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FINNISH METEOROLOGICAL INSTITUTE

Finnish perspective on aerosol research

Harri Kokkola

+ contribution from

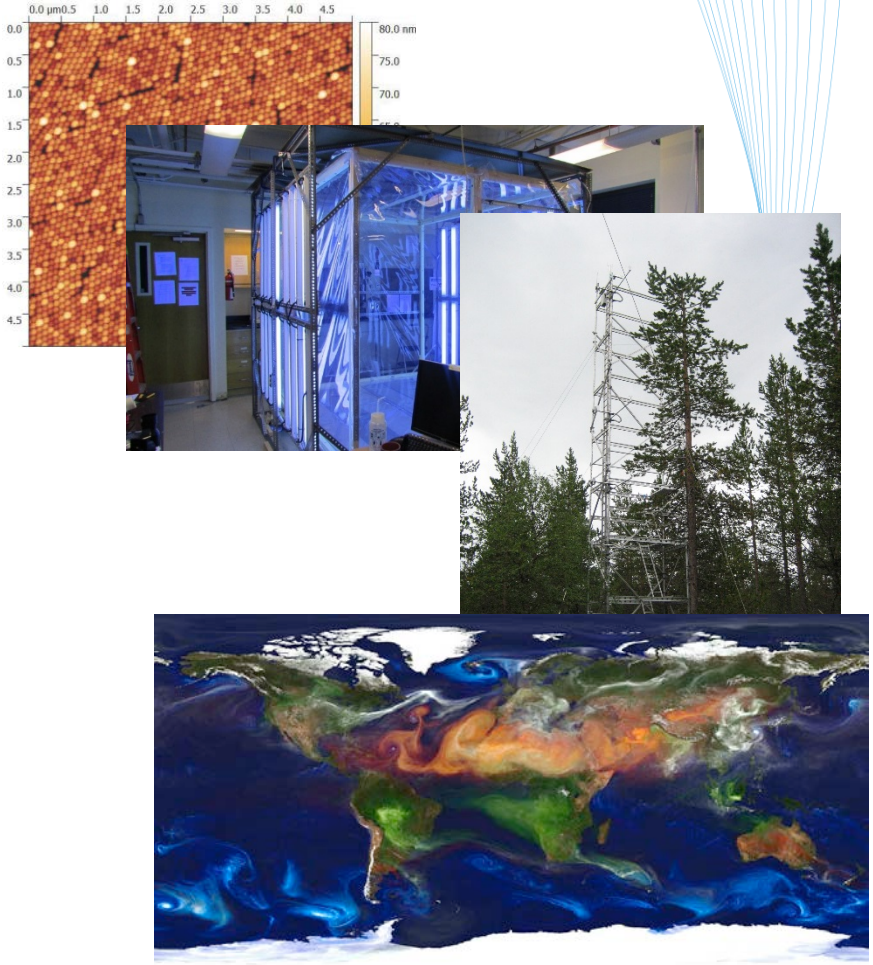
- University of Helsinki
- University of Eastern Finland
- Finnish Meteorological Institute
- University of Oulu
- Finnish Environment Institute

Finnish aerosol research

- First steps towards systematic research of atmospheric aerosol in 1980's
  - Additional motivation from the Chernobyl 1986 nuclear accident

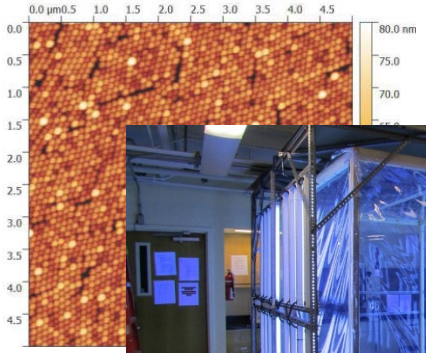
Finnish aerosol research

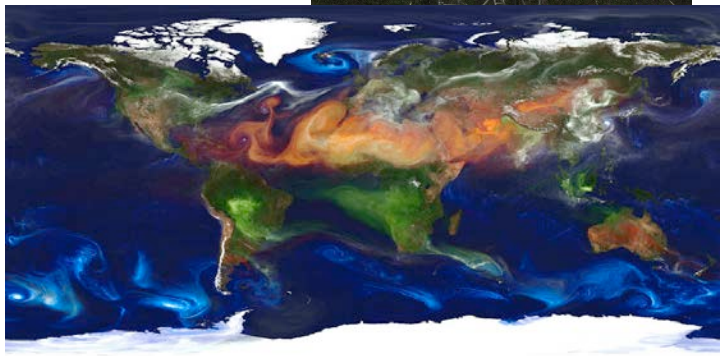
- Quick progress to extensive research in:
  - industrial nanoparticles
  - laboratory measurements
  - field observations
  - remote sensing
    - ground-based, satellite-based
  - modelling
    - from molecular scale to global scale



Institutes

- University of Helsinki
- University of Eastern Finland
- Finnish Meteorological Institute
- Tampere University of Technology
- VTT Technical Research Centre of Finland
- University of Oulu
- Finnish Environment Institute
- National Institute for Health and Welfare





Finnish Center of Excellence in Atmospheric Sciences

Atmosphere – biosphere feedback

From 1986 to 2017

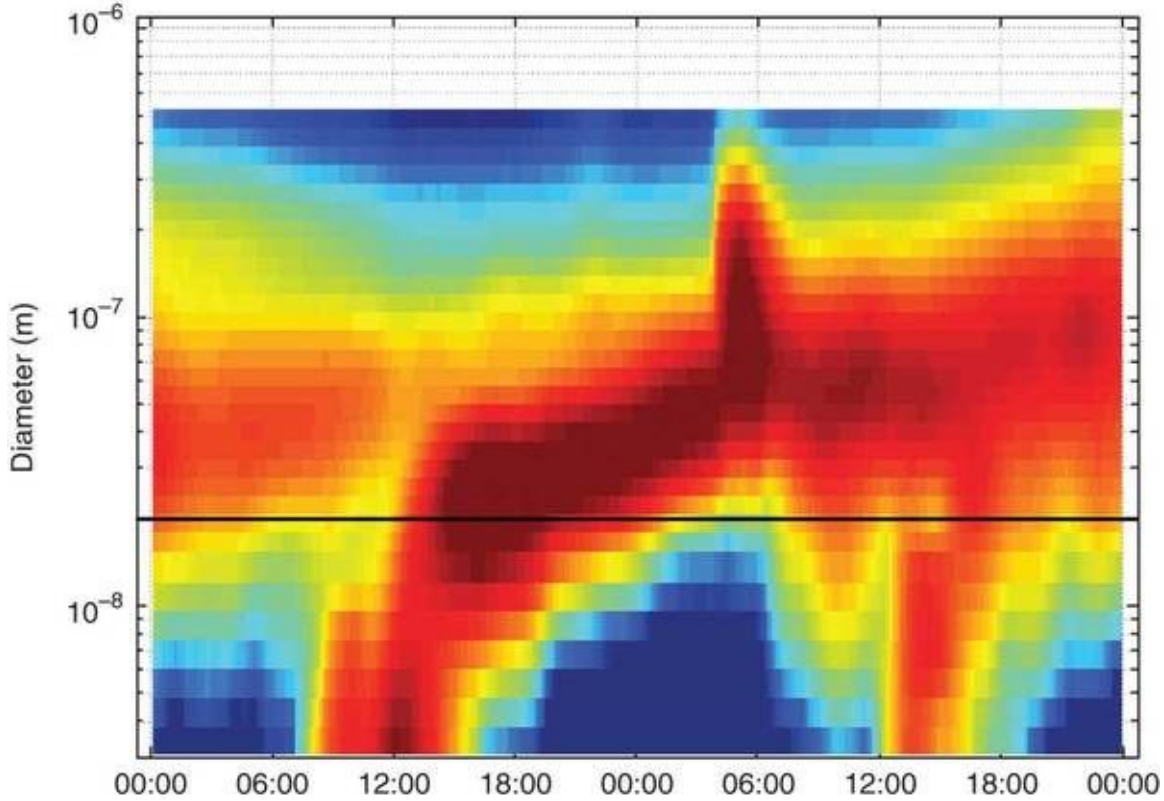
- 5 -> 250 persons years
- Budget: 0.05 -> 15 Meuro
- Infra: 0 -> SMEARs, P-S, ICOS, (ACTRIS), (ANAEE)
- Productivity: 0 -> 150/200 (2-6) papers (in ISI)
- 5/16 ISI Highly Cited Scientists in Finland
- Ca 10% of Nature and Science papers in Finland per year
- 14 ERCs (Finland ca 125)

Core expertise in process scale

Global aerosol-modelling

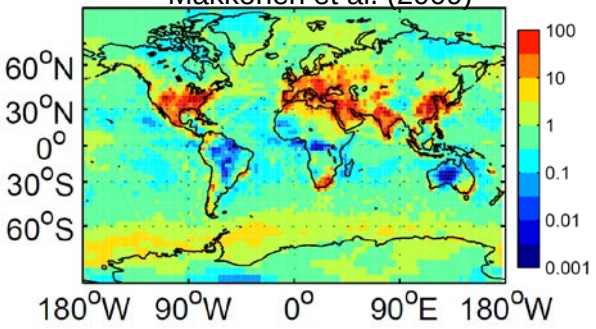
- COSMOS project 2003
- ECHAM-HAMMOZ/MPI-ESM (SALSA for AeroCom)
- NorESM
- EC Earth (CMIP6, AerChemMIP)

Global nucleation

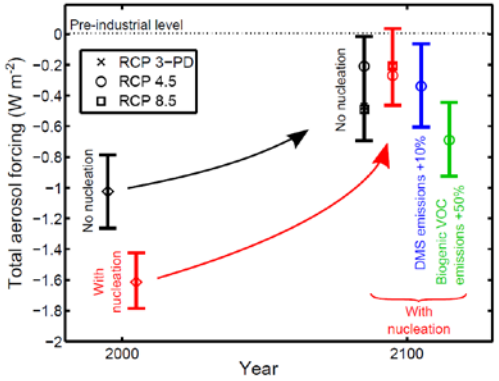


Global nucleation

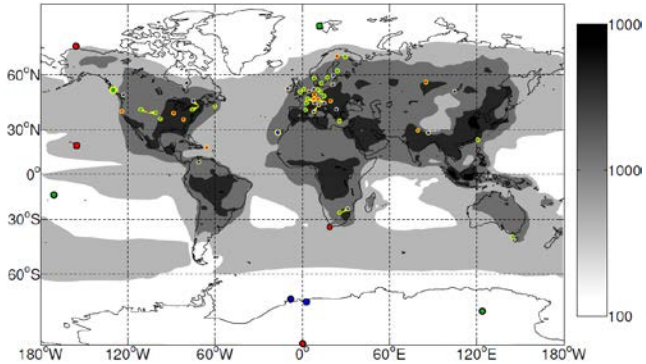
Global nucleation rates (ECHAM-HAM)
Makkonen et al. (2009)



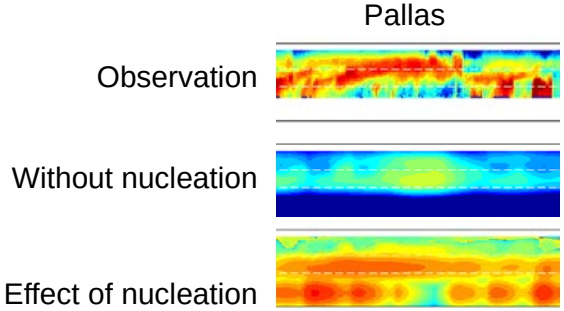
Climate impact of nucleation (ECHAM-HAM)
Makkonen et al. (2012)



Improved number concentrations with explicit nucleation (NorESM)
Makkonen et al. (2014)



Nucleation in EC-Earth-AerChemMIP
(Poster P38)



Satellites / remote sensing

- Started ~ 2006 both in Helsinki & Kuopio
- **AATSR**
- **MODIS**
- MISR
- OMI
- CALIPSO
- AERONET
- SLSTR (Sentinel 3)

How useful are they?

- Global aerosol-climate models
  - should they reproduce e.g. field observations?
  - future predicting crystal balls?
- Satellite data too uncertain to be useful?
  - what data to use and how?
    - anomalies, trends?
    - satellites + models together

Model experiments

RECIA = REgional Climate Impacts of anthropogenic Aerosols

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- Ongoing project to identify robust regional climate effects of anthropogenic aerosols with three climate models:

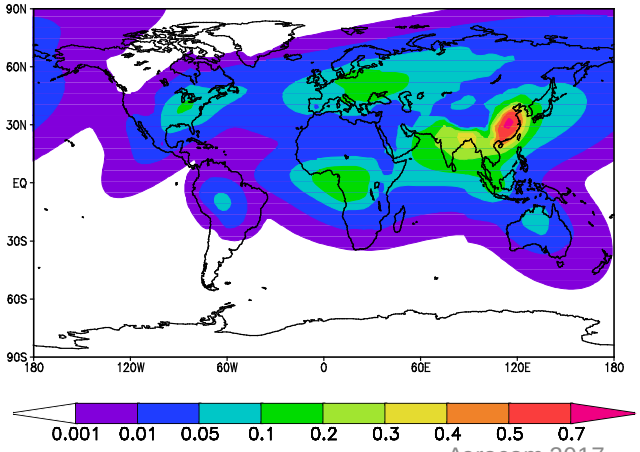
  = ECHAM6 / MPI-ESM, NorESM, EC-Earth (to be included later)

- How similar are regional responses to modern day aerosols when using a standardized aerosol climatology (taken from MACv2-SP)?

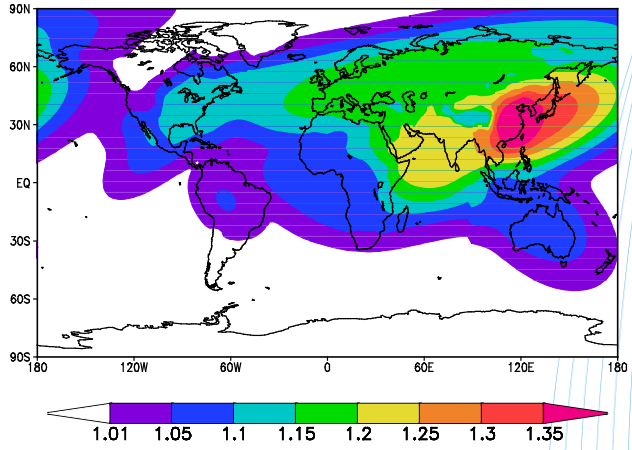
MACv2-SP approach: model-specific background AOD and CDNC are enhanced in anthropogenic aerosol plumes

*Stevens et al., Geosci. Model. Dev., 2017: **MACv2-SP**: a parameterization of anthropogenic aerosol optical properties and an associated Twomey effect for use in CMIP6*

2005 mean AOD enhancement (0.55 µm)



2005 CDNC multiplication factor



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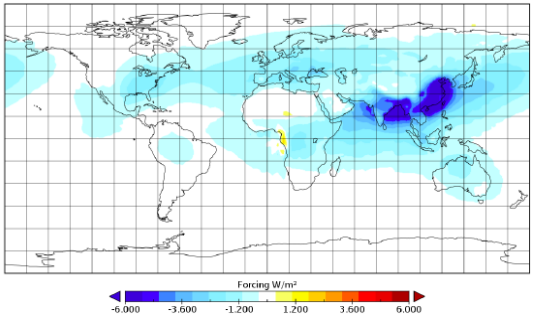
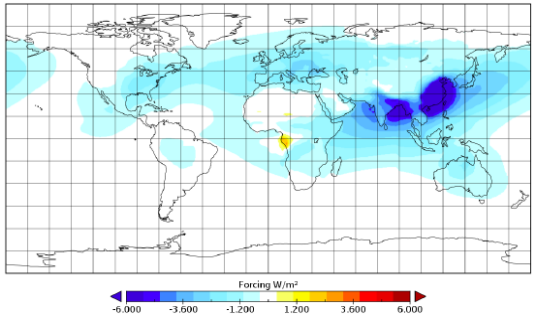
RECIA : Aerosol forcing to Temperature response

•MACv2-SP aerosol climatology results in near identical aerosol forcing across models - below is the instantaneous TOA (direct + 1st indirect) short wave anthropogenic aerosol forcing from ECHAM6 and NorESM:

ECHAM6: global mean -0.63 W/m²

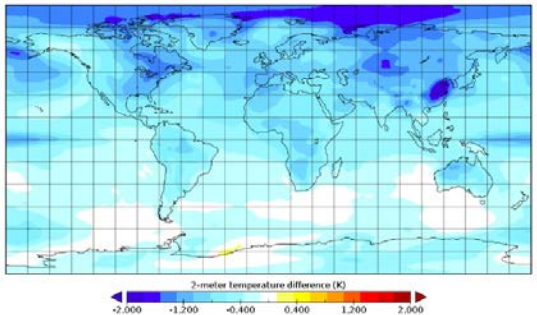


NorESM: global mean -0.66 W/m²

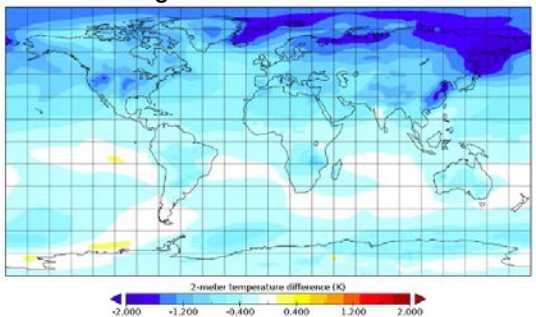


- The resulting atmospheric cooling (from year 2005 slab ocean runs with and without anthropogenic aerosols) correlates very little with the original forcing:

ECHAM6: global mean ΔT=0.55 K



NorESM: global mean ΔT=0.49 K



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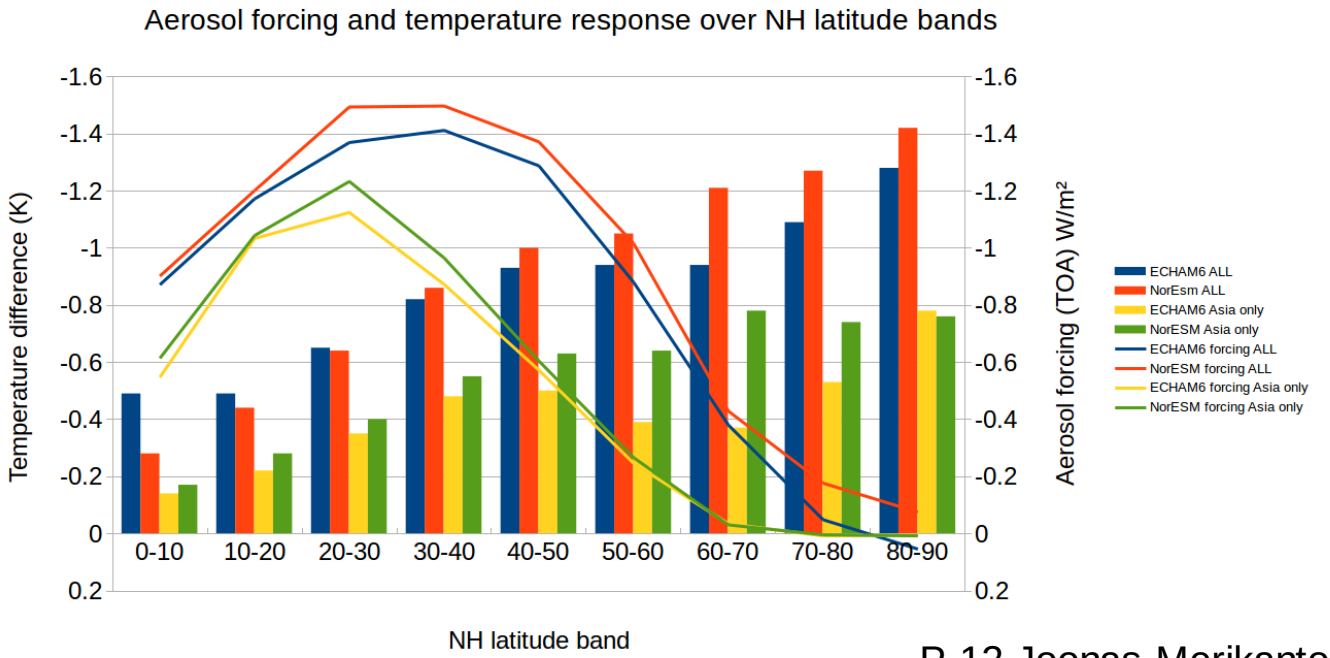
RECIA : Arctic amplification in temperature response

- ECHAM6 and NorESM slab ocean runs show strong arctic amplification of atmospheric cooling due to modern day anthropogenic aerosols (red and blue bars).
- Arctic amplification is also present when only Asian aerosols are taken into account

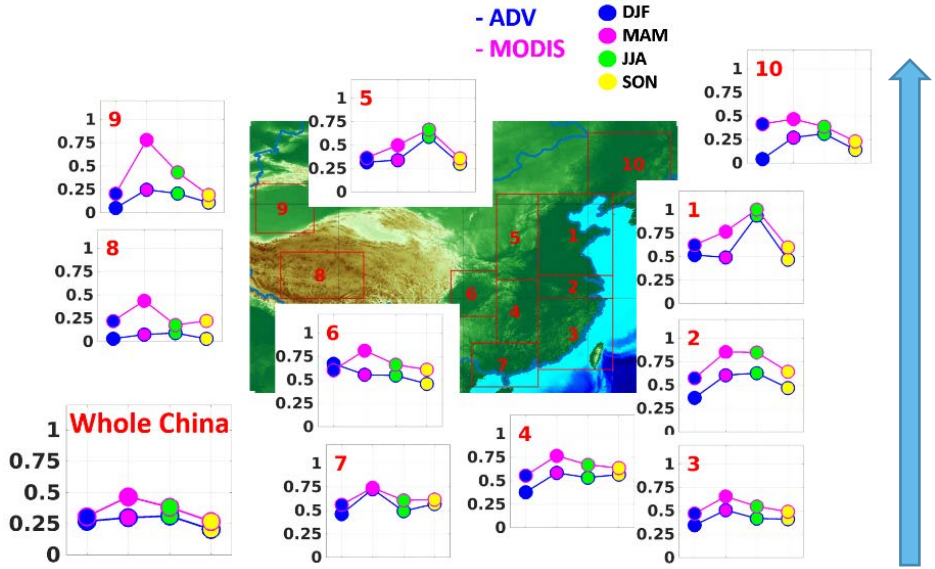
Forcing and temperature response over different NH latitudes: Lines represent forcing, bars are the corresponding temperature difference between different runs

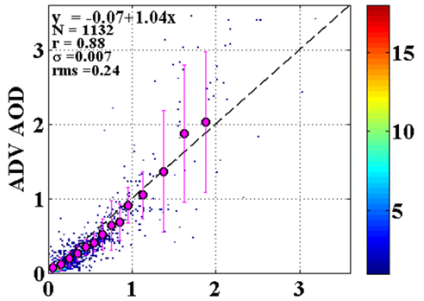


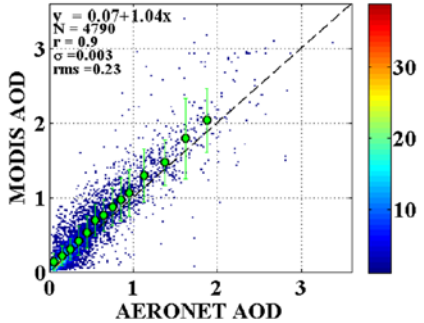
P-12 Joonas Merikanto

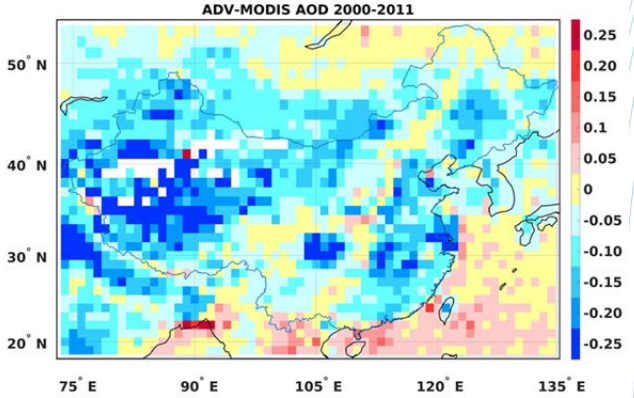
Satellite data

AOD over China from ATSR-2, AATSR and MODIS: seasonality







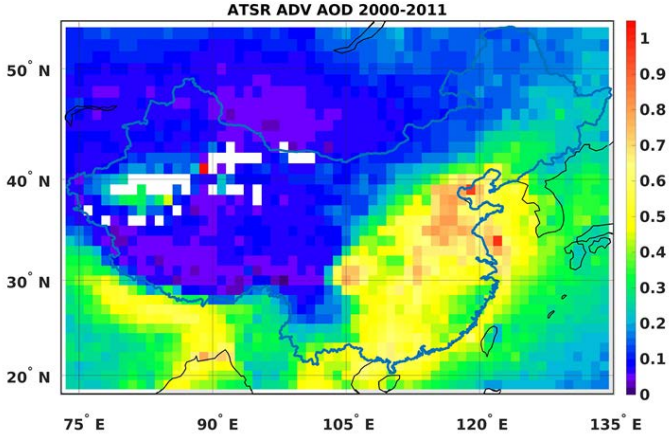


Seasonal variation varies by region;

- tendency similar for MODIS (C6 DTDB merged) and ATSR
- MODIS overestimates, ATSR underestimates
- ATSR has problems over bright surface where MODIS uses DB

Sogacheva et al., in prep.

AOD over China from ATSR-2, AATSR and MODIS: time series



Mainland China: yearly AOD

ATSR-2 + AATSR 2000-2011
L3 (1^o x 1^o)

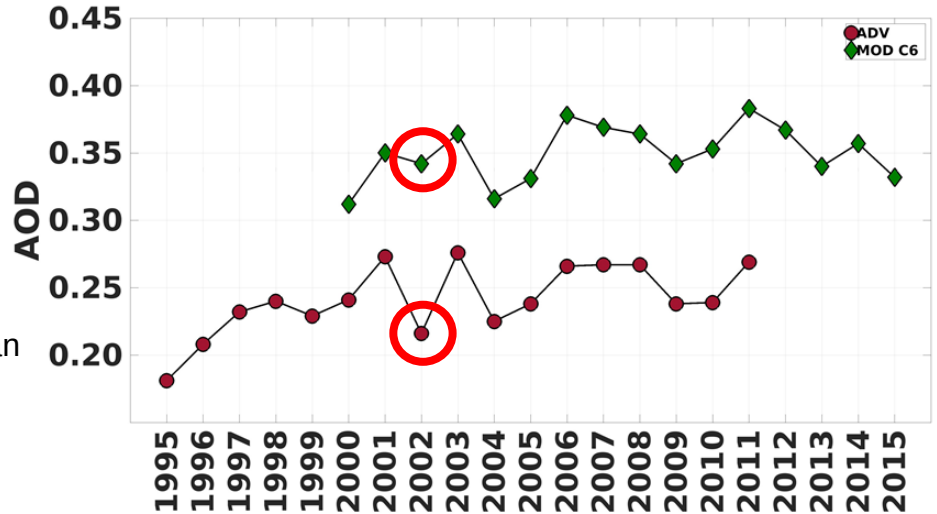
ATSR & MODIS/Terra C6 are complementary:

- ATSR shows the AOD increase before the EOS era
- MODIS/Terra shows the AOD decrease after ENVISAT, in response to emission reductions

Two questions:

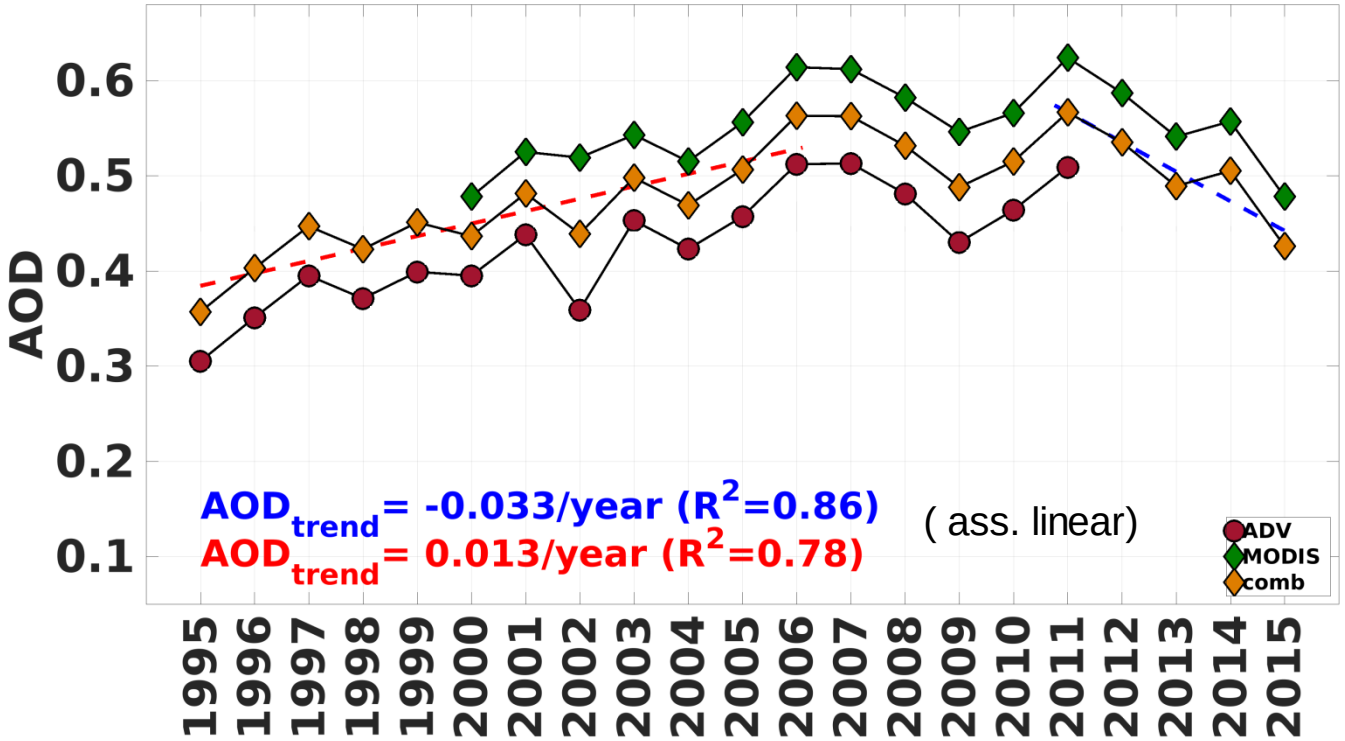
1) ATSR&MODIS are substantially different, can they be used together?
2) How effective are emission reductions?

de Leeuw et al., submitted



C6 DT expected error over land: $\pm(0.05+0.15\tau_{AERONET})$

AOD over China from ATSR-2, AATSR and MODIS: combined time series



Initial increase
Followed by a decrease from ~2011

Linear fits?
Different factors contribute to the temporal variations

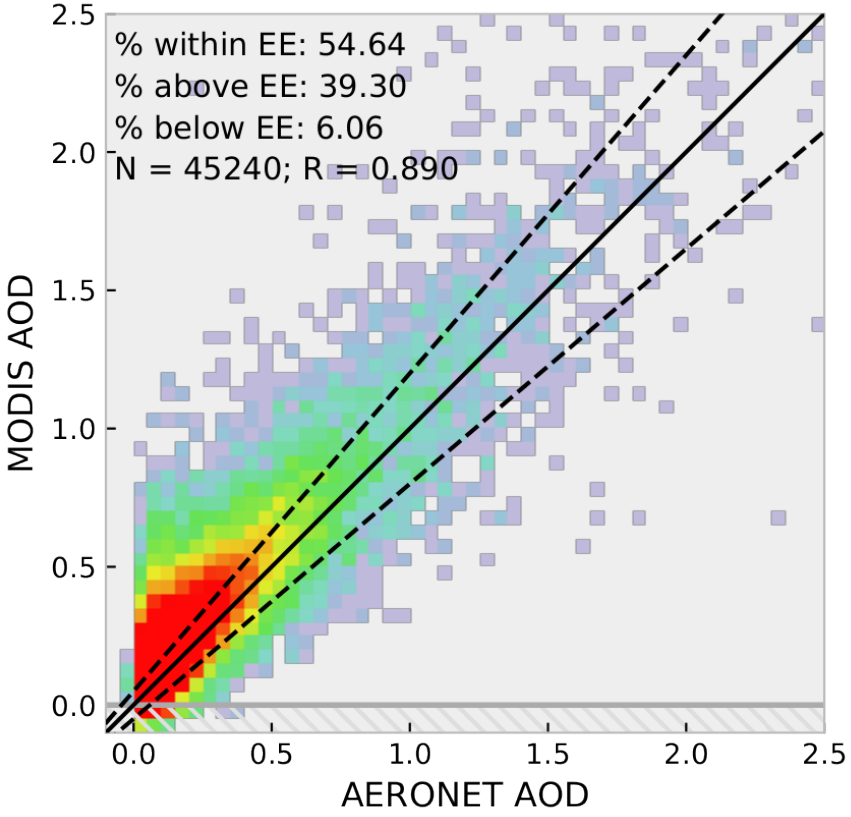
Sogacheva et al., in prep.

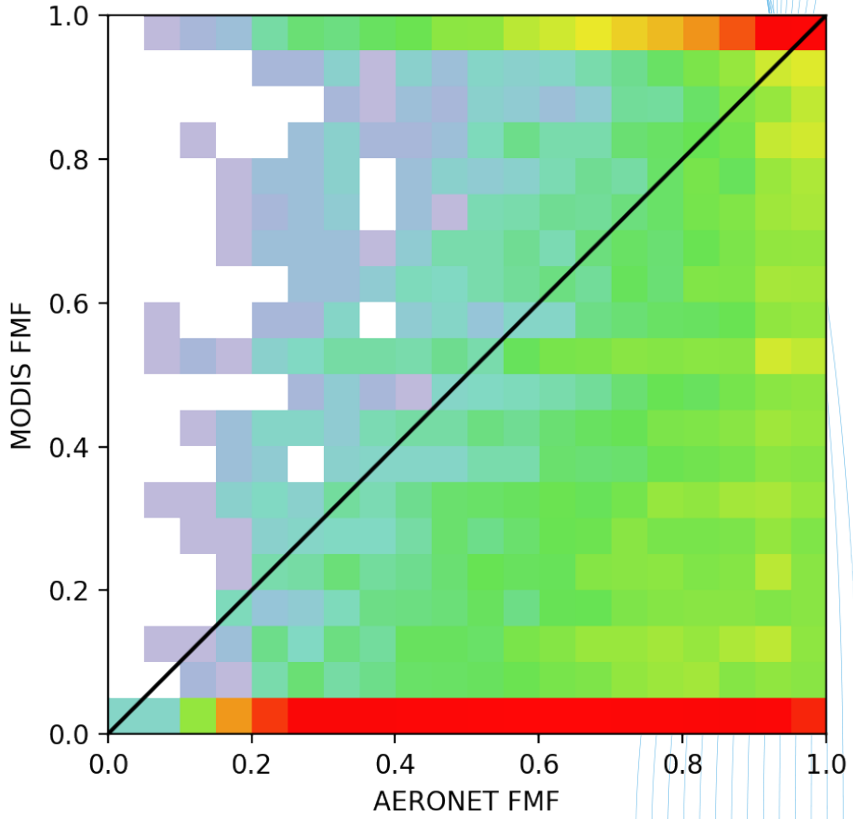
P-64 Larisa Sogacheva

MODIS Bayesian Dark Target algorithm

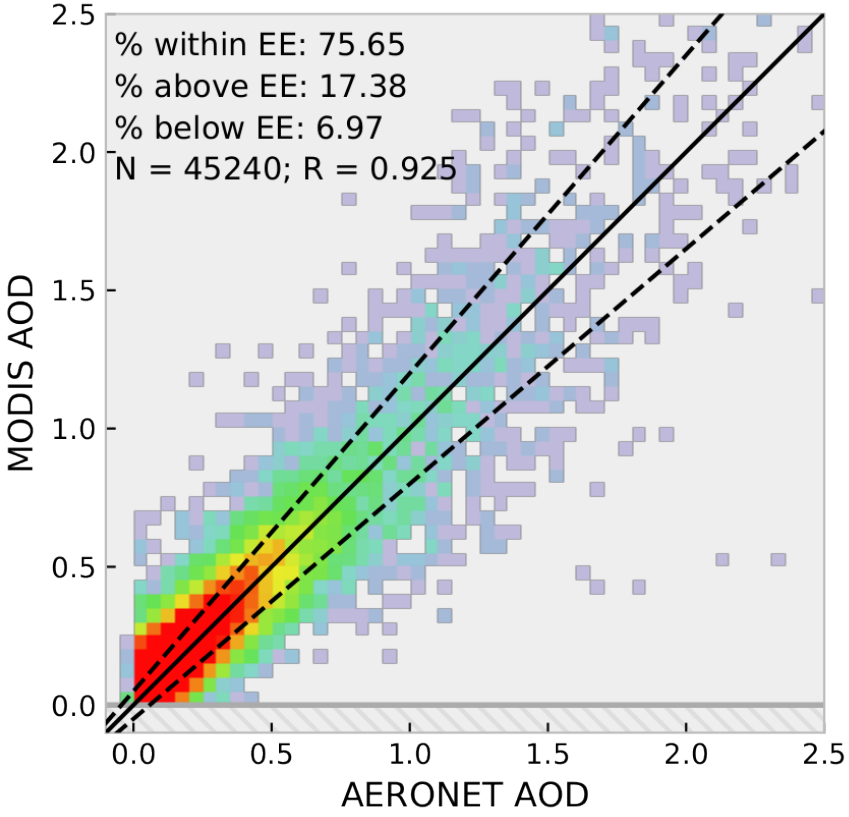
- Bayesian Dark Target (over land)
  - Based on Dark Target over land algorithm
  - Retrieves AOD, fine mode fraction and surface reflectances
  - Quantifies uncertainties related to retrievals on a pixel level
  - Multipixel retrieval (simultaneous retrieval of all pixels in a granule)
  - Spatial correlation models
  - Approximation error model / Uncertainty model for the aerosol models and radiative transfer simulations
  - Significantly improved retrieval accuracy, computationally feasible for near-realtime retrievals

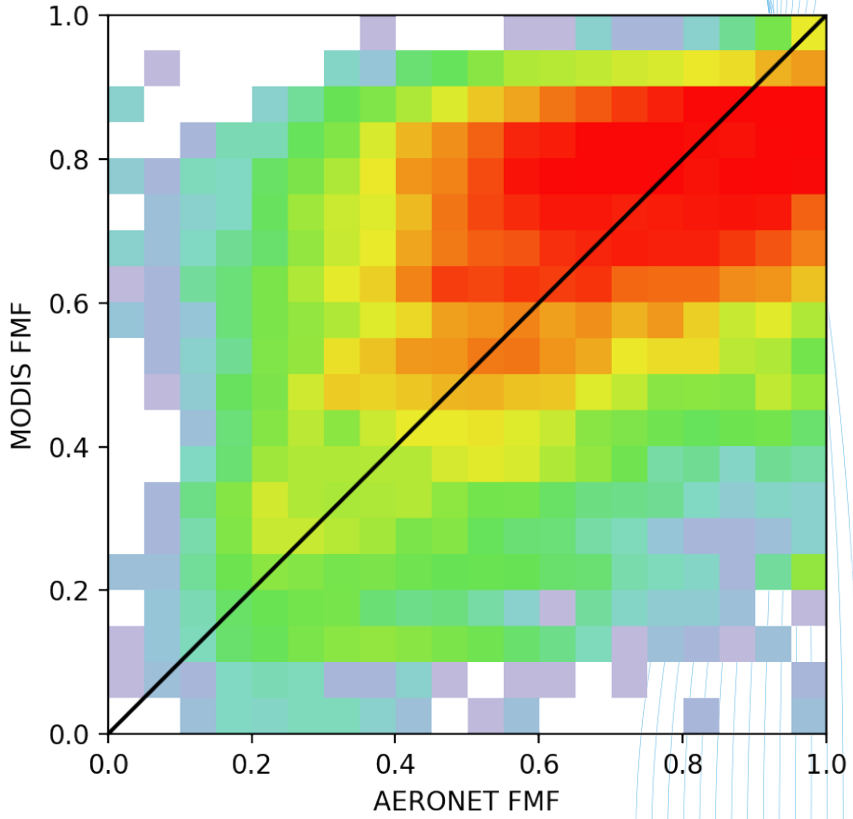
MODIS Dark Target Algorithm



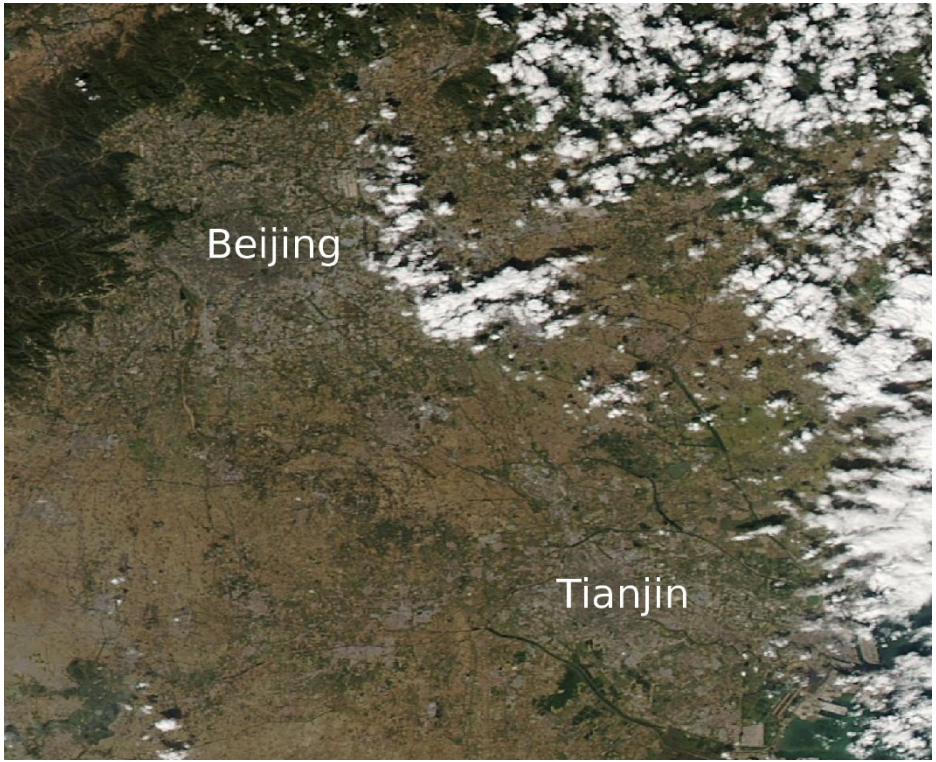


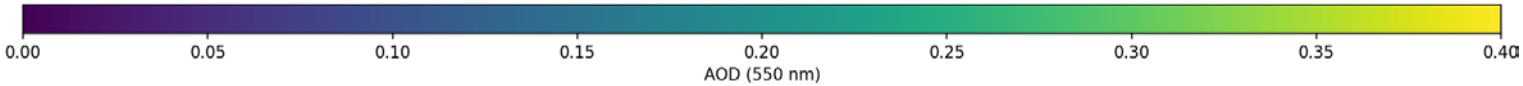
MODIS Bayesian Dark Target Algorithm



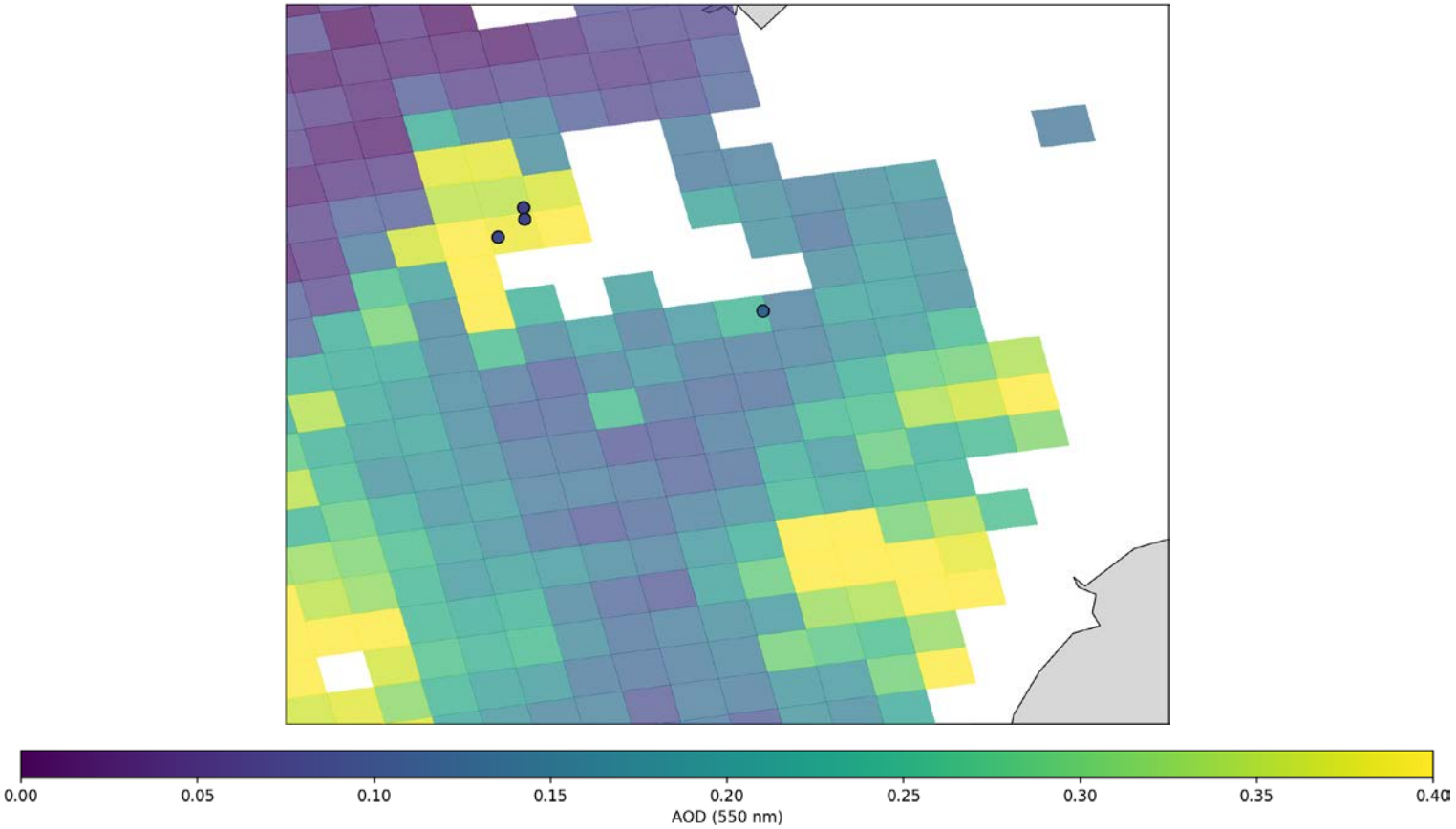


MODIS corrected reflectance

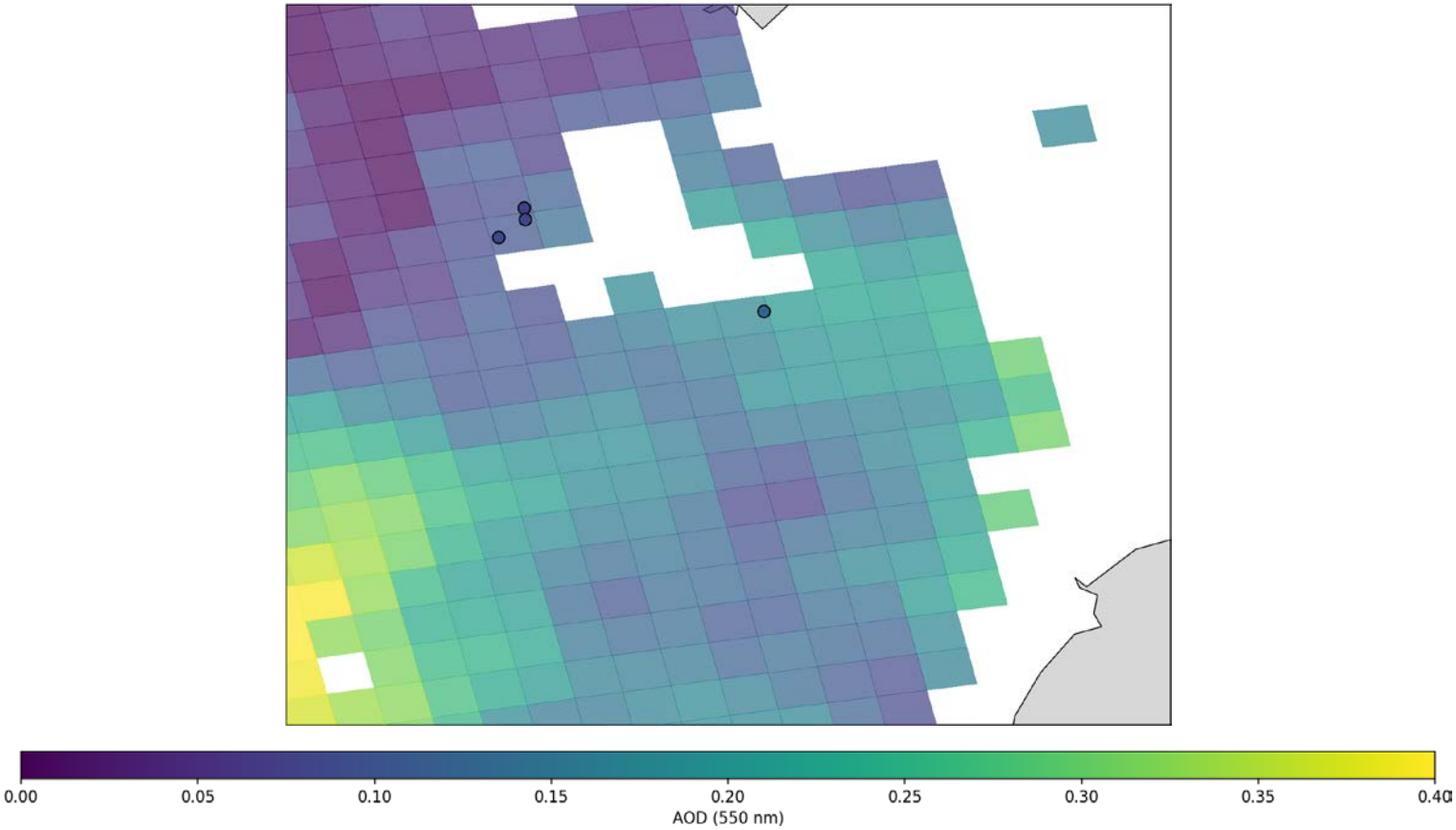




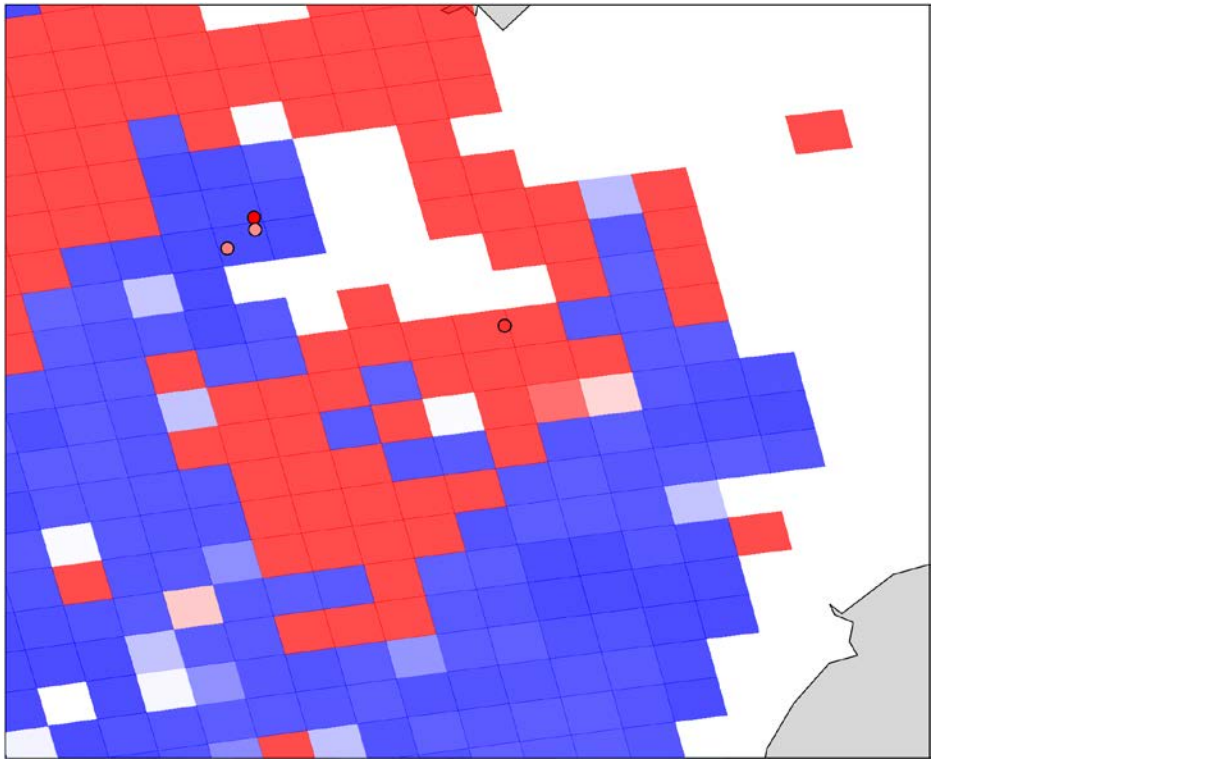
MODIS Dark Target Algorithm



MODIS Bayesian Dark Target Algorithm



MODIS Dark Target Algorithm



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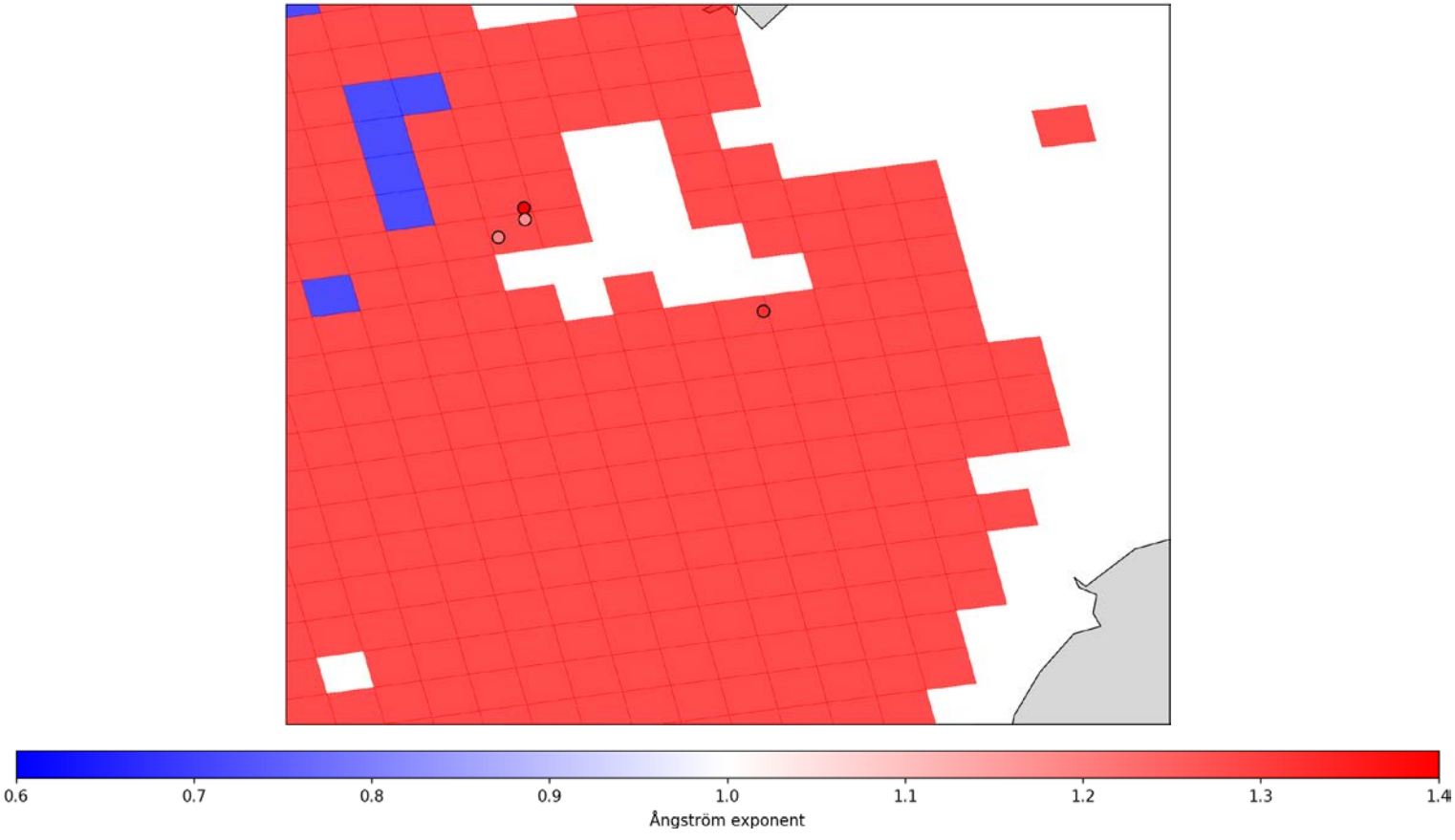

MODIS Bayesian Dark Target algorithm

- Bayesian Dark Target (over land)
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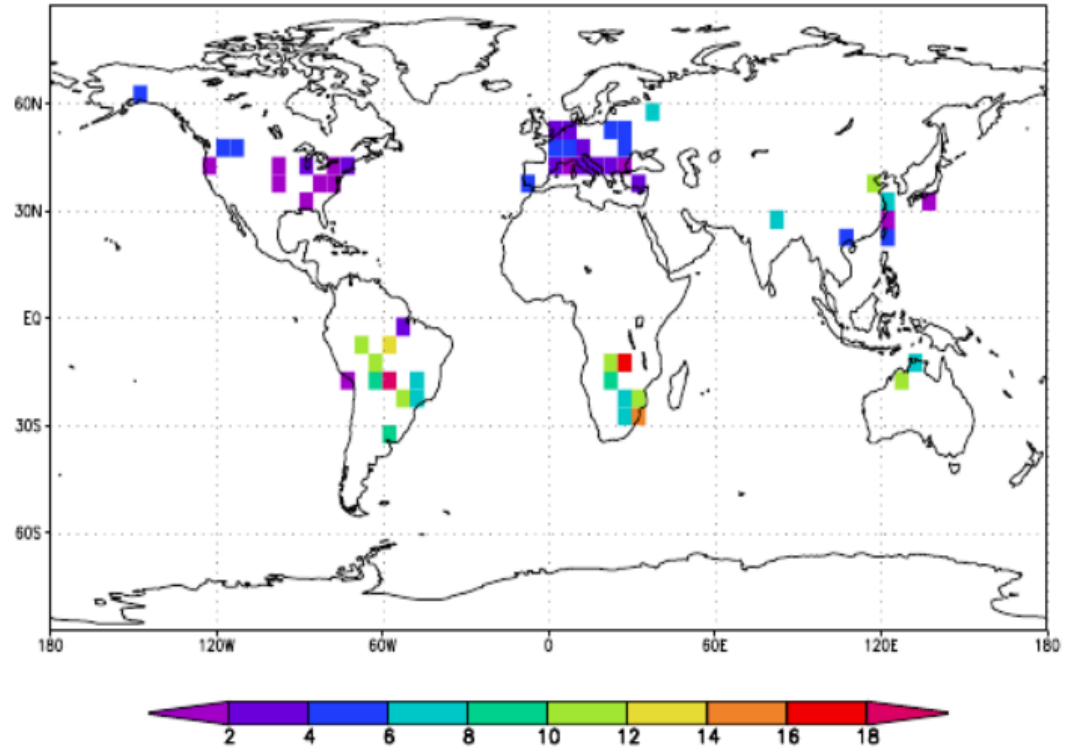
  - Spatial correlation models
  - Approximation error model / Uncertainty model for the aerosol models and radiative transfer simulations
  - Significantly improved retrieval accuracy, computationally feasible for near-realtime retrievals

P-60 Antti Lipponen
Lipponen A., Mielonen T., Pitkänen M.R.A., Levy R.C., Sawyer V.R., Romakkaniemi S., Kolehmainen V. and Arola A., ”Bayesian Dark Target algorithm for MODIS AOD retrieval over land” , *Atmos. Meas. Tech.*, submitted.

AERONET

Retrieving aerosol composition from AERONET

absorbing compounds



Schuster , G. L., O. Dubovik, B. N. Holben, and E. E. Clothiaux, Inferring black carbon content and specific absorption from Aerosol Robotic Network (AERONET) aerosol retrievals, J. Geophys. Res., 110, D10S17, doi:10.1029/2004JD004548, 2005.

Arola, A., Schuster, G., Myhre, G., Kazadzis, S., Dey, S., and Tripathi, S. N.: Inferring absorbing organic carbon content from AERONET data, Atmos. Chem. Phys., 11, 215-225, doi:10.5194/acp-11-215-2011, 2011.

Mean absorbing OC concentration (mg/m^2) inferred from AERONET-retrieved imaginary indices for September.

Retrieving aerosol composition from AERONET

absorbing compounds

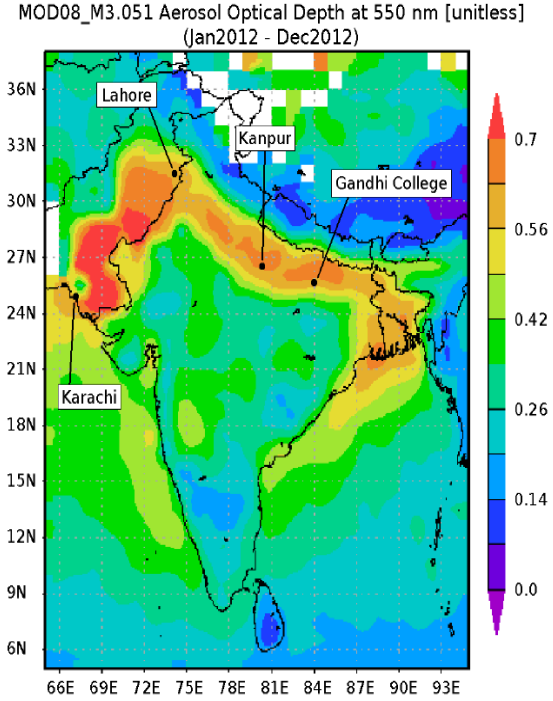


Figure 1. Annual mean AOD from MODIS Terra, with our AERONET study sites overlaid in the map. Source of MODIS data: http://disc.sci.gsfc.nasa.gov/giovanni.

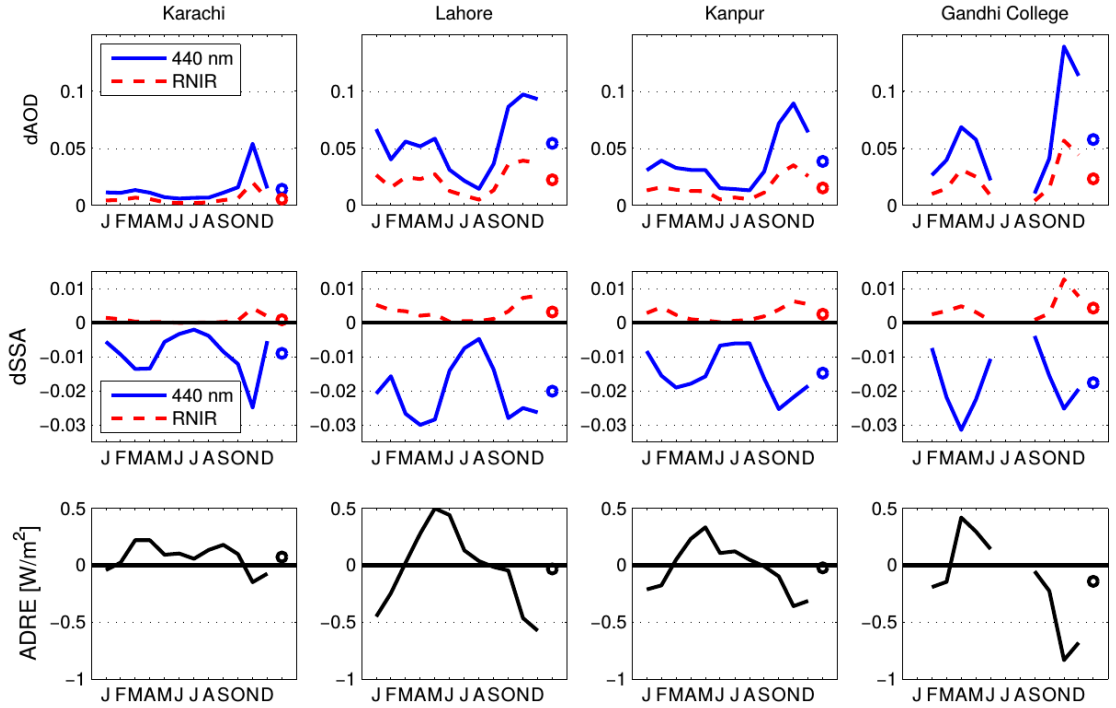
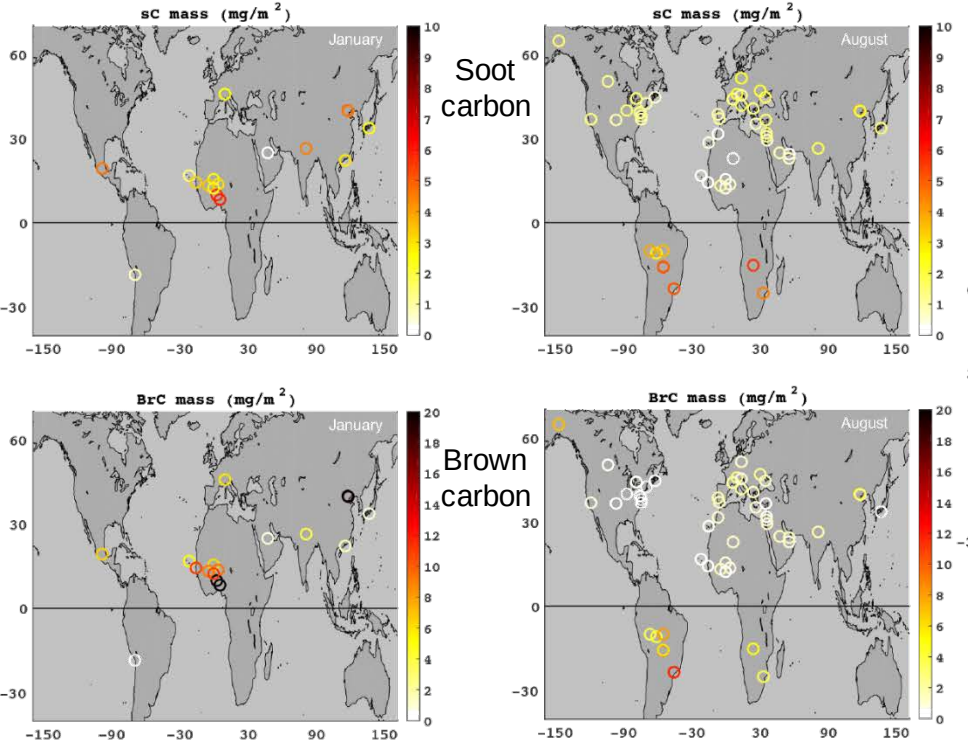


Figure 5. Upper panel: monthly averages of the difference in AOD at 440 nm (blue) and at RNIR (red) between simulations with and without BrC. Middle panel: corresponding cases for SSA. Lower panel: monthly average DRE of BrC. Corresponding annual averages are given by the symbol after December.

Retrieving aerosol composition from AERONET
absorbing compounds



Schuster, G. L., Dubovik, O., and Arola, A.: Remote sensing of soot carbon – Part 1: Distinguishing different absorbing aerosol species, Atmos. Chem. Phys., 16, 1565-1585, https://doi.org/10.5194/acp-16-1565-2016, 2016.

iron oxide

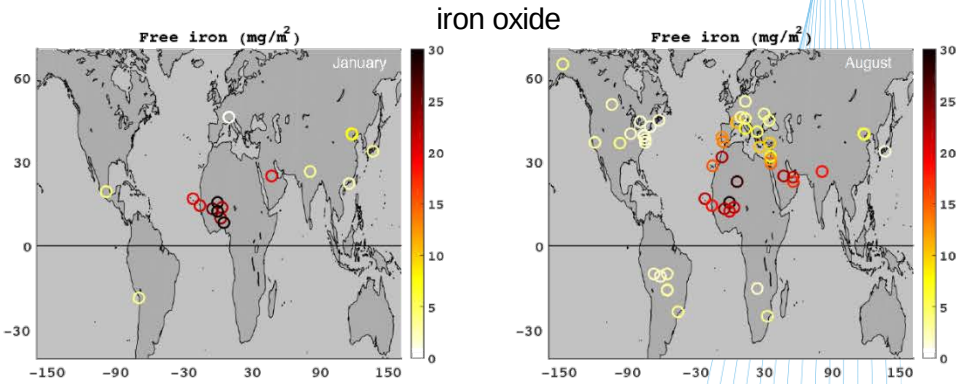


Figure Column mass concentrations of sC (top row), BrC (middle row), and iron oxide (bottom row) retrieved from Level 2.0 AERONETdata for January (left column) and August (right column).

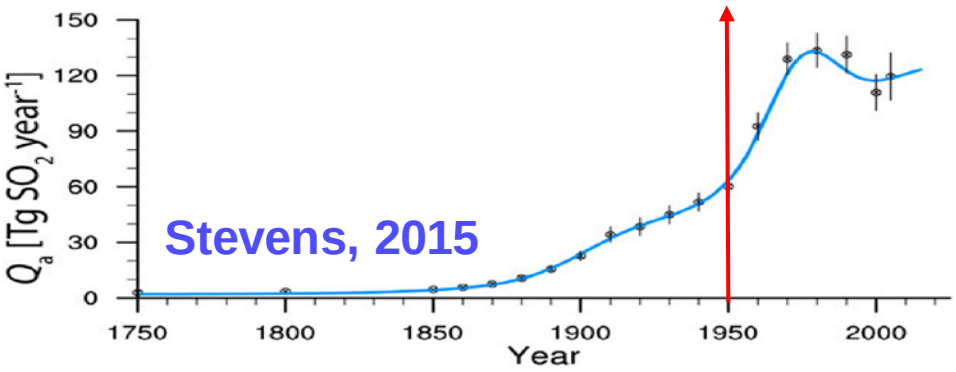
New + old techniques

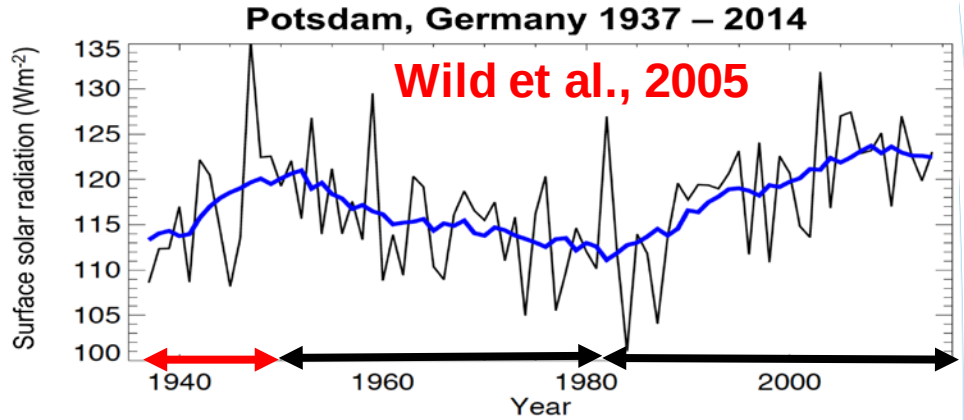
Reconstructing the aerosol load in the past

- The present day anthropogenic aerosol forcing ranges between –0.1 W/m2 and –1.9 W/m2, (*IPCC, 2013)*
- Stevens (2015) reduced the uncertainty over the Northern Hemisphere, it ranges between –0.3 W/m2 and –1.0 W/m2

- based solely on SO2 emissions *vs* AOD comprises black carbon and organic aerosols

- constantly increasing of aerosol load before 1980 *vs* opposite findings of decreasing aerosol load before 1950





Retrieving past AOD from SSR observations

- We applied different machine learning to retrieve AOD from SSR measurements, i.e. measurements not designed for AOD

Photo by: Andreas Christen, UBC

Retrieving AOD from SSR observations

The retrieval was done using four ML methods:
- Gaussian process
- neural network
- random forest
- support vector machine.

We also included a
- look-up-table approach
- a non-linear regression method

for retrieving AOD from the same data (Huttunen et al., 2016). The methods were set up to reproduce the AOD observed by a sun photometer for each observed SSR, solar zenith angle (SZA), and water vapour content (WVC).

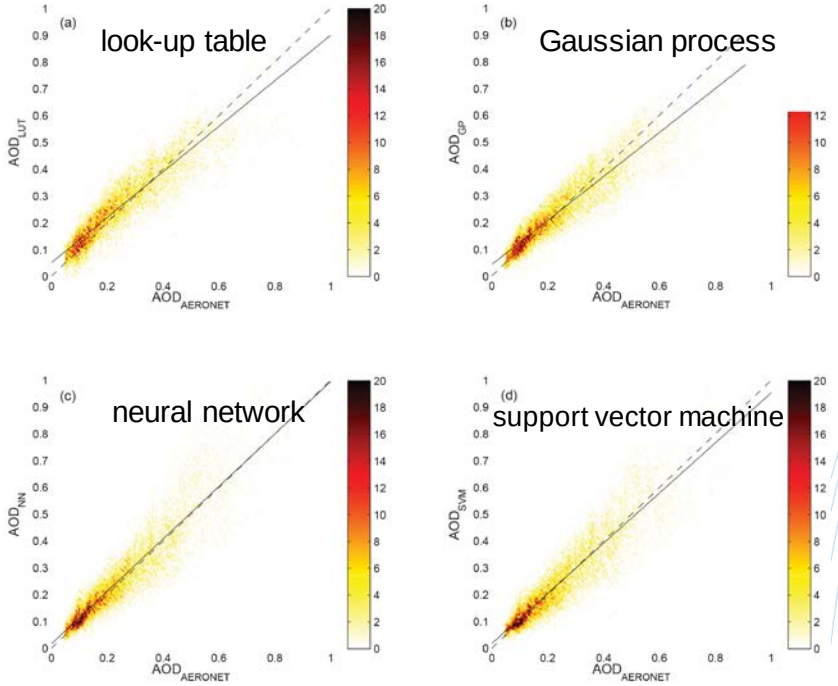
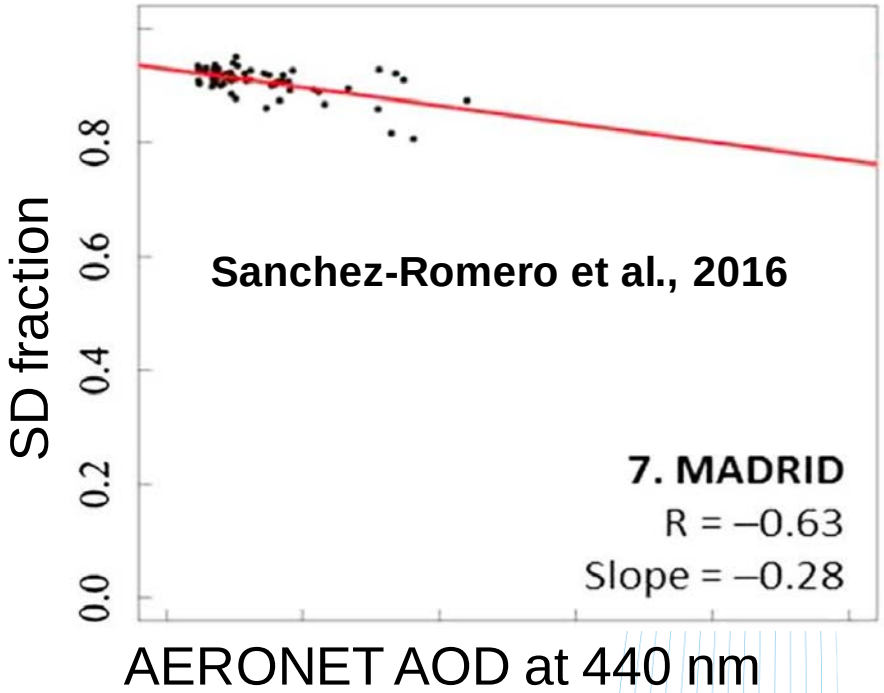


Figure: Observed (AERONET) vs predicted AOD:

Going further back in time with sunshine duration (SD) measurements

Even back to 1800s?

Spain (2012-2014)



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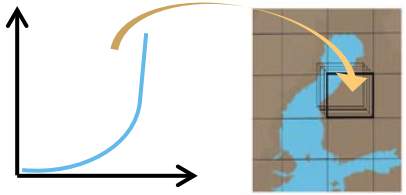
FINNISH METEOROLOGICAL INSTITUTE

Emulation of sub-grid scale aerosol-cloud interactions in climate models (ECLAIR)

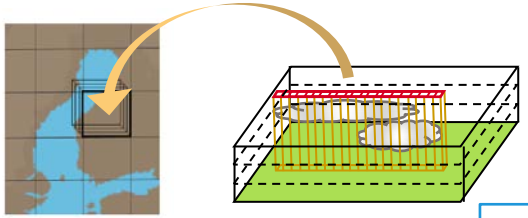
European Research Council

INACCURATE

CONVENTIONAL CLIMATE MODELS



SUPERPARAMETERIZATION (or MMF)

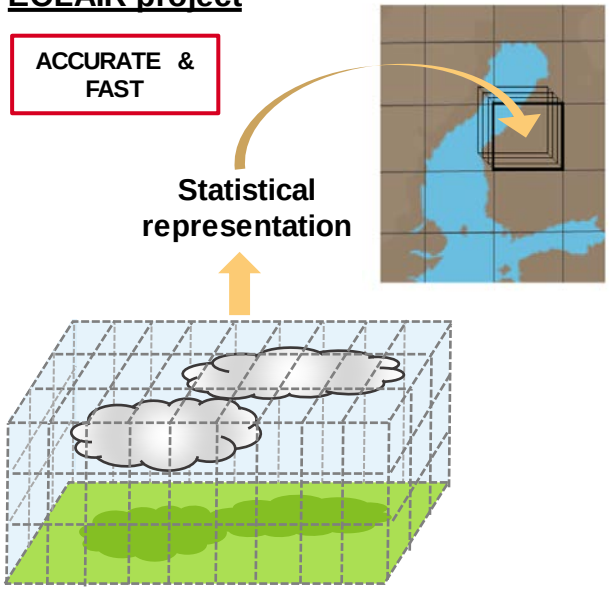


SLOW

ECLAIR project

ACCURATE & FAST

Statistical representation



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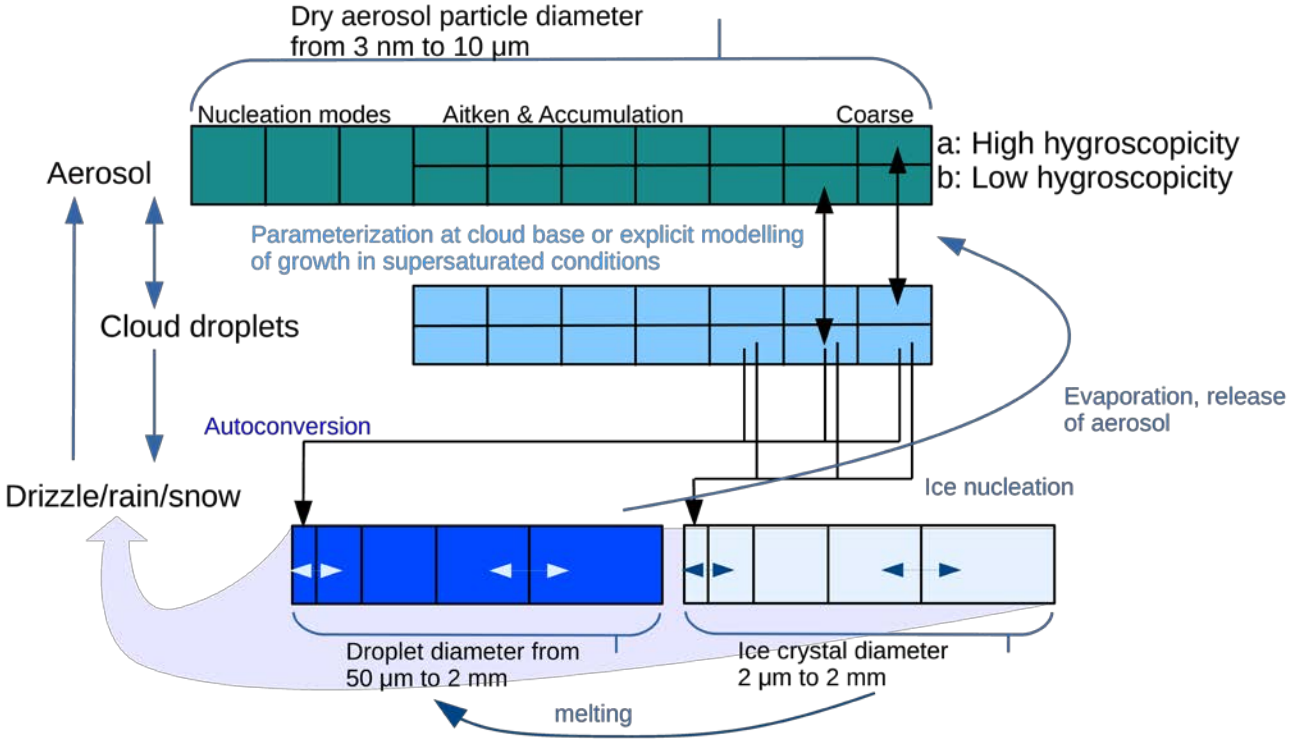
Emulation of sub-grid scale aerosol-cloud interactions in climate models (ECLAIR)

UCLALES-SALSA

ECHAM-HAMMOZ



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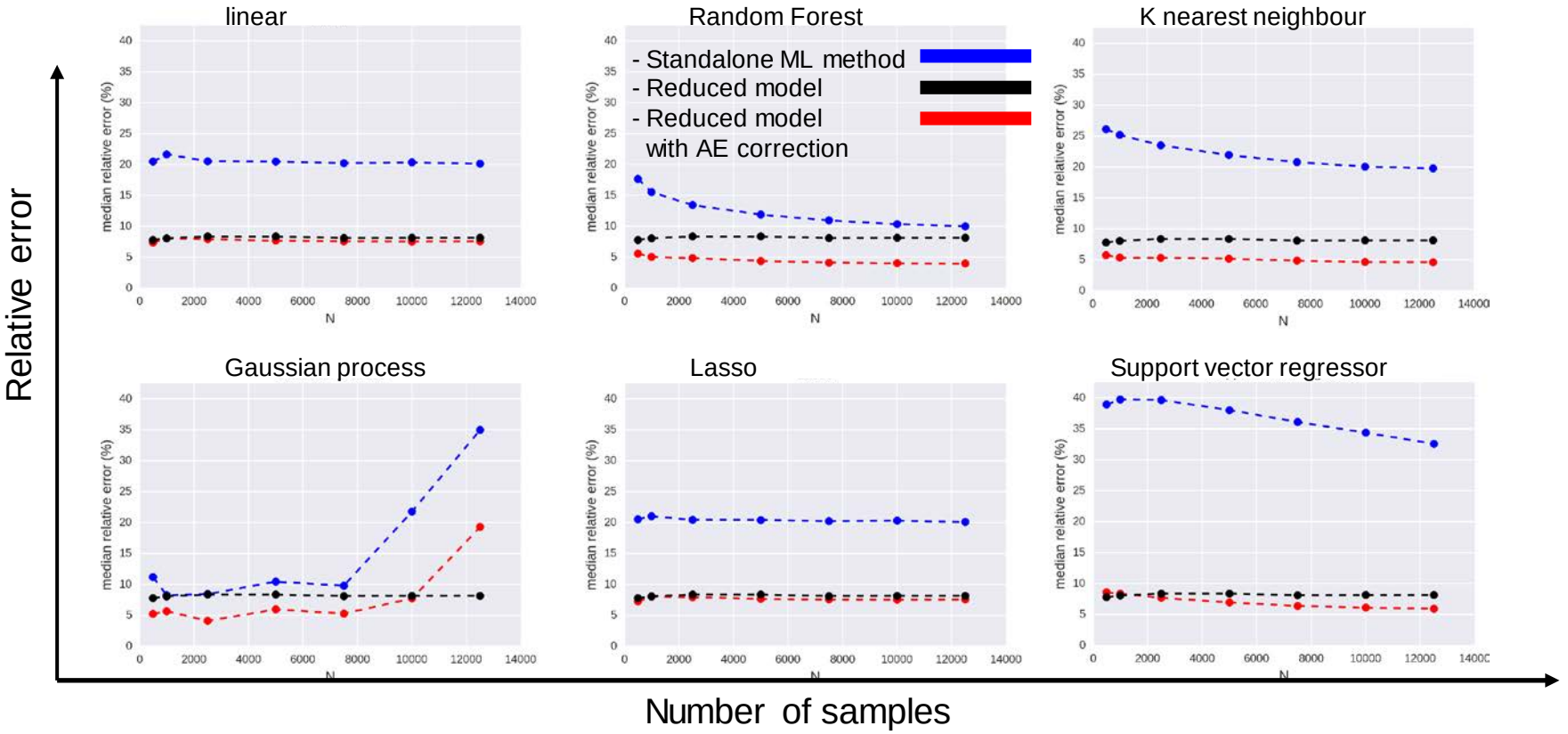
Correction of model reduction error in simulations

Lipponen A., Huttunen J.M.J., Romakkaniemi S., Kokkola H., Kolehmainen V. (in preparation for SIAM J. Sci. Comput.)



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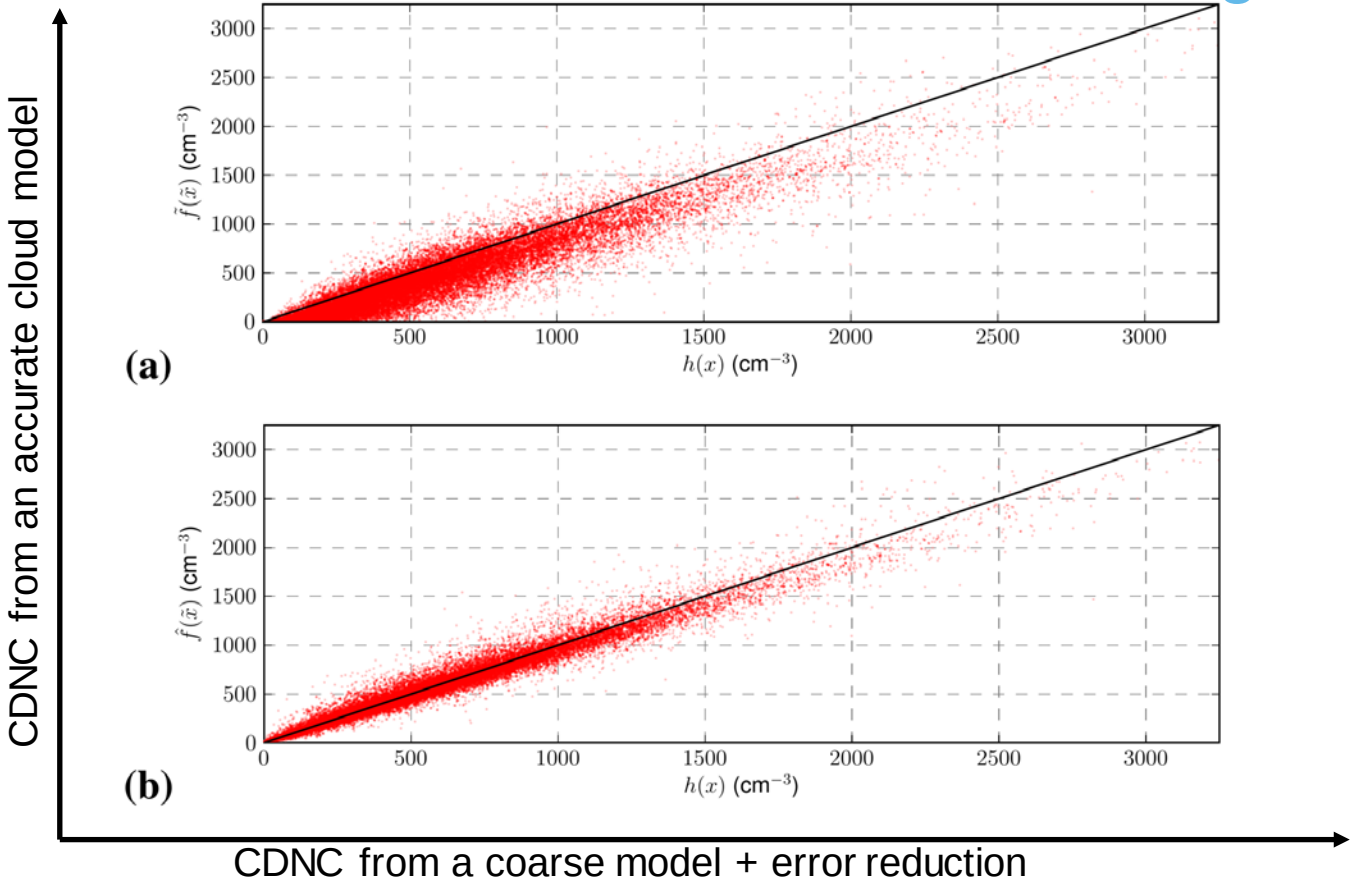
Correction of approximation errors with machine learning methods



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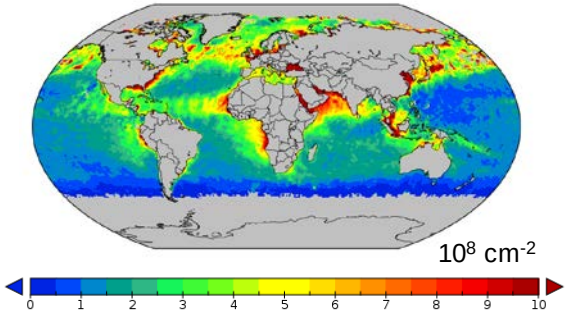
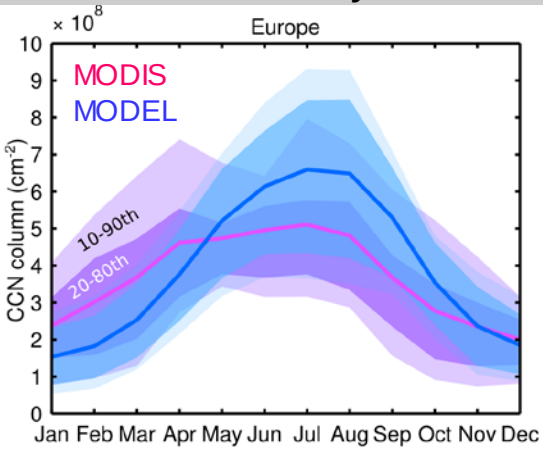
Combining aerosol models + satellite data

Evaluating simulated CCN concentrations from satellite observations

We utilize MODIS *Terra, MOD08_M3.051,1ºx1º, PSML003_Ocean, C6* column product (CCN/cm^2) to evaluate changes in CCN over oceans.

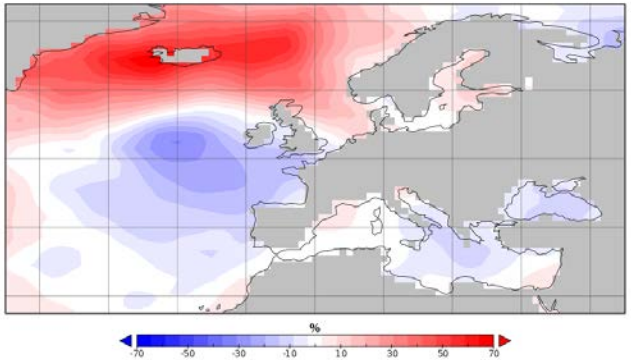


Seasonal cycle

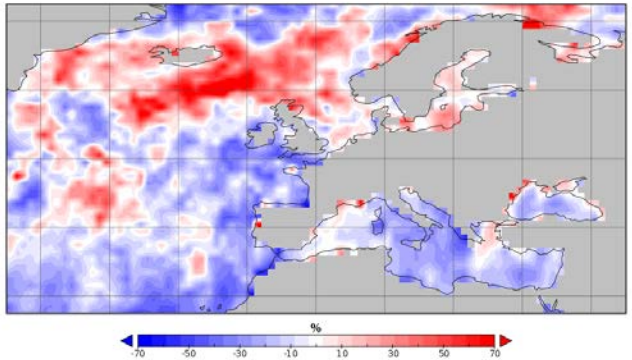


Monthly anomaly for August 2004 (relative, %)

MODEL (ECHAM)



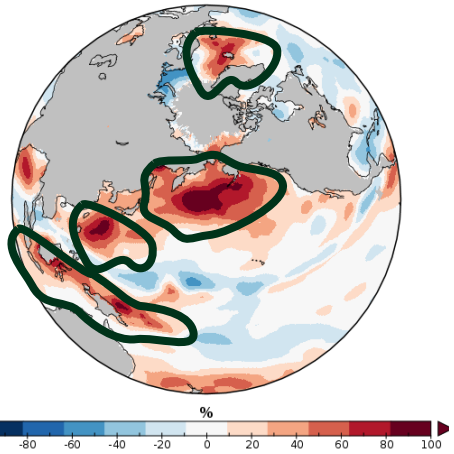
MODIS

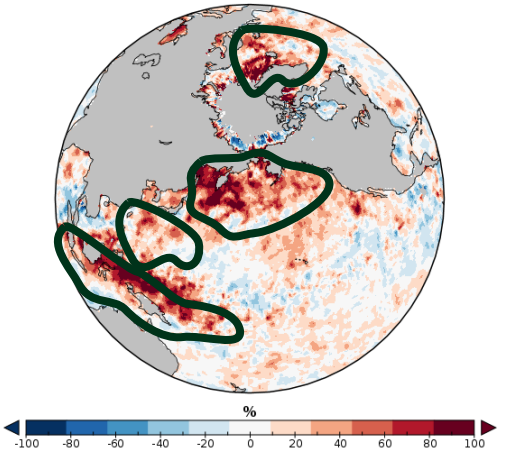


Examples of monthly CCN anomalies

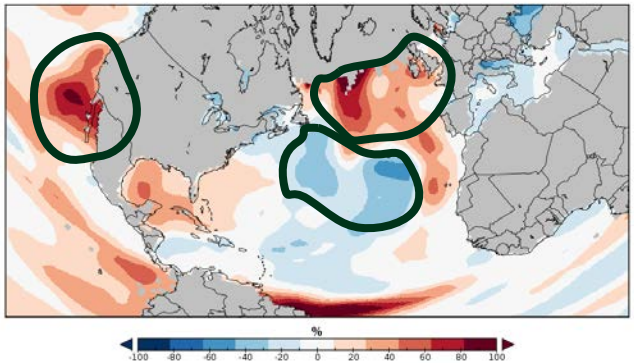
Control-simulation

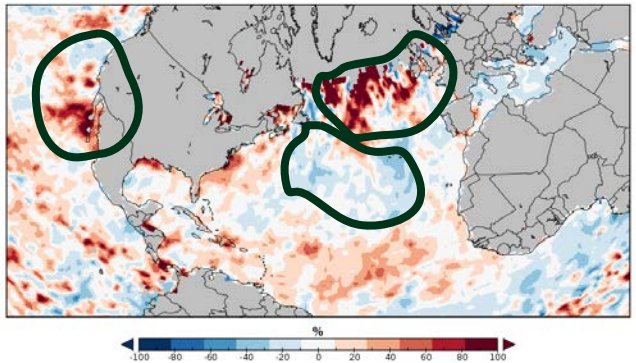
Pacific
September 2002

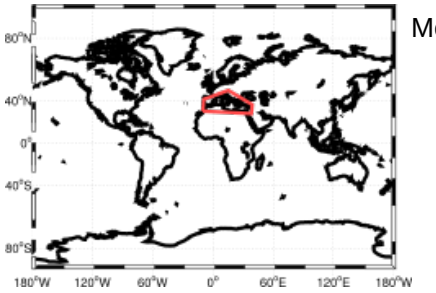




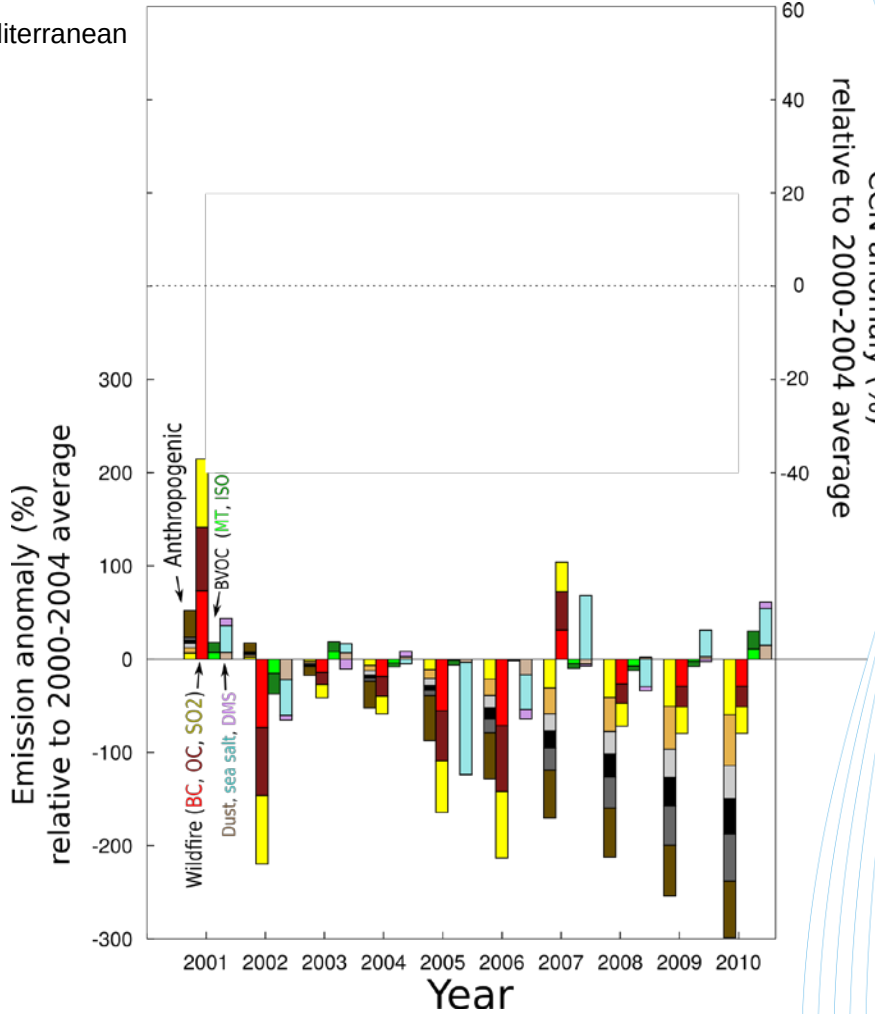
Atlantic
November 2007

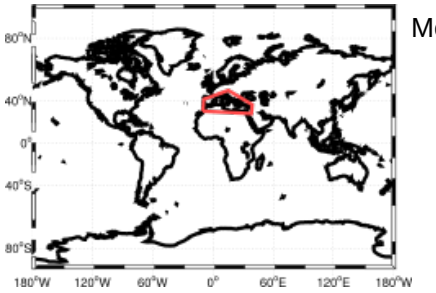






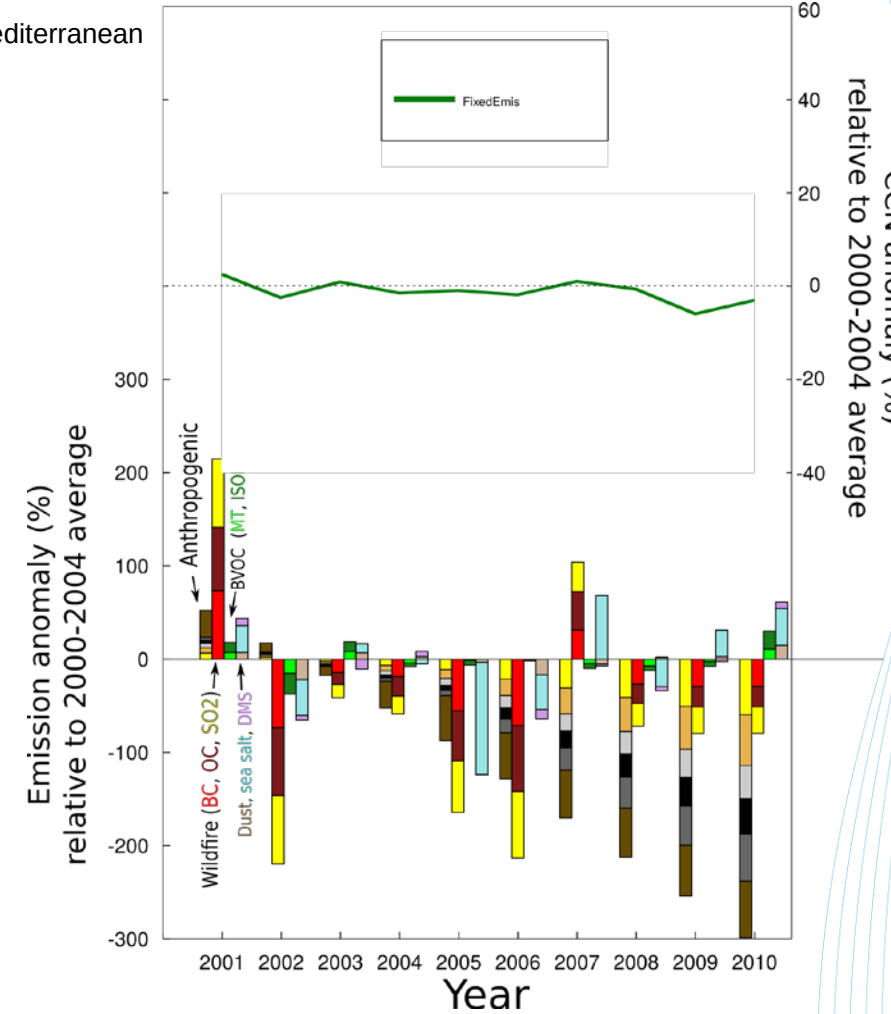
Mediterranean

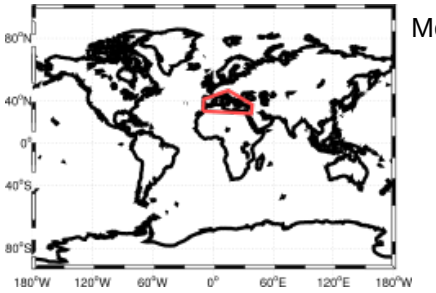




Mediterranean

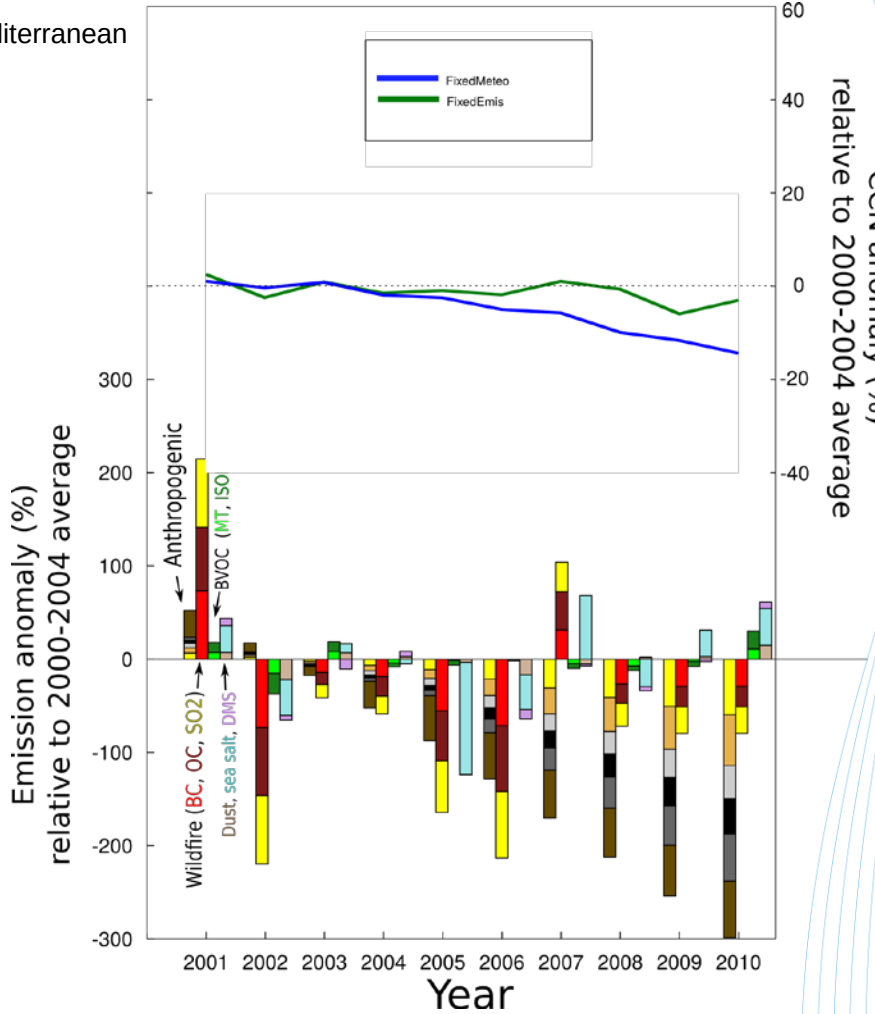
1) FixedEmis indicates <±5% of natural variability in CCN concentration

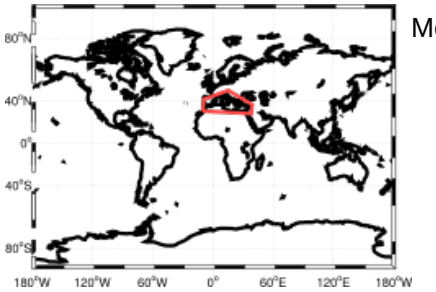




Mediterranean

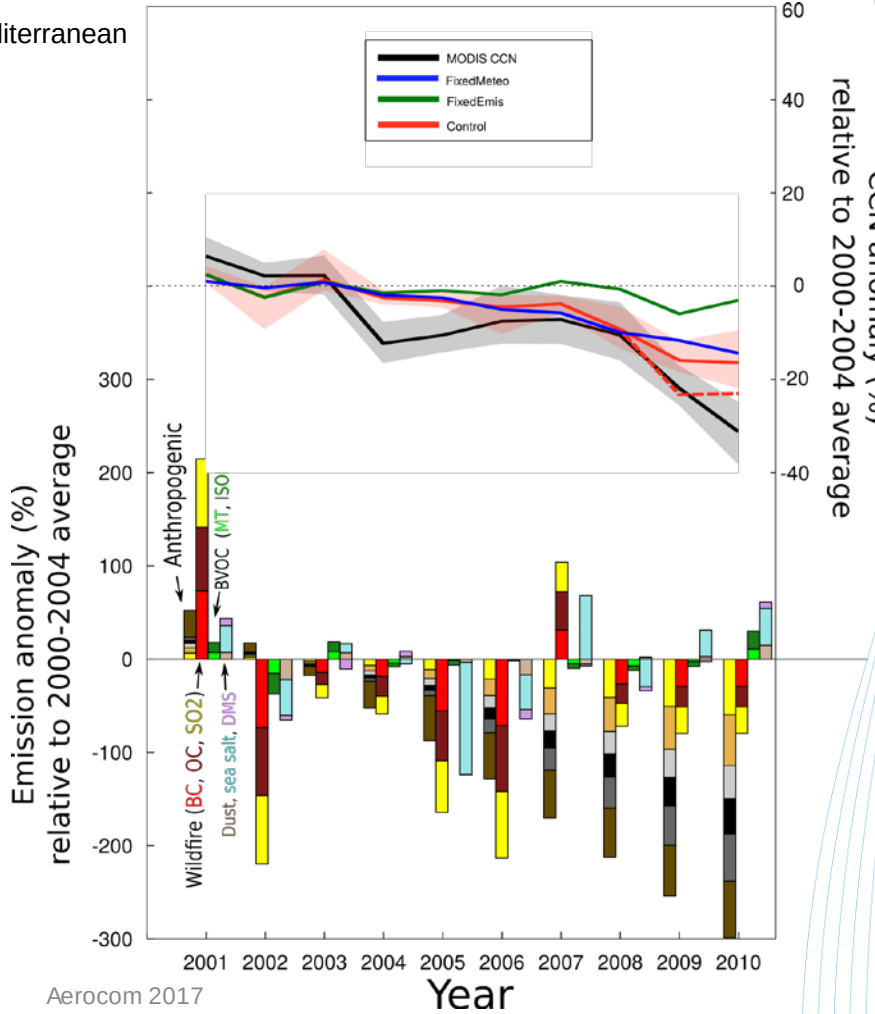
1) FixedEmis indicates <±5% of natural variability in CCN concentration
2) FixedMeteo shows rather steady decrease during the whole period



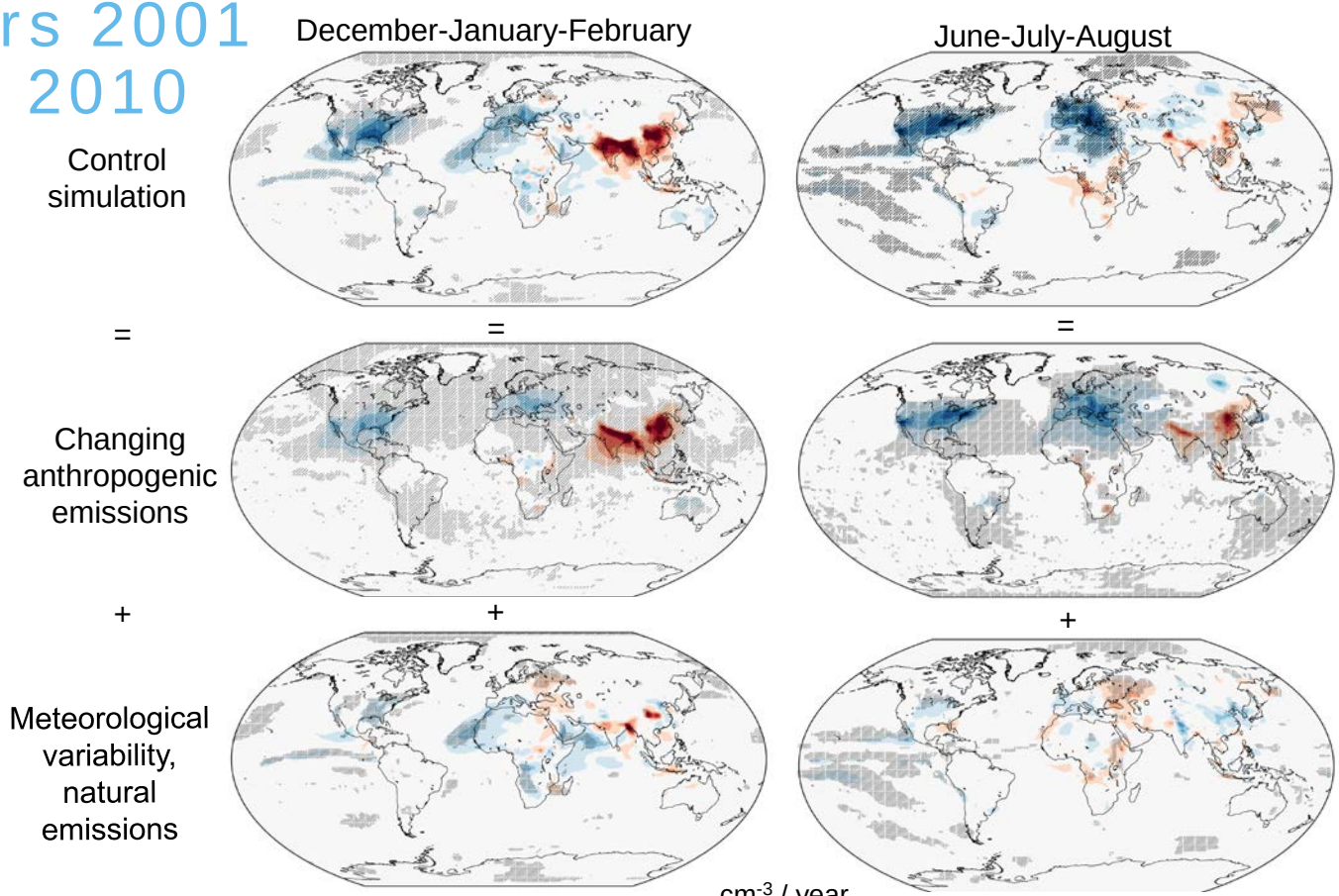


Mediterranean

1) FixedEmis indicates <±5% of natural variability in CCN concentration
2) FixedMeteo shows rather steady decrease during the whole period
3) Control simulation follows the anthropogenic emission anomalies

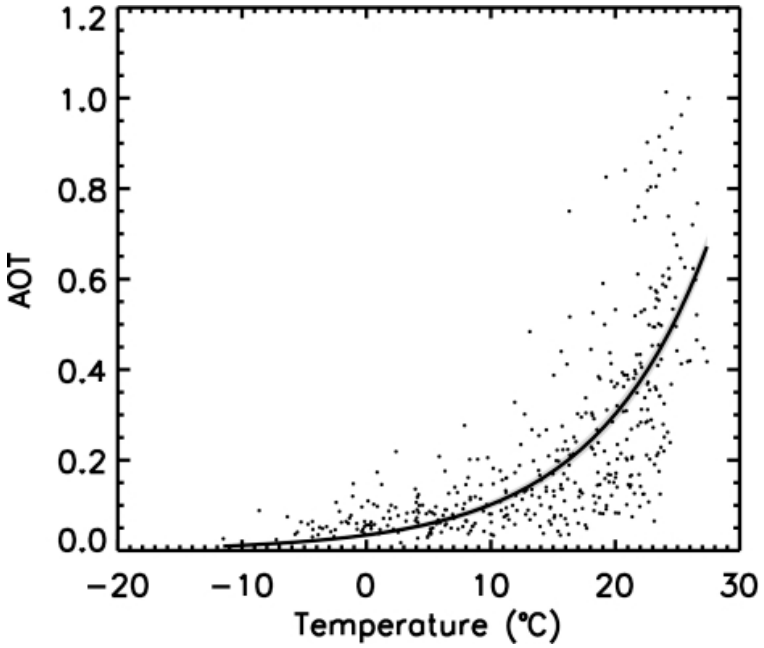


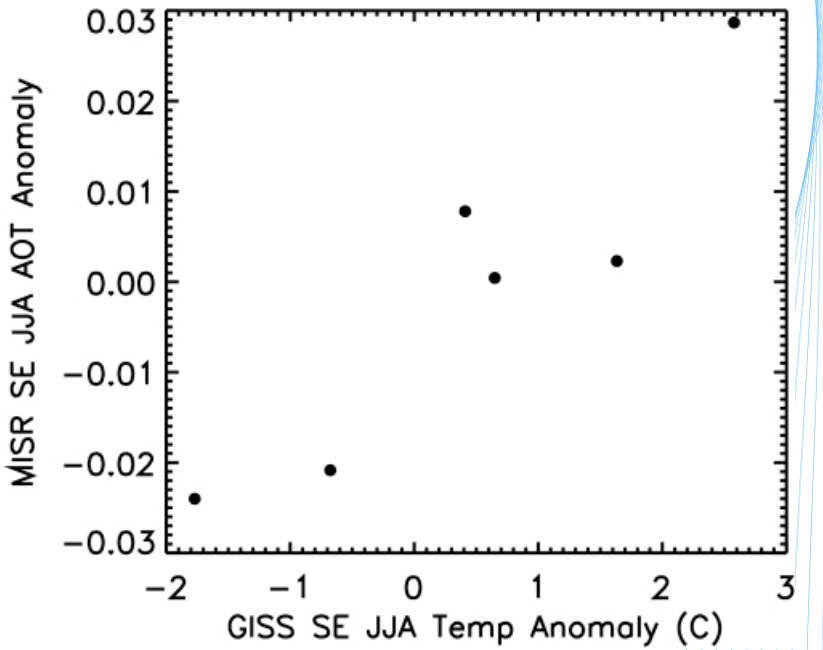
Simulated global trends of CCN(0.2%) between years 2001 and 2010



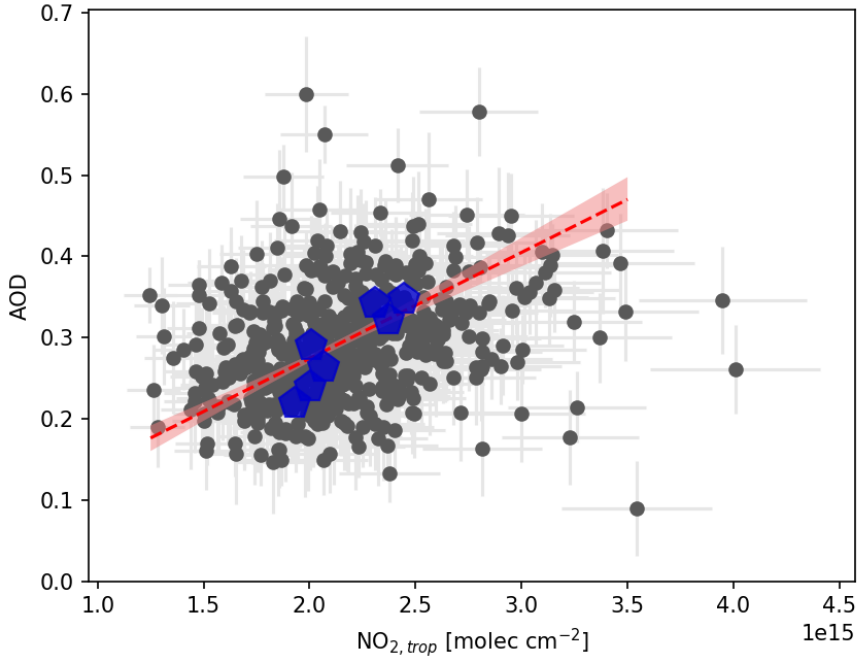
P-43 Risto Makkonen

Temperature dependence of biogenic AOD





Temperature dependence of biogenic AOD



Tropospheric NO2 assumed to be a proxy for anthropogenic AOD

Remaining temperature dependent AOD of biogenic origin

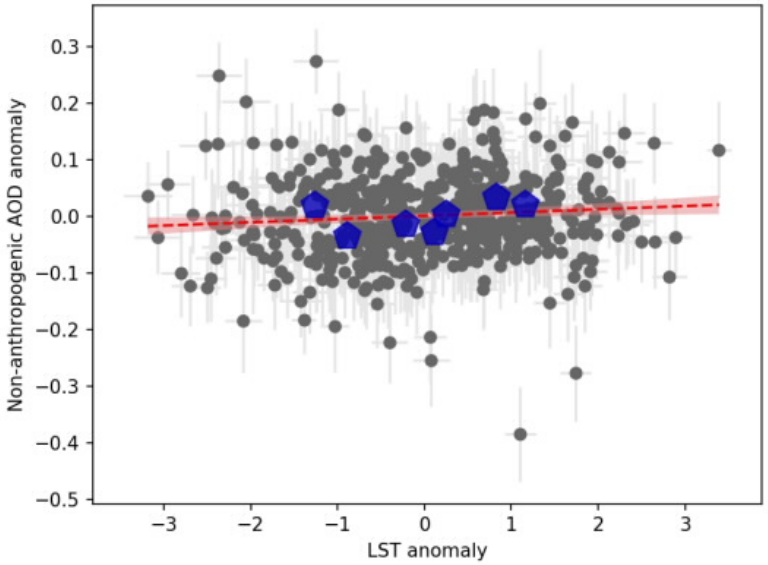
- anthropogenic contribution was estimated with a linear fit between the summertime AOD and tropospheric NO_2 columns ($AOD=1.31e^{-16}NO_{2,trop}+0.013$)

Temperature dependence of biogenic AOD

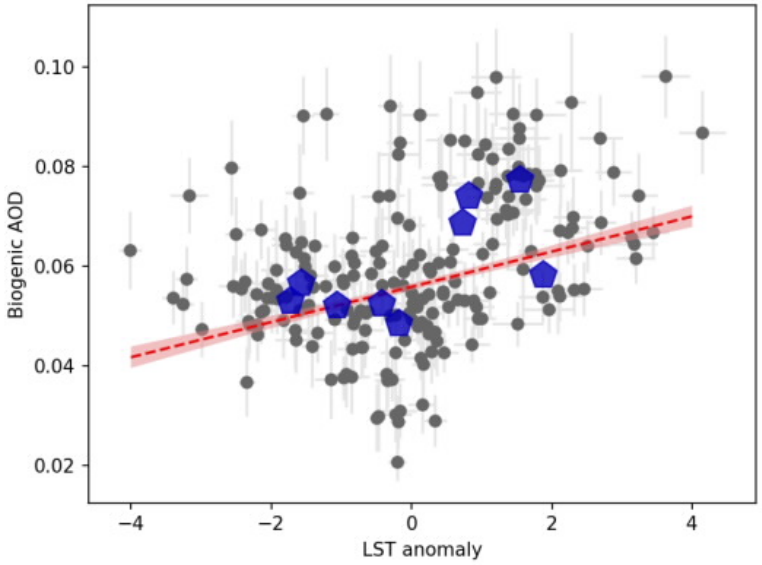
Remaining temperature dependence of biogenic origin?

Residual AOD after NO2 dependence subtracted

Satellite



ECHAM-HAMMOZ



Talk in Session 10: Tero Mielonen

Conclusions

- Nucleation is necessary in models
- Global aerosol models and satellite data can be useful
  - Know their uncertainties and limits
  - Use the to complement each other