Anthropogenic SO_2 emissions from an atmospheric inversion for the decade 2001 to 2010

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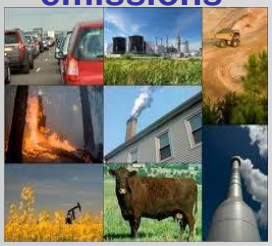
Inversion System

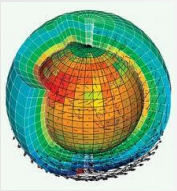
A priori emissions



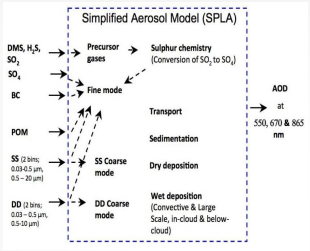
MODIS AOD

PYVAR-AER

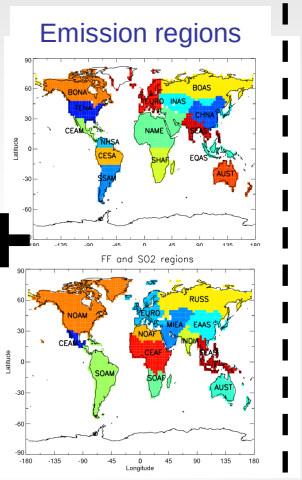
LMDZ



Aerosol model



Emission regions



Emissions of

- Desert dust (DD)
- Sea Salt (SS)
- Black Carbon
- Particulate organic Matter (POM)
- SO_2

Estimate monthly emission of SO_2 and the main aerosol species (DD, SS, BC & POM) through the assimilation of total and fine mode aerosol optical depth (AOD).

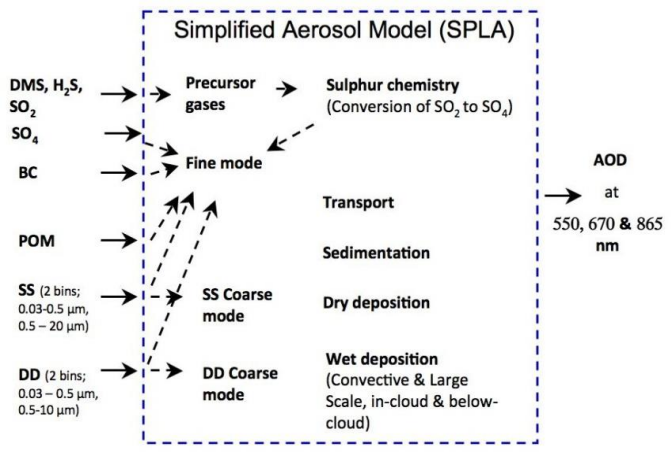
Inversion System

Observations

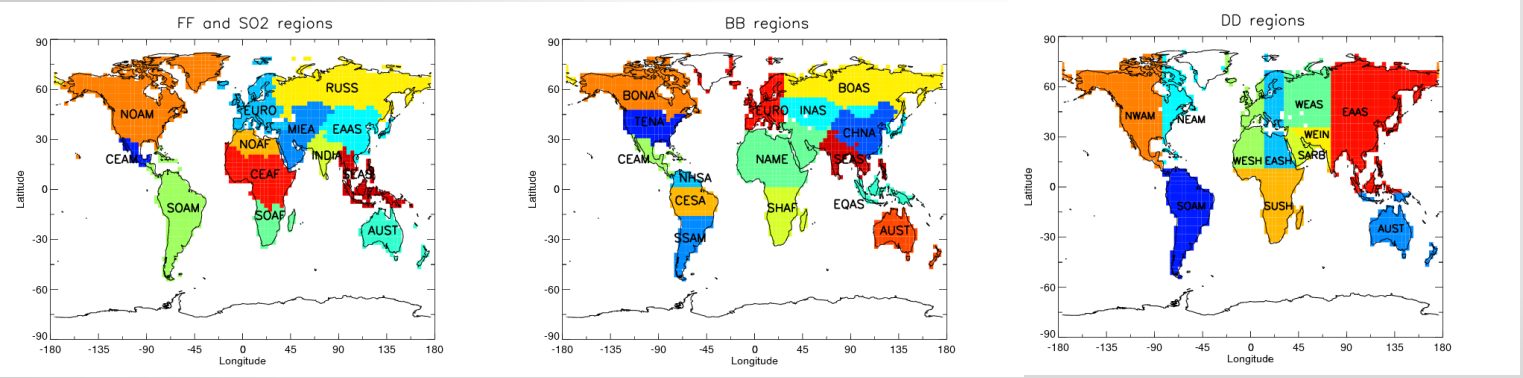
Daily MODIS AOD at 550 nm

- Total (land & ocean)
- Fine mode (ocean only)

Aerosol Model



Emission Regions



Sulfur Emissions (13)

Combustion of fossil fuels (13)

Biomass Burning (15)

Fine mode desert dust (11)

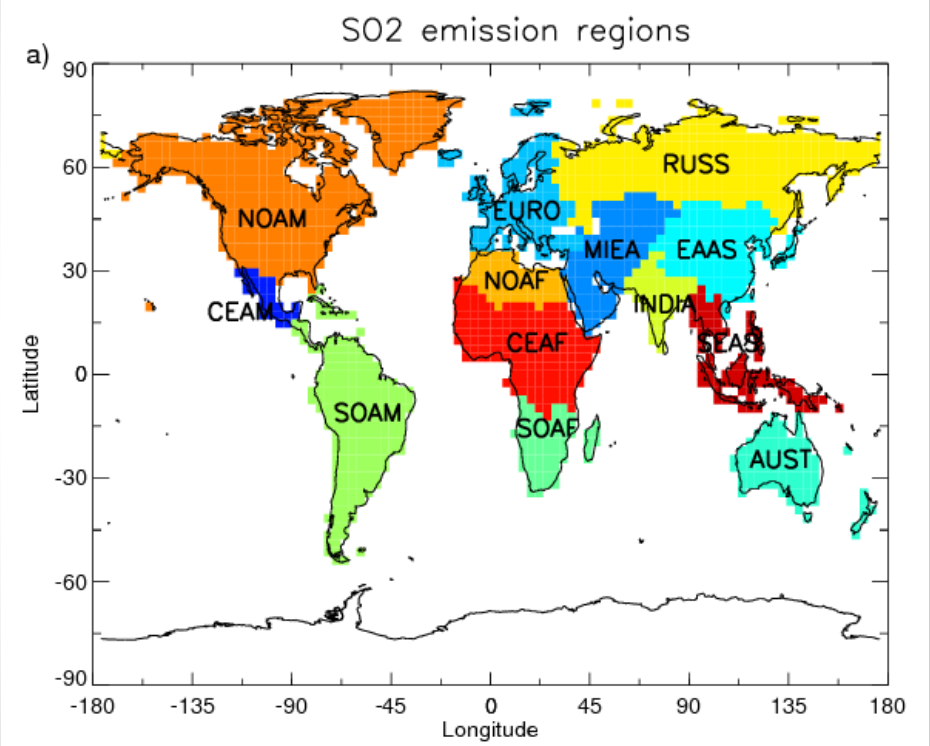
Coarse mode desert dust (11)

Fine mode sea salt (global)

Coarse mode sea salt (global)

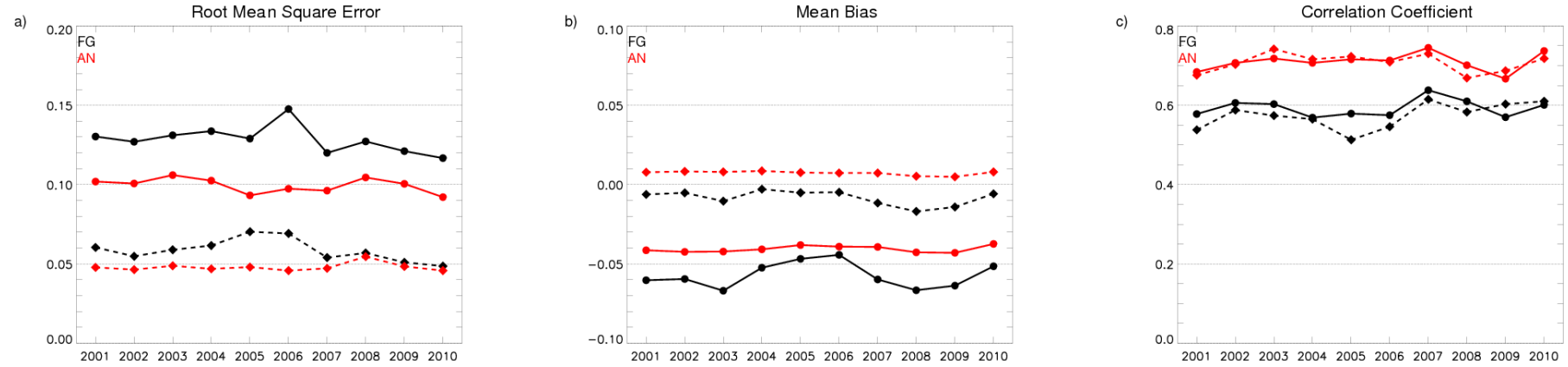
Setup

- The inversion system is applied to the period 2001 - 2010.
- Monthly emissions of each aerosol species and SO_2 are estimated.
- Lamarque et al. (2010) inventory for the year 2000 is used as first guess.
- A priori emission error for SO_2 of 18%
- Observation error (0.2 over land & 0.1 over ocean).
- Model error is also considered (0.02 in AOD).
- Emissions are homogenously increased or decreased within each region.
- Adjustment is done with existing sources

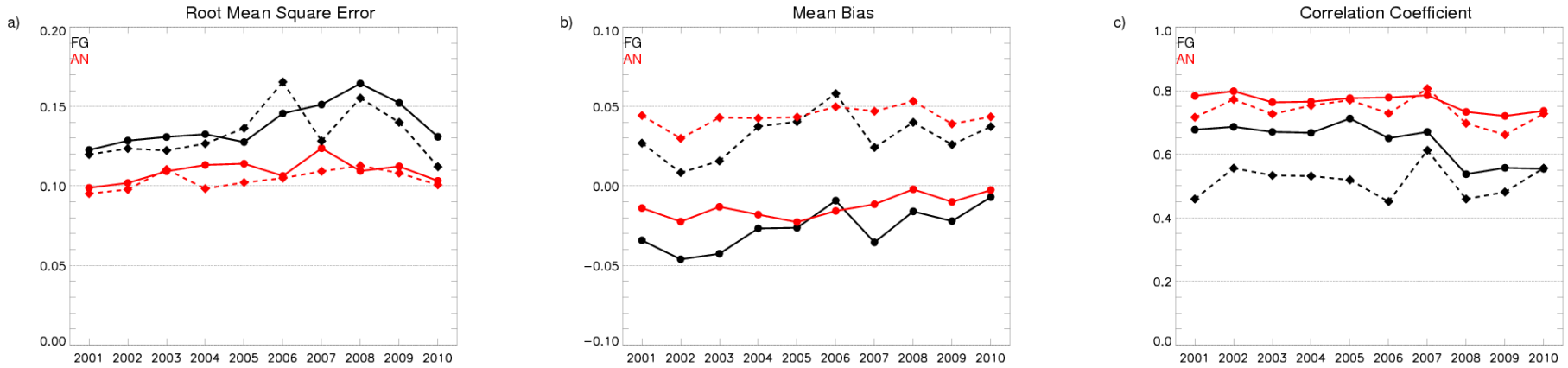


Results

MODIS



AERONET



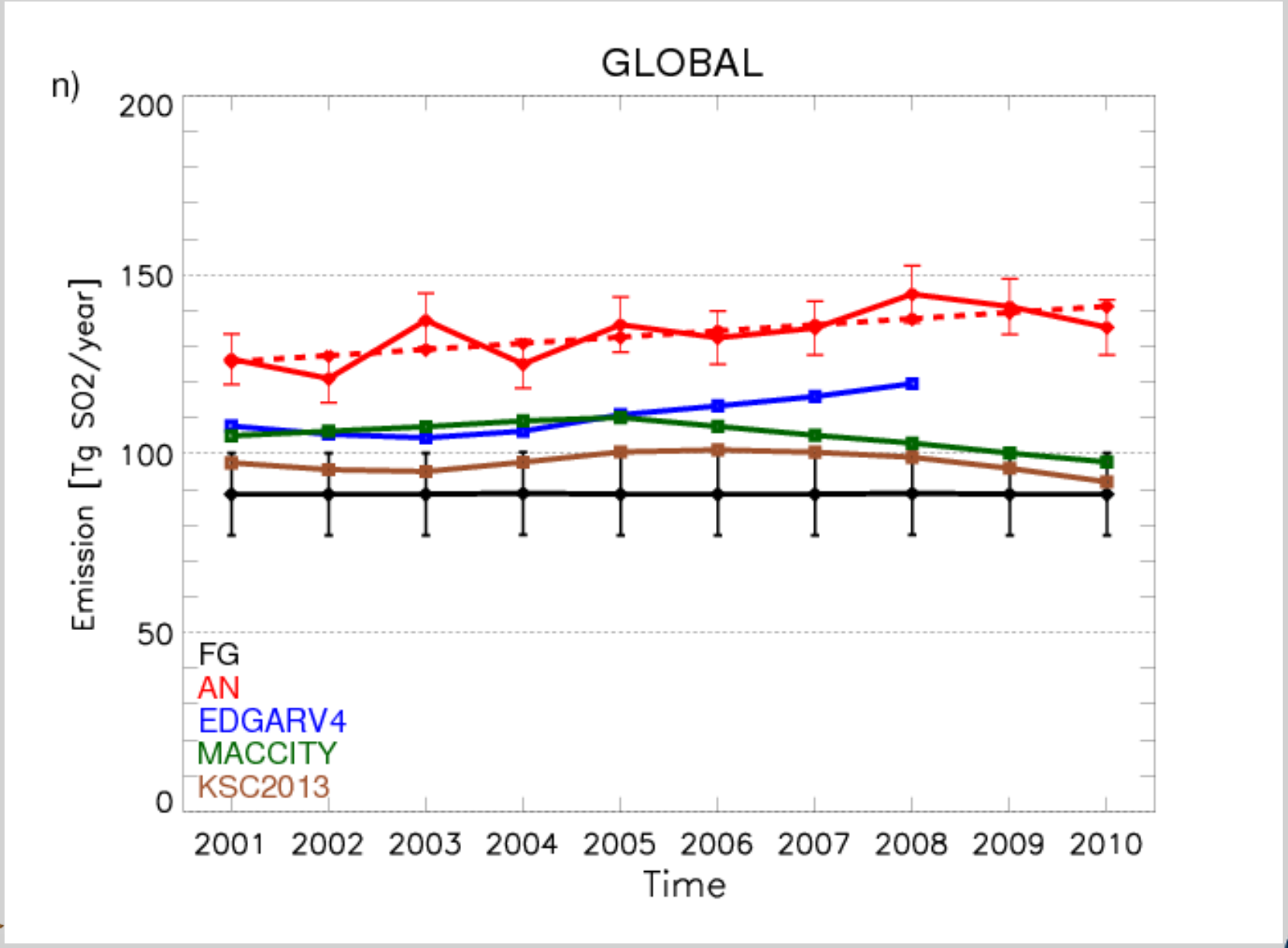
Total AOD - FG

Fine Mode AOD - FG

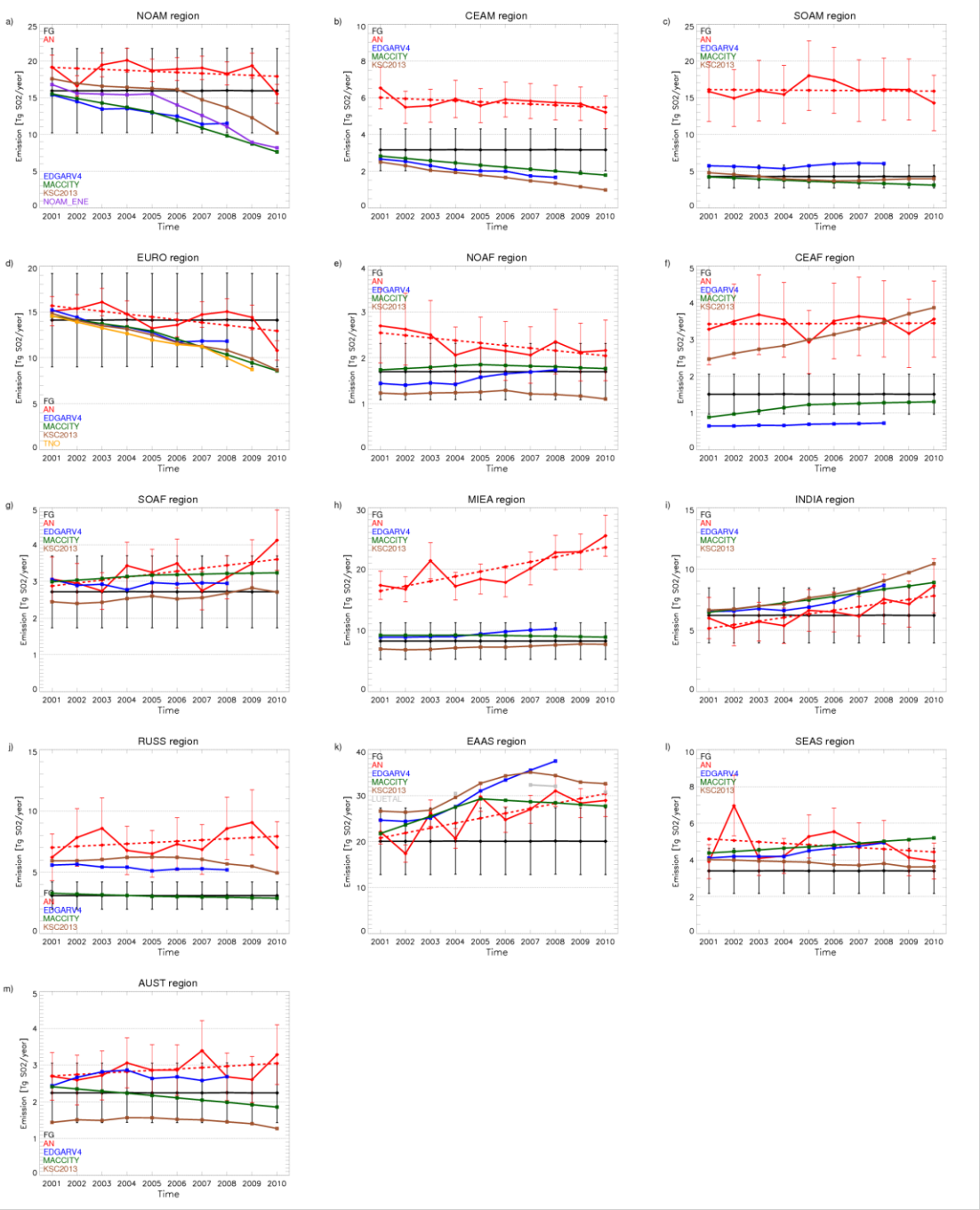
Total AOD - AN

Fine Mode AOD - AN

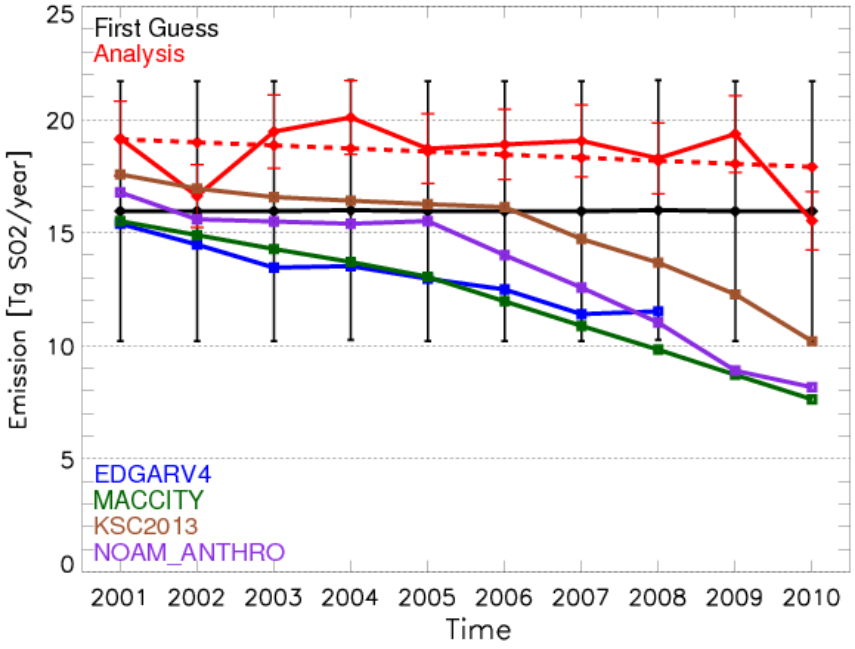
Results


GLOBAL
n)
200
150
100
50
0
Emission [Tg SO2/year]
FG
AN
EDGARV4
MACCITY
KSC2013
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Time

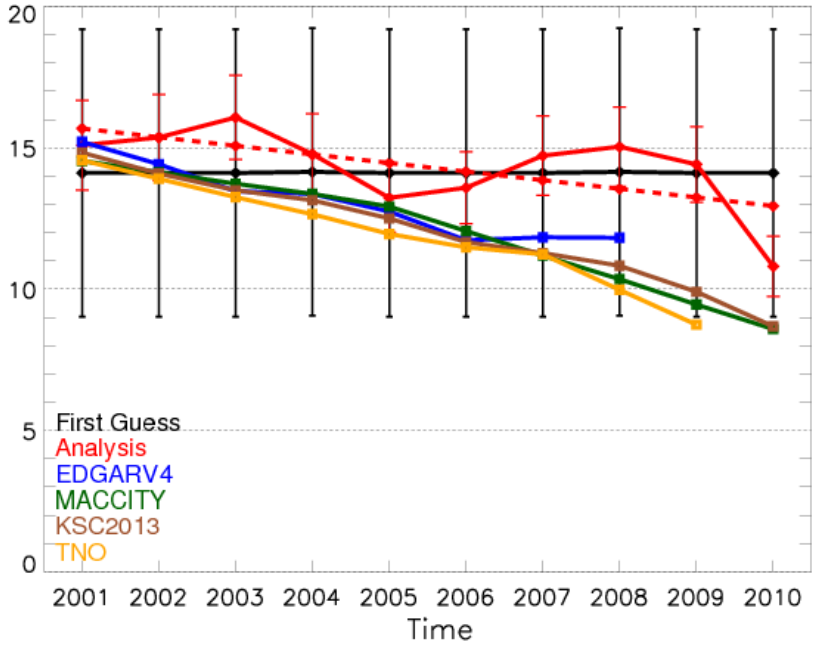
SO_2 emissions per region



North America



Europe

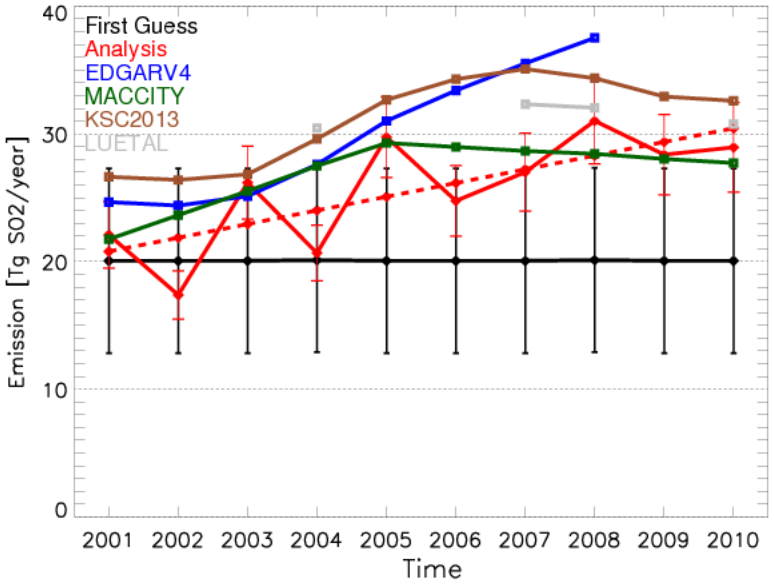


- Inversion estimate reproduces the decreasing emissions but with weaker trends

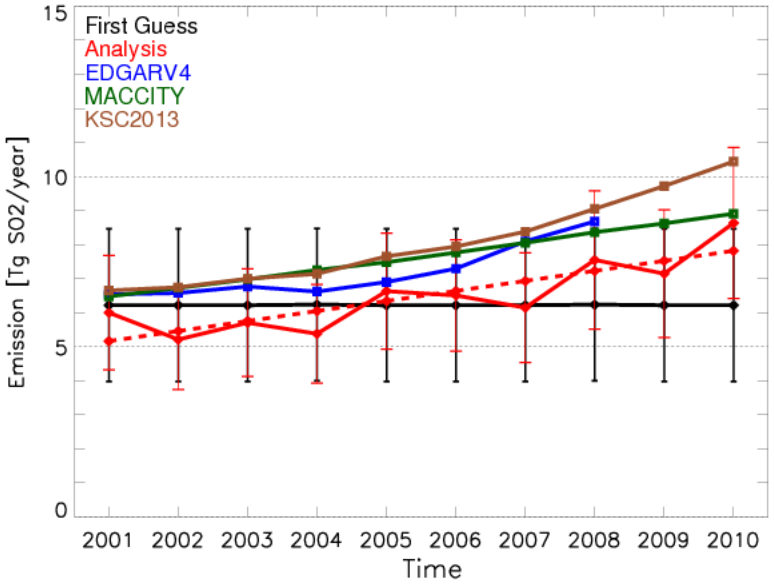
➡ Simplifications in the aerosol model

➡ Definition of the emission region

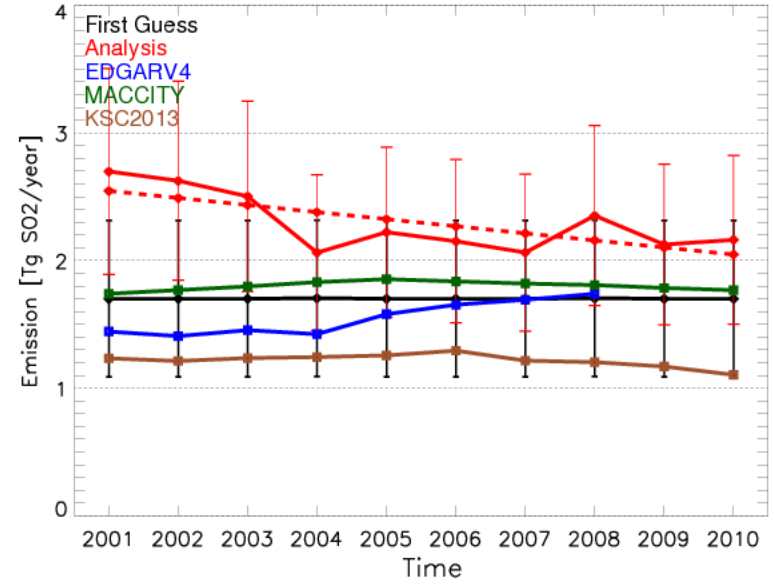
East Asia



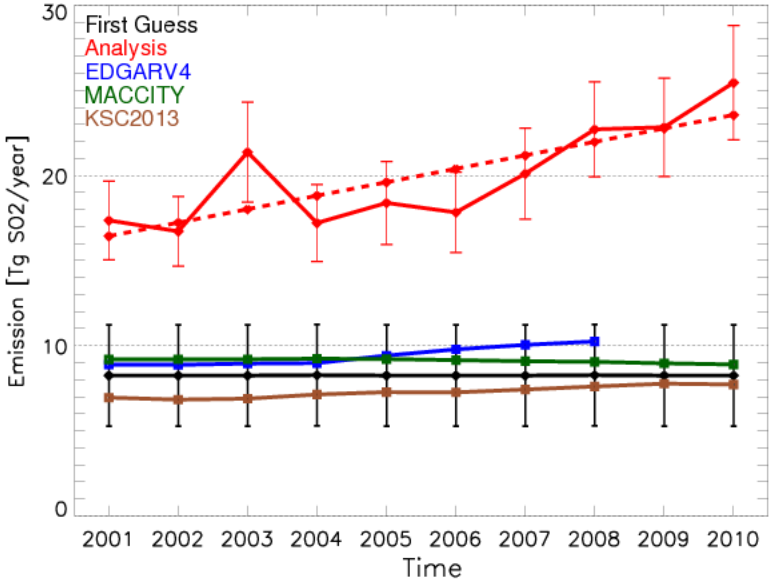
India



North Africa



Middle East

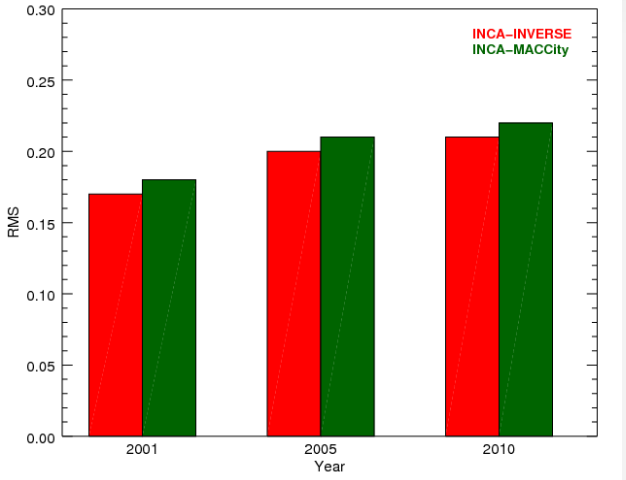


INCA simulations

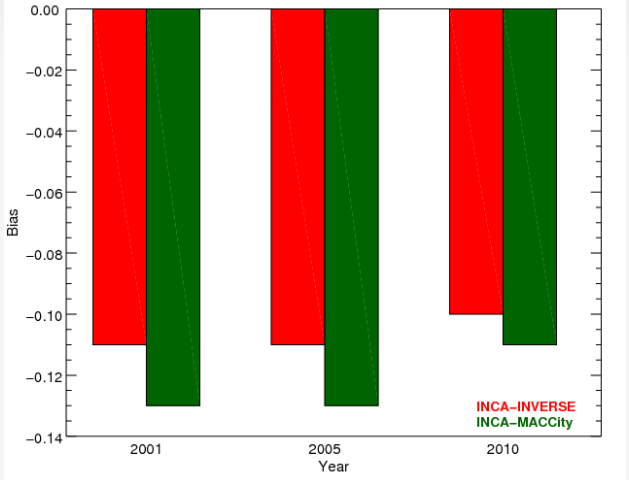
- To assess the general validity of the inverse emissions and explore the impact of the aerosol representation on the resulting emissions
- Years 2001, 2005 and 2010 were simulated with the INCA model
- Two simulations were done differing only in their anthropogenic emissions.
- INCA-MACCity: Anthropogenic emissions of SO2, BC and POM are taken from the MACCity inventory
- INCA-INVERSE: Anthropogenic emissions of SO2, BC and POM are taken from the inversion.
- Remaining emissions are the same in both experiments.
- Outputs are compared against AERONET (global) and EMEP surface concentration in Europe.

Total AOD

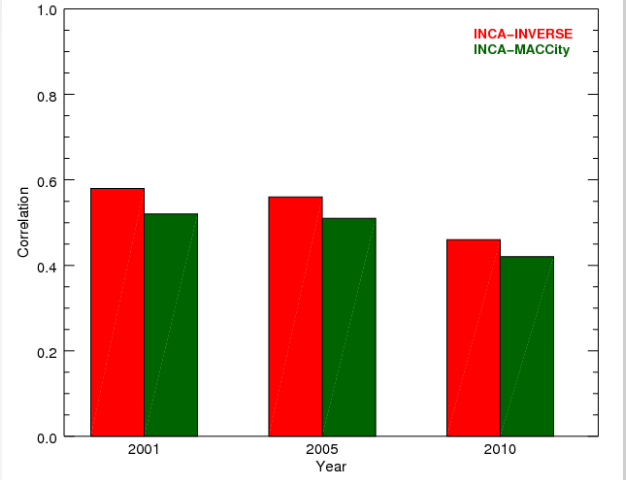
Root mean square error



Mean Bias



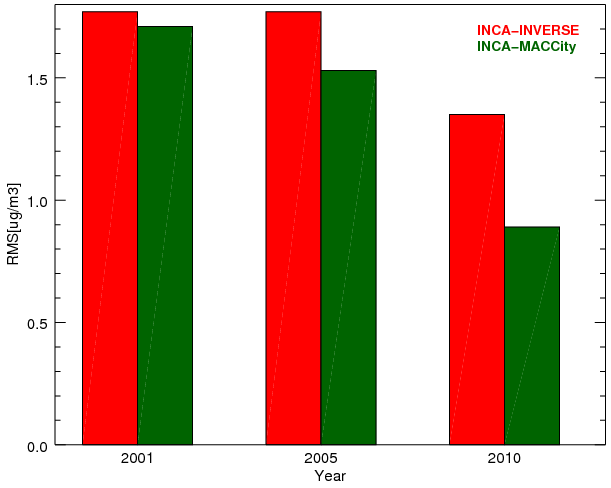
Correlation Coefficient



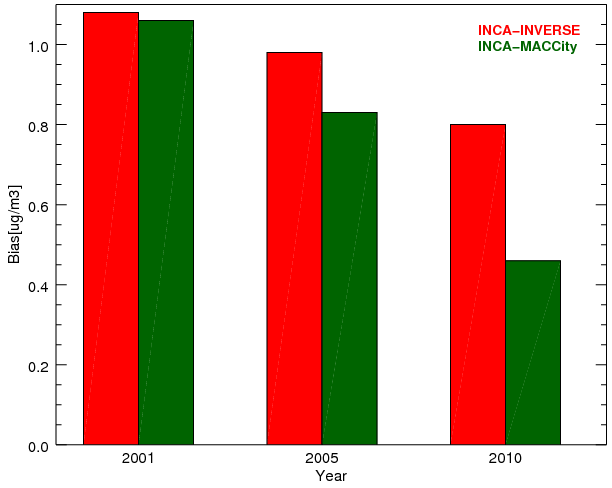
- Comparison to monthly AERONET data for all stations
- Inversion estimates improves statistics for all three years compared to MACCity emissions

SO_2 surface concentration in Europe

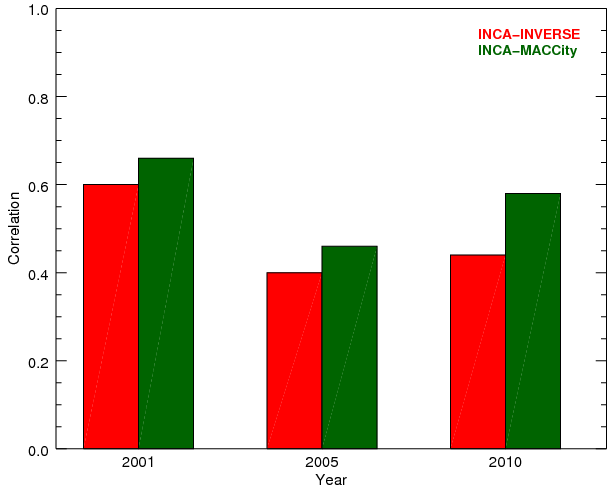
Root mean square error



Mean Bias

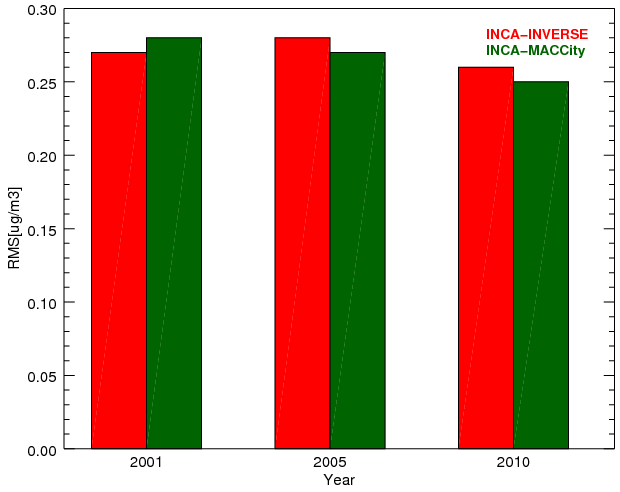


Correlation Coefficient

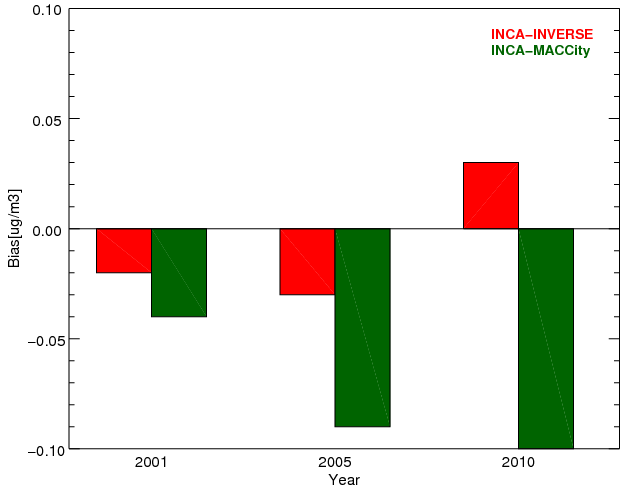


Sulfate surface concentration

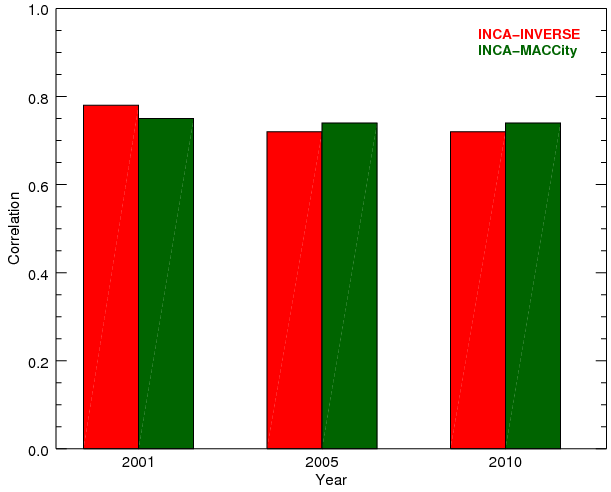
Root mean square error



Mean Bias



Correlation Coefficient



Conclusions

- Monthly emissions of SO_2 were estimated for the period 2001-2010.
- Estimated emissions improve statistics with respect to MODIS and independent AERONET data.
- Statistics are also improved when inventory emissions are used in an aerosol model of increased complexity compared to results using MACCity.
- Inversion emissions degrade performance in terms of SO_2 but improve it for sulphate for the bias and all statistics for 2001.
- Simplification in the aerosol model on the inversion system might explain biases in the results.
- Definition of emission regions could also introduces biases in the estimates.
- Vertical distribution and boundary layer height also influence performance to reproduce surface concentration.
- Inversion results highlight areas where discrepancies are large and where dedicated study is recommended.

Thank you

Objective

Estimate monthly emission of SO_2 and the main aerosol species (DD, SS, BC & OM) through the assimilation of total and fine mode aerosol optical depth (AOD).

Method:

$$J=(x-x_b)^T\boldsymbol{B}^{-1}(x-x_b)+(y-H[x])^T\boldsymbol{R}^{-1}(y-H[x])$$

$$x_a=x_b-(\mathbf{H}^T\boldsymbol{R}^{-1}\mathbf{H}+\boldsymbol{B}^{-1})^{-1}\mathbf{H}^T\boldsymbol{R}^{-1}(H[x_b]-y)$$

$$x_a=x_b+\mathbf{K}(y-H[x_b])$$

$$\mathbf{K}=(\mathbf{H}^T\boldsymbol{R}^{-1}\mathbf{H}+\boldsymbol{B}^{-1})^{-1}\mathbf{H}^T\boldsymbol{R}^{-1}$$

H= Linear operator

R = observation error covariance matrix

B = background error covariance matrix