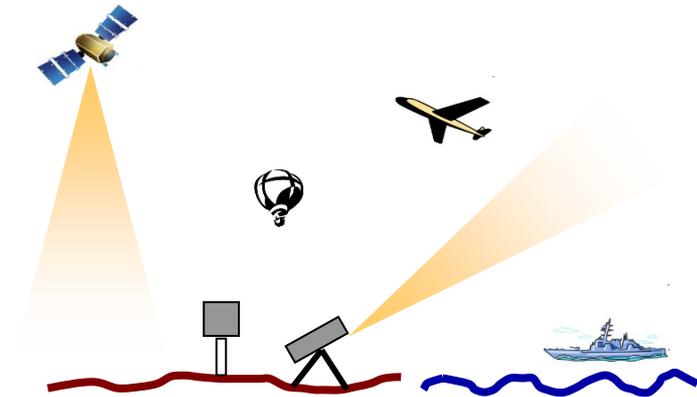


# Spatio-Temporal Optimal Interpolation of Aerosol Optical Depth Observations Using a Chemical Transport Model

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# Atmospheric aerosol has a considerable impact on air quality and climate

Aerosol distribution in the Earth's atmosphere is studied using measurements from many satellite and ground-based instruments



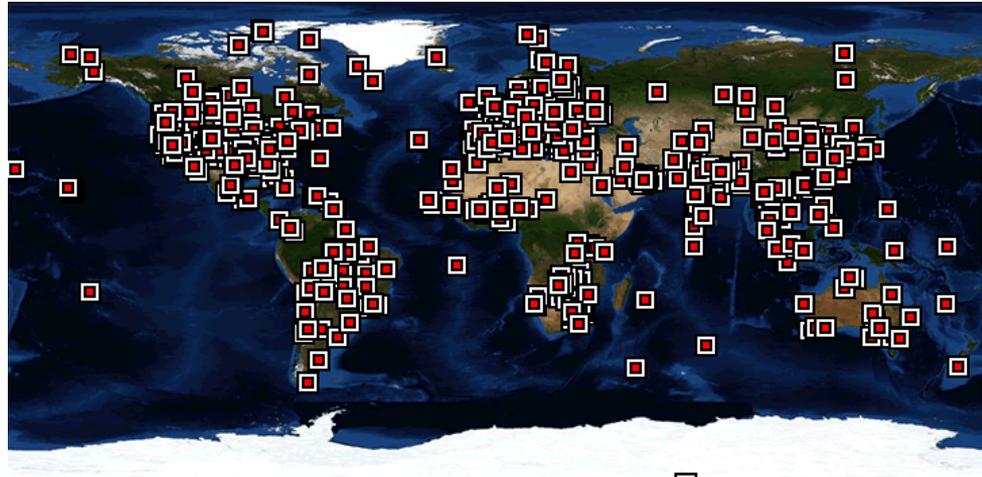
However, the distribution and properties of atmospheric aerosols are still not sufficiently known

One of important characteristics of atmospheric aerosol is aerosol optical depth (AOD), which is a measure of light extinction by aerosol

# Aerosol optical depth (AOD) observations

One of the valuable sources of atmospheric aerosol data is observations by a ground-based network of sun photometers AERONET (AERosol RObotic NETwork)

AERONET provides AOD data with low uncertainty (about 0.01 for wavelengths  $> 440$  nm)



<http://aeronet.gsfc.nasa.gov/>

AERONET observations represent specific point measurements and have limited spatial coverage

Chemical transport models provide estimates of AOD with full (within the resolution of the calculational network) space–time coverage of the target area

One of the widely used global chemical transport models is GEOS-Chem



<https://geos-chem.seas.harvard.edu/>

GEOS-Chem is a global three-dimensional chemical transport model. It is applied by research groups around the world to a wide range of atmospheric composition problems. Scientific direction of the model is provided by the international GEOS-Chem Steering Committee and by User Working Groups. The model is managed by the GEOS-Chem Support Team, based at Harvard University and Dalhousie University with support from the US NASA Earth Science Division, the Canadian National and Engineering Research Council, and the Nanjing University of Information Sciences and Technology. GEOS-Chem is a grass-roots open-access model owned by its users.

# Model simulation



V12.1.1

## Input:

### meteorological data

- winds
- temperature
- humidity
- convective mass fluxes
- cloud properties
- surface properties
- etc.

### emissions data

- fossil fuel
- biomass burning
- biofuel burning
- biogenic
- aerosol emissions

## Output:

- tracer concentrations
- chemical production and loss
- dry deposition fluxes and velocities
- etc.
- aerosol optical depths:  
440, 675 and 870 nm

Horizontal resolution: 0.25° in latitude, 0.3125° in longitude

# Optimal interpolation

”The interpolation which is linear relative to the initial data and whose root-mean-square error is minimum” (Wiener)

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{K} (\mathbf{y} - \mathbf{H}\mathbf{x}^b)$$

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

$\mathbf{x}^a$  is a vector containing estimated values at regular grid points

$\mathbf{x}^b$  is a vector containing values calculated by a model at regular grid points

$\mathbf{y}$  is a vector containing values of observations at the observational points

$\mathbf{K}$  is a matrix containing weighting coefficients

$\mathbf{H}$  is an observation operator providing the link between the analysis variables and the observations

$\mathbf{B}$  is a covariance matrix of model errors

$\mathbf{R}$  is a covariance matrix of observational errors

The matrix of weighting coefficients  $\mathbf{K}$  is to be determined by minimizing the mean-square error in the estimate

# Spatio-temporal optimal interpolation

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{K} (\mathbf{y} - \mathbf{H}\mathbf{x}^b)$$

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

For a given grid cell:

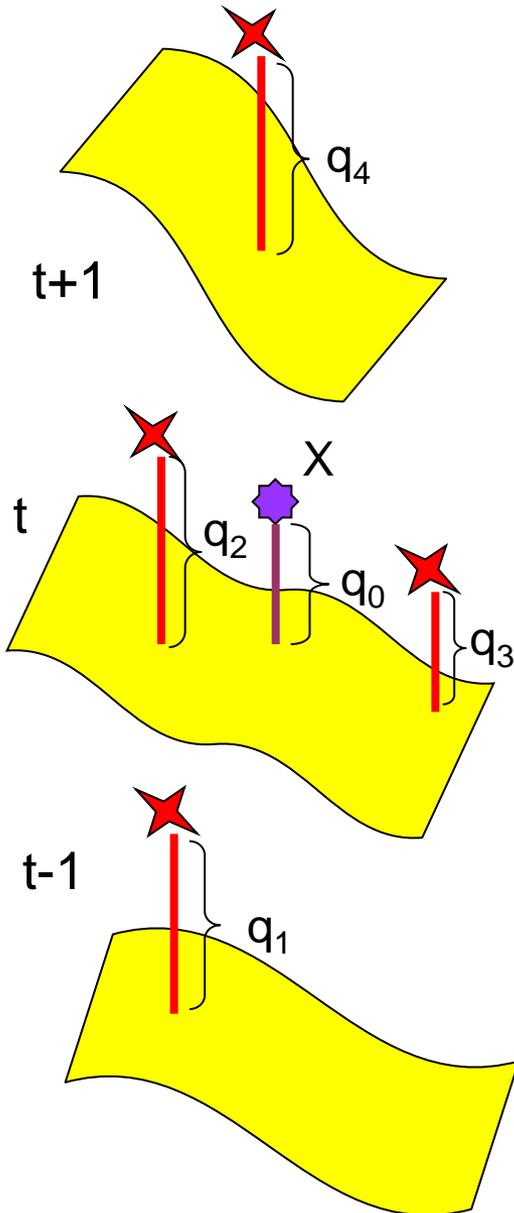
$$x_0^a = x_0^b + q_0$$

$$q_0 = \sum_i k_i q_i$$

$q_0$  is a deviation of the observation from a model state in the spatio-temporal point being updated

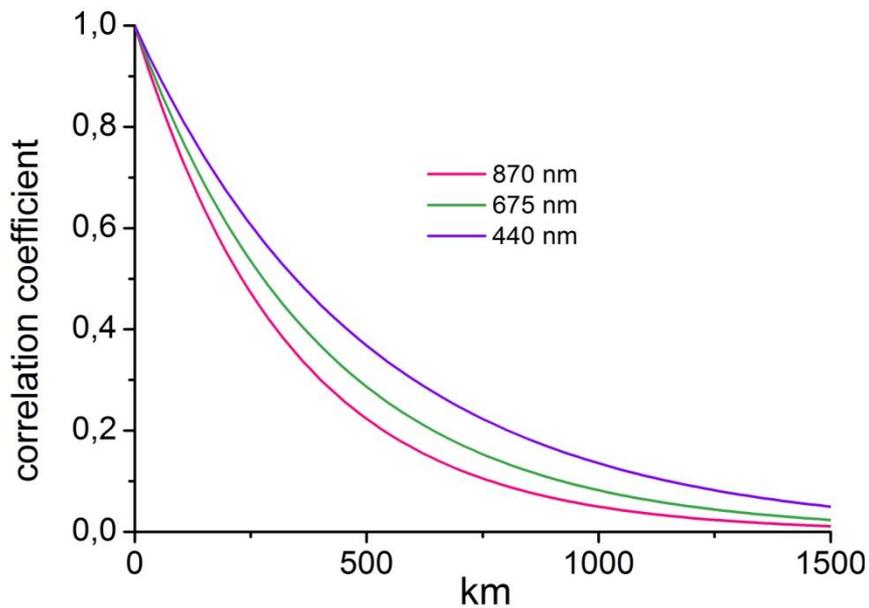
$q_i$  is a deviation of the observation from a model state in the spatio-temporal point of the observation

Only a number of observations is taking into consideration in the vicinity of the spatio-temporal point being updated

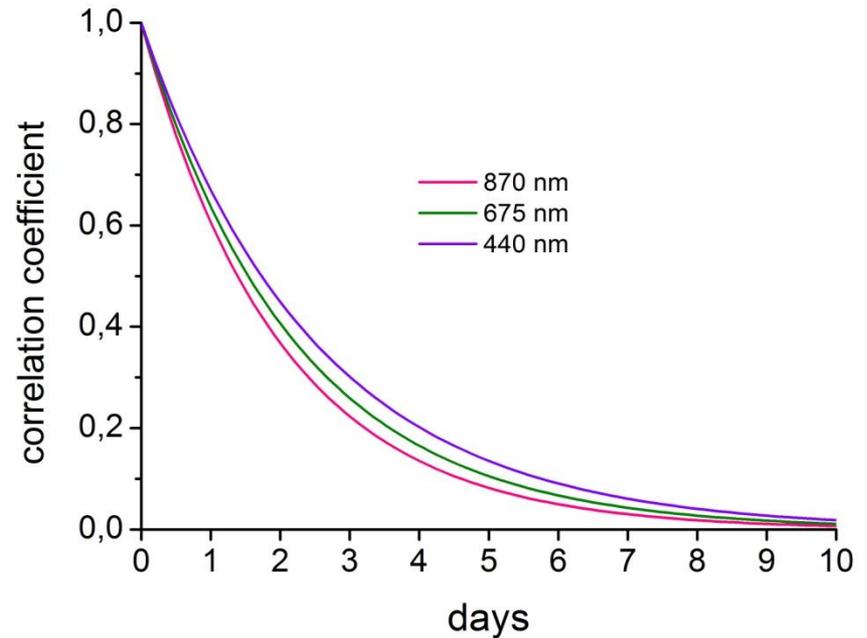


# Correlation functions for the European region obtained using data from 88 AERONET sites for 2015-2016

Covariances are modeled by analytic functions



Spatial correlation function

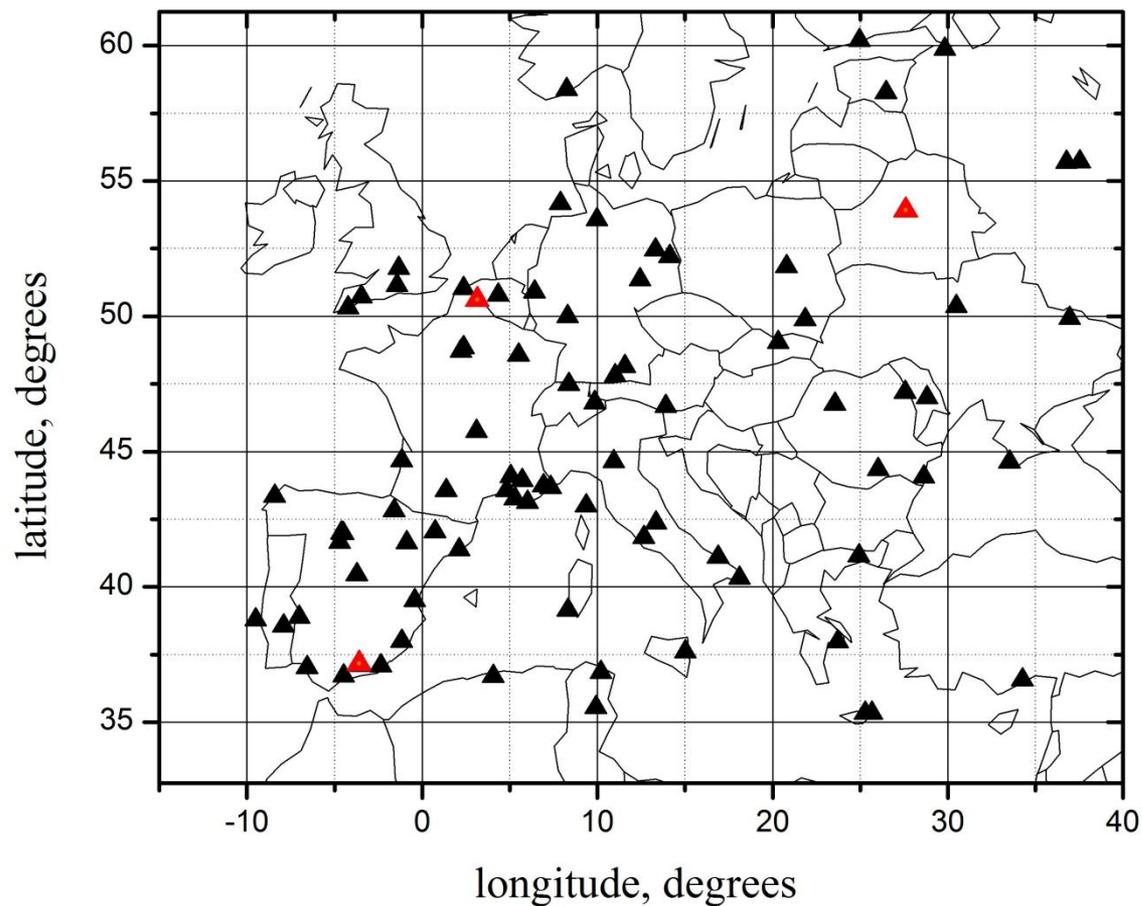


Temporal correlation function

# Location of the AERONET stations considered in the assimilation scheme

In red there are marked the sites chosen for validation:

**Granada** (Spain), **Lille** (France), **Minsk** (Belarus)

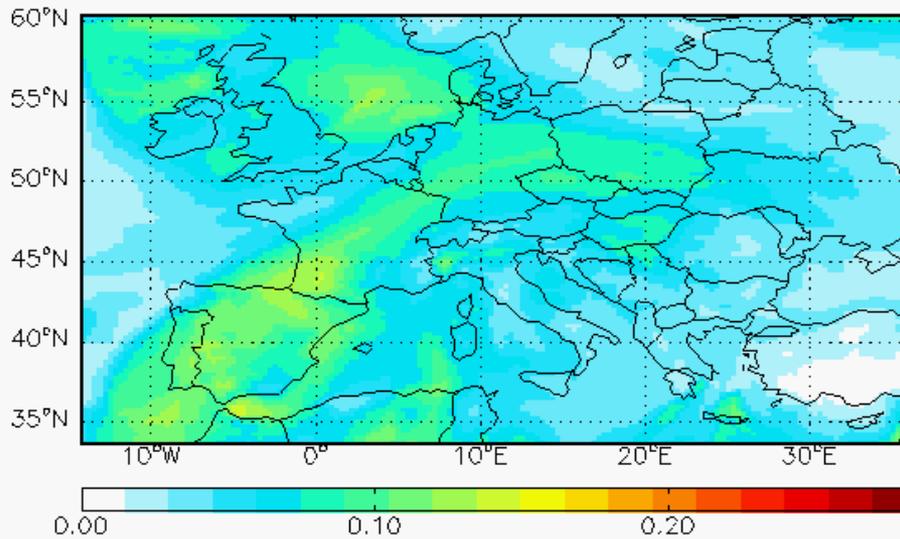


# An example of optimal interpolation

## AOD distribution for 17 July 2015 at 870 nm

Before optimal interpolation

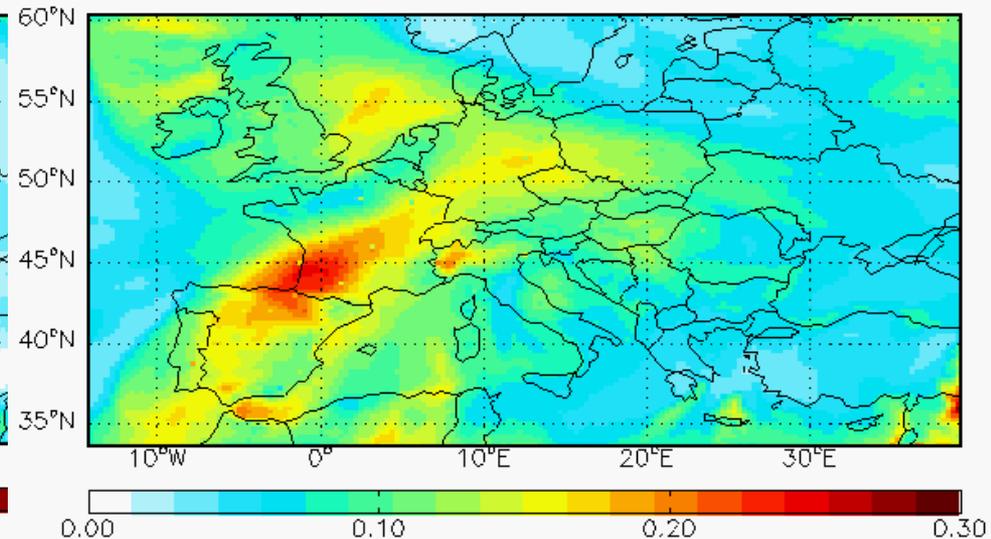
AOD\_eu\_GC\_870\_20150717



GEOS-Chem simulation

After optimal interpolation

AOD\_eu\_DI\_870\_20150717



Estimate with assimilated  
AERONET data

# Validation

Root-mean-square errors of the GEOS-Chem-calculated and STOI-estimated AOD as compared to AERONET-observed AOD

Wavelength nm	Granada		Lille		Minsk	
	GEOS-Chem	STOI	GEOS-Chem	STOI	GEOS-Chem	STOI
440	0.127	0.046	0.091	0.055	0.090	0.068
675	0.113	0.034	0.057	0.032	0.047	0.036
870	0.111	0.034	0.046	0.023	0.032	0.026

Averaged over three wavelengths reduction in root-mean-square error of the estimate after STOI is:

68% for Granada, 45% for Lille, 22% for Minsk

# Conclusion

Spatio-temporal optimal interpolation is a computationally efficient technique able to decrease the errors significantly in comparison with the model calculation