EnKF developments and other things

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EnKF developments

Projects

GOSAT, GCOM-C, SALSA

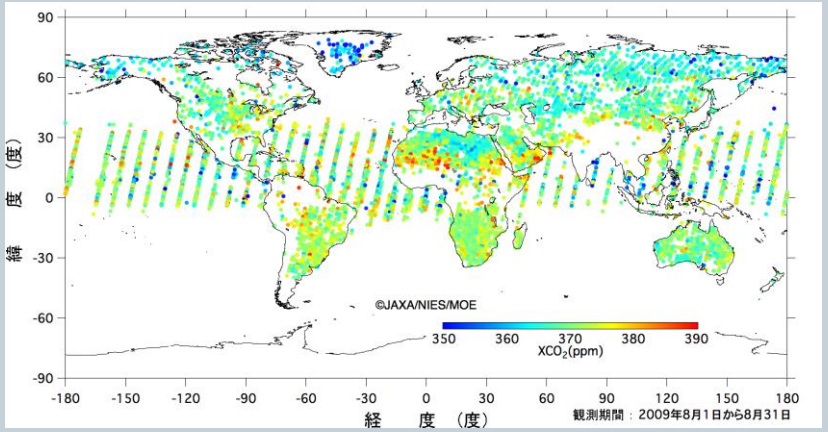
- Better AOT, DARF, PM25
- Through better mixing ratios
- Temp. res.: ~ 3 hr
- MIROC or NICAM-SPRINTARS
  - Mass scheme
- Ensemble Kalman filter

GASSP

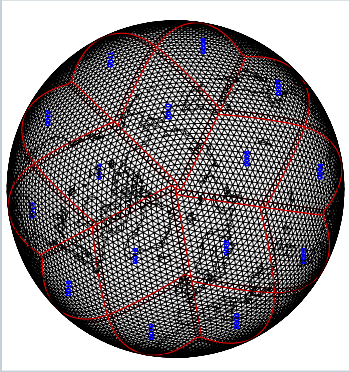
- Better CCN (& IARF)
- Through better model parameters
- Temp. res.: ~ 1 mth
- HadGEM-UKCA (ECHAM-HAM)
  - Mass & numbers scheme
- Emulators & history matching

GOSAT, SALSA

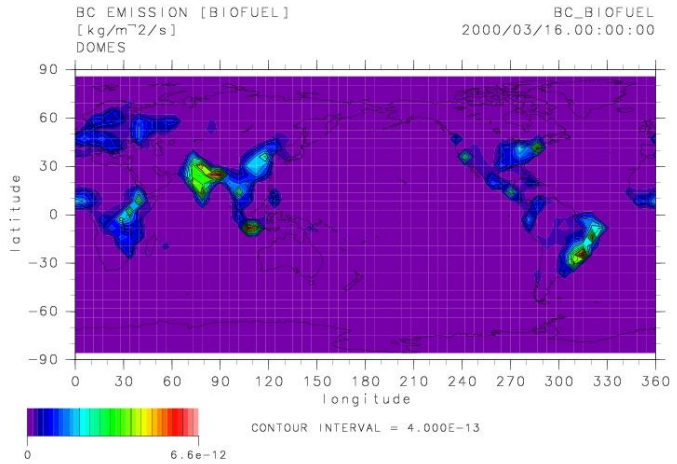
- Support for GOSAT CO2 retrieval
  - Currently running at NIES
  - MIROC-SPRINTARS

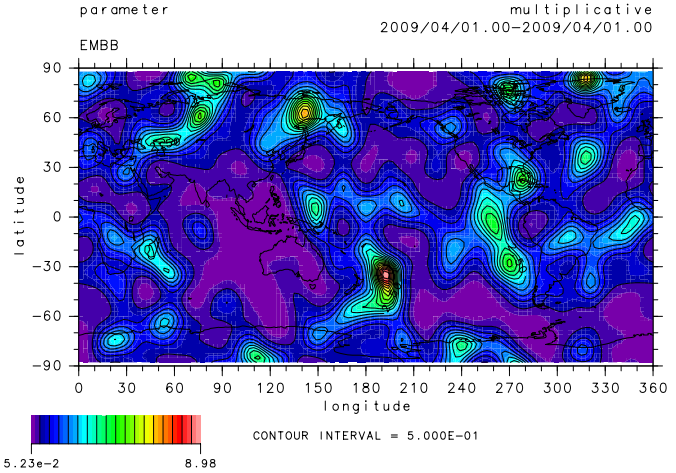


- Air pollution forecasts (SALSA)
  - Dai et al. *Atmos. Environ.* 2013
  - Dai et al. *Environ. Poll.* 2014
  - NICAM-SPRINTARS

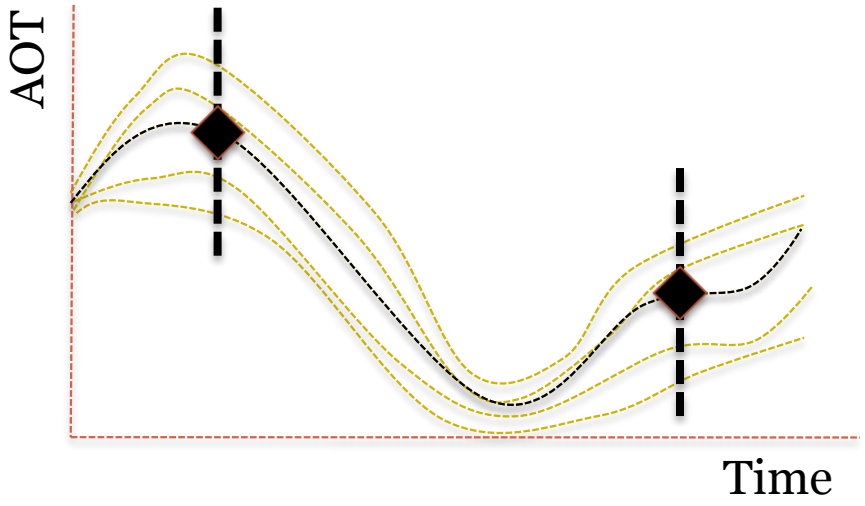


Emission perturbations





$$E(f,q) = E_0(f,q)\ f_{\text{rnd}}(f,q)$$



Kalman equation

$$\mathbf{x}_a = \mathbf{x}_f + \mathbf{P}_a\mathbf{H}^T\mathbf{R}^{-1}\left(\mathbf{y} - \mathbf{H}\mathbf{x}_f\right)$$

$\mathbf{x}_f$ Mixing ratio forecast → $\mathbf{x}_a$ Mixing ratio analysis

$\mathbf{y}$ Observations

$\mathbf{H}\mathbf{x}_f$ Simulated observation

} Disparate observations: AOT, AE, β, $PM_{2.5}$ etc.

$\mathbf{R}$ Observational error covariance

Relative accuracy: e.g. MODIS vs AERONET

$\mathbf{P}$ Model prediction error covariance

'Propagating ' the observation information in the grid

} Relative accuracy: observations vs model

Estimating mixing ratios or emissions

Mixing ratios

Emissions

Kalman filter

Kalman smoother

Observation operator

Mixing ratio

Observation errors

$$\mathbf{x}_a = \mathbf{x}_f + \mathbf{P}_a\mathbf{H}^T\mathbf{R}^{-1}\left(\mathbf{y} - \mathbf{H}\mathbf{x}_f\right)$$

Emissions

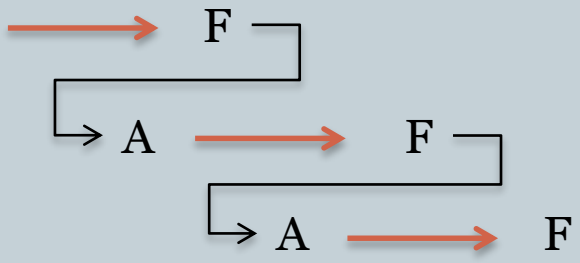
Observation errors

Transport operator
&
Observation operator

Estimating mixing ratios

Mixing ratios

Emissions



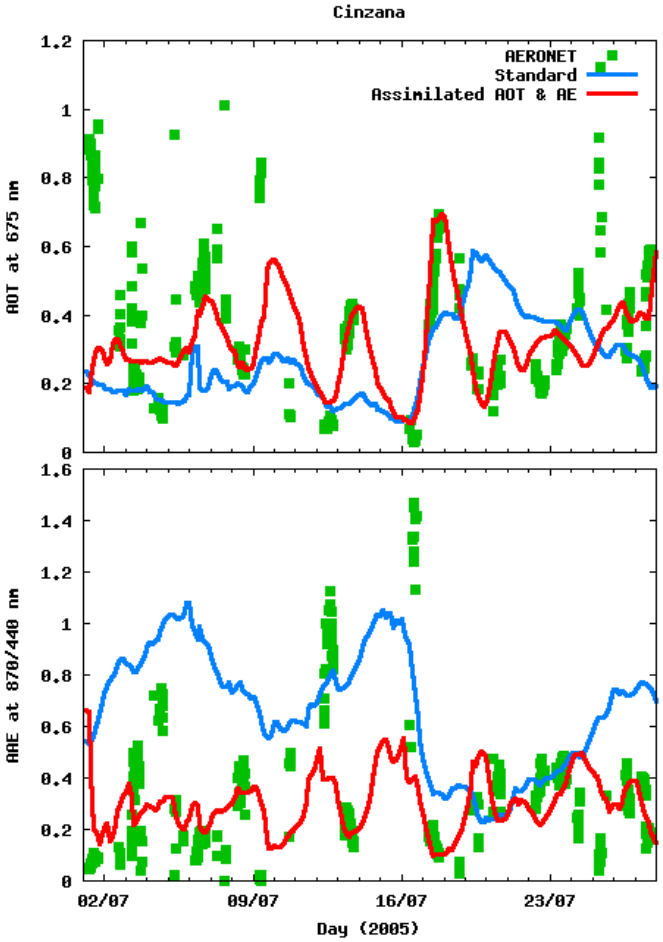
- 1 day forecast
- All observations during day assimilated
- New forecast starts where old forecast ended

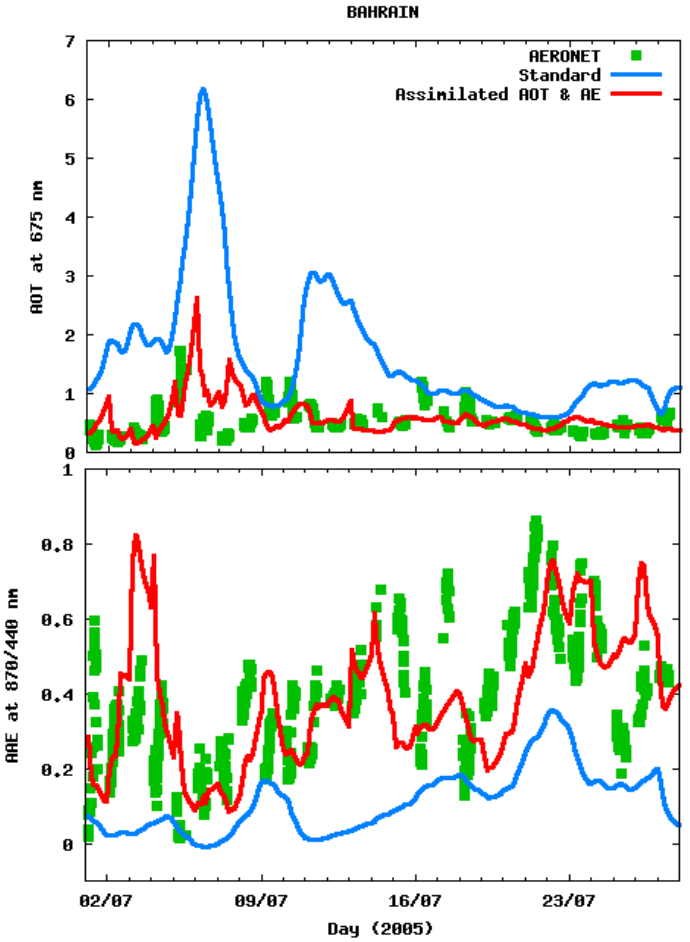
Kalman filter

Kalman smoother

$$\mathbf{x}_a = \mathbf{x}_f + \mathbf{P}_a \mathbf{H}^T \mathbf{R}^{-1} \left(\mathbf{y} - \mathbf{H}\mathbf{x}_f \right)$$

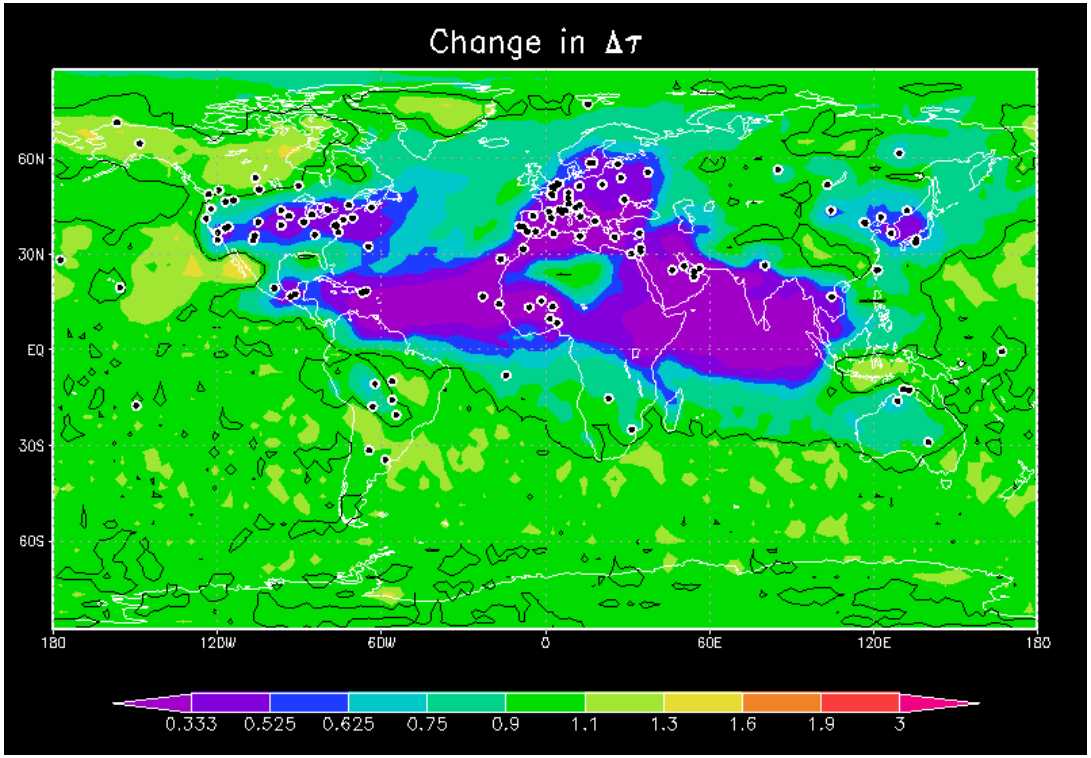
Assimilating AERONET





Schutgens et al. *ACP* 2010a,b

Analysis spread / free spread

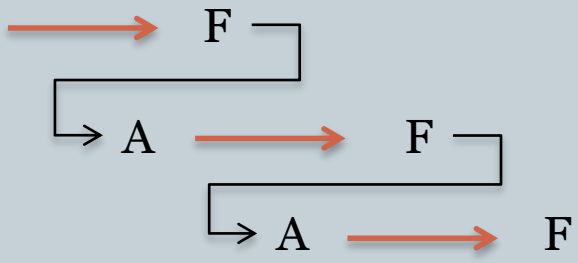


June 2005, assimilation of AERONET AOT & AE

The estimated error in AOT (ensemble spread) evolves naturally, i.e. according to the physics of the model and the information content of the observations.

Estimating emissions

Mixing ratios

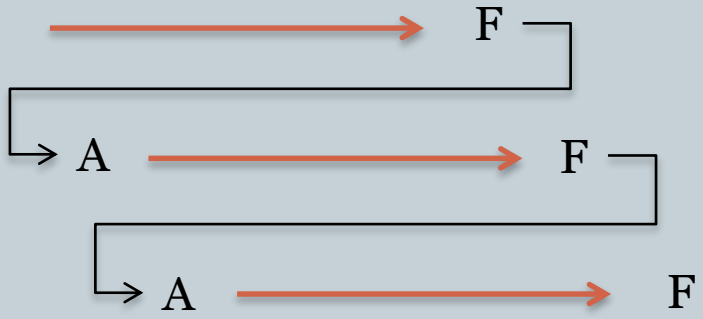


- 1 day forecast
- All observations during day assimilated
- New forecast starts where old forecast ended

Kalman filter

$$\mathbf{x}_a = \mathbf{x}_f + \mathbf{P}_a\mathbf{H}^T\mathbf{R}^{-1}\left(\mathbf{y} - \mathbf{H}\mathbf{x}_f\right)$$

Emissions

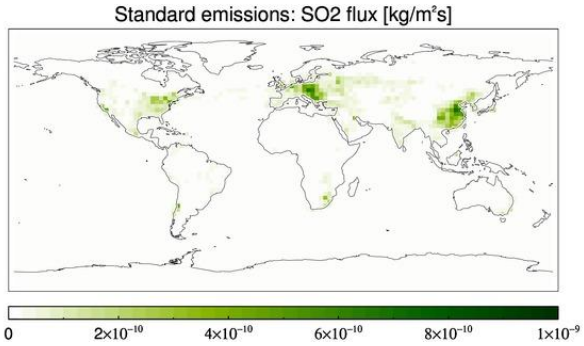


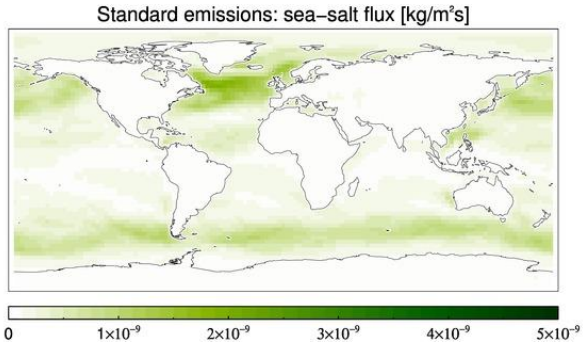
- 6 day forecast
- All observations during last day assimilated
- New forecast starts 1 day after old forecast *started*

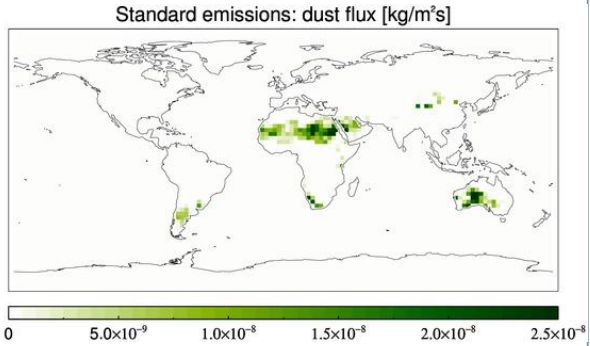
Kalman smoother

Estimating emissions

Standard emissions

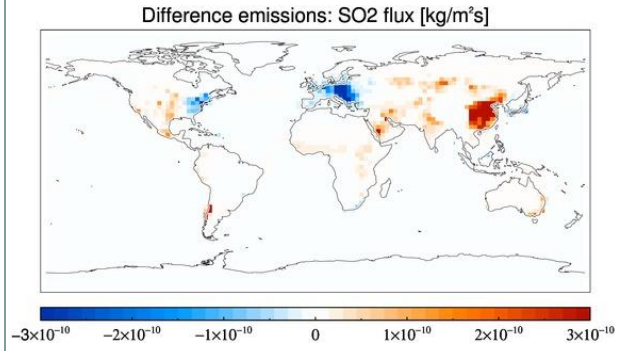


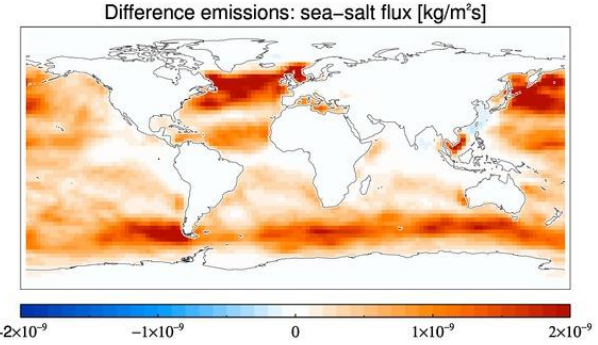


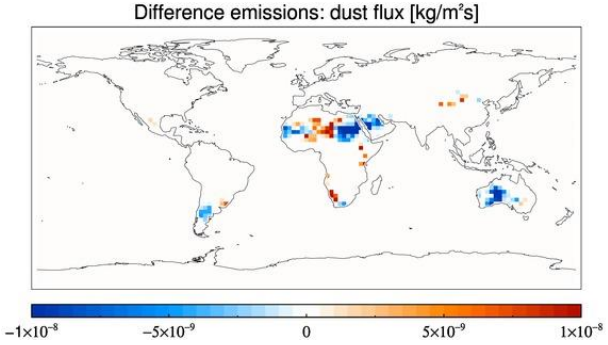


Estimating emissions from MODIS Terra over ocean and AERONET

Difference of newly estimated emissions (April 2009)







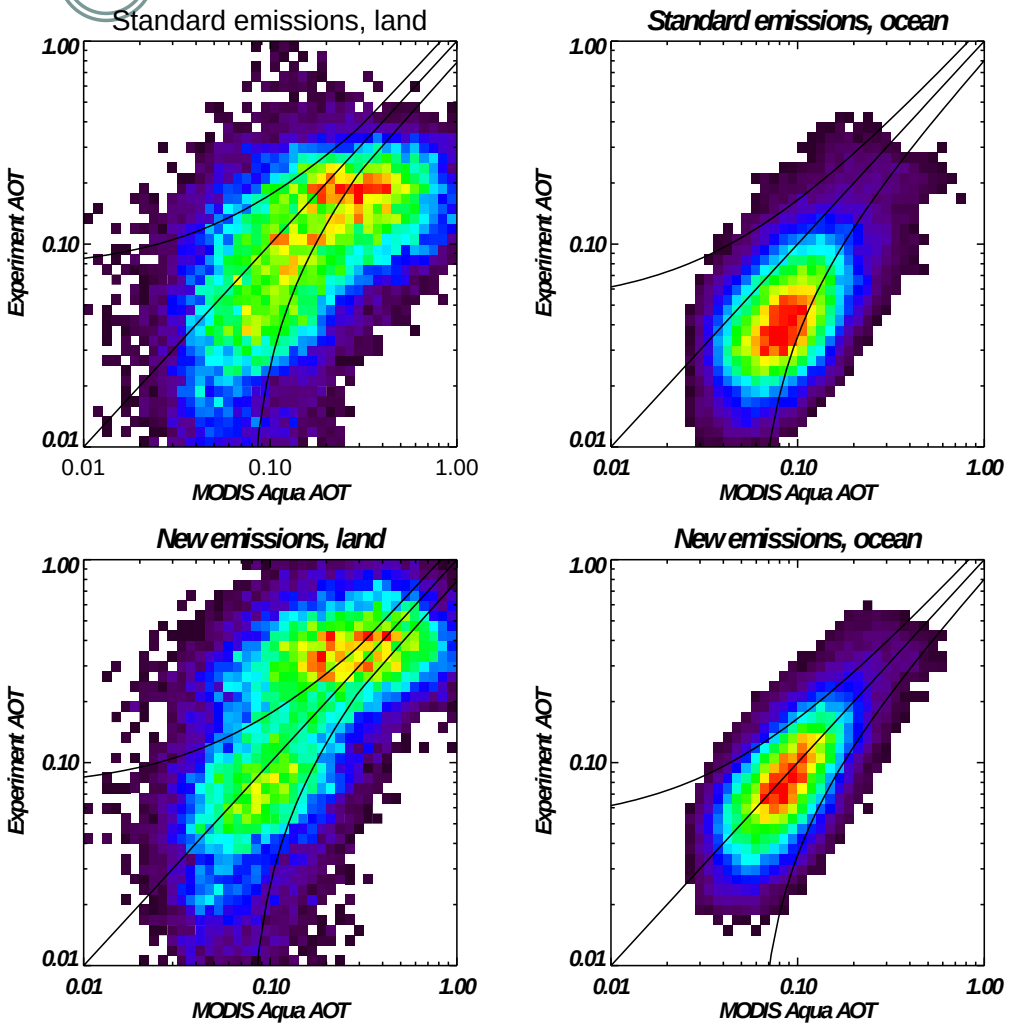
Evaluation of new emissions

Emission estimation using Terra AOT over ocean and AERONET AOT & AE

Evaluation using Aqua AOT:

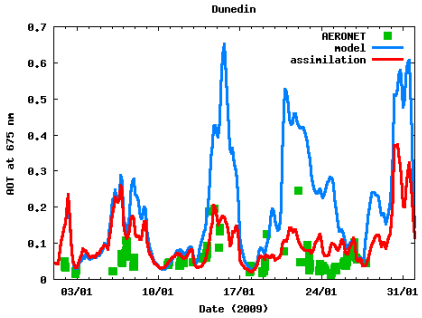
		bias	slope	corr.
land	std	-0.045	0.31	0.51
	new	0.008	0.8	0.57
ocean	std	-0.04	0.34	0.50
	new	0.005	0.79	0.64

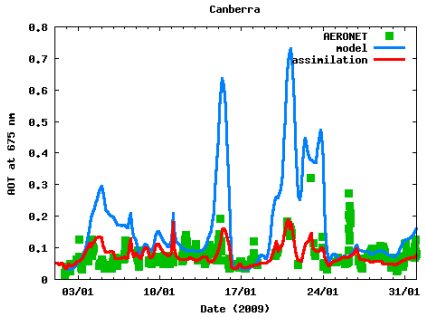
Schutgens et al. *Rem. Sens.* 2012



CALIOP observations

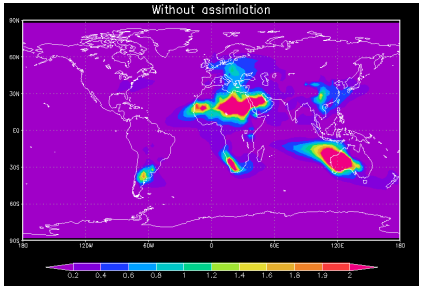
- Attenuated backscatter is assimilated
- Night-time obs only
- dust: randomly oriented spheroids

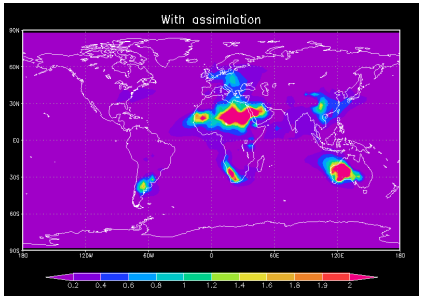


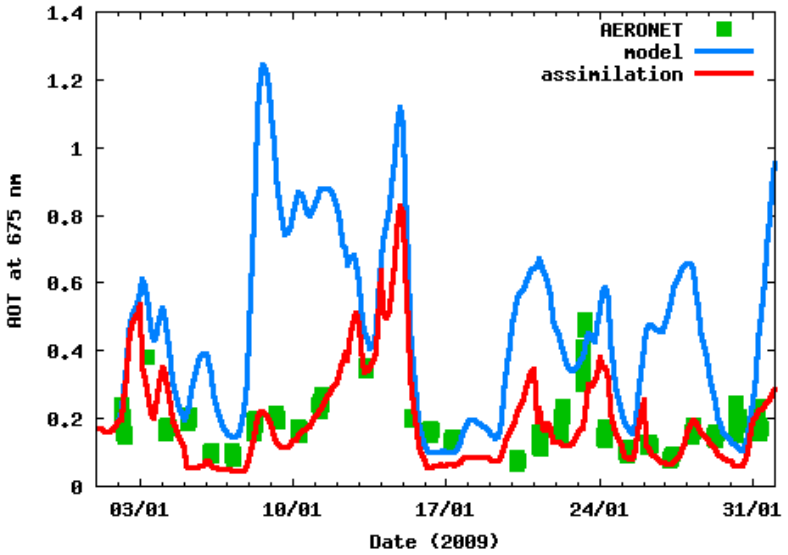


- Sensor does not often probe boundary layer
- Swath is very narrow

so global impact small:



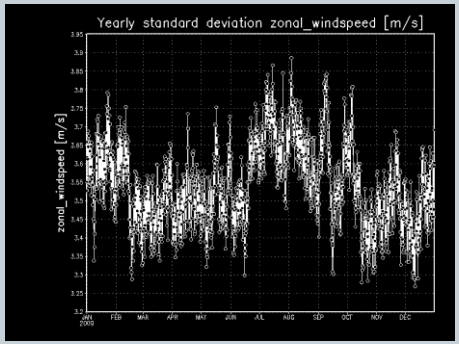


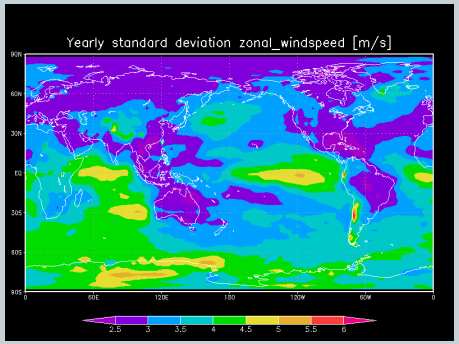


Flow uncertainty

MIROC is nudged to reanalysis meteorology. How accurate is this reanalysis?

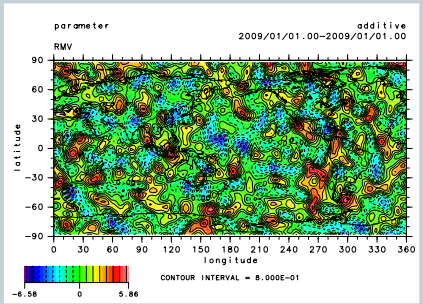
Here we compare one year of NCEP and JMA reanalysis:

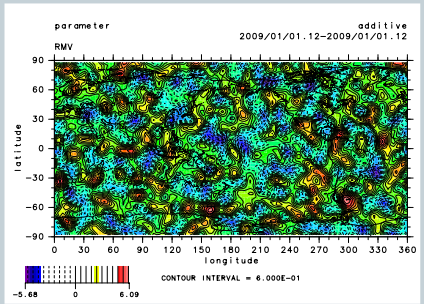




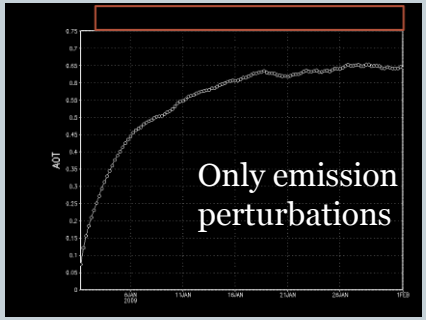
[m/s]	Mean	Stddev
Δzonal windspeed	0.0	3.5
Δmeridional windspeed	0.0	3.2

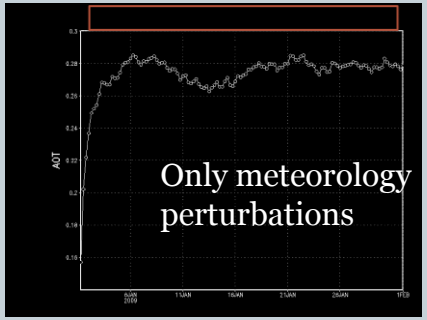
Perturb reanalysis meteorology with spatio-temporally correlated noise:





Impact on global AOT ensemble spread:

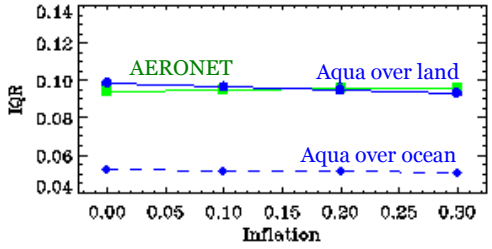


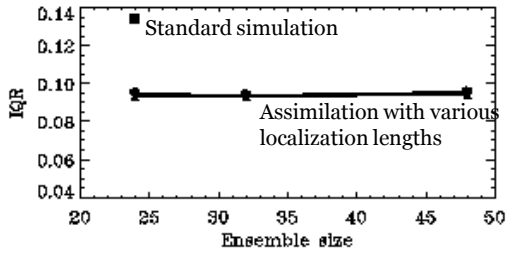


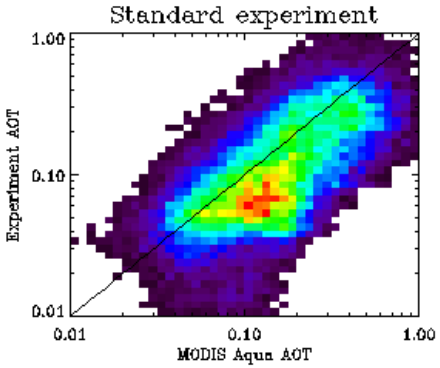
MIROC5-SPRINTARS

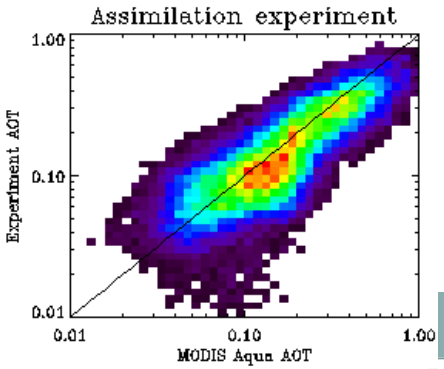
- Similar to SPRINTARS v3.84 (official version)
- Boundary layer very different
- Nudging to perturbed reanalysis
- Emission perturbations using spatially correlated noise
- More perturbed emissions (e.g. DMS emissions)

Robust results irrespective of ensemble size, localization length, inflation, etc:









Std error	standard	assimilation
All AERONET	0.11	0.10
Moderate AERONET	0.12	0.09
Best AERONET	0.07	0.05

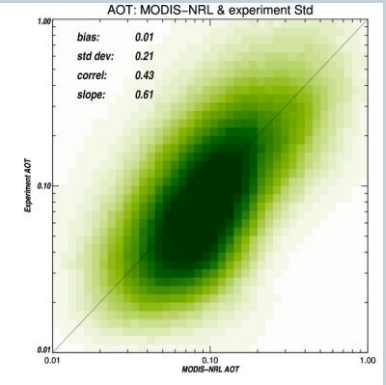
Linear slope	standard	assimilation
All AERONET	0.055	0.64
Moderate AERONET	0.45	0.71
Best AERONET	0.49	0.76

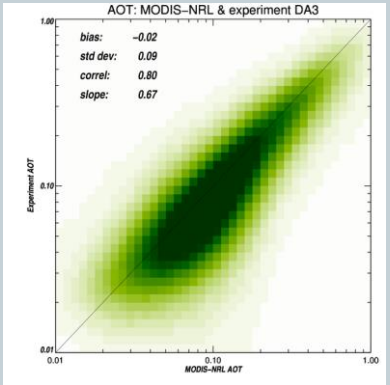
Year long experiment

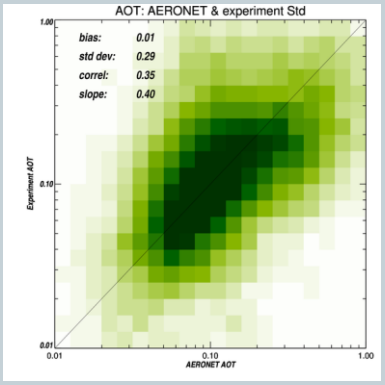
One year (2009) experiment where AERONET AOT & AE, MODIS AOT and CALIOP backscatter were assimilated.

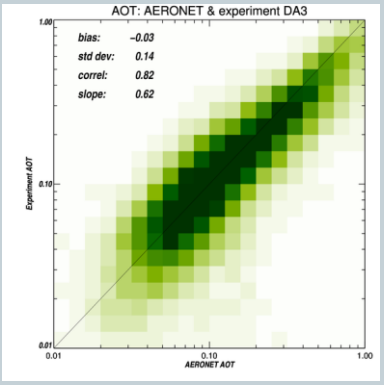
Ensemble size: 24 members; assimilation window: 1 day (observations every 6 hours).

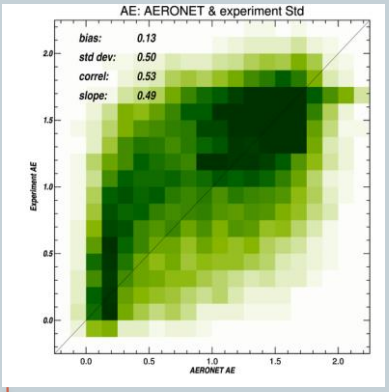
Model vs MODIS Aqua & Terra

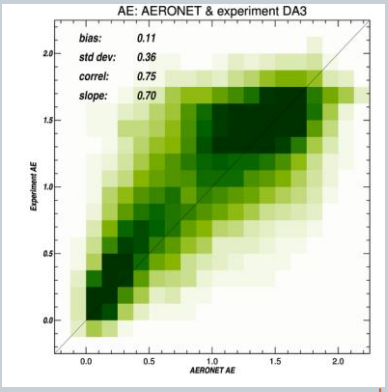






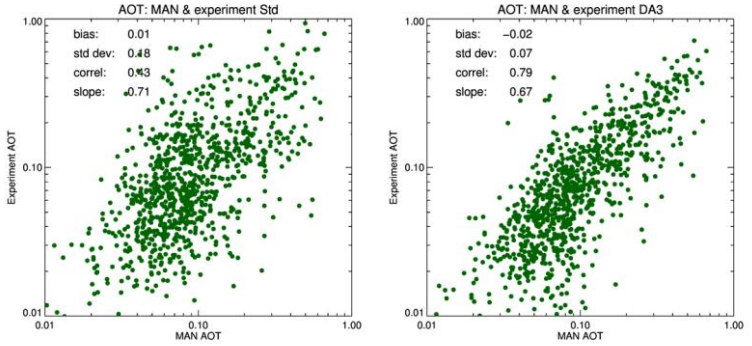


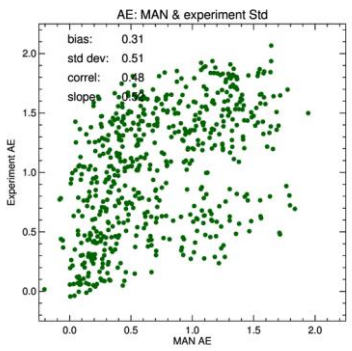


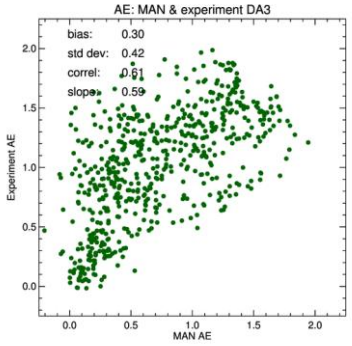


Model vs AERONET

Verification & impact

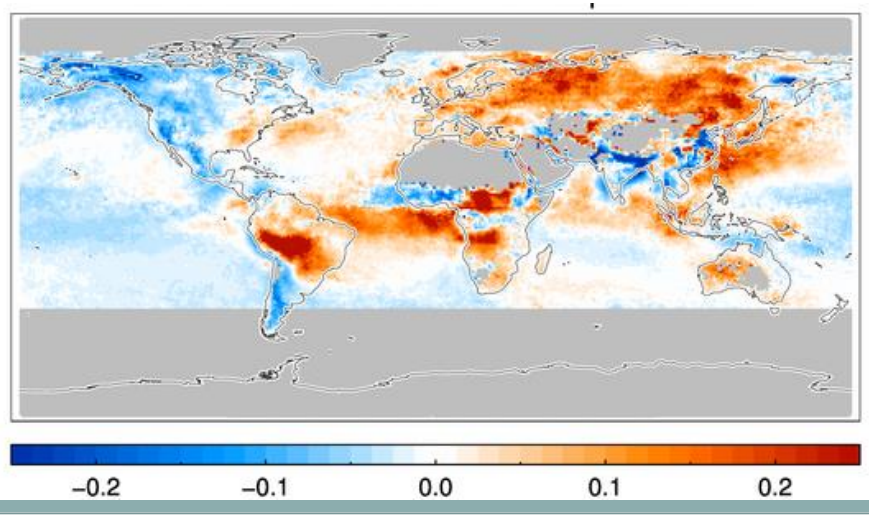




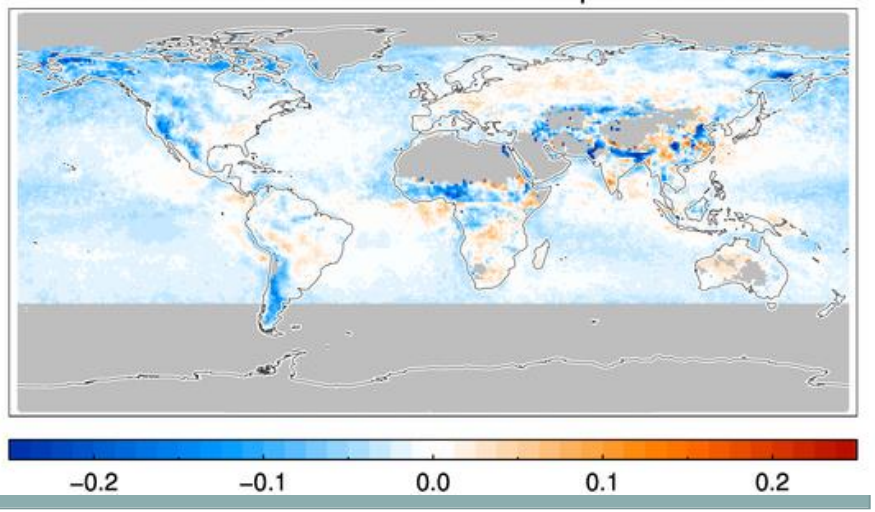


Model vs Maritime Aerosol Network (ship-based) observations

Model - MODIS

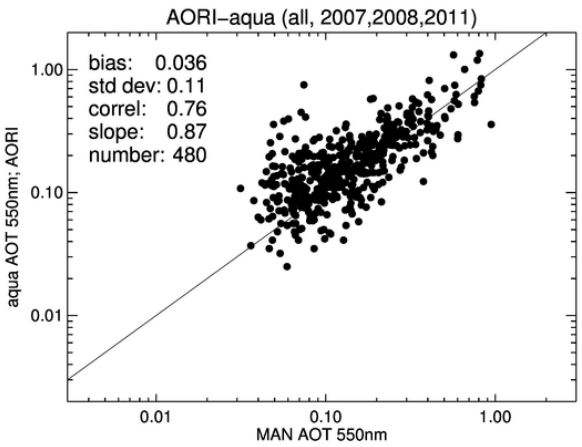


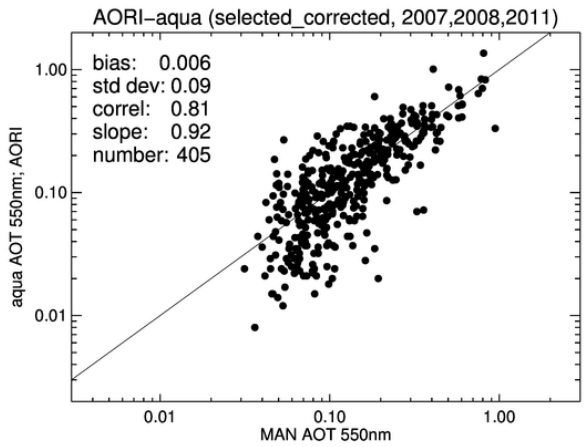
Analysis - MODIS



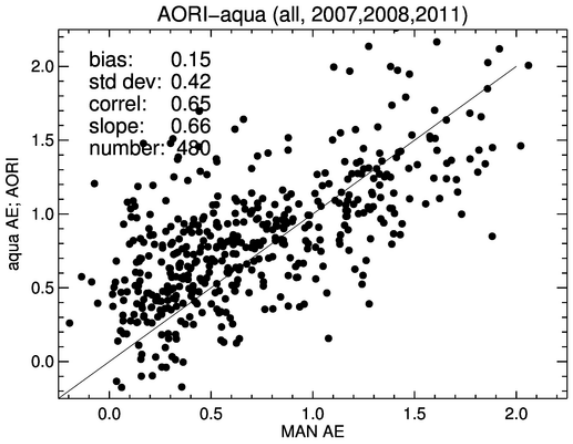
And other things: Empirical correction of MODIS AOT & AE over ocean

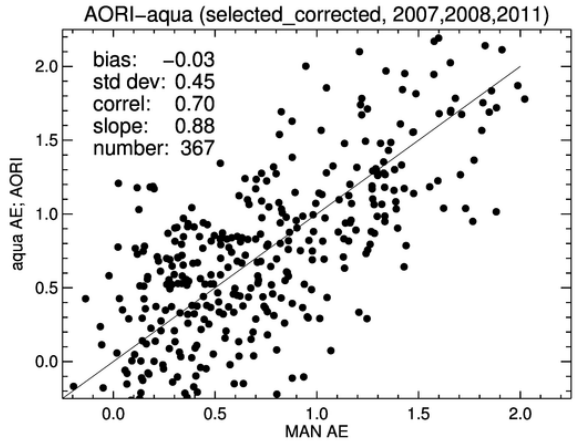
MODIS Coll. 5 L2 over ocean





Correction uses ancillary information on wind speed and cloud fraction





Schutgens et al. *AMT* 2013

And more other things: Community Intercomparison Suite

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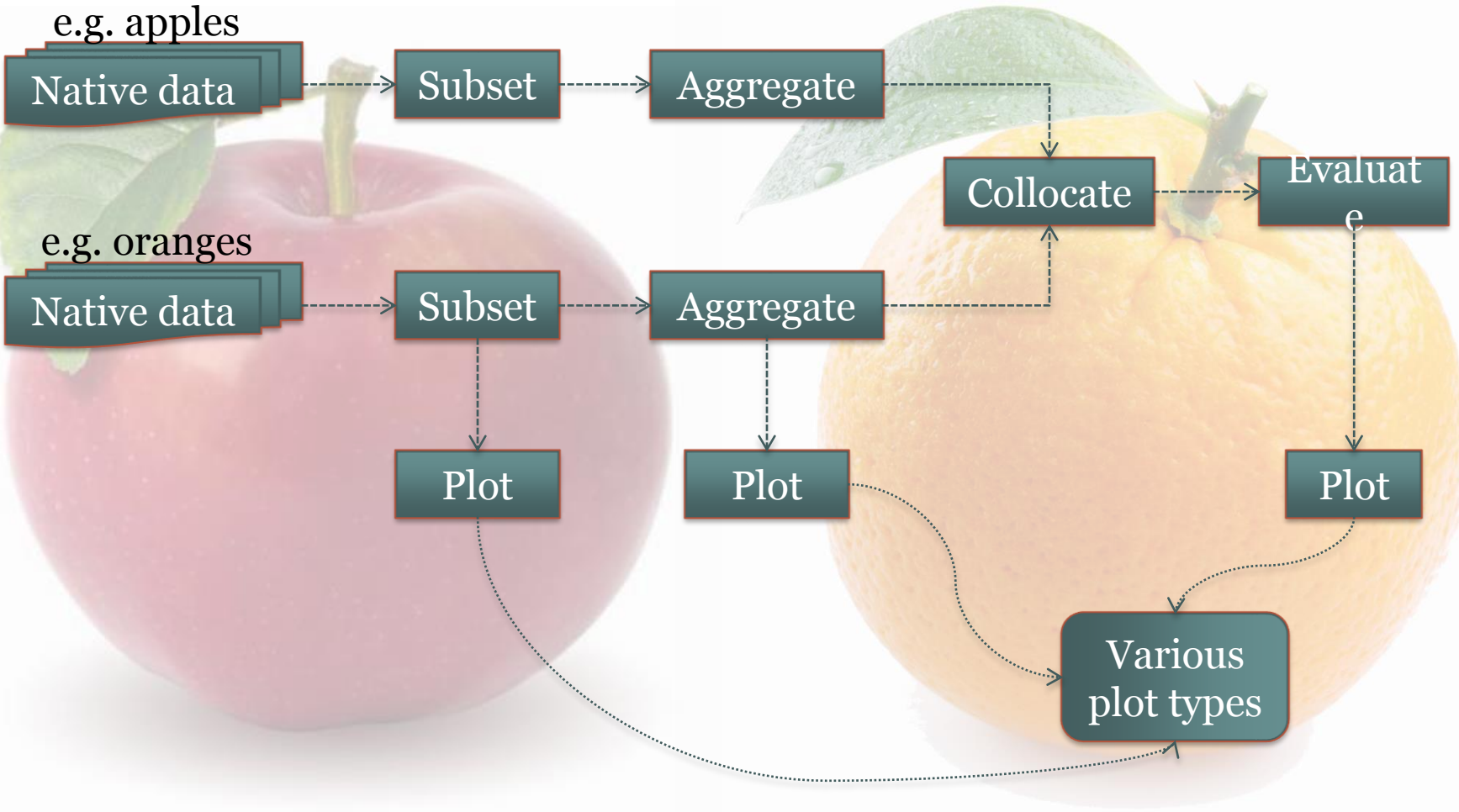
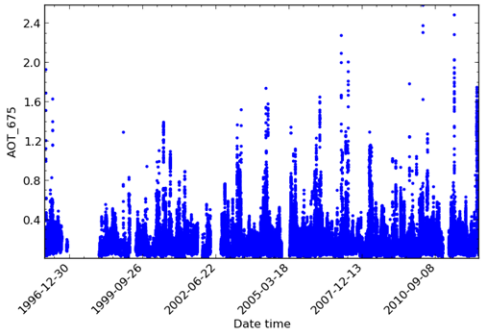
SCIENCE AND TECHNOLOGY FACILITIES COUNCIL
NATURAL ENVIRONMENT RESEARCH COUNCIL

A typical CIS work-flow

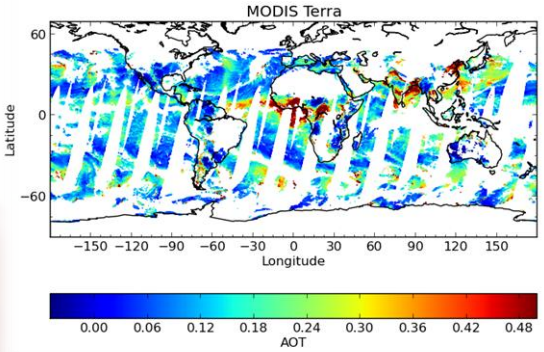


Plotting original data

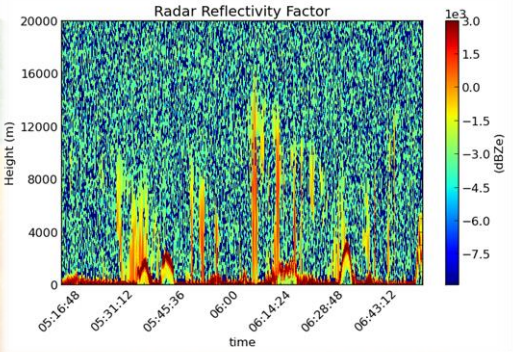
AERONET station data



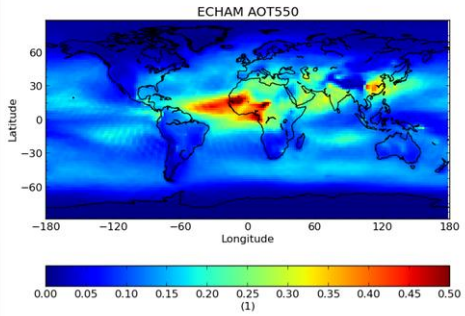
Satellite imager data

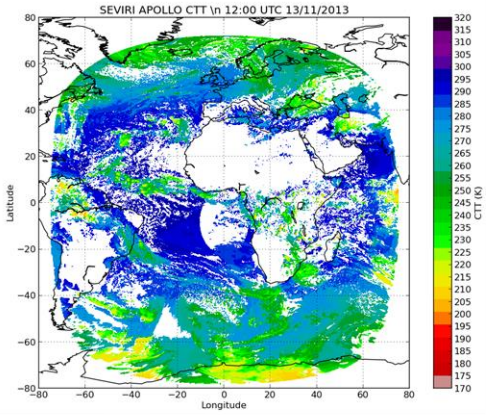


Satellite active profiler data

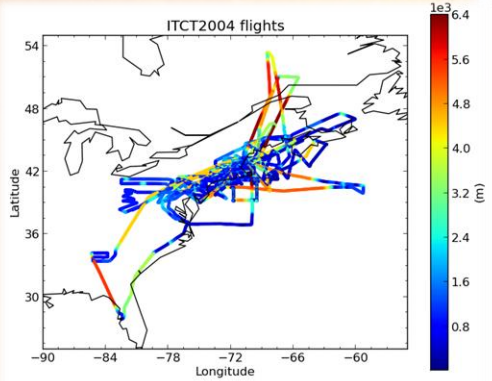


Model data



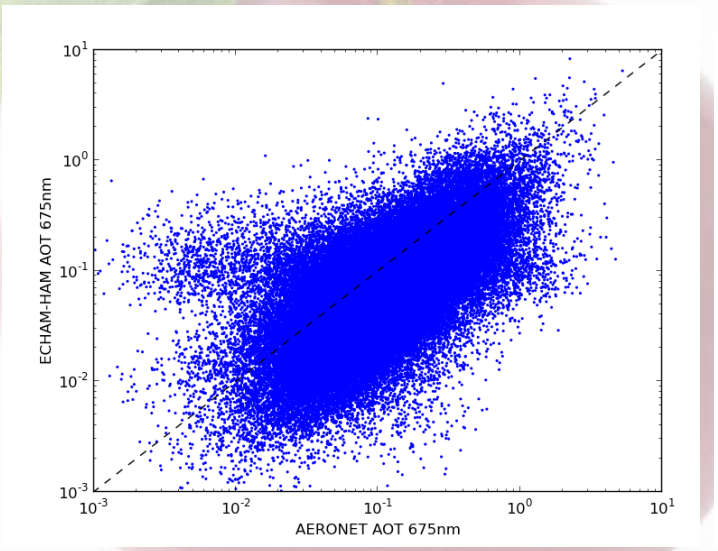


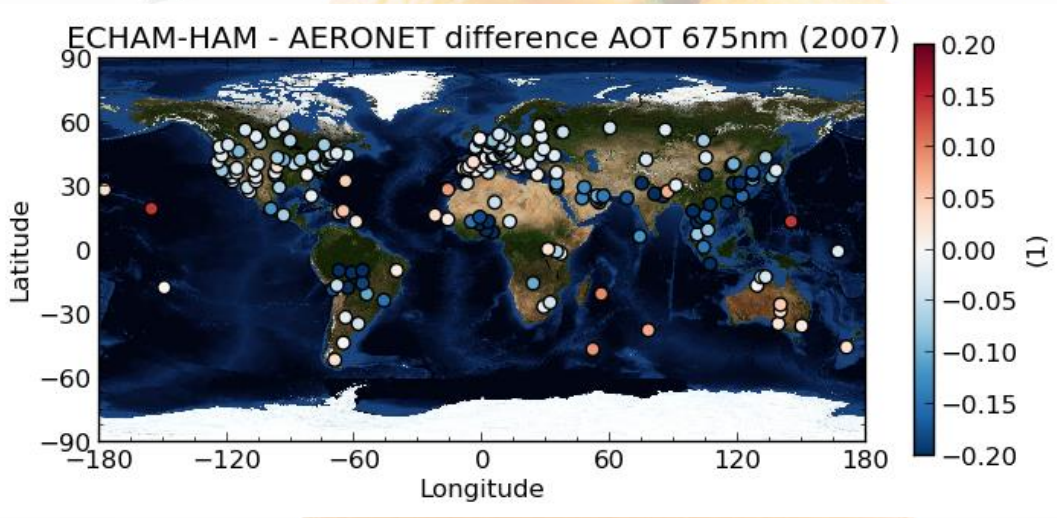
Flight campaign data



Spatio-temporal collocation

- Model gives global output every 3 hours for a full year
- Observations are day-time measurements, every 15 min for ~20 years





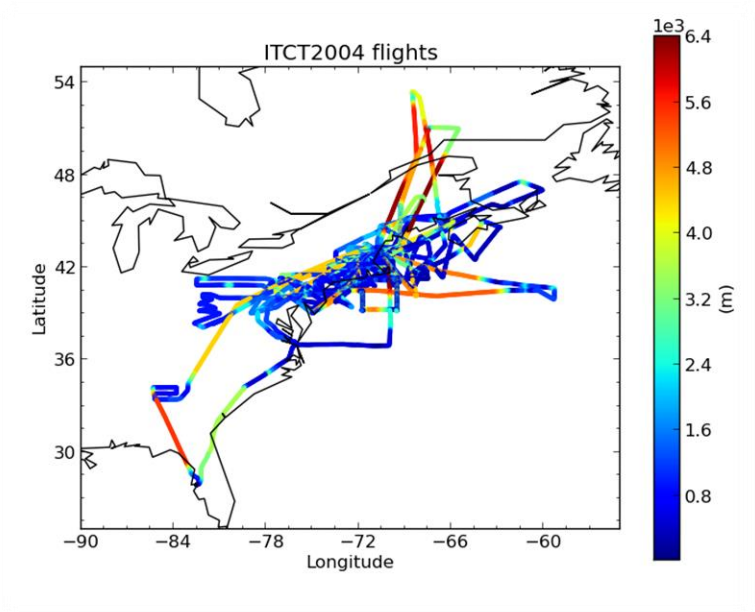
A grand total of 6 commands are required!

And now for something different: Project GASSP

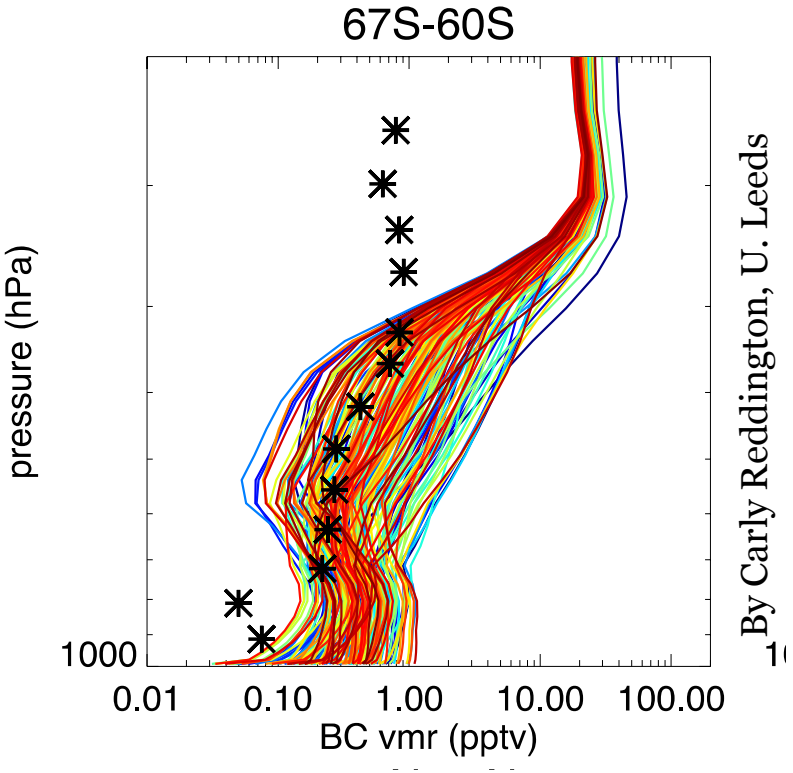
GASSP

Collaboration: Leeds, Oxford & Manchester U. PI: Ken Carslaw.

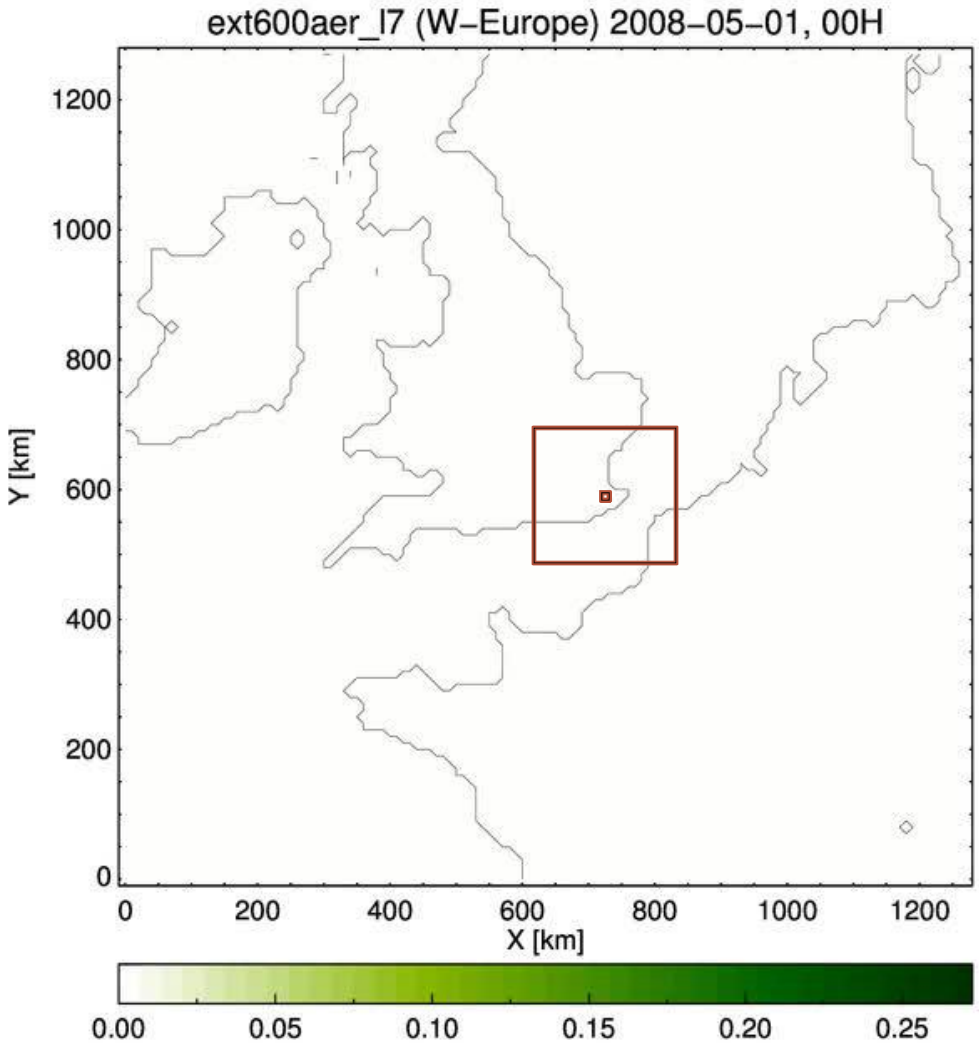
1. Large collection of in-situ data (in particular flight campaigns) are converted to the same data format (NetCDF)



2. Parametric uncertainty and structural error



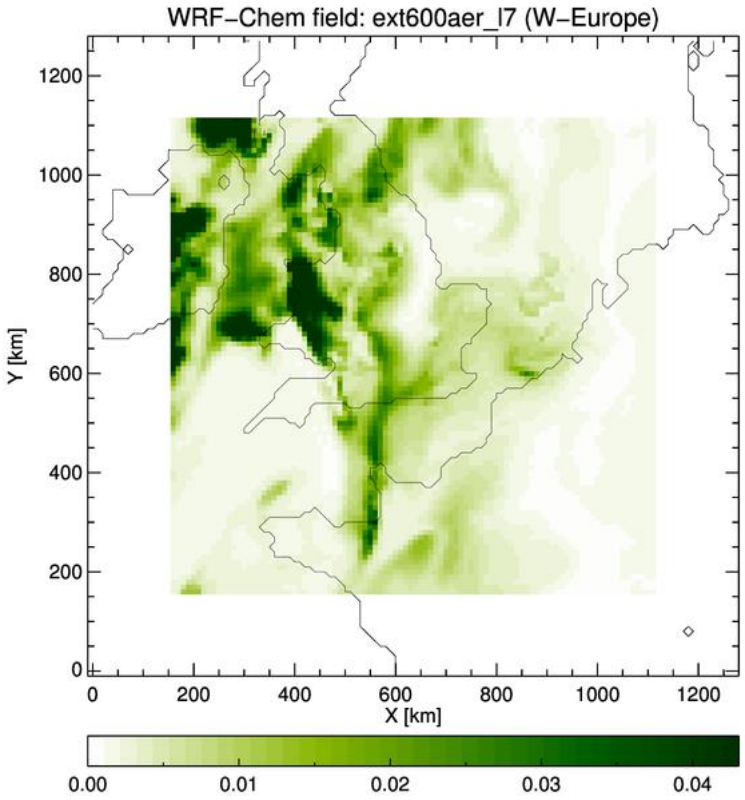
Perfect models & perfect observations

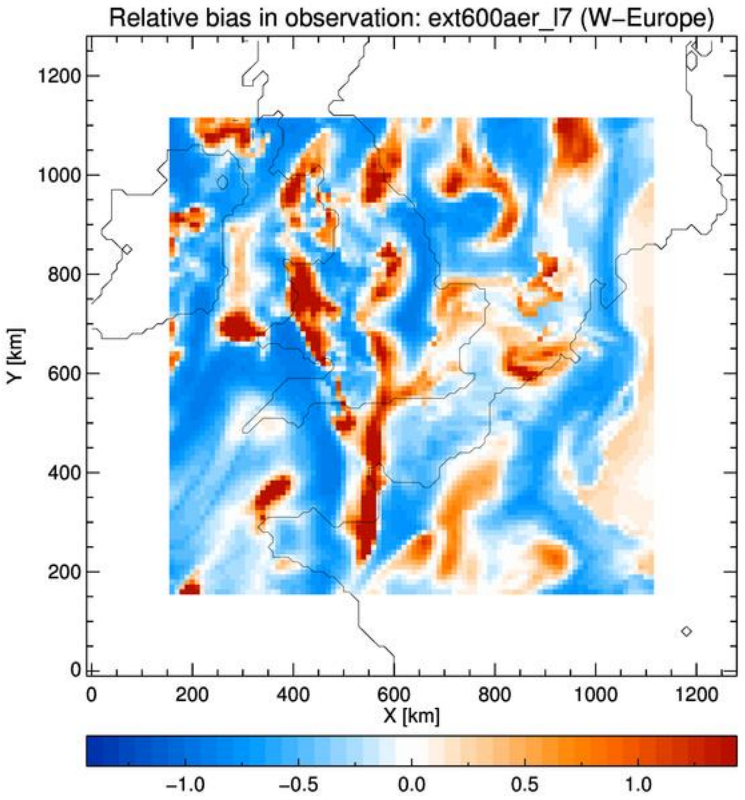


Aerosol extinction at an altitude of ~ 2km

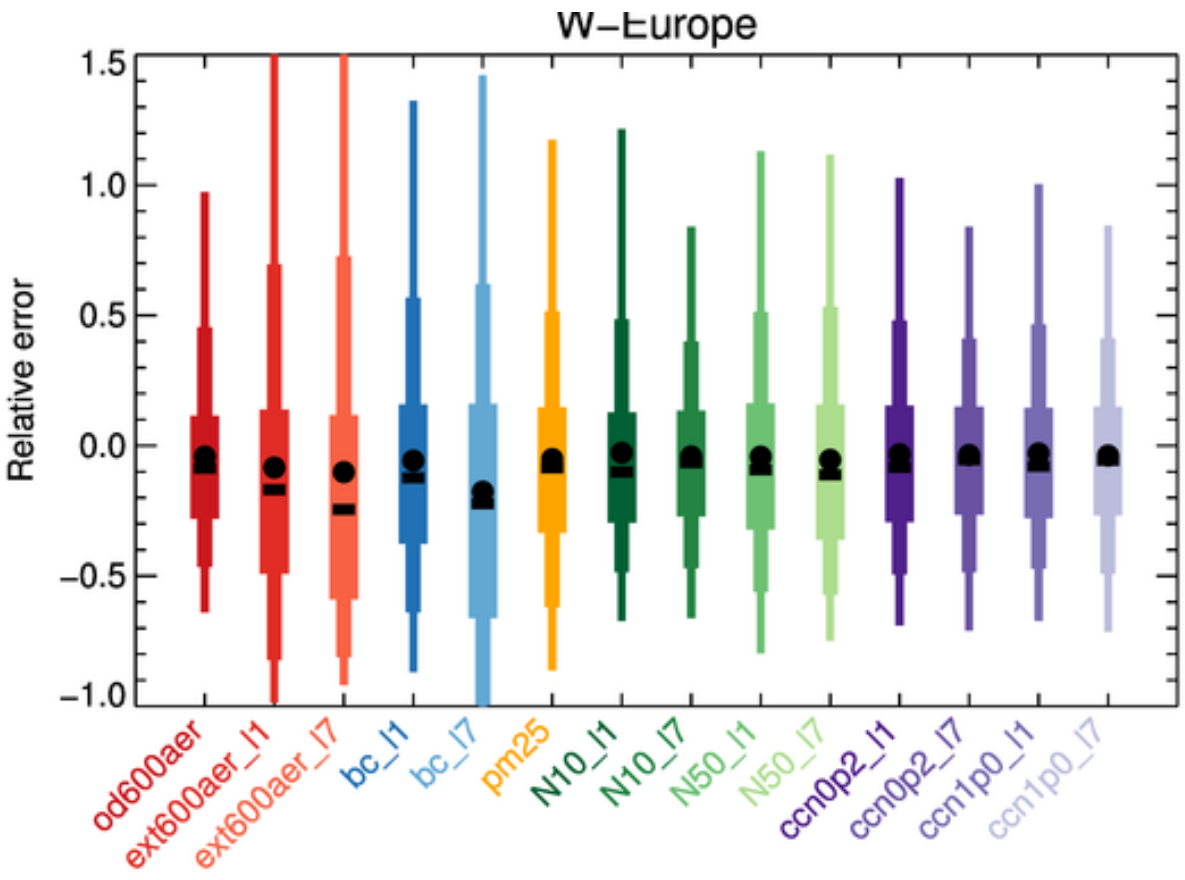
Instantaneous fields

Representation error

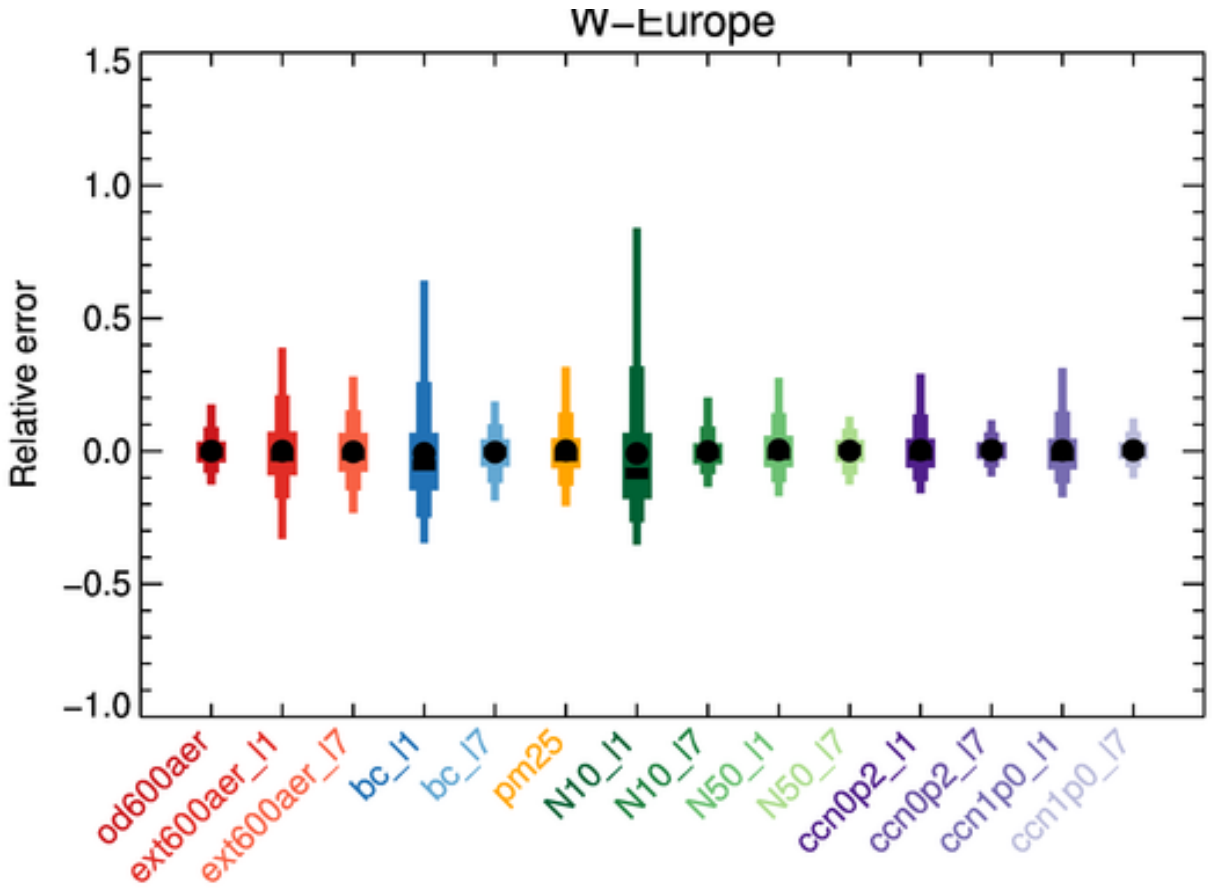




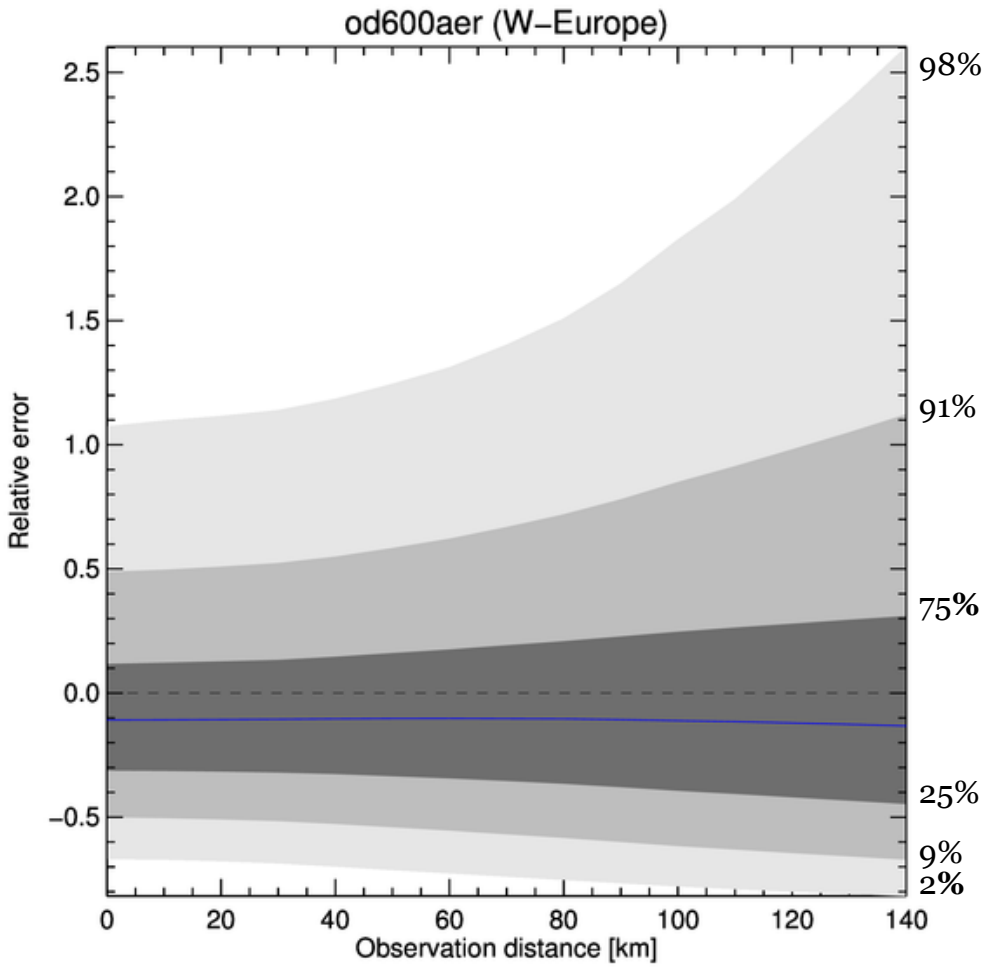
Other observables

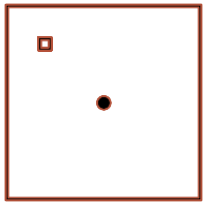


For monthly averages



Observations offset from grid-point



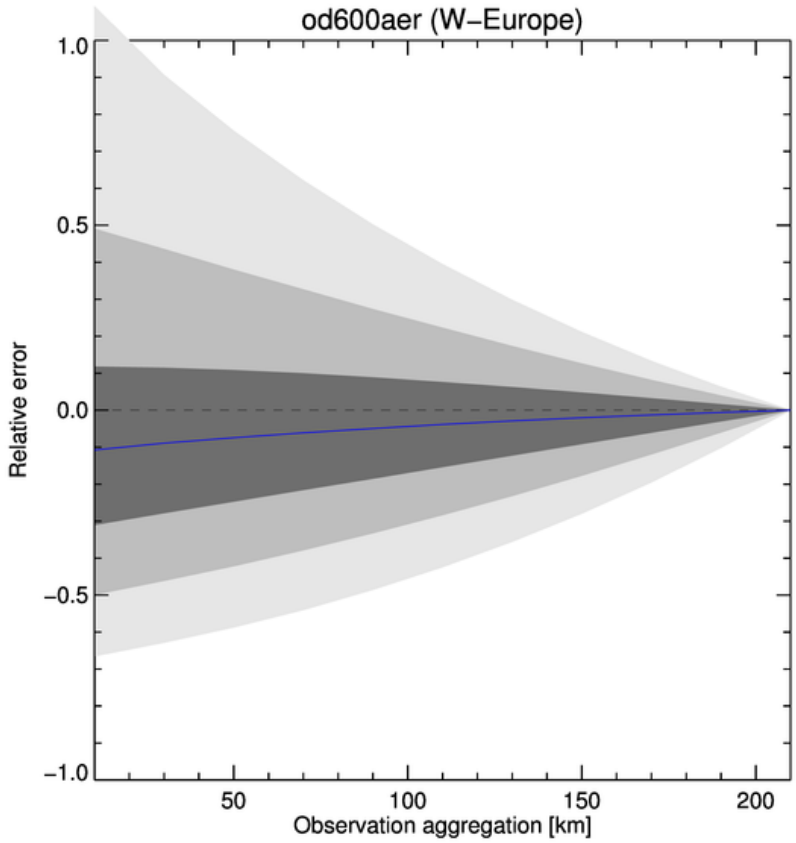


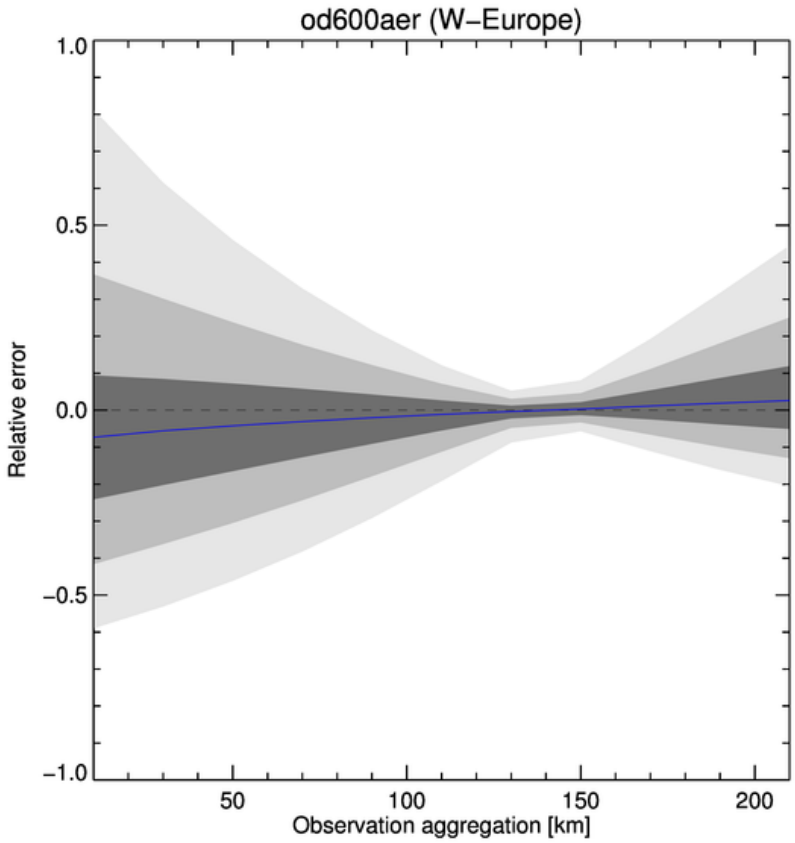
Toy model for representation errors

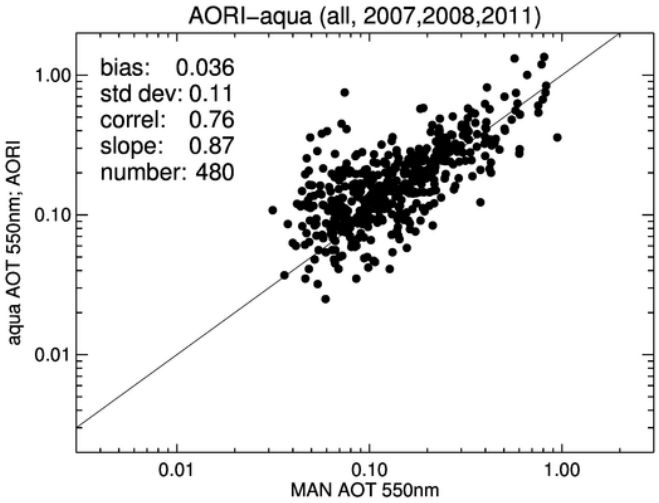
- Estimates of representation errors
- Sensitivity of those errors to
  - Region
  - Sampling strategies
  - Grid-box sizes
  - …
- Implications for
  - Surface measurements
  - Flight campaigns
- Suggestions for best practices

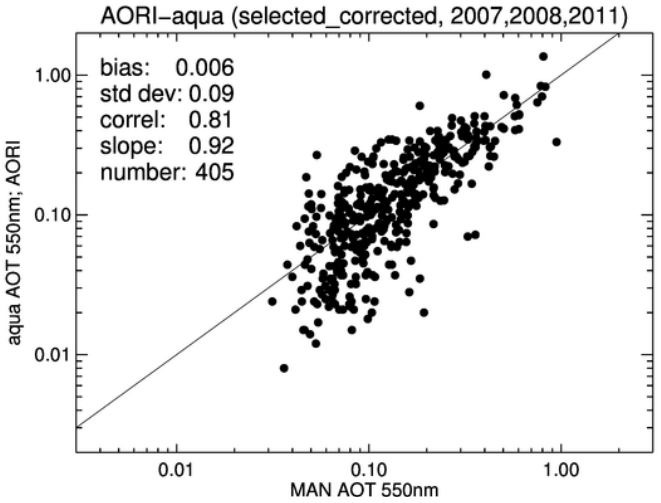
Summary

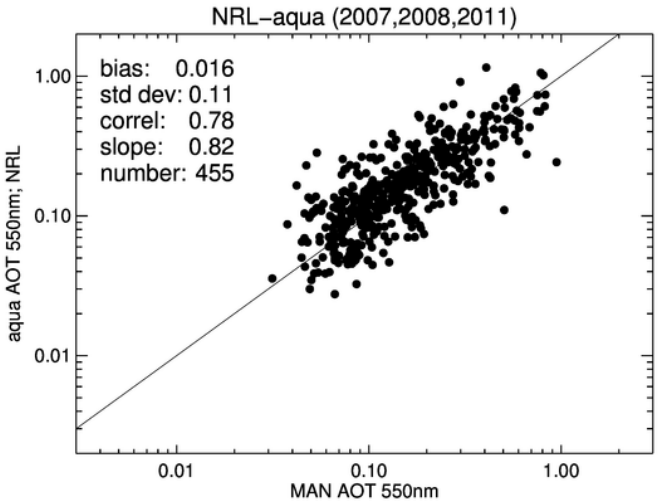
- EnKF developments
  - Emission and meteorology perturbations
  - CALIOP backscatter
  - Extensive tuning
  - Multiple sensor DA
- Community Intercomparison Suite
- GASSP
  - Large collection of in-situ data
  - Structural vs parametric errors
- Study of representation errors


od600aer (W−Europe)
1.0
0.5
0.0
−0.5
−1.0
Relative error
50
100
150
200
Observation aggregation [km]


od600aer (W−Europe)
1.0
0.5
0.0
−0.5
−1.0
Relative error
50
100
150
200
Observation aggregation [km]


AORI–aqua (all, 2007,2008,2011)
bias: 0.036
std dev: 0.11
correl: 0.76
slope: 0.87
number: 480
aqua AOT 550nm; AORI
MAN AOT 550nm
1.00
0.10
0.01


AORI–aqua (selected_corrected, 2007,2008,2011)
bias: 0.006
std dev: 0.09
correl: 0.81
slope: 0.92
number: 405
aqua AOT 550nm; AORI
MAN AOT 550nm
1.00
0.10
0.01


NRL–aqua (2007,2008,2011)
bias: 0.016
std dev: 0.11
correl: 0.78
slope: 0.82
number: 455
aqua AOT 550nm; NRL
MAN AOT 550nm
1.00
0.10
0.01