Evaluation of aerosol absorption in CMIP6 simulations

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Many thanks to model groups (CMIP6 simulations) and data providers for evaluation (AERONET, GRASP-POLDER, MACv2)

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Introduction : Aerosol Absorption

- Some aerosol species (dust, black carbon, brown carbon, ...) absorb solar radiation *(Stier et al. 2007 ; Moosmüller et al., 2009 ; Bond et al. 2013 ; ...)*

- Significative effect on global and regional climate : radiative budget, atmospheric stability, cloud formation, precipitation, … *(Samset et al. 2018 ; Allen et al. 2019, PDRMIP, ...)*

- However still large uncertainties on absorption aerosol properties

- Few evaluation of these properties in climate simulations

- <u>Objective :</u> evaluate aerosol absorption in recent CMIP6 simulations
  - Focus on recent period (2003-2014) in historical CMIP6 simulations
  - Evaluation of single scattering albedo (SSA) and absorption aerosol optical depth (AAOD) at 550 nm against different datasets
  - Consequences on shortwave atmospheric absorption (A_{atm})

Data sets

- 28 CMIP6 simulations (historical, JJA 2003-2014)

abs550aer : AAOD

od550aer : AOD

SSA

SW Atmospheric Absorption

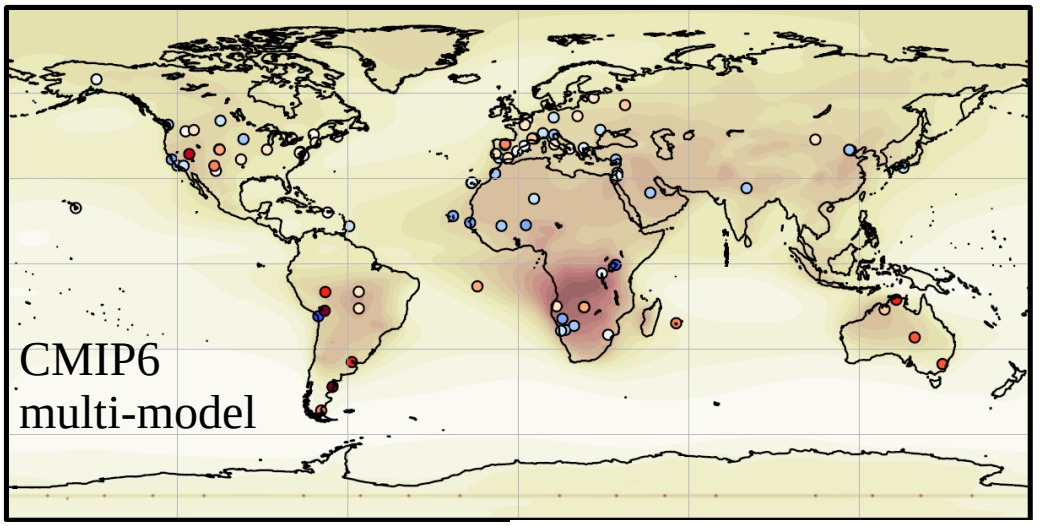
A_{atm} = rst - rss

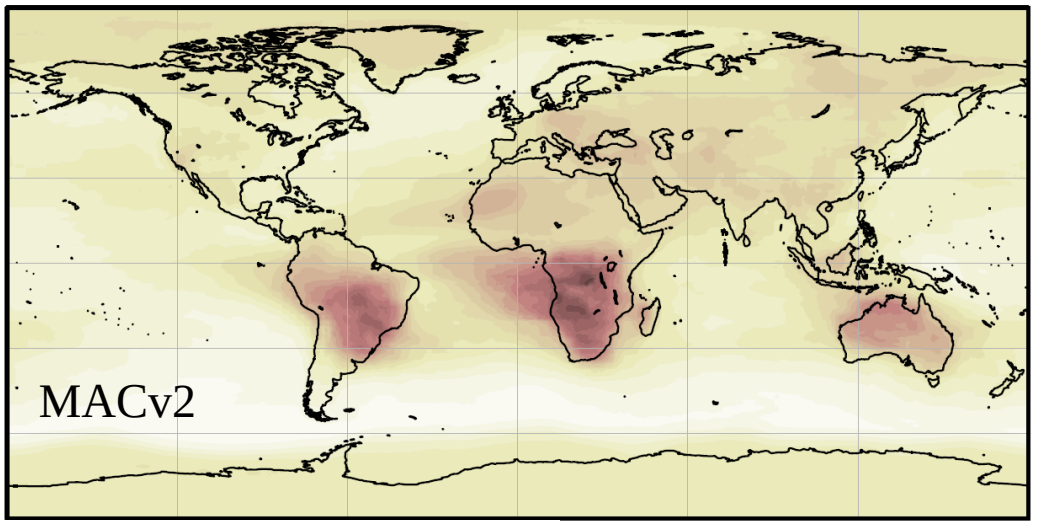
Models	Institute	Country	Member
AWI-ESM-1-1-LR	AWI	Germany	r1i1p1f1
CanESM5	CCCma	Canada	r1i1p1f1
CanESM5-CanOE	CCCma	Canada	r1i1p2f1
CESM2	NCAR	USA	r1i1p1f1
CESM2-FV2	NCAR	USA	r1i1p1f1
CESM2-WACCM	NCAR	USA	r1i1p1f1
CESM2-WACCM-FV2	NCAR	USA	r1i1p1f1
CMCC-CM2-SR5	CMCC	Italy	r1i1p1f1
CNRM-CM6-1	CNRM-CERFACS	France	r1i1p1f2
CNRM-CM6-1-HR	CNRM-CERFACS	France	r1i1p1f2
CNRM-ESM2-1	CNRM-CERFACS	France	r1i1p1f2
E3SM-1-0	E3SM-Project	USA	r1i1p1f1
E3SM-1-1	E3SM-Project	USA	r1i1p1f1
E3SM-1-1-ECA	E3SM-Project	USA	r1i1p1f1
GFDL-CM4	NOAA-GFDL	USA	r1i1p1f1
GFDL-ESM4	NOAA-GFDL	USA	r1i1p1f1
HadGEM3-GC31-LL	MOHC	UK	r1i1p1f3
HadGEM3-GC31-MM	MOHC	UK	r1i1p1f3
INM-CM4-8	INM	Russia	r1i1p1f1
INM-CM5-0	INM	Russia	r1i1p1f1
IPSL-CM6A-LR	IPSL	France	r1i1p1f1
KACE-1-0-G	NIMS-KMA	South Korea	r1i1p1f1
MIROC-ES2L	MIROC	Japan	r1i1p1f2
MPI-ESM1-2-HR	MPI-M	Germany	r1i1p1f1
MPI-ESM1-2-LR	MPI-M	Germany	r1i1p1f1
MRI-ESM2-0	MRI	Japan	r1i1p1f1
NorESM2-LM	NCC	Norway	r1i1p1f1
UKESM1-0-LL	MOHC	UK	r1i1p1f2

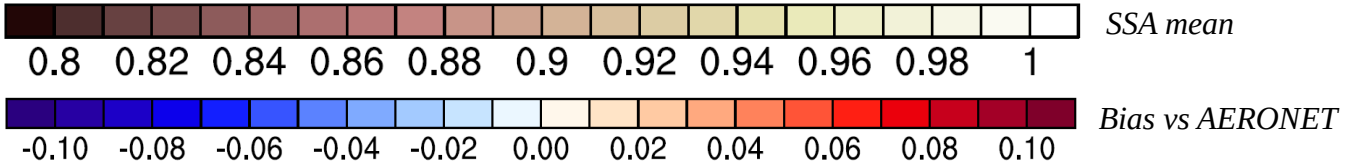
- For evaluation :
  - MACv2 climatology *(Kinne et al. 2019)*
  - Satellite data : GRASP algorithm product from PARASOL/POLDER data *(Chen et al. 2020)* and CERES-EBAF product *(Loeb et al. 2009)*
  - AERONET stations *(Holben et al. 1998)* : only stations where at least 3 years with 8 days of measurements per month

Aerosol absorption in CMIP6 models : SSA

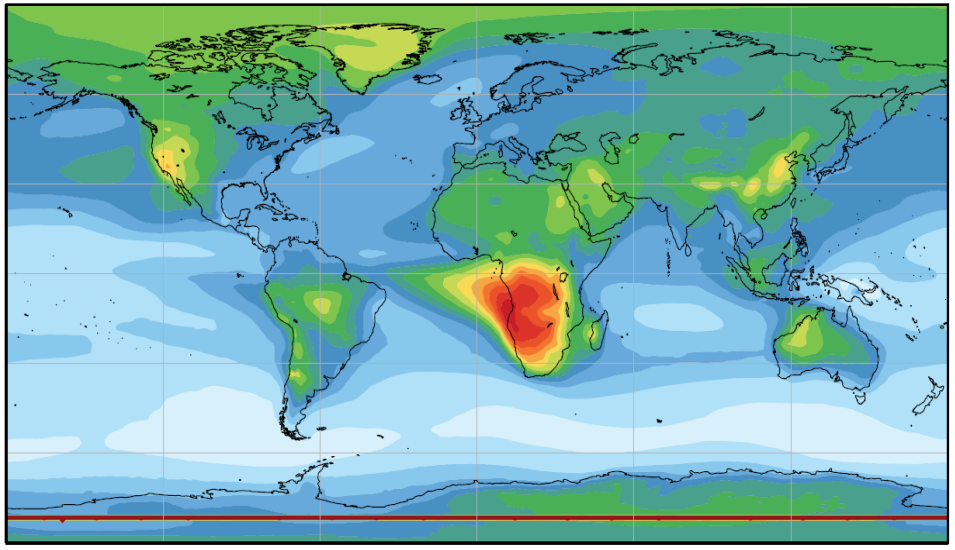
- Multi-model mean SSA (550 nm) vs AERONET (circles) and MACv2 climatology







- SSA standard deviation in CMIP6 ensemble :



— Main absorbing aerosols coming from fires (e.g. tropical Africa), deserts (e.g. Sahara) and pollution areas (e.g. east Asia)

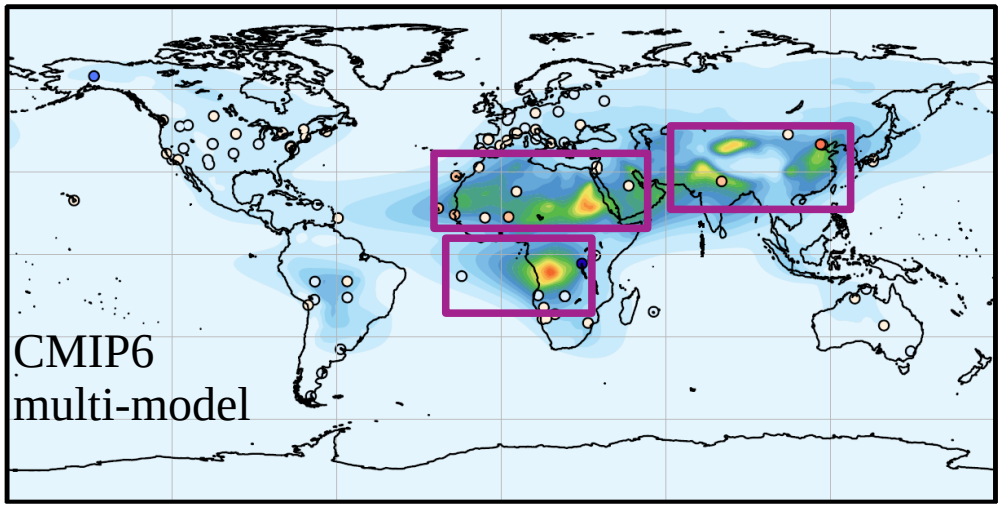
— Large differences among CMIP6 models

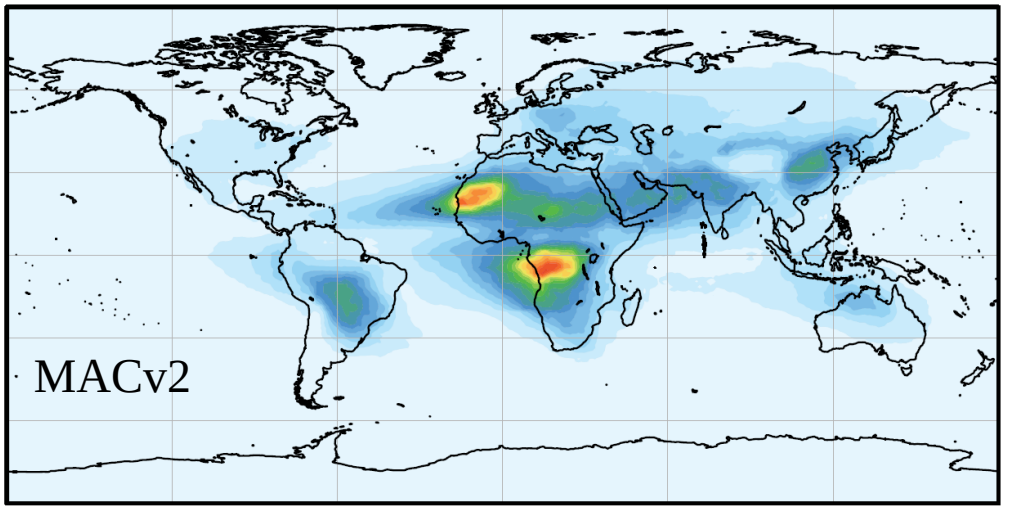
— Regional biases against AERONET :

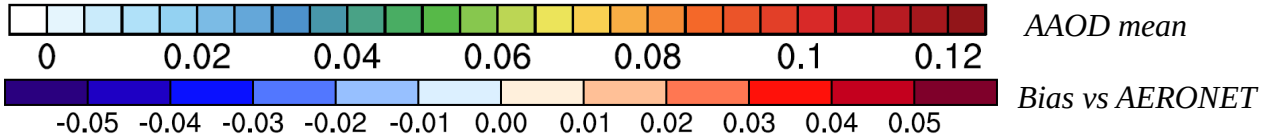
- Positive bias over the tropics (biomass burning aerosols ?)
- Negative bias over Sahara
- Negative bias over Eastern Asia

Aerosol absorption in CMIP6 models : AAOD

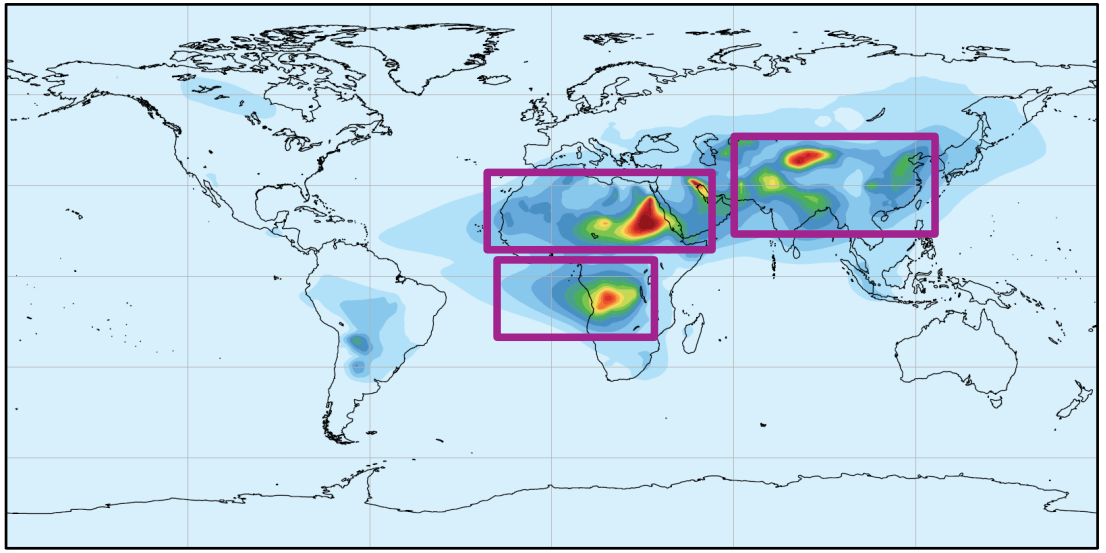
- Multi-model mean AAOD (550 nm) vs AERONET (circles) and MACv2 climatology

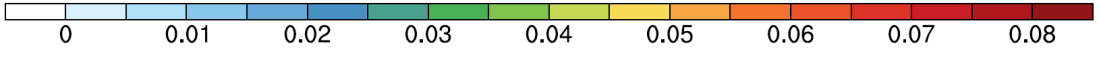






- AAOD standard deviation in CMIP6 ensemble :





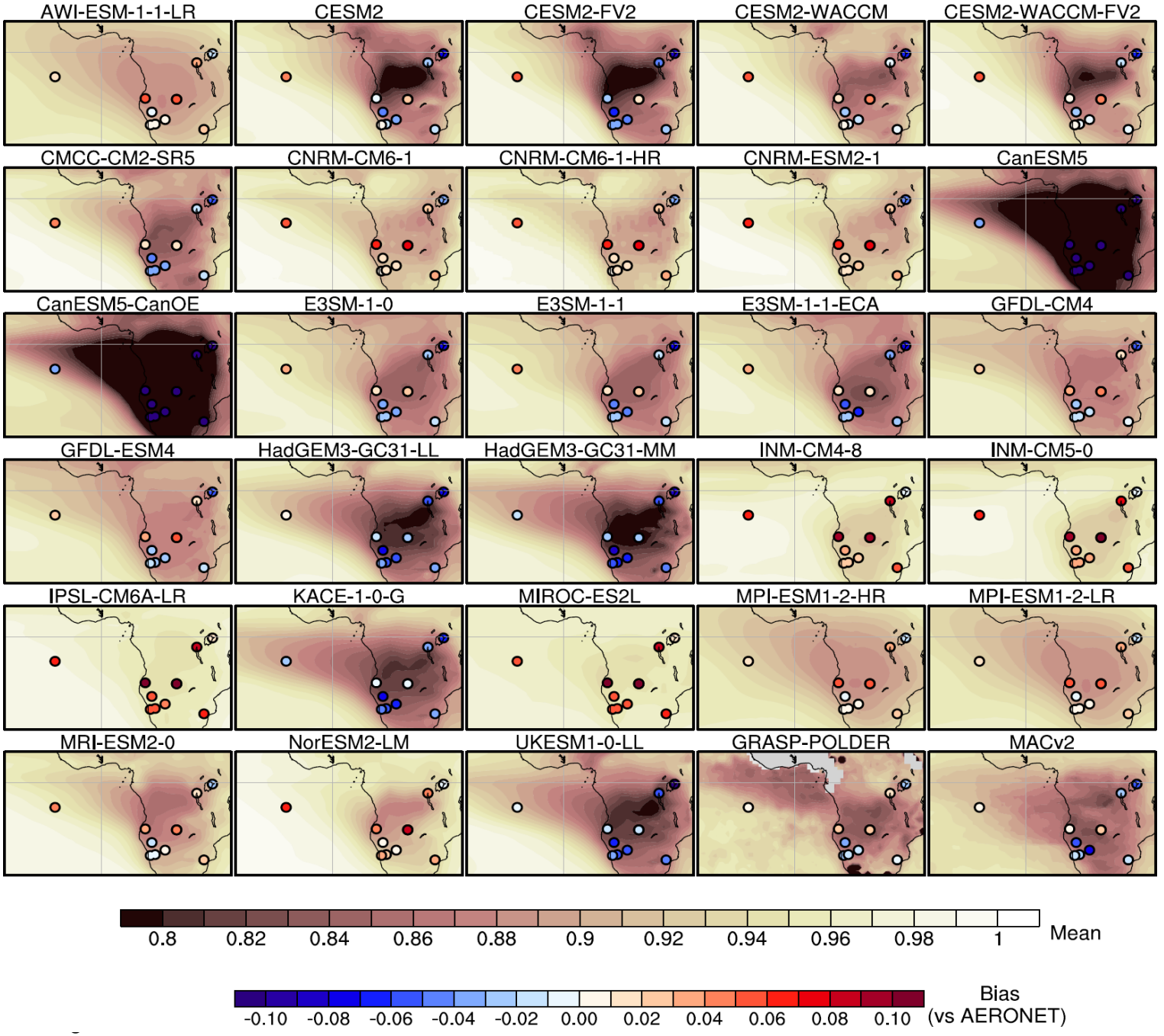
- As for SSA, large differences among CMIP6 models
- Regional biases against AERONET

=> Focus on 3 regions :

- SouthEastern Atlantic
- Sahara
- Eastern Asia

1) SouthEastern Atlantic : evaluation of SSA

Single scattering albedo (SSA, 550 nm) in CMIP6 models



- Strong differences in SSA between CMIP6 models :

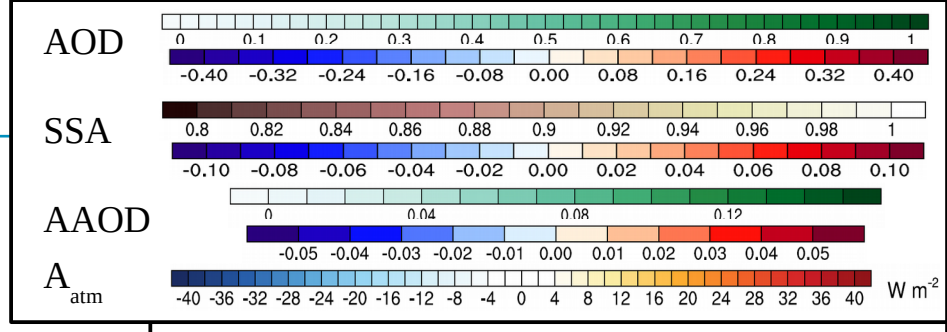
  => very absorbing to scattering aerosols

- Biases related to the transport of biomass burning aerosols

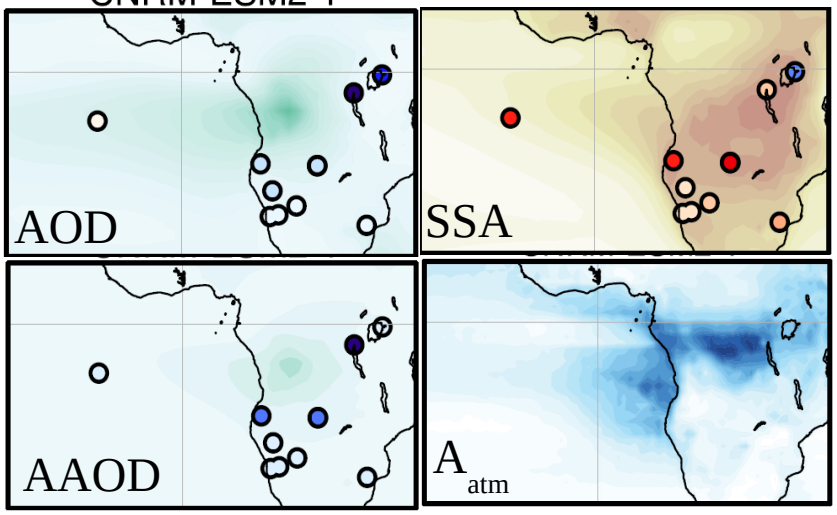
- Few models able to reproduce aerosol properties compared to AERONET, GRASP-POLDER and MACv2

1) SouthEastern Atlantic (SEA) : understanding model biases

- Example of models with different behaviours :



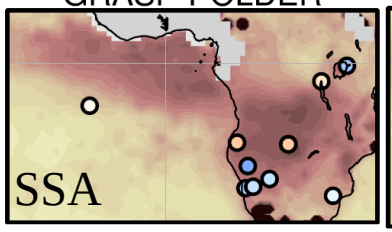
CNRM-ESM2-1



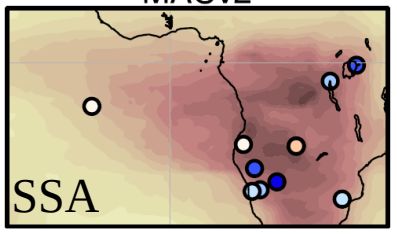
=> Large underestimation of AAOD :
- SSA too high
- AOD too low

=> A_{atm} underestimated

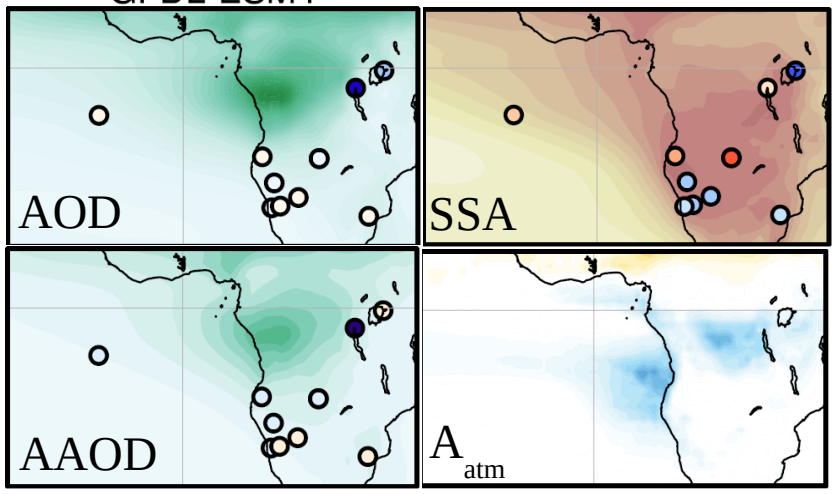
GRASP-POLDER



MACv2



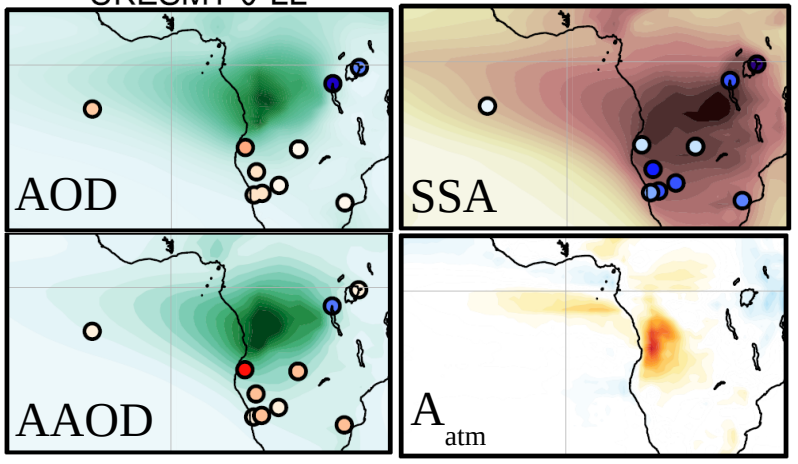
GFDL-ESM4



=> Slight underestimation of AAOD :
- SSA too high
- AOD closer to observations

=> A_{atm} slightly underestimated

UKESM1-0-LL

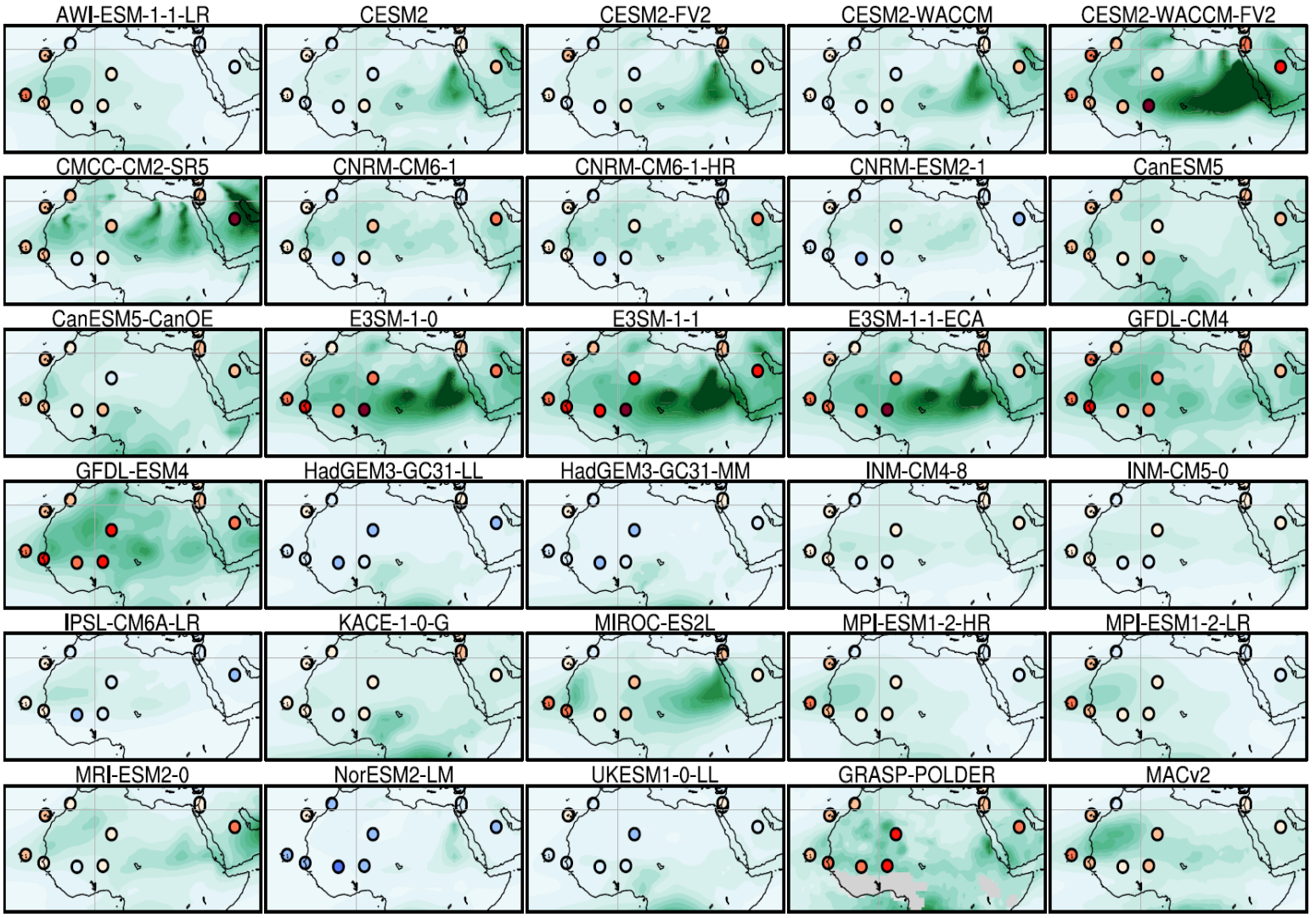


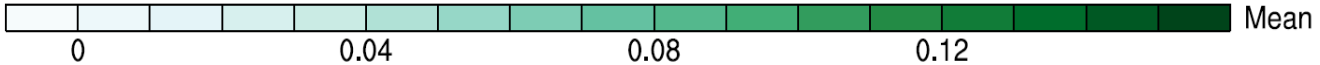
=> Better representation of biomass burning aerosols
=> A_{atm} closer to observations

=> Transport of biomass burning aerosols over SEA is underestimated by several CMIP6 models
=> Role of low-level clouds over SEA needs to be taken into account

2) Sahara : evaluation of AAOD

Absorption AOD (AAOD, 550 nm) in CMIP6 models

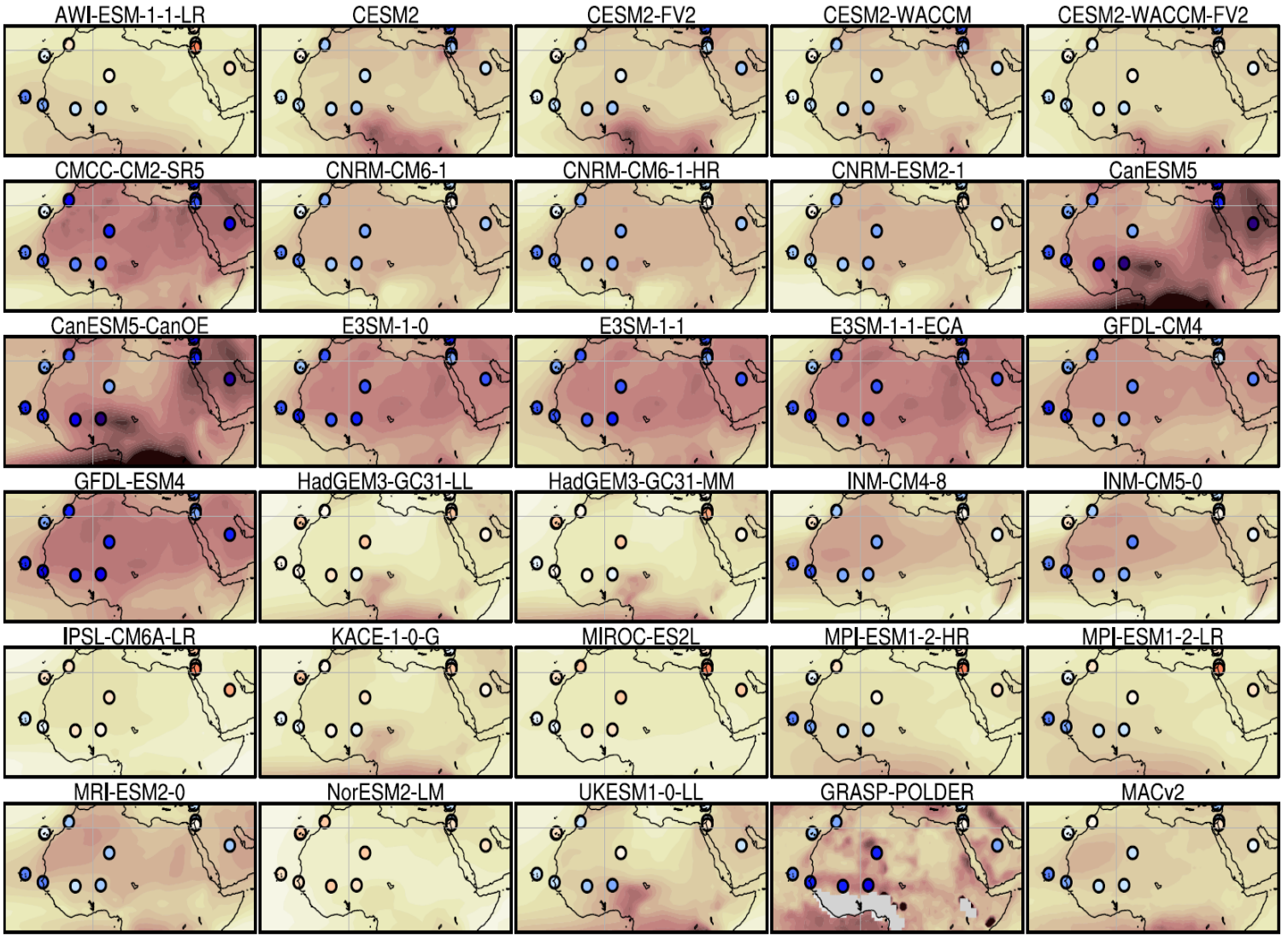




- Large differences in AAOD over Sahara between CMIP6 models
- Possible overestimation of dust emissions in several models
  (in particular over Eastern Sahara)
- Uncertainties in observations : GRASP-POLDER and MACv2 have higher AAOD than AERONET

2) Sahara : evaluation of SSA

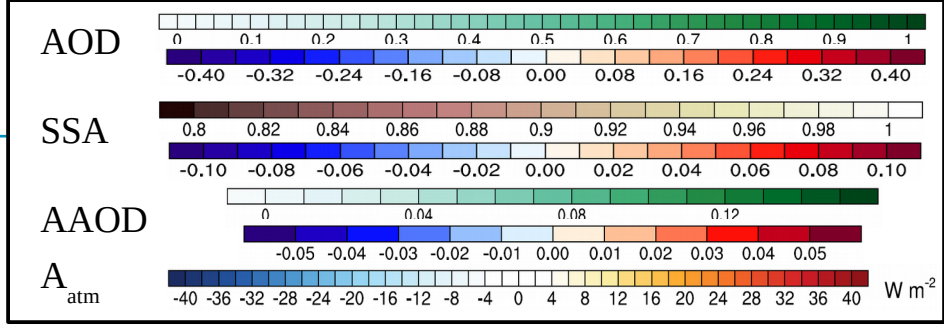
Single scattering albedo (SSA, 550 nm) in CMIP6 models



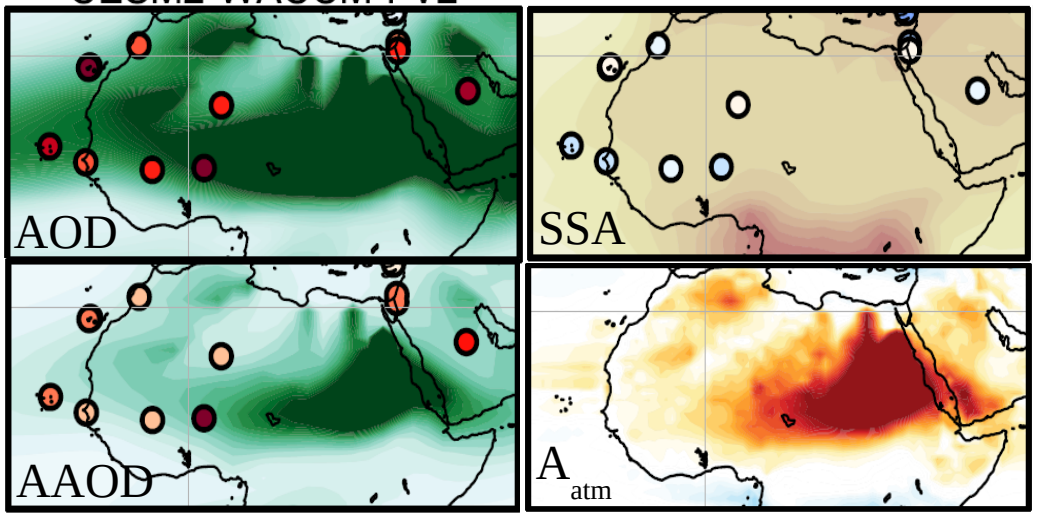
- As for AAOD large differences in SSA over Sahara between CMIP6 models, but not always the same models
- Possible too absorbing dust aerosols in several models
- SSA lower in GRASP-POLDER over western Sahara

2) Sahara : understanding model biases

- Example of models with different behaviours :

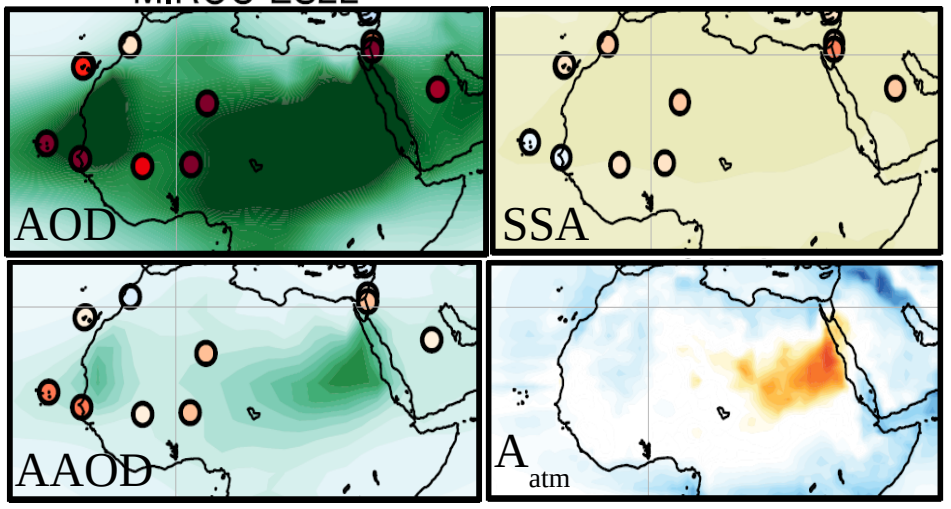


CESM2-WACCM-FV2



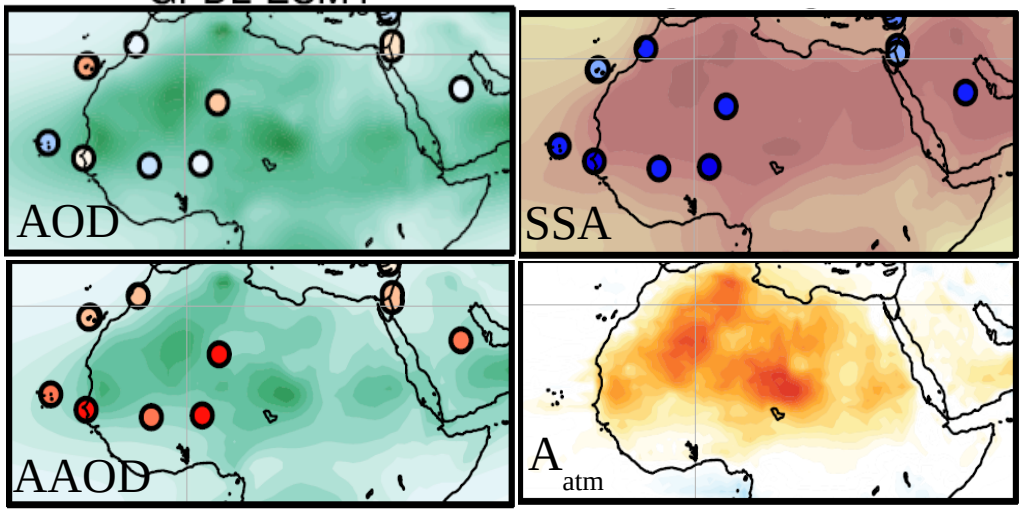
=> Overestimation of AAOD and A_{atm} because of high AOD (but correct SSA)

MIROC-ES2L



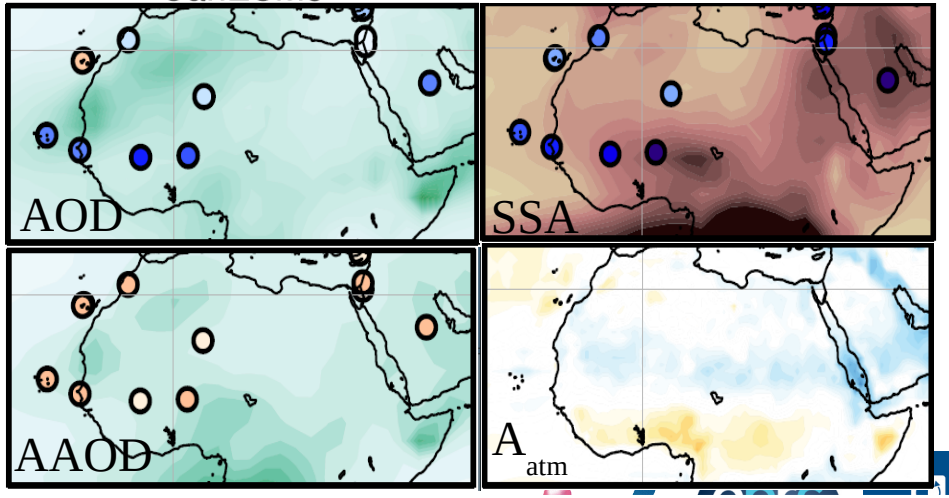
=> Error compensation : high AOD and high SSA

GFDL-ESM4



=> Overestimation of AAOD and A_{atm} because of high SSA (but correct AOD)

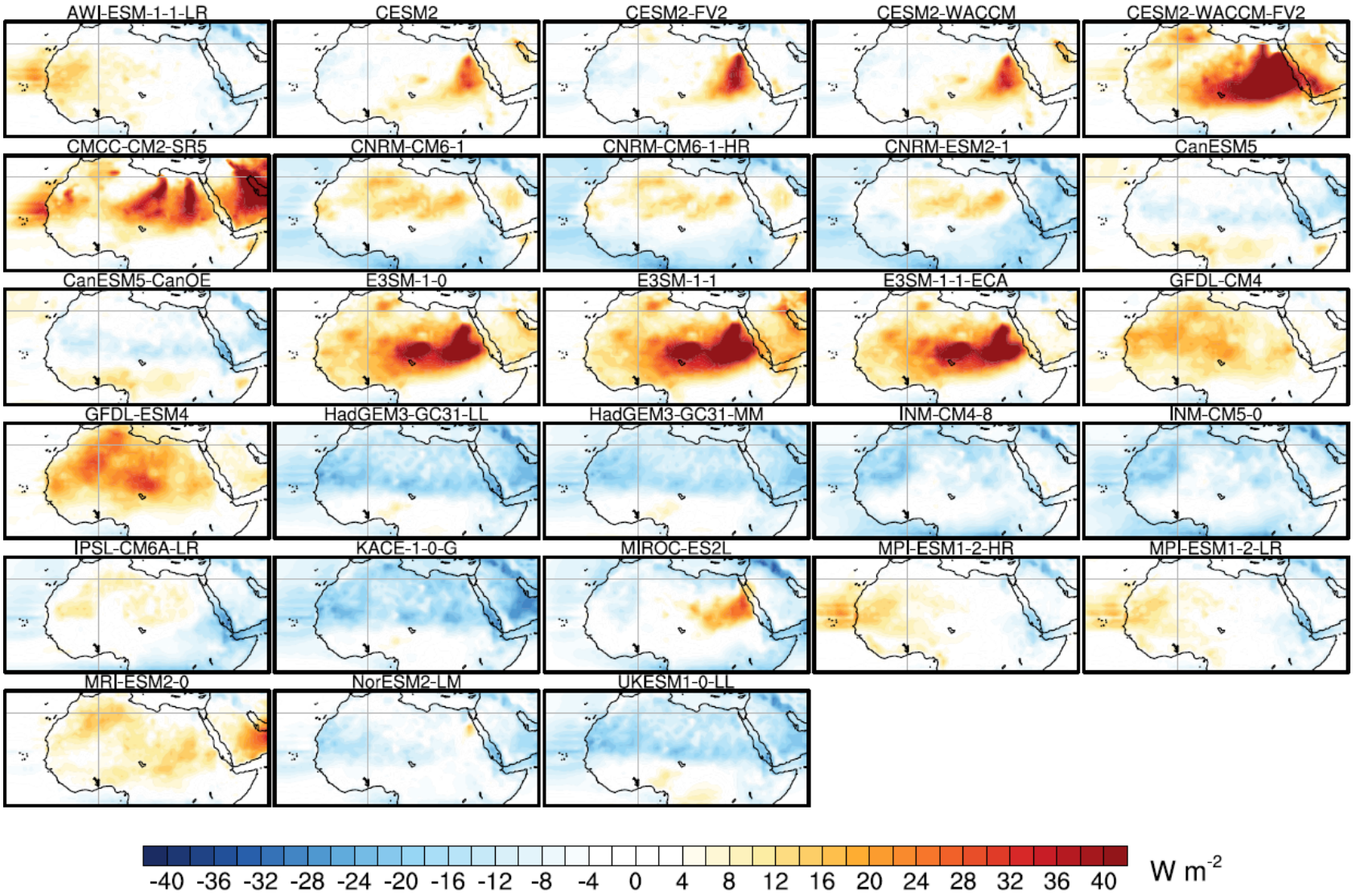
CanESM5



=> Error compensation : low AOD and low SSA

2) Sahara : overview of biases in SW atmospheric absorption

A_{atm} : *CMIP6 models – CERES (JJA average)*

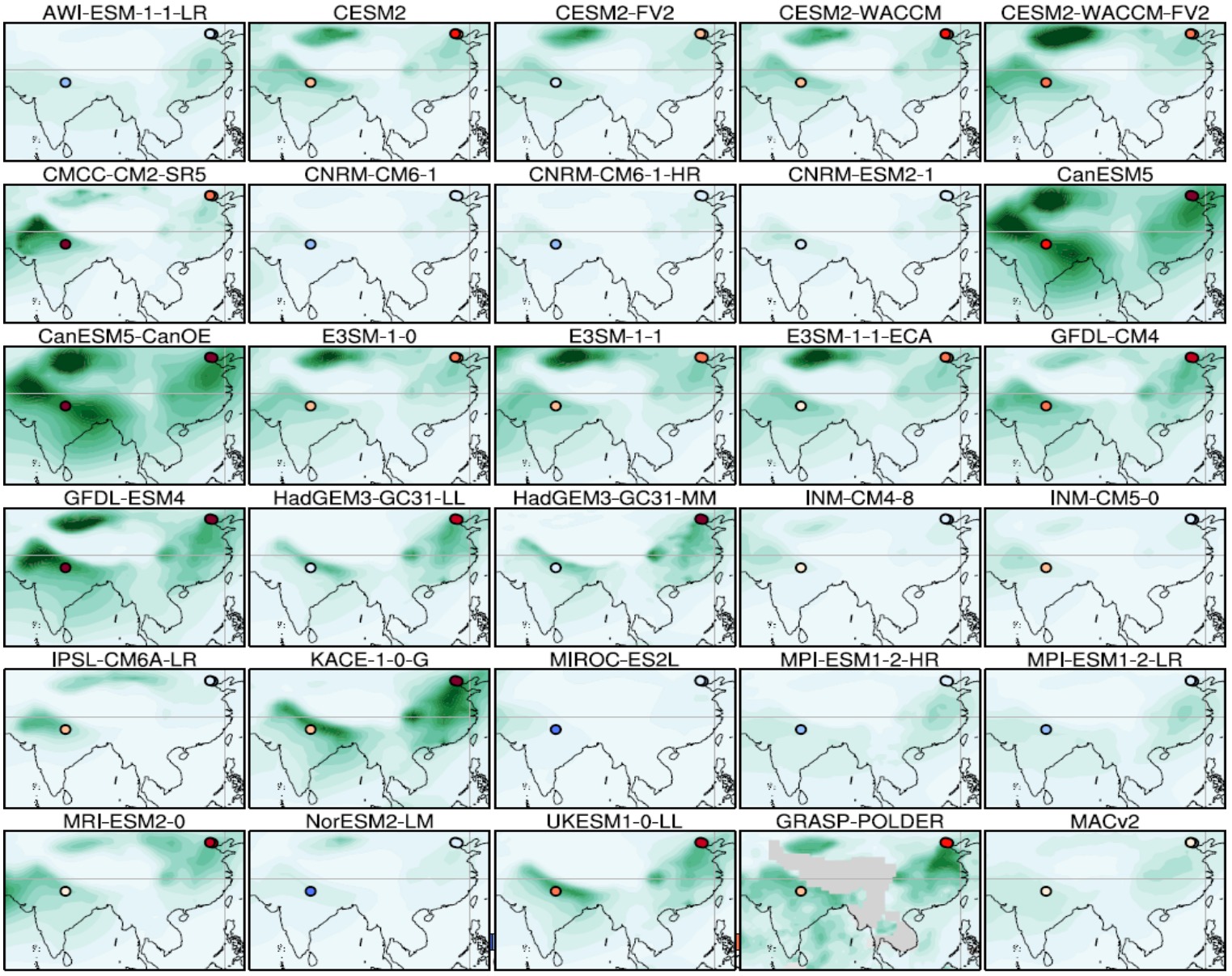


=> Large biases in SW atmospheric absorption in the different CMIP6 models, which can be linked with biases in aerosols (AOD and/or SSA)

=> Possible implications on atmospheric circulation

3) Eastern Asia : evaluation of AAOD

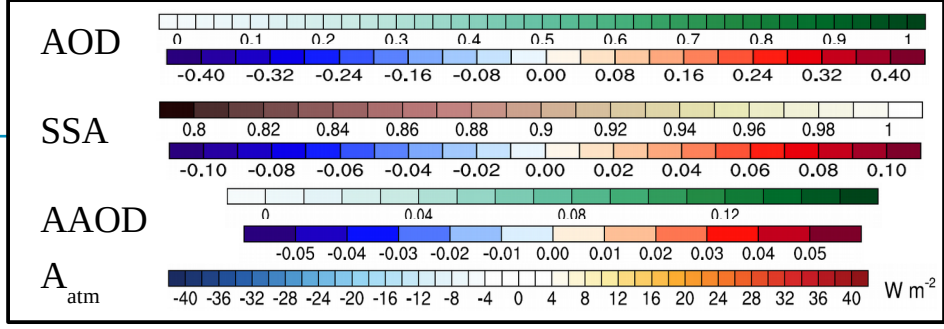
Absorption AOD (AAOD, 550 nm) in CMIP6 models



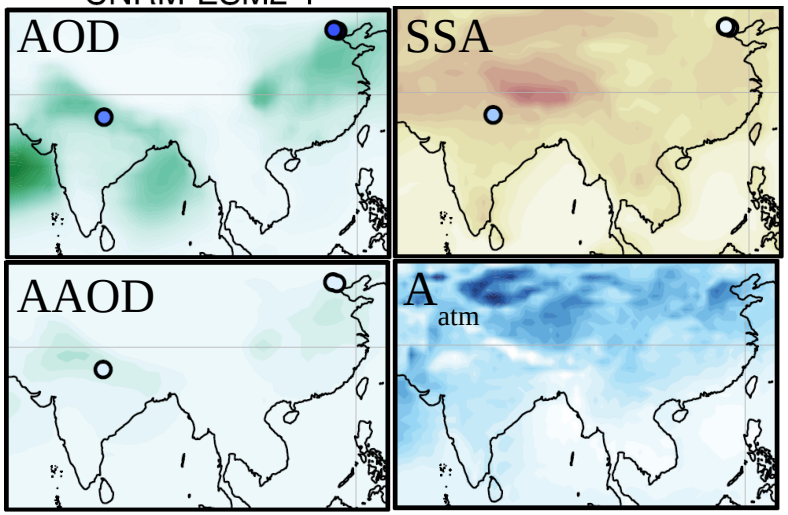
- Large differences in AAOD between CMIP6 models over China, northern India and Gobi desert
- Possible biases in anthropogenic emissions (eastern China, northern India), and/or dust emissions (Gobi desert)
- Few AERONET stations with enough measurements, disagreement with GRASP-POLDER and MACv2

3) Eastern Asia : understanding model biases

- Example of models with different behaviours :



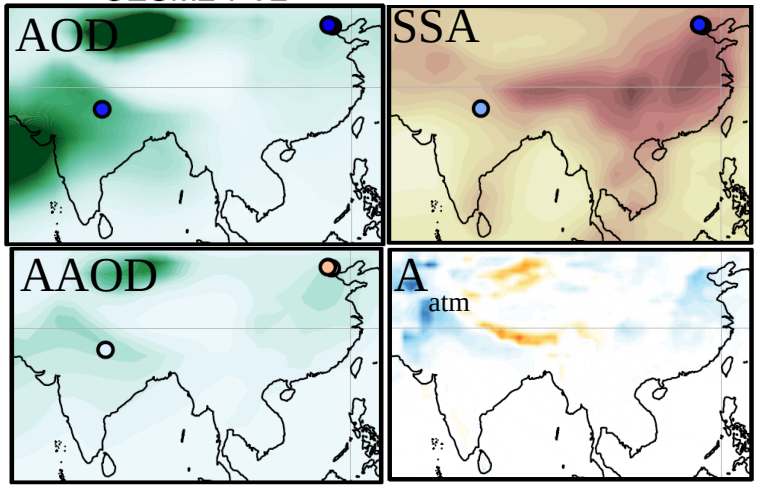
CNRM-ESM2-1



- AOD underestimated
- Correct SSA

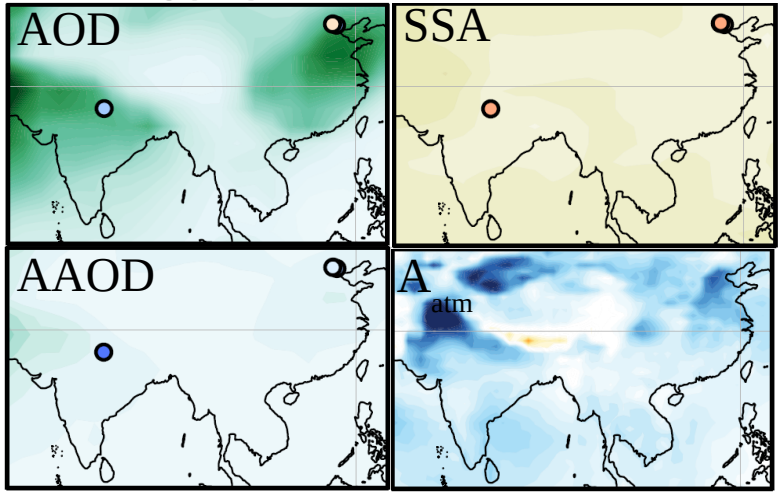
=> AAOD and A_{atm} underestimated

CESM2-FV2



=> Error compensation : low AOD and low SSA

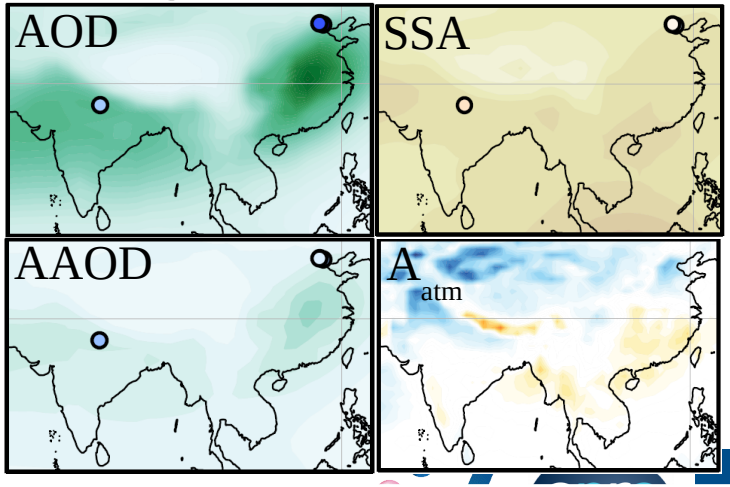
MIROC-ES2L



- Correct AOD
- SSA overestimated

=> AAOD and A_{atm} underestimated

MPI-ESM1-2-LR



=> Better AAOD thanks to both AOD and SSA

Conclusion

- First evaluation of aerosol absorption in CMIP6 historical simulations has been carried out
- Large differences among CMIP6 models
- Strong regional biases against observations, which could explain biases in SW atmospheric absorption
- Prospects :
  - Understanding of model differences with documentation on aerosol representation
  - Need to focus on other variables (cloud cover, aerosol emissions, ...)
  - Other regions of interest (South America, Australia, …)
  - I would be happy to collaborate (article in preparation), and to have more models (abs550aer is essential !)

Thanks for your attention !
Contact : pierre.nabat@meteo.fr