FINNISH METEOROLOGICAL INSTITUTE

How to take uncertainties into account when quantifying relationships between different quantities?

Tero Mielonen, et al.

Today's menu

- **Definitions**
- **Uncertainties in satellite observations**
- **Uncertainties in modeling**
- **Example on how we have tried to take uncertainties into account when using simulations and observations**

Definitions

- Error and uncertainty are two different things:
  - **Error** – the concept of ‘wrongness’
    - How different is the measured value from the (unknown) true value of the measurand?
  - **Uncertainty** – the concept of ‘doubtfulness’
    - Given the measured value, what range of values is it reasonable to attribute to the measurand?
    - Quantification: “Standard uncertainty” is the standard deviation of the (estimated) error distribution.

Error is often unknown (and if we did know what it was we would correct for it). We therefore consider uncertainty, a measure of the dispersion of the error distribution.

(Based on GlobTemp presentations by C. Merchant and D. Ghent)

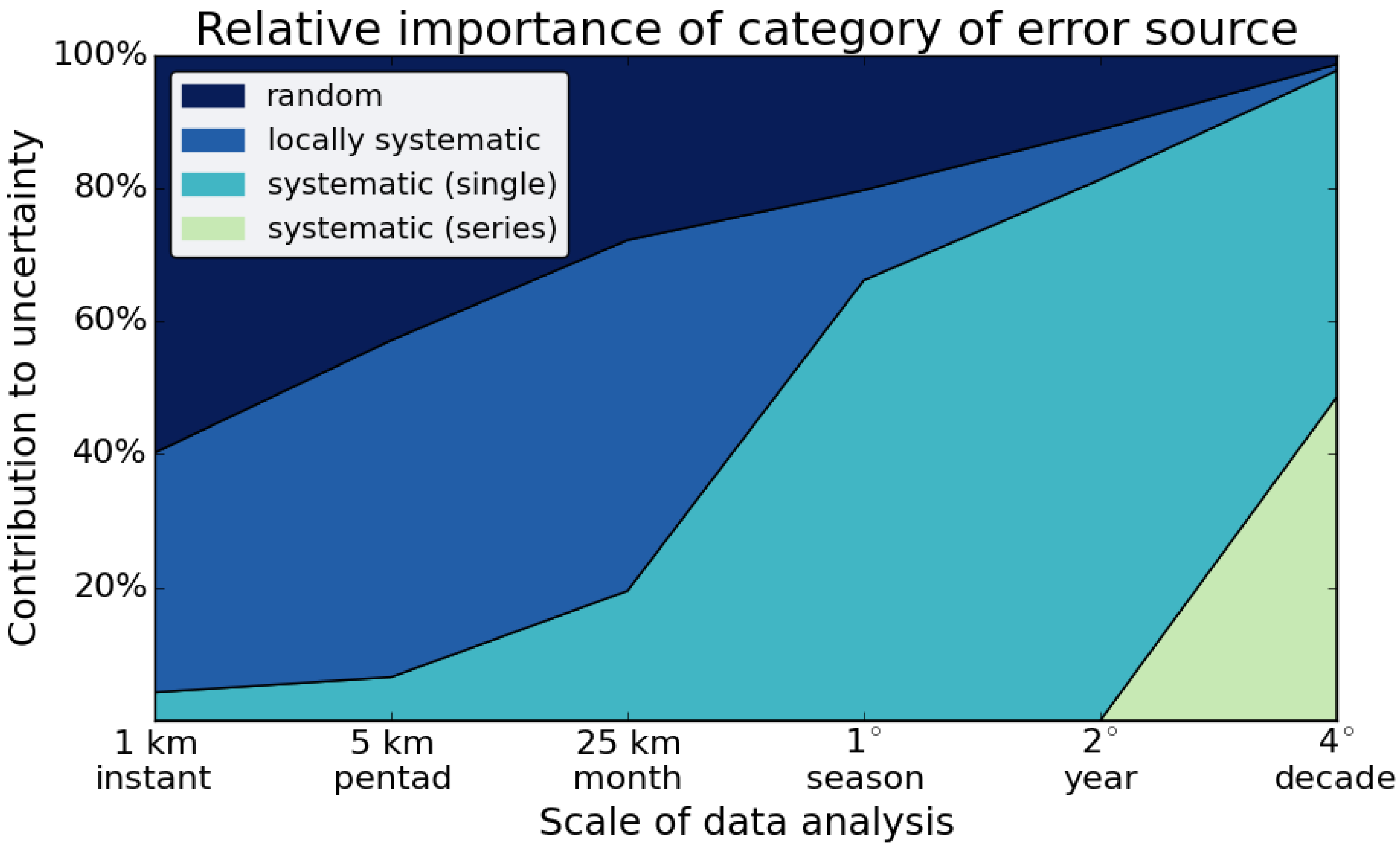
Definitions

- **Random effect**
  - a source of errors that are uncorrelated between repeated measured values
    - note: errors can be random (uncorrelated); uncertainty cannot be random (or systematic)

- **Systematic effect**
  - a source of correlated errors that you could correct for if you understood it
    - note: this is not the same as bias
    - in Earth observation systematic errors correlate on particular scales of time and space very commonly → can be "locally" systematic

(Based on GlobTemp presentations by C. Merchant and D. Ghent)

Uncertainties in satellite observations



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Uncertainties in satellite observations

Propagation of uncertainties from L2 to L3 gridded products:

- Uncertainties from random effects reduce as $1/\sqrt{n}$
- Uncertainties from locally correlated effects are reduced only at larger scales
- Sampling uncertainty is an additional uncorrelated effect introduced when the grid box is not fully sampled in space or time

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→ estimation of L3 uncertainties is very complicated thus rarely done but people are working on it.

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Uncertainties in model simulations

Stochastic models do what you make them do → no uncertainty

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  - multi-model ensembles
  - perturbed simulations from a single model
    - ensemble averages and ensemble standard deviation as a measure of uncertainty

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- Some pitfalls
  - each model/simulation are thought to produce independent data, and their errors are expected to cancel each other out
    - while models are different, they are not independent in any strict statistical sense; they all are limited by similar computational constraints and have developed in the same modeling tradition.
  - which parameters to perturbate? Just the atmospheric state or all the parameterizations related to the studied process? What are the ranges for the perturbations?

Comparing simulations with observations

Simulations and observations have different spatial and temporal scales/sampling

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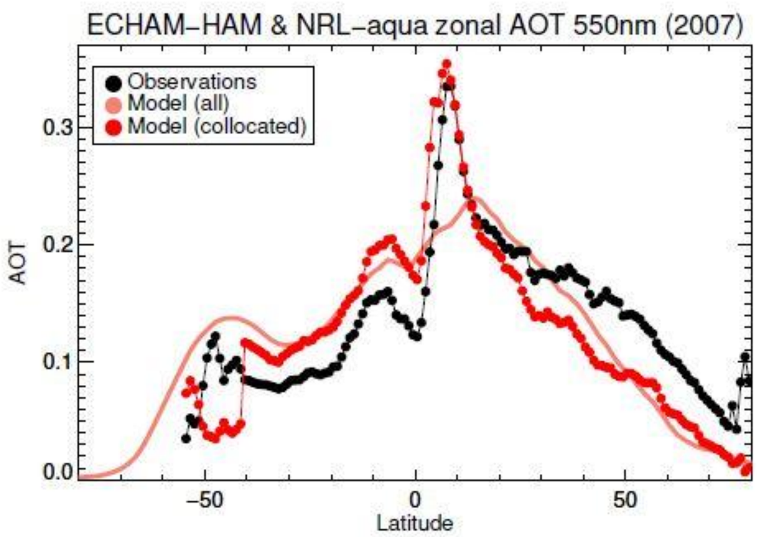

(From Schutgens et al. 2016a and 2016b)

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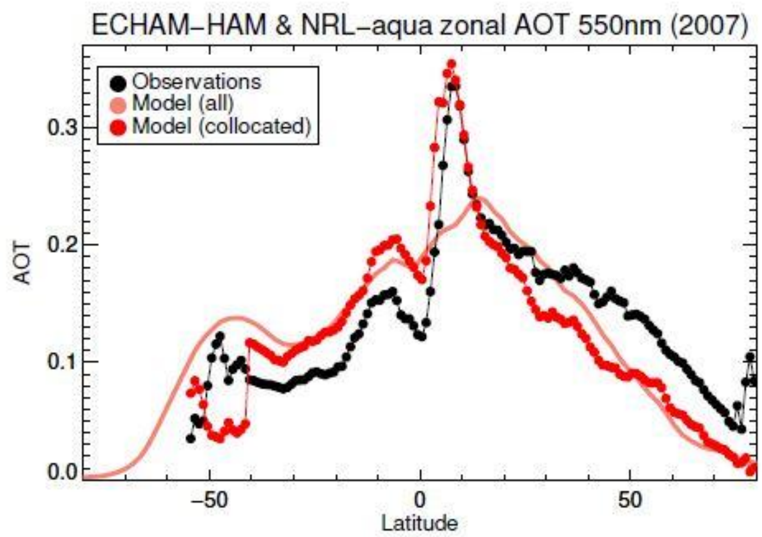

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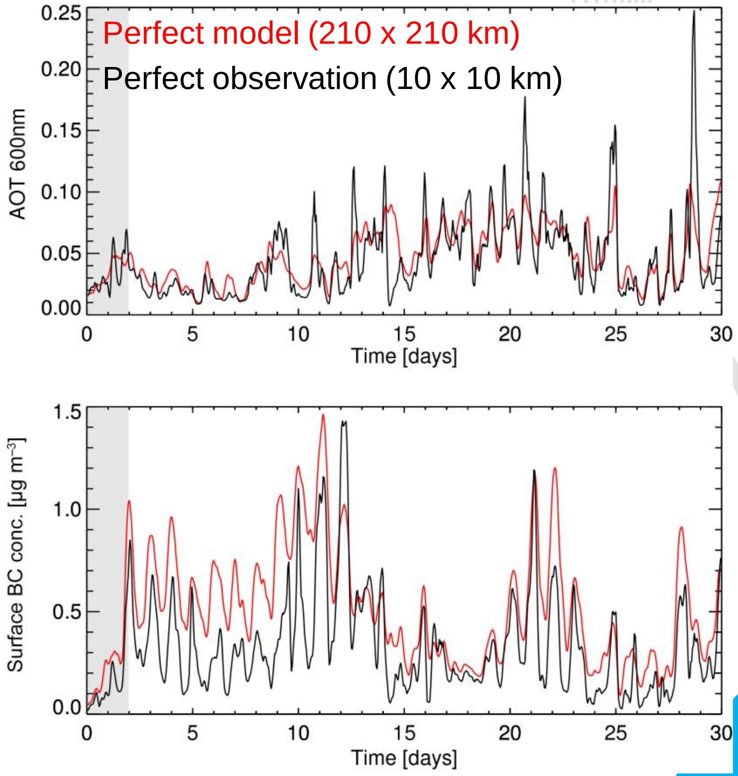

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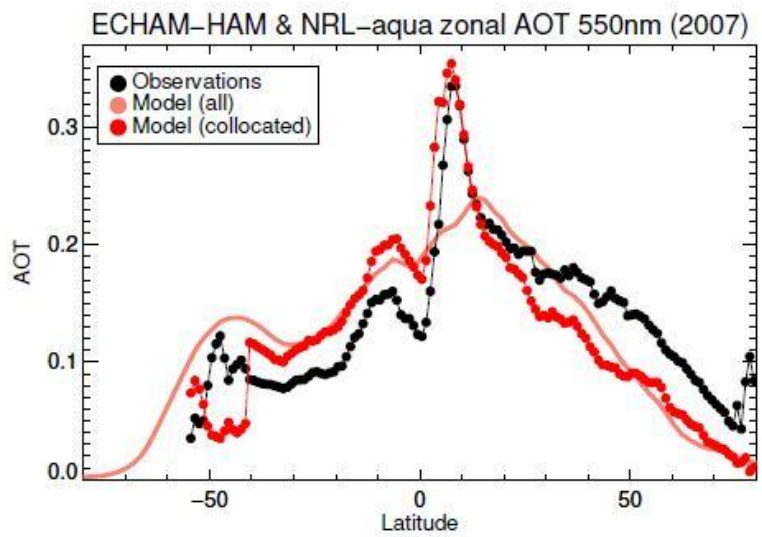

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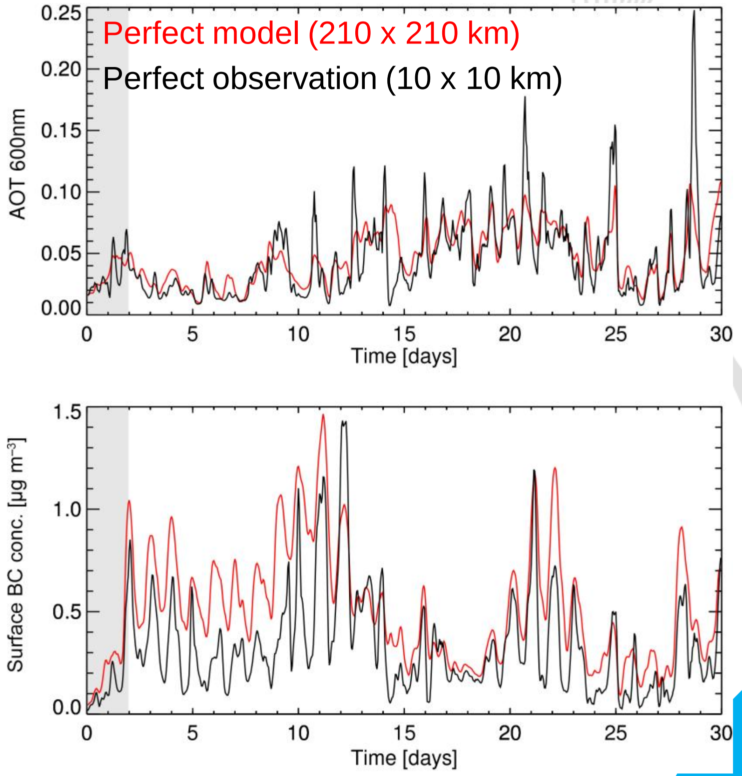


- Model data and observations should be spatio-temporally averaged to ensure best agreement
    - Model data need to be spatially interpolated to and temporally collocated with the observations

Example: the ITICA project

• investigate if biogenic emissions could explain the positive correlation between atmospheric aerosol load (AOD) and temperature (LST) and quantify their radiative effects

- over the Southeastern US (Goldstein et al. 2009)
- over boreal regions (Paasonen et al. 2013)

• estimate the significance of the negative feedback caused by a warming-induced increase in the aerosol direct radiative effect

Satellite products used in the project

(2005-2011, Level 3)

- AATSR Land surface temperature (LST)
    - pixel level uncertainty for the L3 data (0.05° x 0.05°)
- AATSR Aerosol Optical Depth (AOD)
    - variability within L3 pixels (standard deviation)
- OMI Nitrogen Dioxide (NO2)
    - 20 % uncertainty based on literature

Products mainly collocated to a daily, 1° x 1° grid

Model simulations done in the project

- Simulations with ECHAM6.1-HAM2.2-SALSA
    - CONTROL (2002-2010)
    - noBIOSOA: without biogenic SOA formation

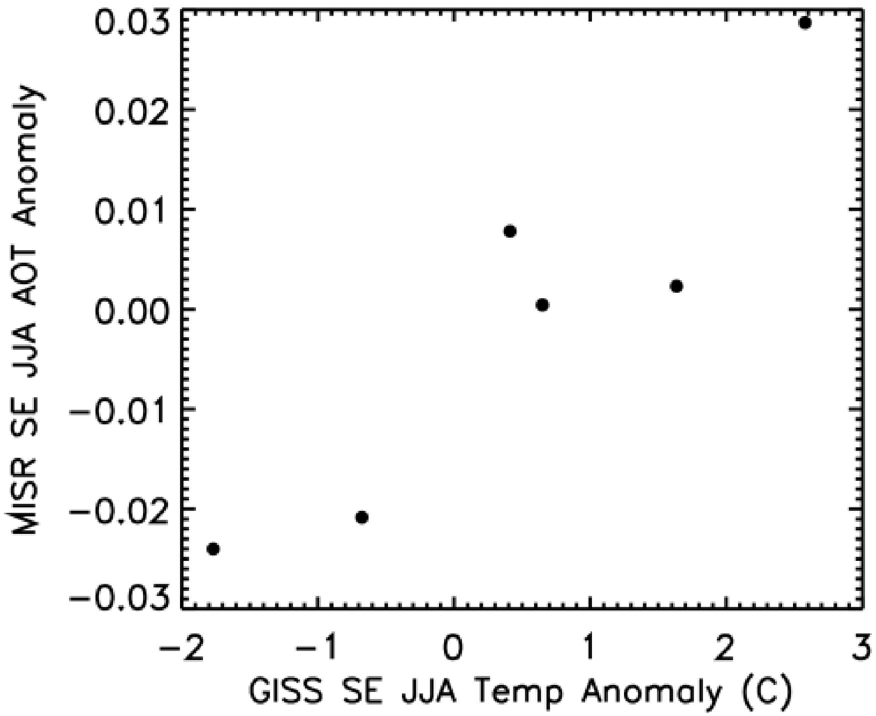
- Uncertainty/variability estimation based on the variability between daily values within the summer months
    - used a statistical method called bootstrapping
    - information on how well the averaged value represents the underlying distribution

Linear fitting

- As a “sanity check” we tested statistically if a linear relationship between the parameters was more likely than a random relationship

- Linear fitting was done using Bayesian inference
    - uncertainties in both dependent and independent variables were taken into account
    - the method produced credibility intervals for the estimated parameters

Results:
Southeastern US



Goldstein et al. (2009)
Years 2000-2005

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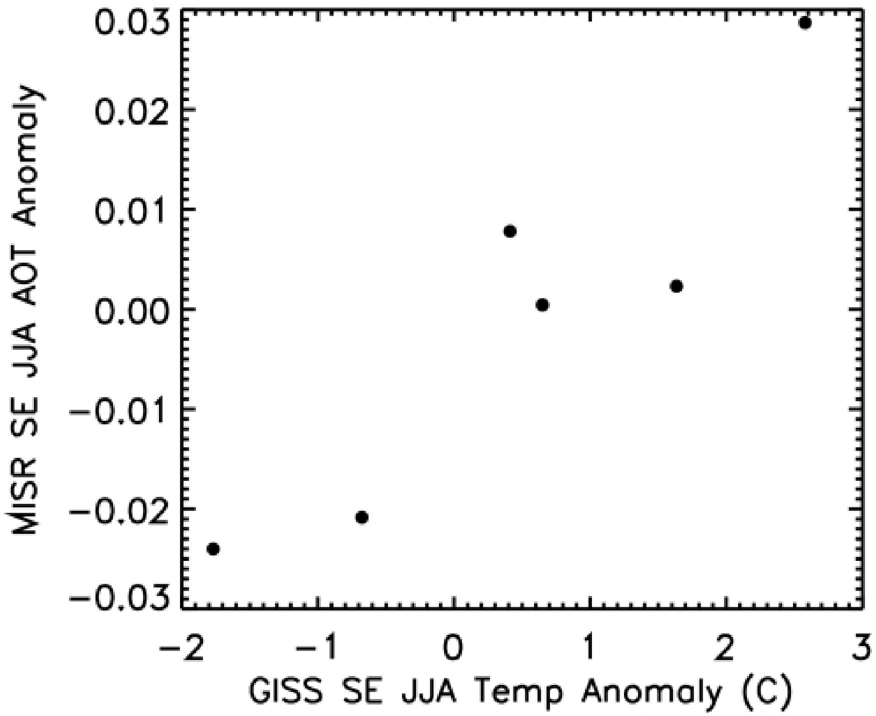

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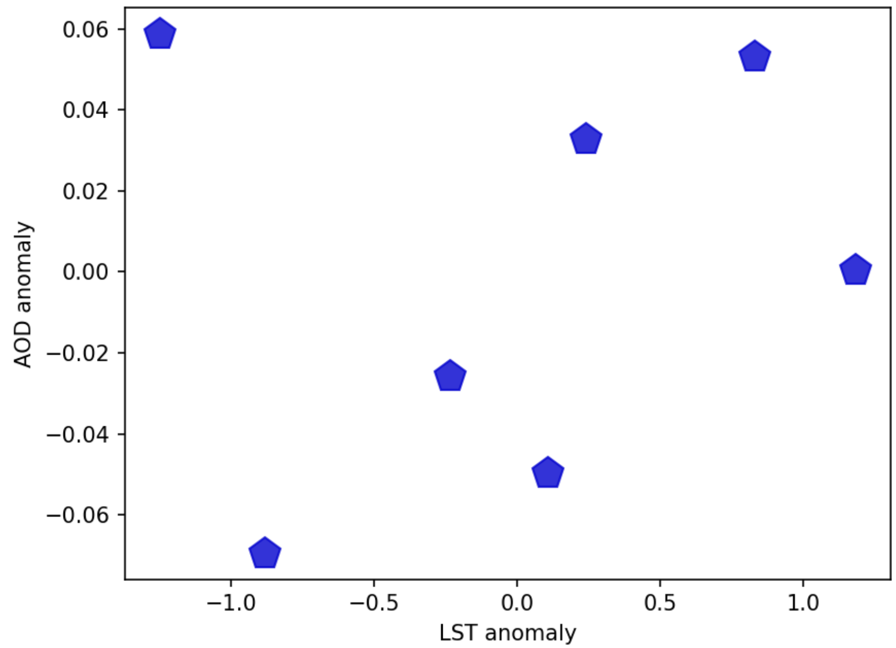
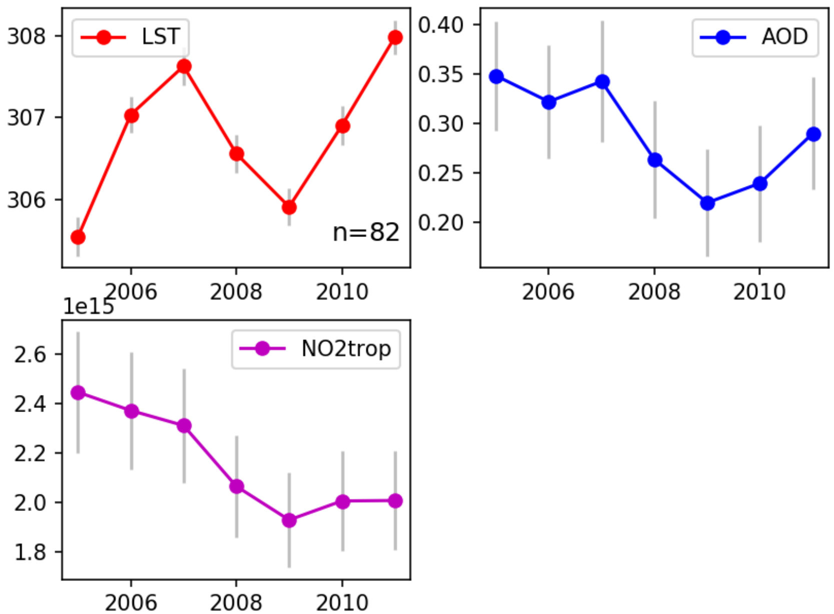


AATSR data (JJA)
Years 2005-2011

Results:
Comparison of summers in the southeastern US



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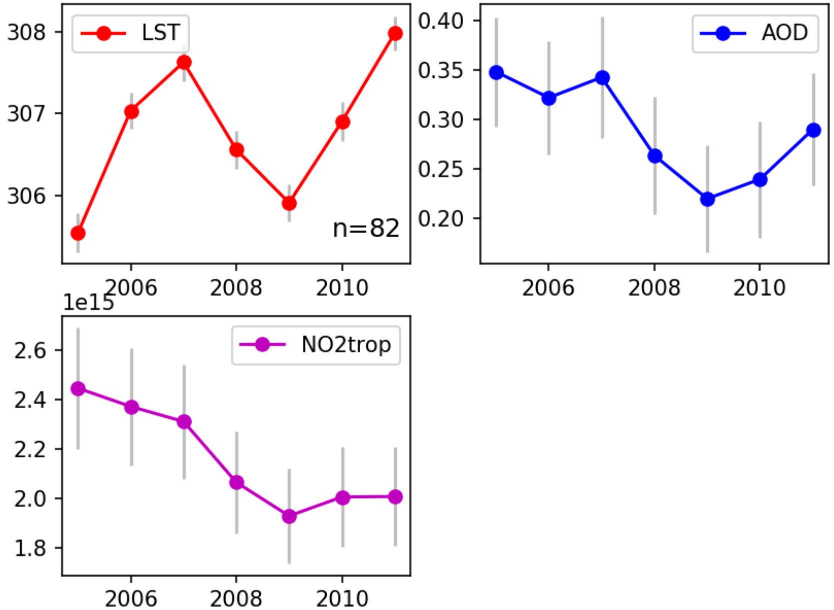

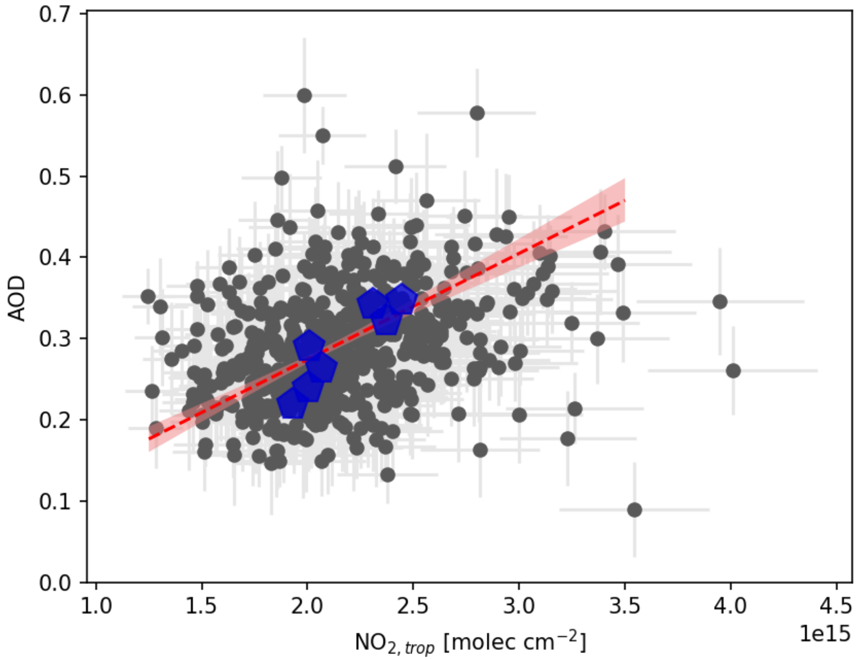

Results:
Calculation of “non-anthro” AOD

- anthropogenic contribution was estimated with a linear fit between the summertime AOD and tropospheric NO_2 columns ($AOD=1.31e^{-16}NO_{2,trop}+0.013$)
- with this relationship the anthropogenic AOD was estimated from the observed tropospheric NO_2 values
- the “non-anthro” AOD was estimated by subtracting the anthropogenic AOD from the total AOD

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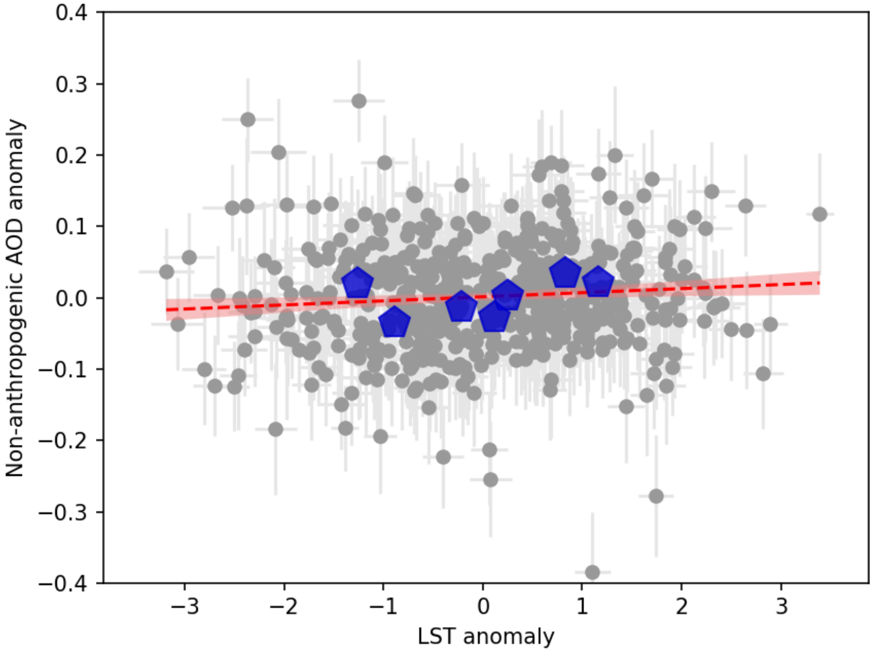

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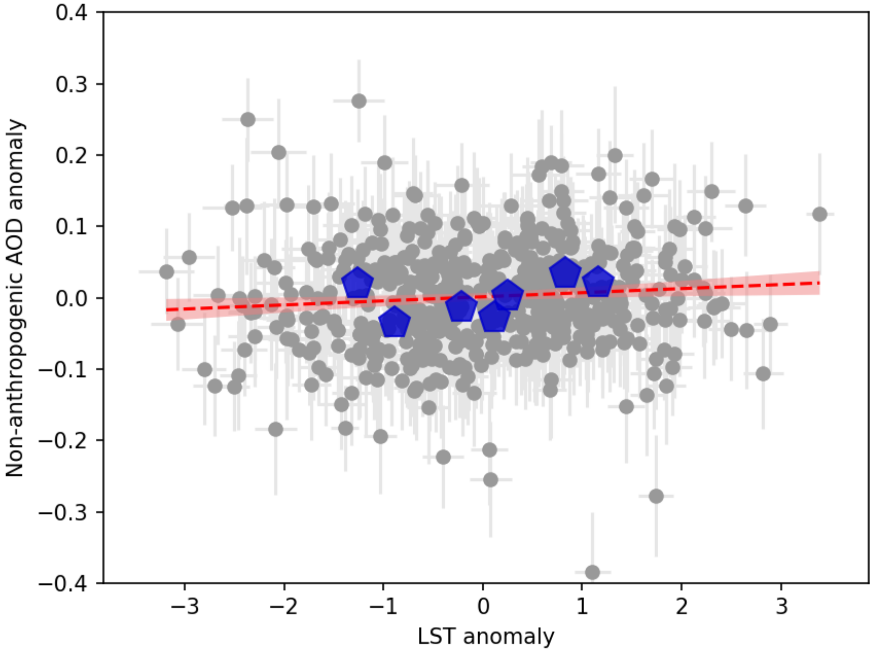
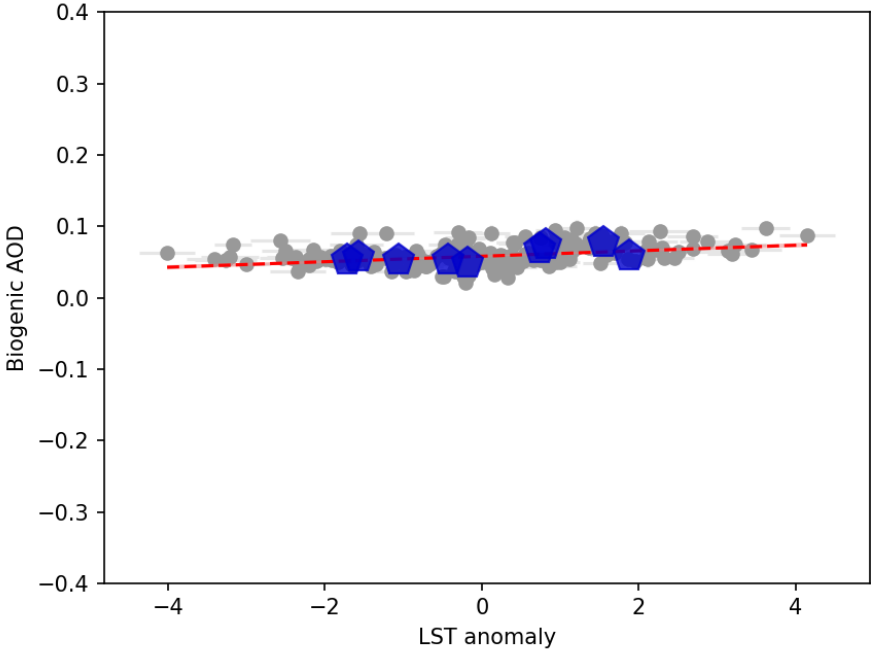
Results:
Model comparison

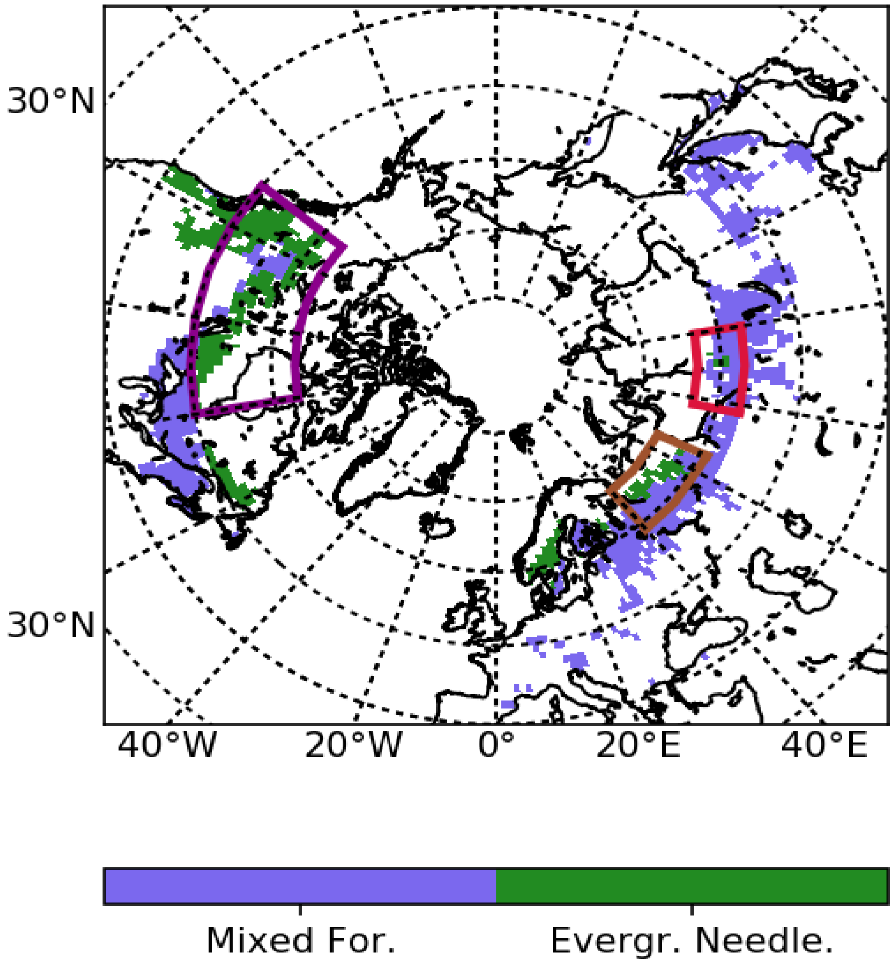




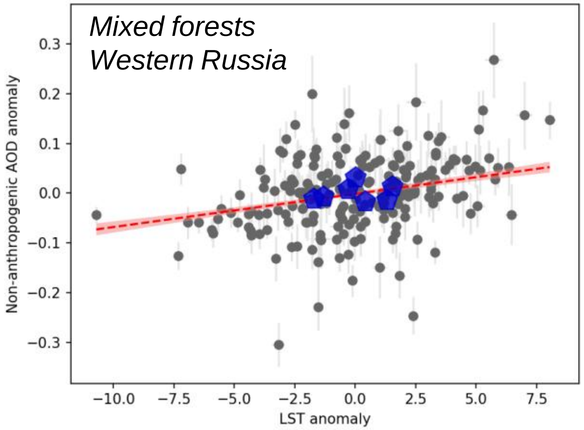
$AOD_{NA,ano}=0.006(\pm 0.004)*LST_{ano} - 0.001$

$AOD_{bio}=0.004(\pm 0.001)*LST_{ano} + 0.056$

Results:
Boreal regions



Results:
Western and Eastern Russia



$$AOD_{NA,ano}=0.007(\pm0.001)*LST_{ano} - 0.001$$

Results:
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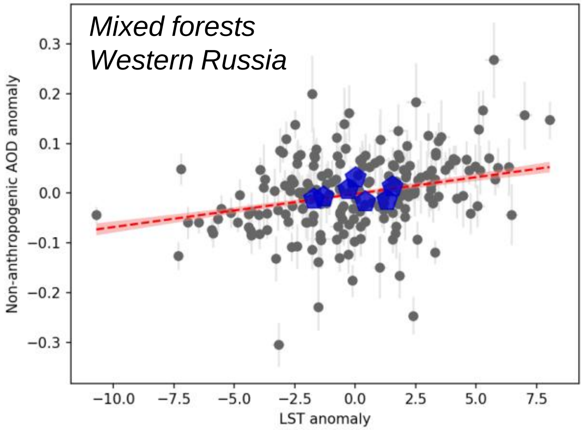

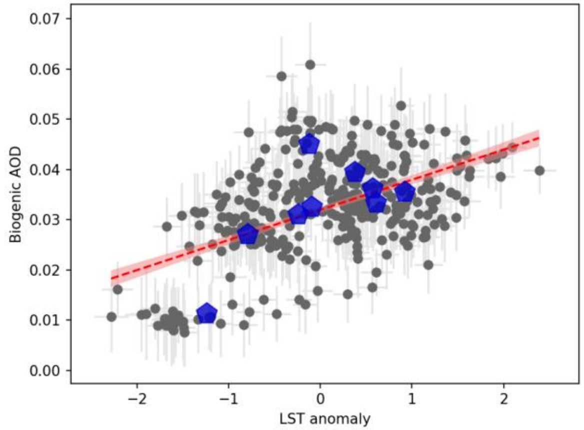

$AOD_{NA,ano}=0.007(\pm0.001)*LST_{ano} - 0.001$ $AOD_{bio}=0.006(\pm0.001)*LST_{ano} + 0.032$

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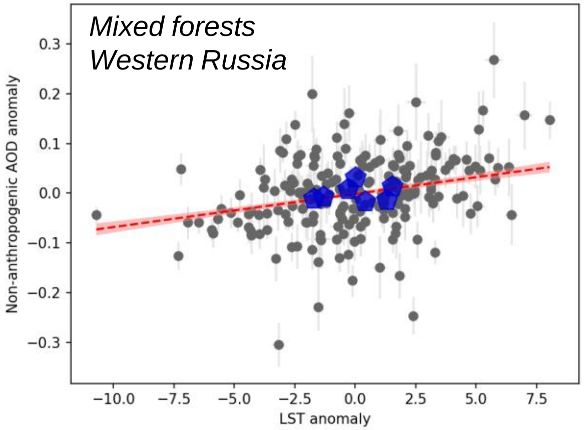
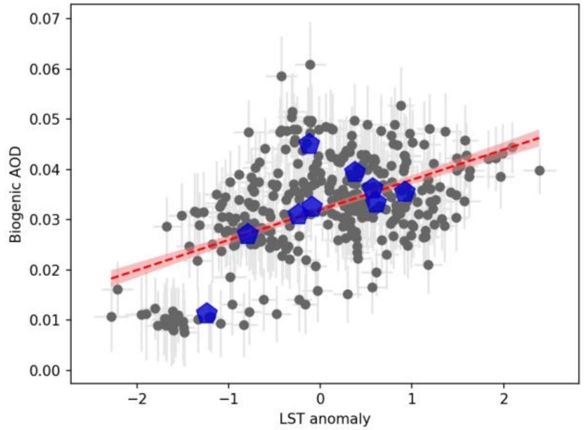
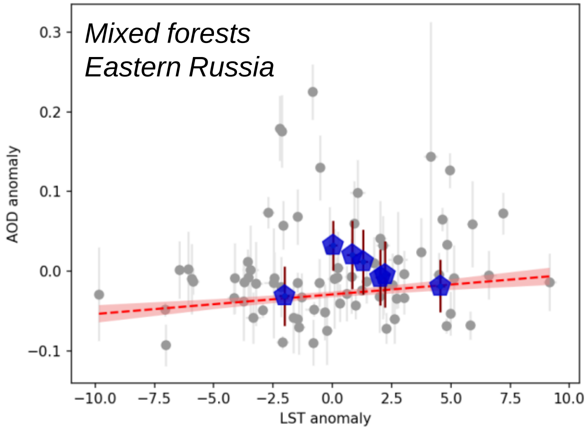


$AOD_{NA,ano}$=0.007(±0.001)*LST_{ano} - 0.001

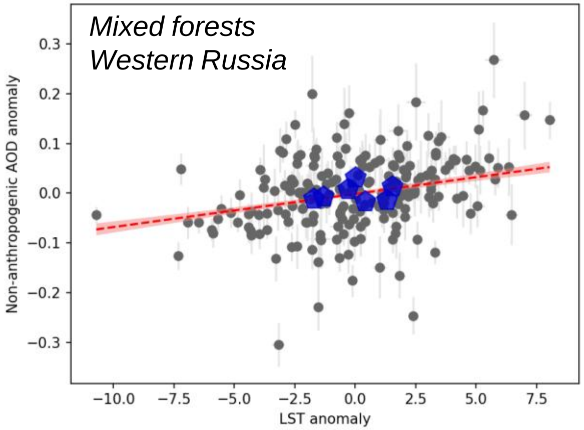


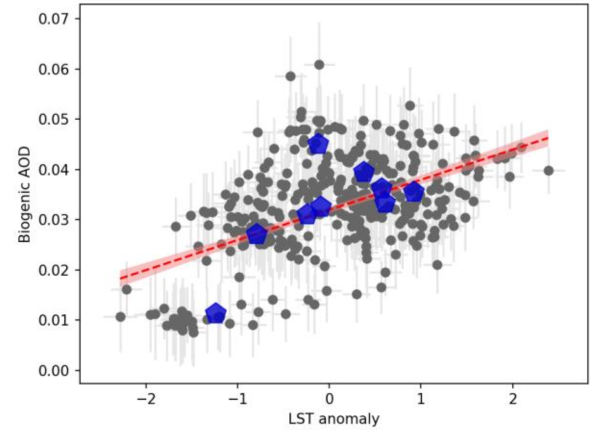
AOD_{bio}=0.006(±0.001)*LST_{ano} + 0.032



AOD_{ano}=0.0025(±0.0010)*LST_{ano} - 0.003

Results:
Western and Eastern Russia





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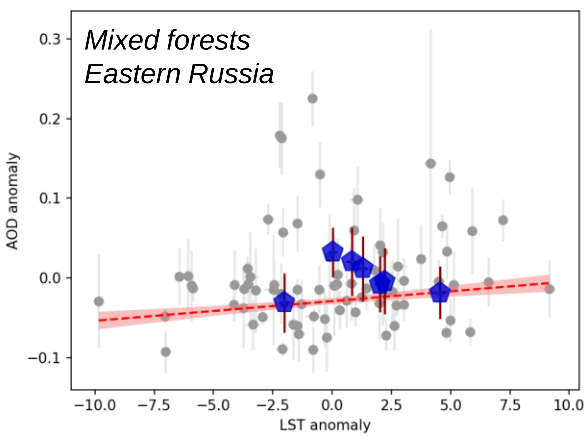

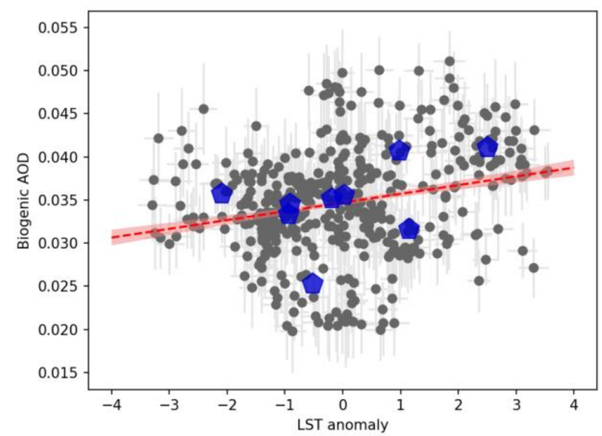

$AOD_{ano}=0.0025(\pm 0.0010)*LST_{ano} - 0.003$

$AOD_{bio}=0.0012(\pm 0.0002)*LST_{ano} + 0.035$

Conclusions

- In order to get meaningful results and conclusions, uncertainties of the used data sets should be considered

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- Models are not able to reproduce observations perfectly
  - → use them to test hypotheses
  - → instead of absolute values you can use anomalies and variability

Thank you!

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