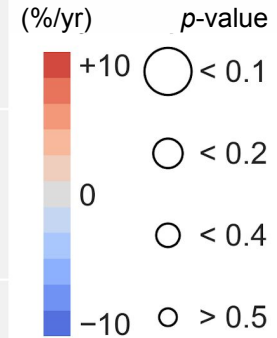
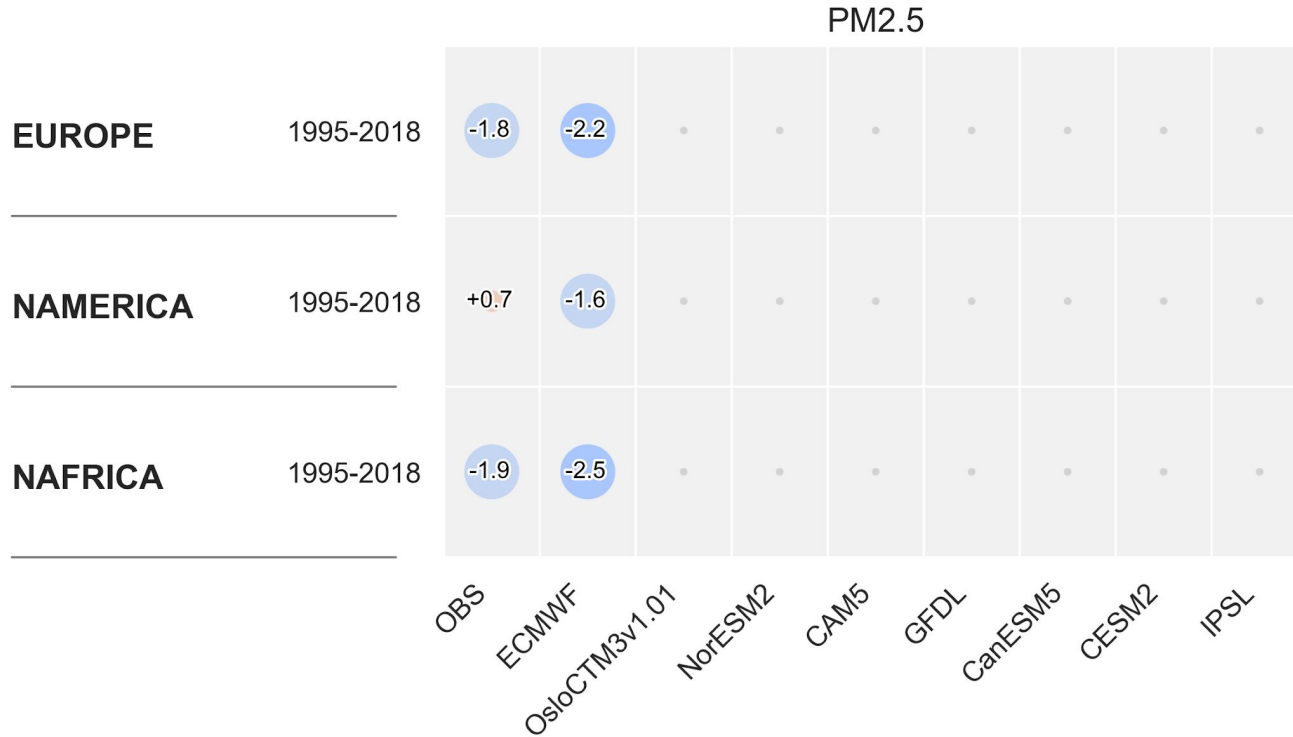
AOD > 1 μ m

		AOD > 1 μ m								
Region	Period	OBS	ECMWF	OsloCTM3v1.01	NorESM2	CAM5	GFDL	CanESM5	CESM2	IPSL
EUROPE	1995-2018	-1.7	+1.1	-3.4	•	-2.4	+0.1	•	•	•
ASIA	1995-2018	-3.0	-2.2	-4.5	•	-3.8	-3.6	•	•	•
NAMERICA	1995-2018	-1.1	+0.9	+0.2	•	+0.2	+0.3	•	•	•
SAMERICA	1995-2018	-0.4	+10.7	+3.9	•	+2.7	+4.5	•	•	•
NAFRICA	1995-2018	-2.4	-1.2	-1.8	•	-1.9	-2.5	•	•	•
SAFRICA	1995-2018	-3.7	+18.0	•	•	•	-0.1	•	•	•



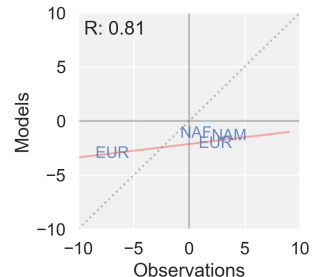
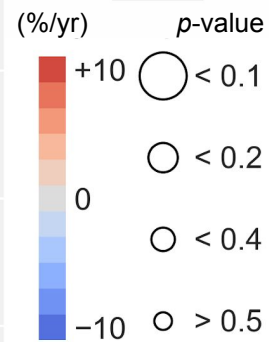
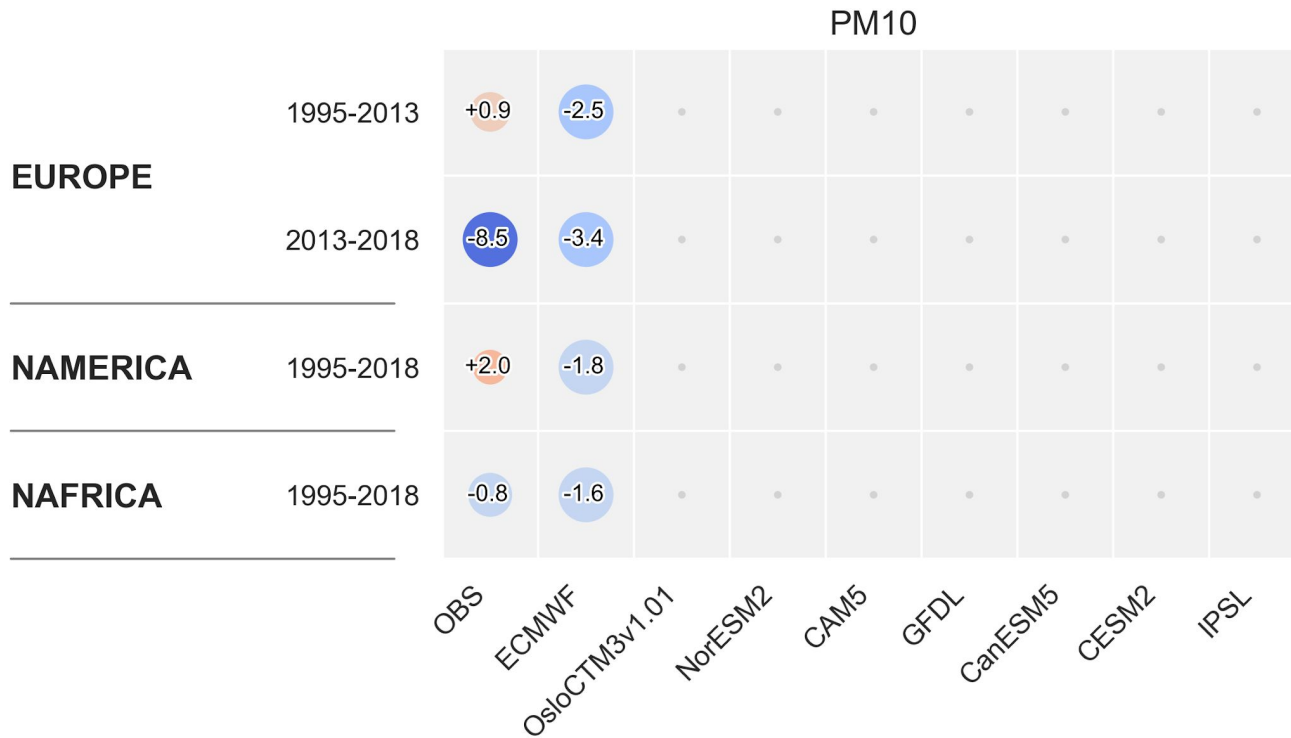
4. Model Trends Evaluation

PM2.5



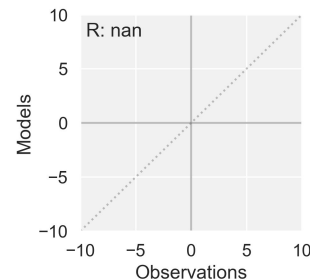
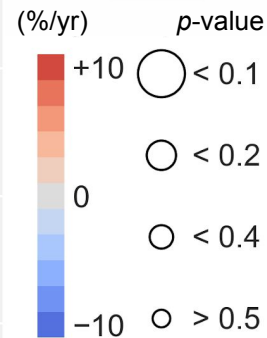
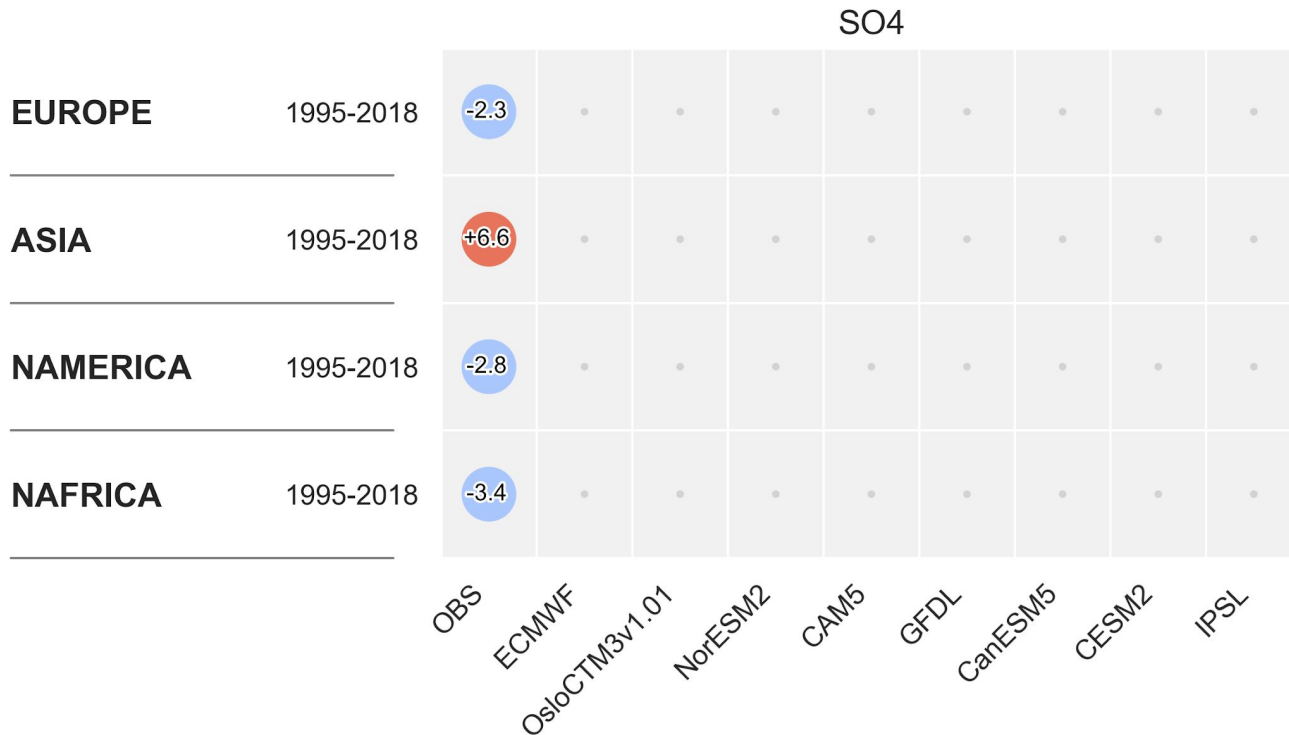
4. Model Trends Evaluation

PM10



4. Model Trends Evaluation

SO4



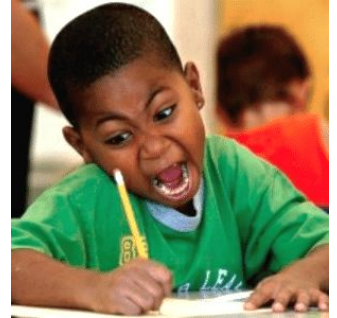
In summary

Conclusions & Outlook

- **Computation of regional time series in AeroCom regions** → *avoid overlaps?*
- **Observed (significant) trends**
 - **extensive** parameters:
 - **decrease** in all regions
except in
 - **ASIA: increase** of AOD[seg1], AOD<1 μ m, SO₄
 - **intensive** parameters:
AE: - **decrease** in EUROPE[seg2], NAMERICA, SAMERICA[seg1], SAFRICA[seg1] → *add SSA?*
- **increase** in ASIA (consistent with AOD_{fine/coarse}), SAFRICA[seg2] → *exclude oceans in study?*
→ *or redefine regions?*
- **Representativity** of the trends in Space and Time
 - Space_Score[AE] > Score[AOD]
 - High Time_Score for PM_{2.5/10}
- **Model trends evaluation** → *complete heatmaps*
 - AOD: R = 0.66
 - AE: R = 0.49
 - AOD<1 μ m: R = 0.52
 - AOD>1 μ m: R = 0.17
 - ...

Paper by the end of the year(?)!!

- **Which model** results shall be used (CMIP6, AerChemMIP, AeroCom, coupled, fixedSST...)
- Is the **difference** between models and observations **significant**? What is the explanation?
- Can we explain **inter-model differences** for the different regions? Emissions, life-time, transport & removal
- Which results can still be used until **Dec 2019**? Dry scat and abs from models!!??
Which model results are still coming in?
- Should we include **SSA trends** at least from the models? **AAOD** is probably underexploited?
- How **different** are **AOD trends** and **SSA trends** in the **models**, irrespective of observations? Has the **radiative impact** of aerosols decreased since 1990?



Additional slides

3. Assessment of Networks Representativeness

AOD<1 μ m

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			Overall
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	$Time\ exp.$	$Space\ exp.$	$Total$	Time	Space	Total	
AOD<1 μ m	GFDL	EUROP	1995-2018	-2.3	-2	-1	0.3	1	0.65	67	11	34	24
		ASIA	1995-2018	3.3	1.7	1.3	1.6	0.4	1	0	58	11	
		AUSTR	1995-2018	-0.1	-0.3	-0.1	0.2	0.2	0.2	74	74	74	
		NAFRI	1995-2018	-2.7	-0.5	0.2	2.2	0.7	1.45	0	30	1	
		SAFRI	1995-2018	3.1	0.9	0.6	2.2	0.3	1.25	0	67	4	
		NAMER	1995-2018	-2.1	-1.9	-0.9	0.2	1	0.6	74	11	39	
		SAMER	1995-2018	-2.6	-0.1	-0.1	2.5	0	1.25	0	80	4	
									30	47			

3. Assessment of Networks Representativeness

AOD>1 μ m

Parameter	Model	Region	Segment	Trends (%/yr)			Trends Absolute Difference (%/yr)			Score (%)			Overall
				Ref_{time}	Exp_{time}/Ref_{space}	Exp_{space}	Time exp.	Space exp.	Total	Time	Space	Total	
AOD>1 μ m	GFDL	EUROP	1995-2018	0.1	-0.3	0.1	0.4	0.4	0.4	58	58	58	30
		ASIA	1995-2018	-3.6	-0.1	0.1	3.5	0.2	1.85	0	74	0	
		AUSTR	1995-2018	-0.1	-0.3	-0.2	0.2	0.1	0.15	74	78	76	
		NAFRI	1995-2018	-2.5	0.2	0.2	2.7	0	1.35	0	80	2	
		SAFRI	1995-2018	-0.1	1.1	0.2	1.2	0.9	1.05	4	16	9	
		NAMER	1995-2018	0.4	-0.1	0.1	0.5	0.2	0.35	48	74	62	
		SAMER	1995-2018	4.5	0	0.2	4.5	0.2	2.35	0	74	0	
									26	65			