# Ensemble assimilation for aerosol

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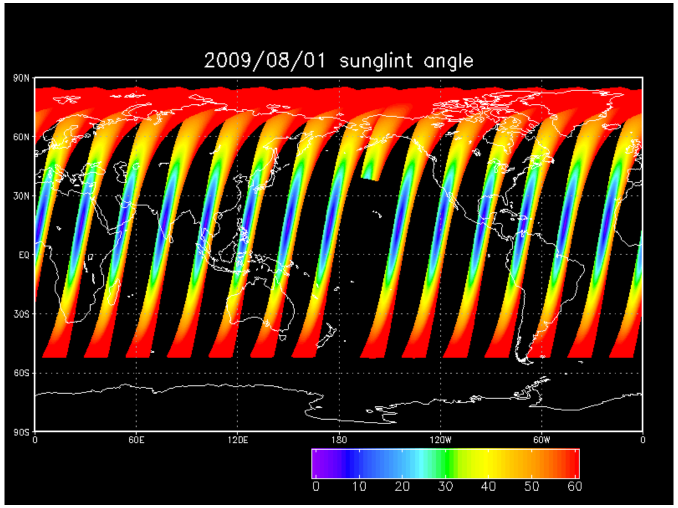
# Introduction

- What are our goals ?
  - More reanalysis than forecast
- What is our approach ?
  - Model
  - Observations
  - Assimilation
- Does it work ?
- Model parameter estimation

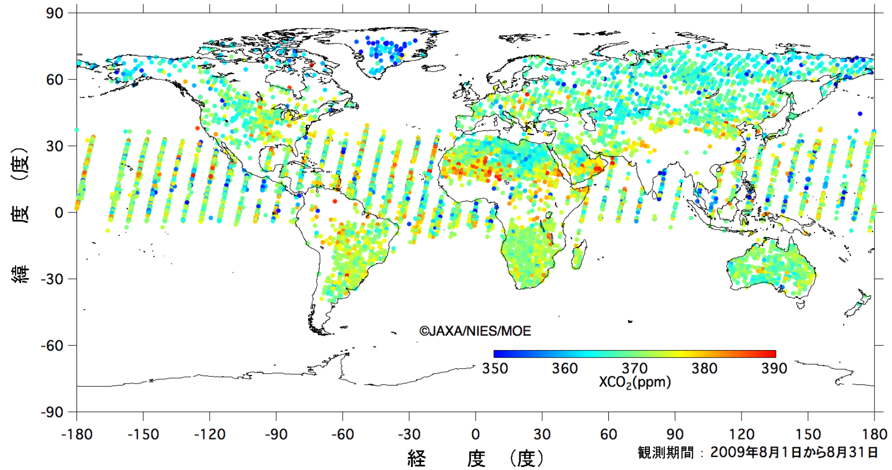
# GOSAT

Greenhouse gases Observing satellite

- Greenhouse gases Observing satellite
  - FTS for $CO_2$
  - CAI for clouds and aerosol
- $CO_2$ retrievals require aerosol information
- FTS has strong $CO_2$ signal where CAI has a weak aerosol signal
  - Ocean glint
  - Bright land surface
- Retrieve aerosol elsewhere and fill in the “gaps” with assimilation
- Over land: use 380nm channel
- Not yet operational




Courtesy S. Fukuda



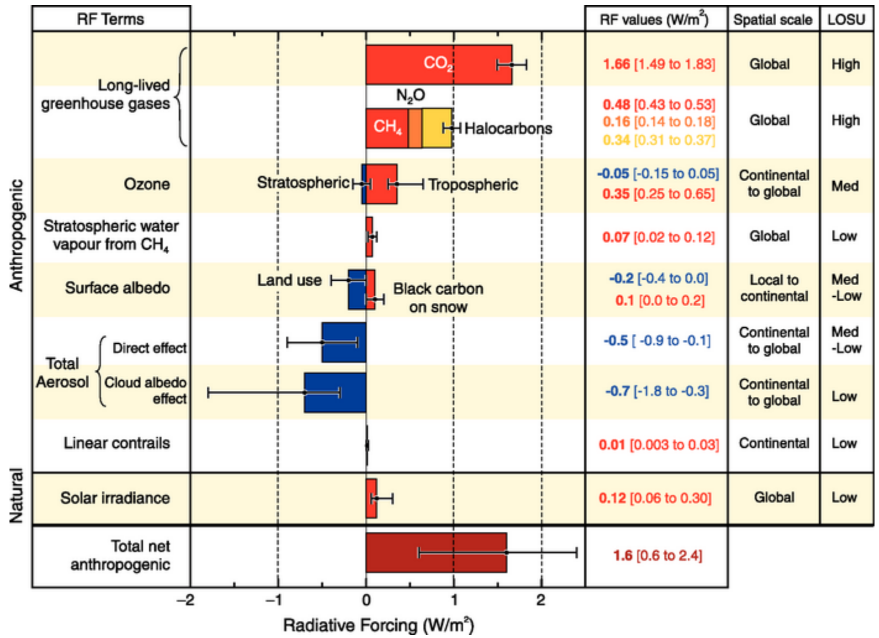

Imasu & Yokota 2010

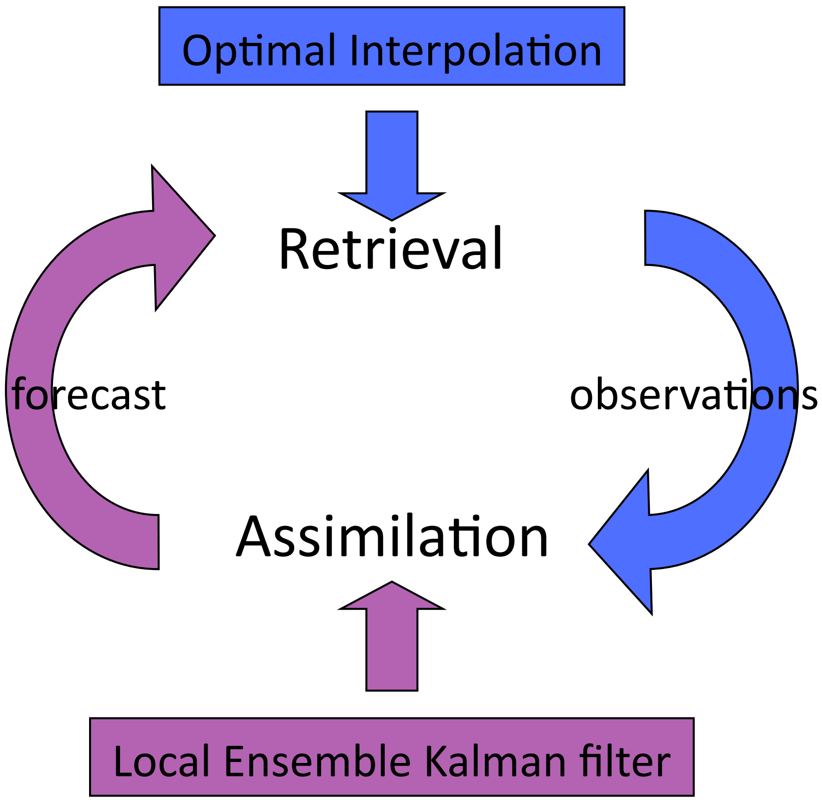
# G C O M - C

## Global Change Observation Mission – Carbon cycle

- Global Change Observation Mission – Carbon cycle
  - Multi-angle & polarimetric channels will allow retrieval of
    - AOT & AE (algorithm by S. Fukuda)
    - Particle size
    - SSA (for high AOT, algorithm by I. Sano)
  - Aerosol direct radiative forcings

Courtesy of IPCC FAR

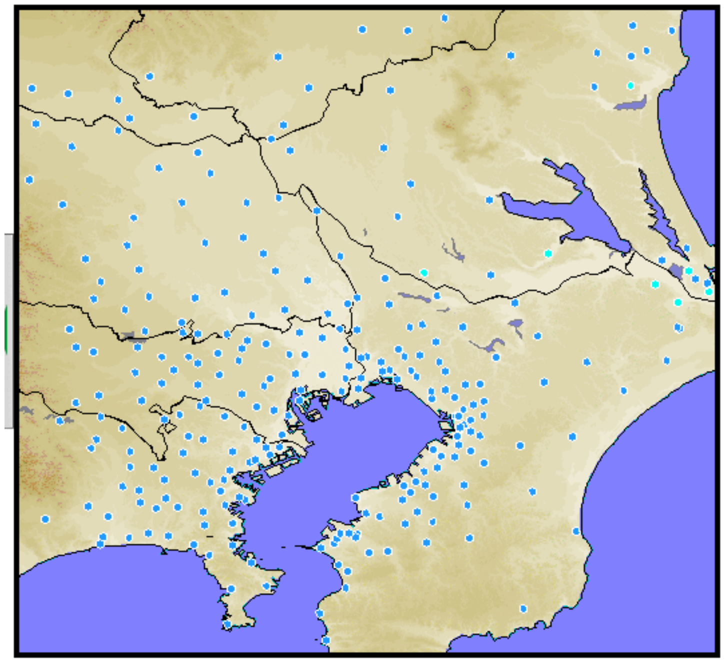


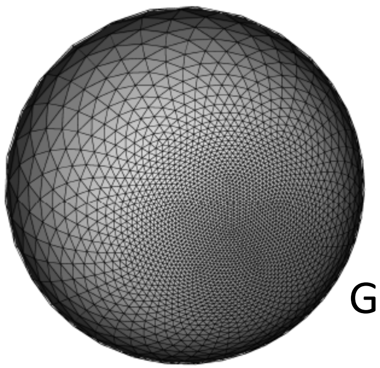



# S A L S A

Air-quality forecasts for Tokyo

- Seamless chemical AssimiLation System and its application for Atmospheric environmental materials
- Air-quality forecasts for the Greater Tokyo Metropolitan Area
  - Aerosol & $O_3$ (T. Dai)
  - $CO_2$ (Y. Niwa)
- Regional version of nonhydrostatic global NICAM model (3.5 km) with aerosol module
- Initialized by assimilation of SPM measurements (~ $PM_7$)



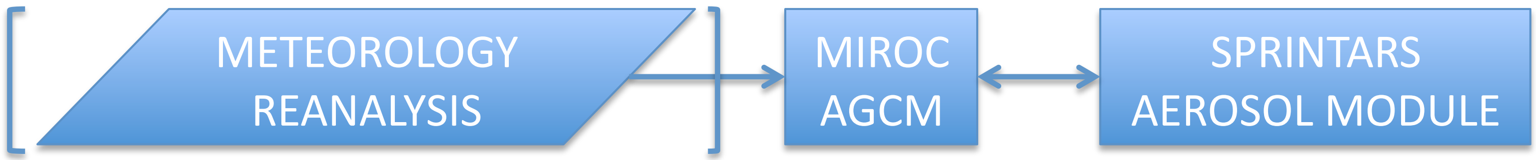


Global NICAM grid

# Global aerosol model

## SPRINTARS

Spectral Radiation-Transport model for Aerosol
(Takemura et al., 2000, 2002, 2005, 2009)




- Wind speeds, temperature, specific humidity
- NCEP or GPV-JMA

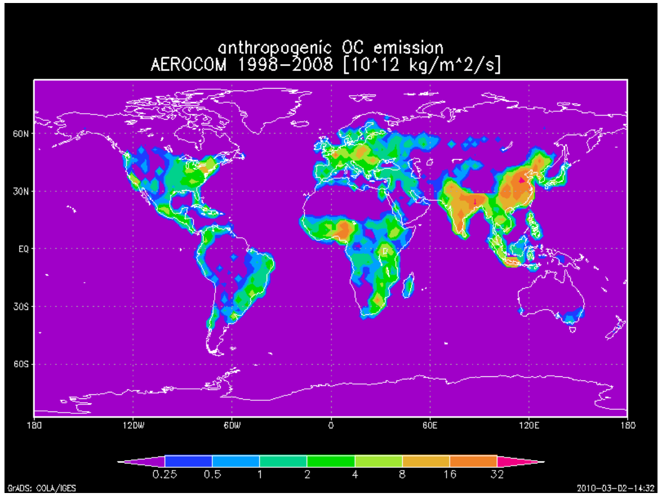
- T42/20 levels, (T106/20 or 56 levels)
- Flux-form semi-Lagrangian
- Arakawa-Schubert cumulus convection

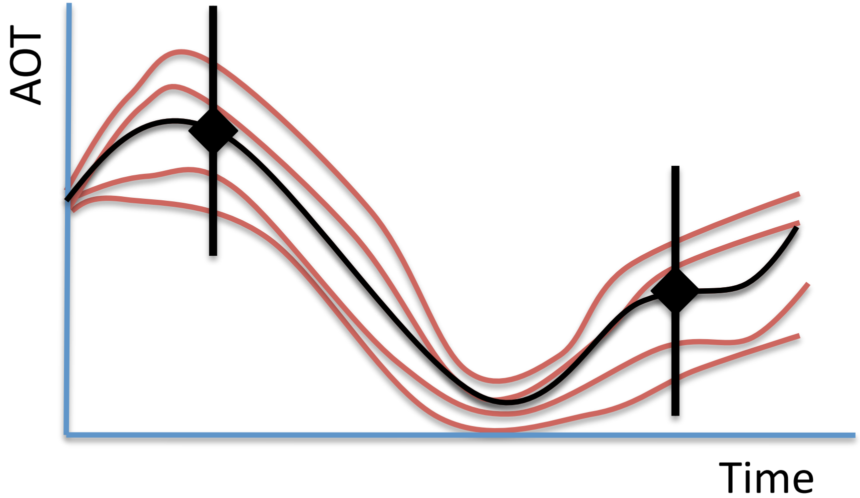
- Direct aerosol effect on radiative balance
- 1st and 2nd indirect aerosol effects on clouds

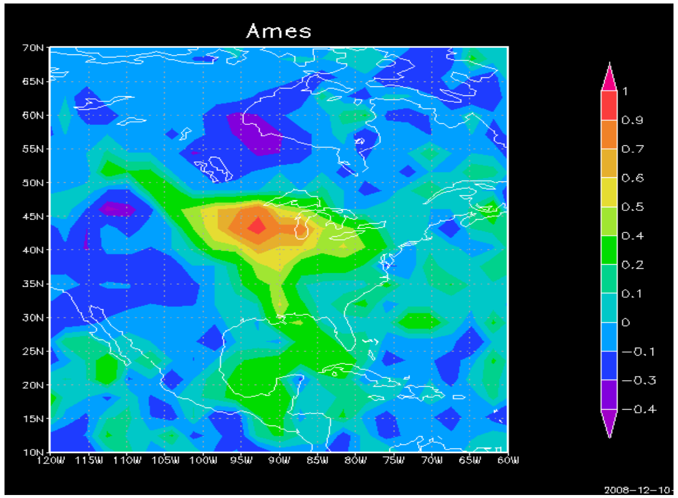
- Sea salt: $w_{10}$ (Ericksson or Monahan)
- Mineral dust: $w_{10}$, vegetation, soil moisture, snow cover, LAI
- Sulfate: fossil fuel, biomass burning, volcanoes
- DMS: plankton, vegetation
- Carbons: fossil fuel, biomass burning, agricultural activities, plant emissions
- Chemistry: sulfur oxidation, (SOA chemistry, nitrate thermal eq.)
- Removal through wet & dry deposition, gravitational settling

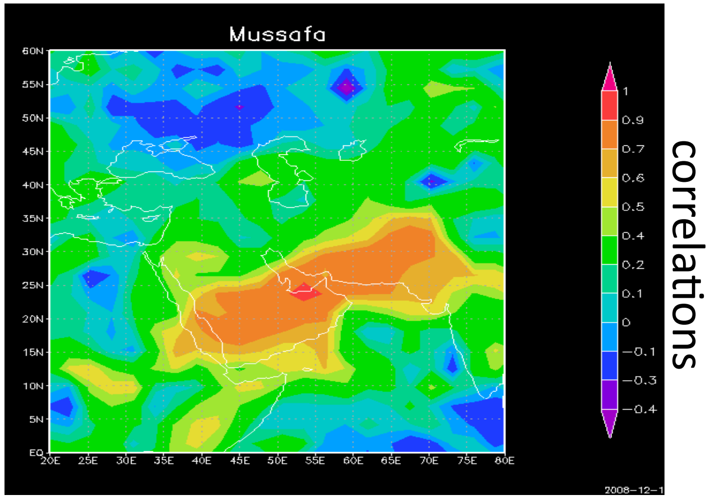
# Ensemble assimilation

The basics



# E n s e m b l e

## LETKF for aerosol

- Create an ensemble of perturbed emissions for aggregate aerosol
- Initialize ensemble: month-long simulation,  with perturbed emission inventories
- Usual ensemble size: 24 – 32
- Start sequence of assimilation and simulation; do not change perturbed emissions but analyze atmospheric mixing ratios
- Local Ensemble Transfrom Kalman filter (Hunt et al 2007, Miyoshi & Yamane 2007)
- Assimilation window: 1 day ("4D-LETKF without temporal localization", "no-cost smoother")
- Localization: adjust observational errors based on spatial separation
- Observation operator uses ensemble-averaged scattering properties
- Analyzed variable: aggregated aerosol mixing ratios (e.g. fine & coarse)
- Inflation: not very important. Emission ensemble introduces variation.

# Sensitivity experiments

With the ensemble Kalman filter

| Parameter | Range | Importance | Optimal | Comments |
|---|---|---|---|---|
| Ensemble size | 10 - 40 | | 20 | |
| Local patch size | 2 - 6 | | 4 | |
| Inflation factor | 1.0 - 1.3 | | 1.03 | |
| Emission length-scale | 1 - 128 | | 128 | ensemble spread |
| Observation type | AOT / AOT & AE / 2 AOT | | AOT & AE | |
| Analyzed variable | 2 or 3 modes | | 2 modes | fine: carbon & sulfate |
| Ensemble spinup | yes or no | | yes | ensemble spread |
| | | | | |
| MODIS aggr. pixel size | $0.25^{o}$ - $1.0^{o}$ | | $0.5^{o}$ | |
| Smoother time window | $12^{h}$ - $48^{h}$ | | $24^{h}$ | |
| Observation time window | $2^{h}$ - $3^{h}$ | | $3^{h}$ | |
| Observational error | normal or halved | ? | | |
| Seasalt parametrisation | Ericksson or Monahan | | Monahan | |
| | | | | |

Schutgens et al. ACP 2010b

# M E R I T S

Of ensemble Kalman filter/smoother technique

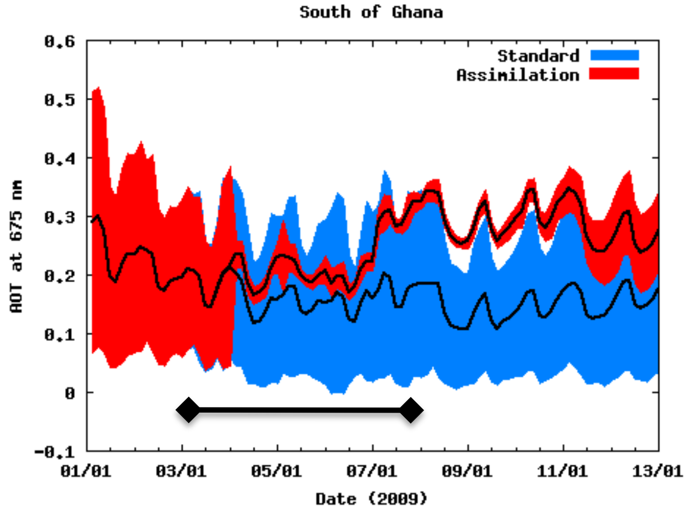
The next 5-10 yr will show whether EnKF becomes the operational approach of choice, or 4DVAR [..] remains the preferred advanced data assimilation method.

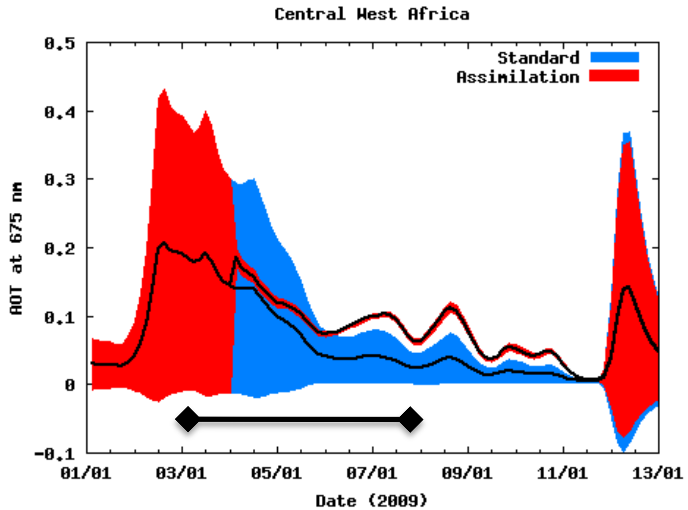
*Kalnay et al., Tellus 2007*

- Advantages of ensemble Kalman assimilation:
  - Simple to design and maintain (uncertain aerosol parametrisations!)
  - Flow-dependent model covariant
  - Generates optimal analysis ensemble (forecast plume)

- Disadvantages of ensemble Kalman assimilation:
  - High CPU costs (yet competitive with 4DVAR)

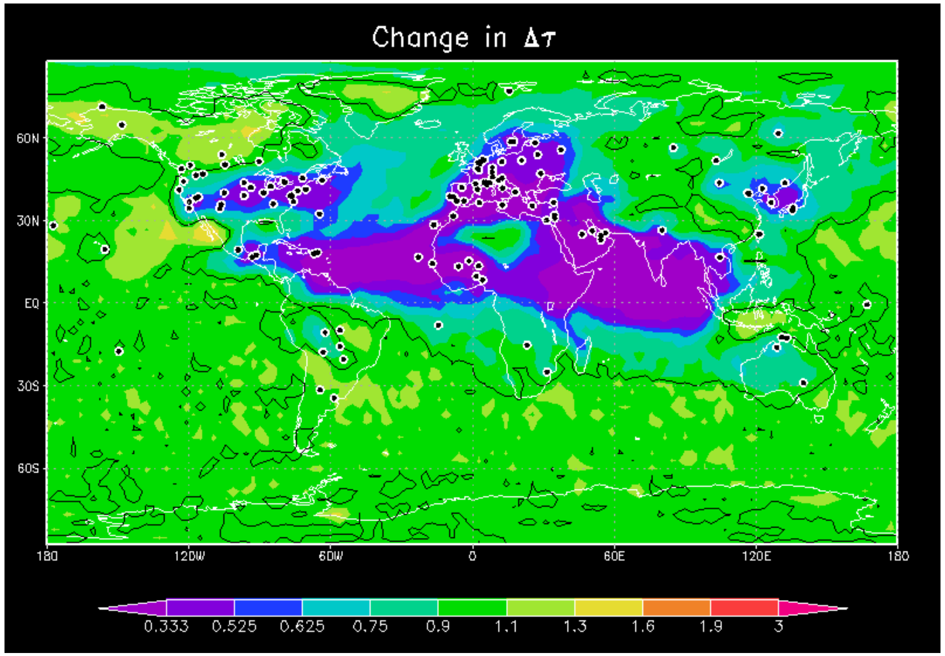
# Ensemble spread




assimilation

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.



# Observations

Currently used datasets

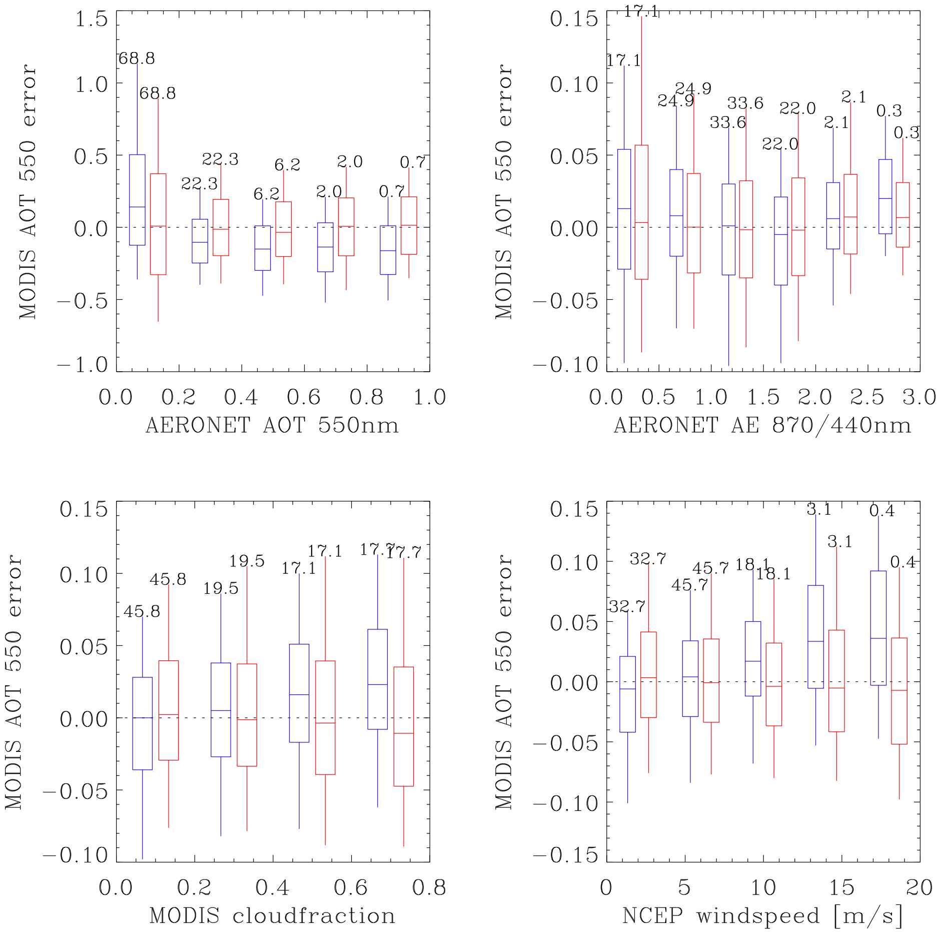
| Dataset | Location | Observables | Treatment | | *n*/day |
|---|---|---|---|---|---|
| AERONET | Global, land | AOT, AE, (SSA) | As is (!) | $3^h$ | ~400 |
| SKYNET | SE Asia | AOT, AE | As is | $3^h$ | ~20 |
| CSHNET | China | AOT, AE | As is | $3^h$ | ~30 |
| MODIS | Global, ocean | AOT, (AE) | Debiased | $0.5^o$ | ~5000 |
| ADNET | SE Asia | Att. β | Cloud-screened | $3^h$ | |
| CALIOP | Global | Att. β | As is (!) | $3^h$ | |
| (MISR | Global, land | AOT | ? | ? | ?) |

Care is taken to use only observations with uncorrelated errors:

- AOT and AE instead of multiple AOT
- Attenuated backscatter profiles instead of retrieved extinction profiles

# MODIS errors

Over ocean



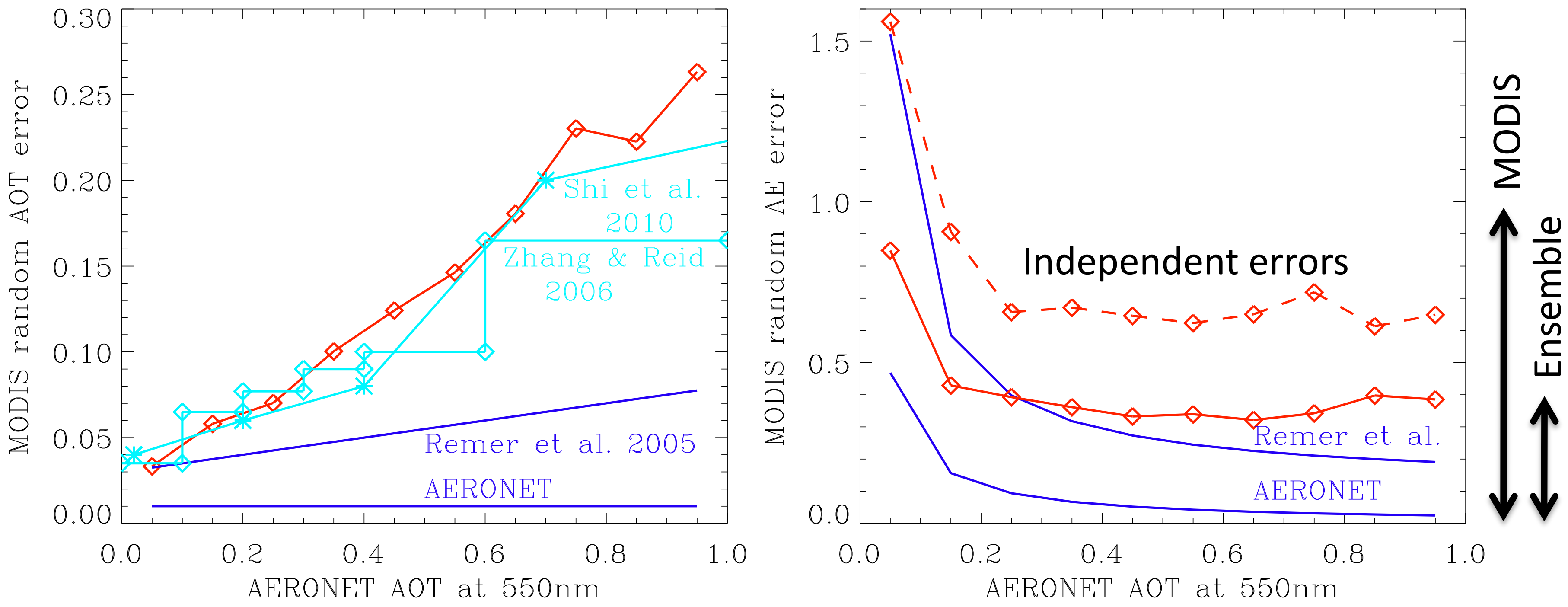

- Coastal AERONET sites
- 2003 – 2009
- Both Terra & Aqua
- Independent observations
- Innovative error correction
- Collaboration with

  M. Nakata from Kinki U.

New AOT = $a_0$ + $a_1$ AOT + $a_2$ AE + $a_3$ CLOUD-FRACTION + $a_4$ WINDSPEED

# M O D I S e r r o r s

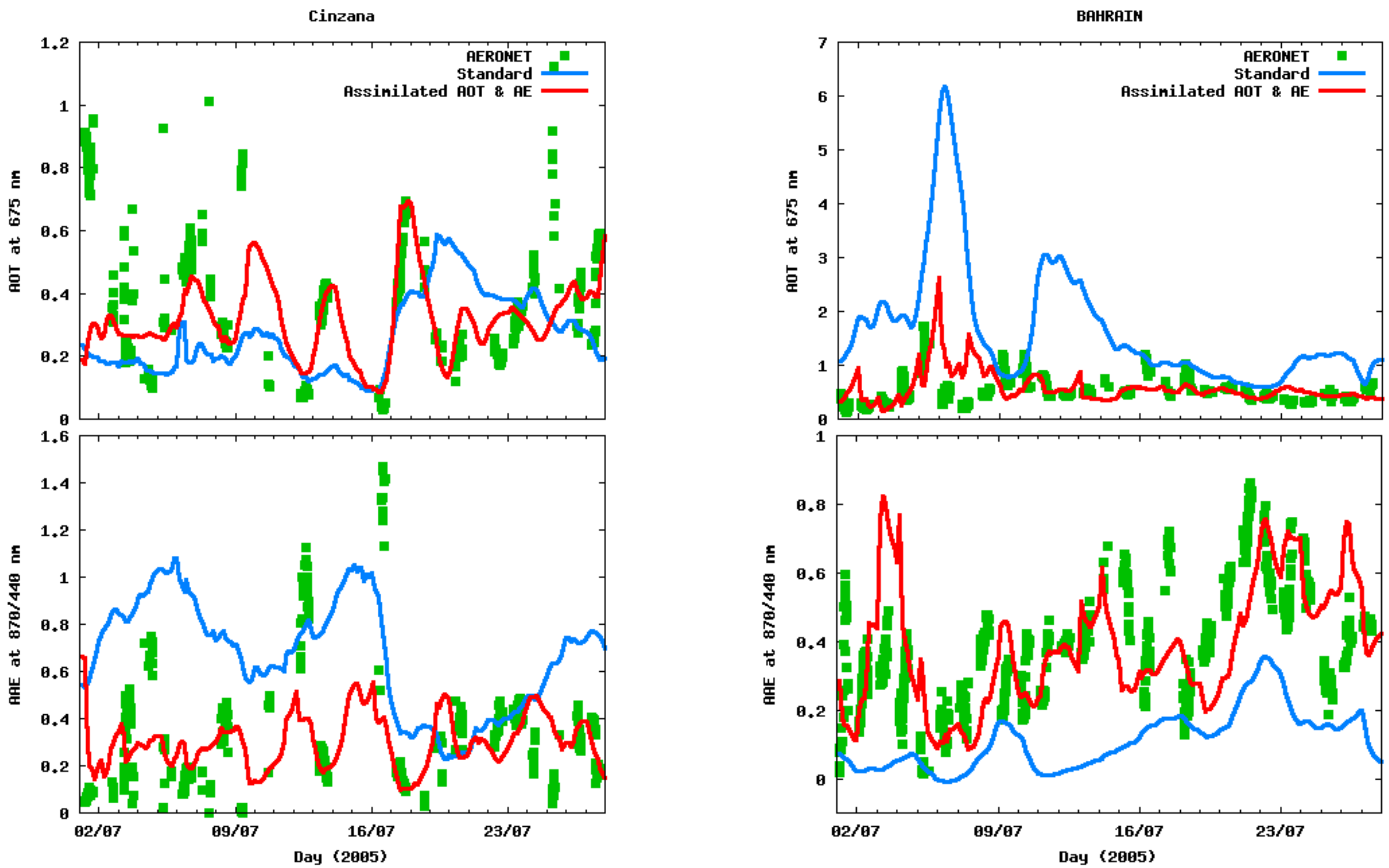
Random error characterization



# Kalman filter results

Assimilation of AERONET AOT & AE

Validation of the Kalman filter through independent AERONET data

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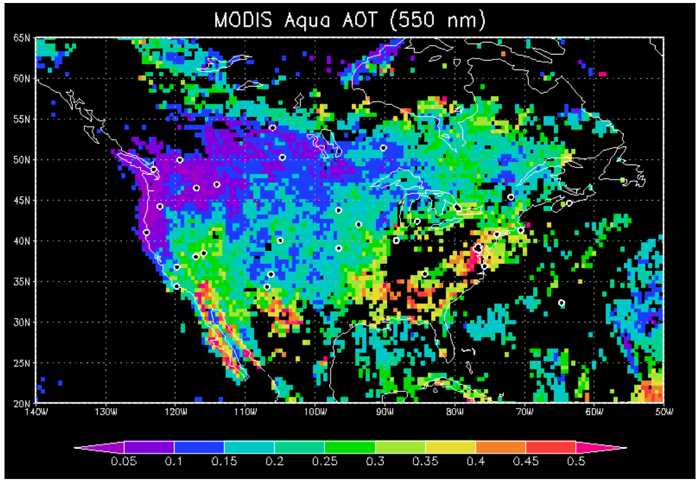
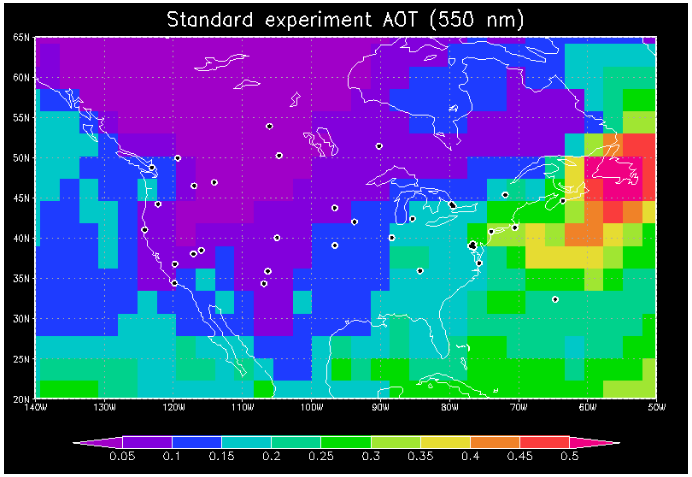
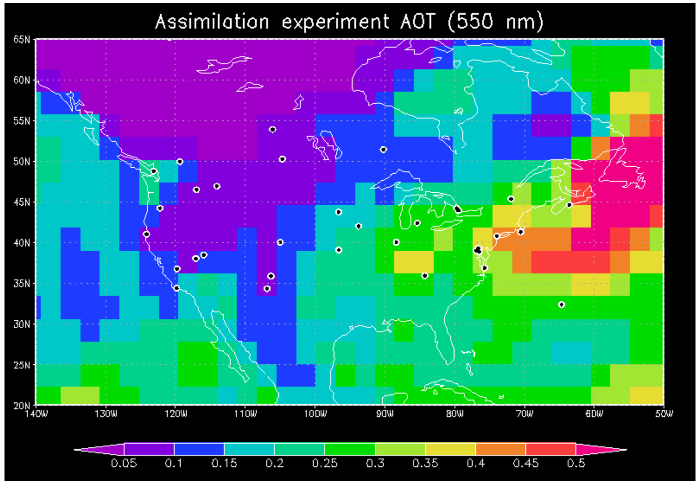
# Kalman filter results

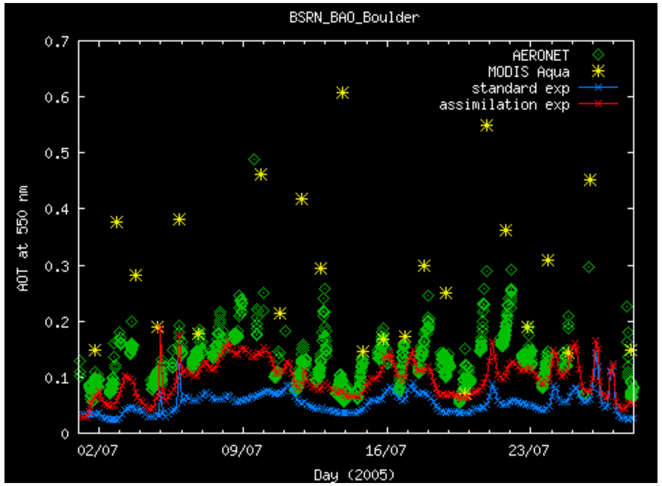
## Assimilation of AERONET AOT & AE

Validation of the Kalman filter through independent MODIS Aqua data




Schutgens et al. ACP 2010a

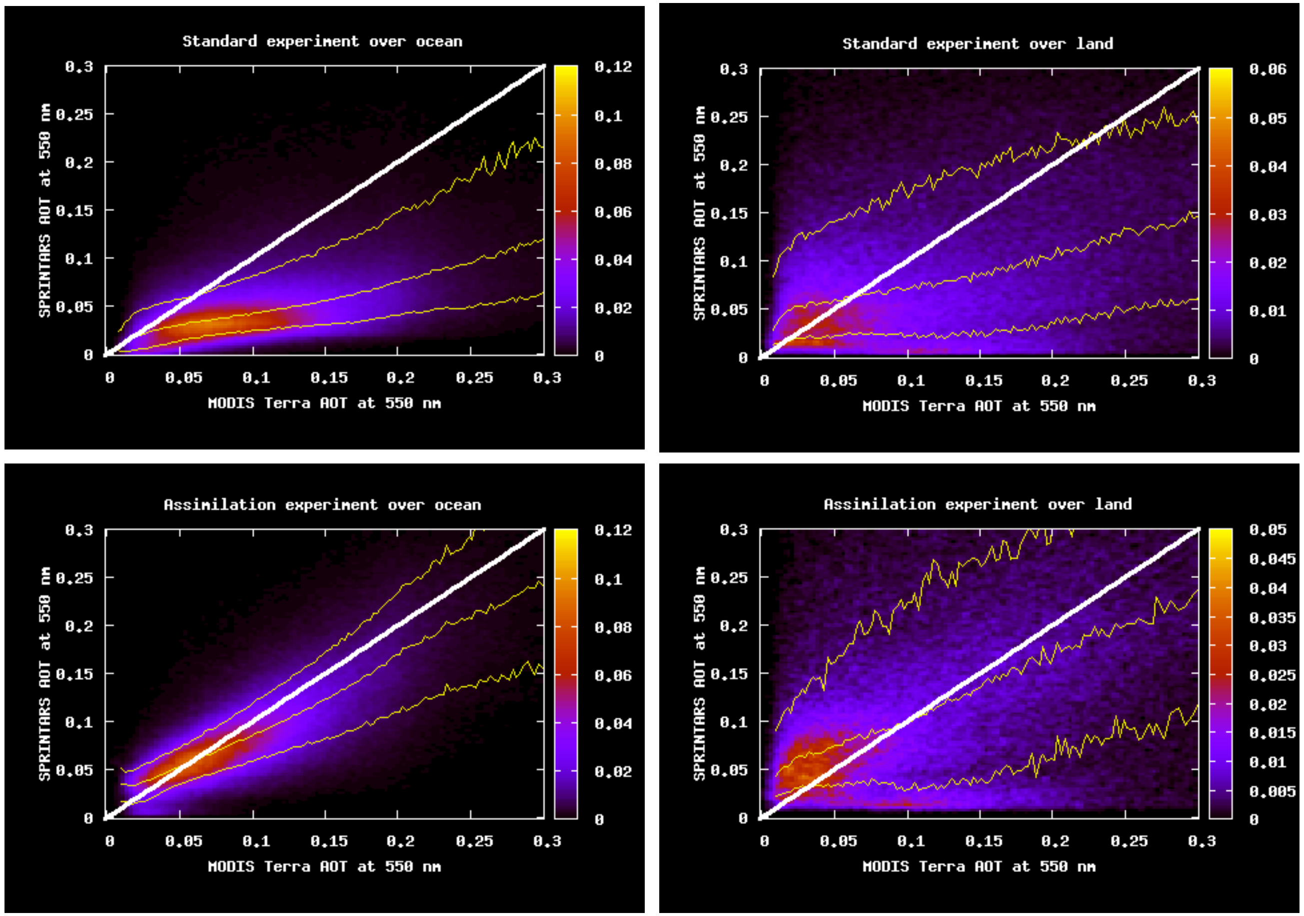
# K a l m a n   f i l t e r   r e s u l t s

Assimilation of MODIS AOT and AERONET AOT & AE

Ocean Land

Standard

Assimilation



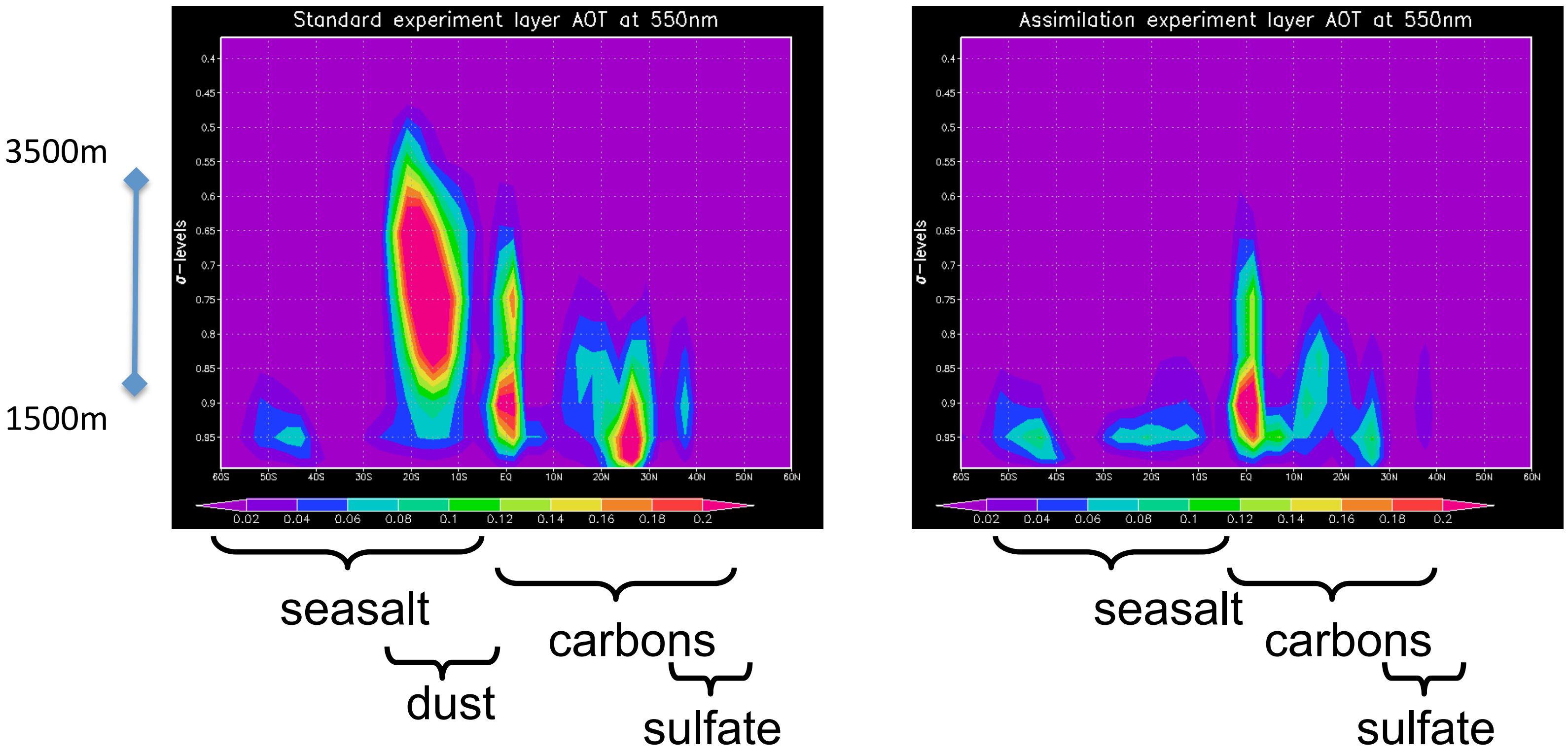

After assimilation, RMS errors are comparable to MODIS observational errors.

# Kalman filter results

Assimilation of MODIS AOT and AERONET AOT & AE

Although we assimilate column-integrated properties (MODIS Terra AOT, AERONET AOT & AE), the ensemble approach leads to redistributed profiles.

January 18-22, 2009

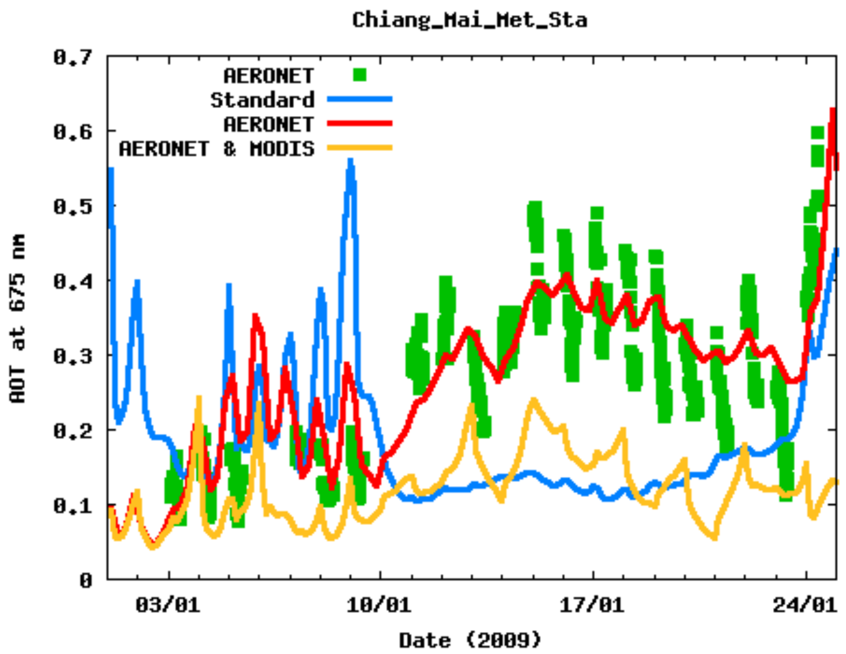


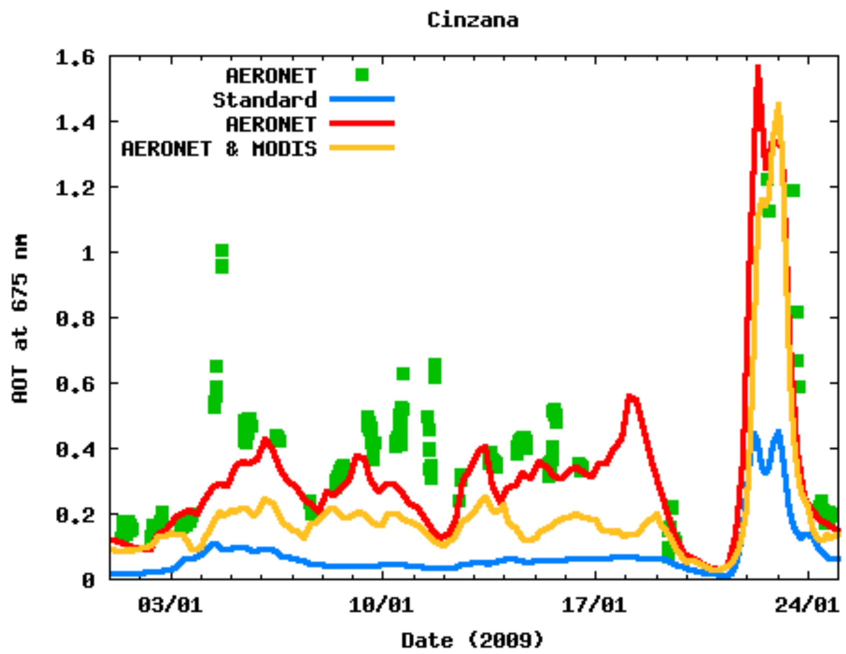
# Kalman filter results

## Assimilation of MODIS AOT and AERONET AOT & AE

MODIS over land observations sometimes has a negative impact on the consistency of the AOT after assimilation and AERONET AOT

- due to regional biases in MODIS AOT ?
- due to regional correlations in MODIS AOT error ?

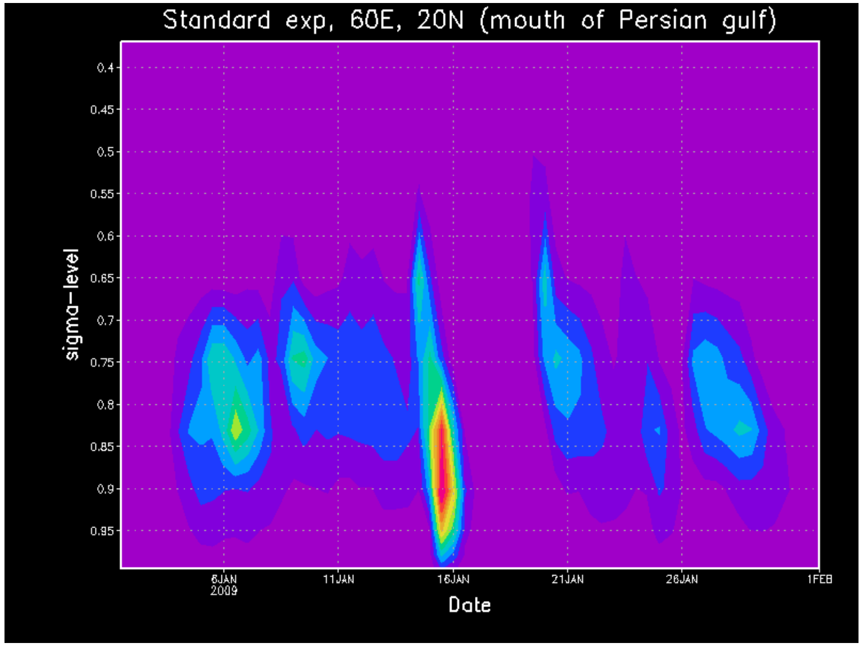


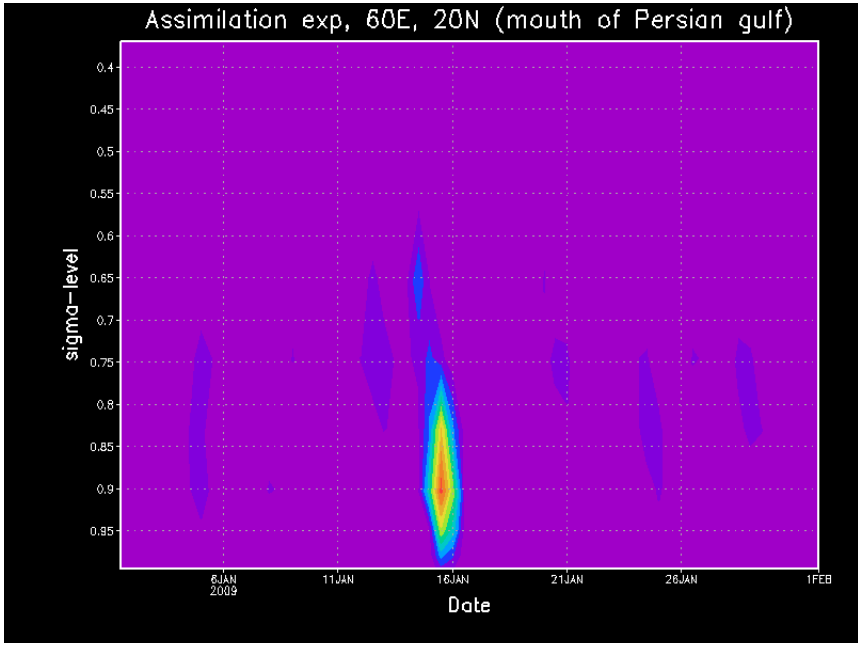



# Kalman filter results

Assimilation of CALIOP attenuated backscatter at 532nm

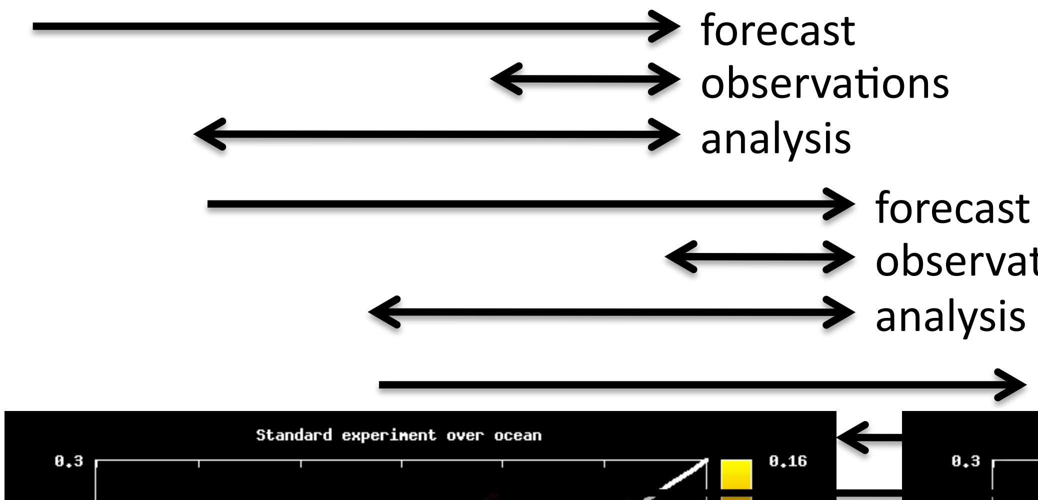
First experiments show strong impact on dust storms in free troposhere. Boundary layer is seldom sampled. Validation in progress (E. Oikawa)



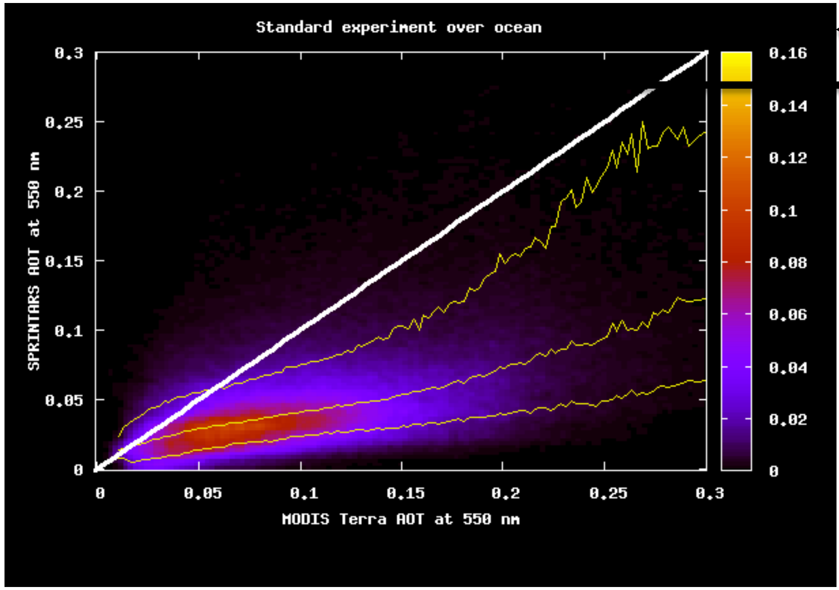



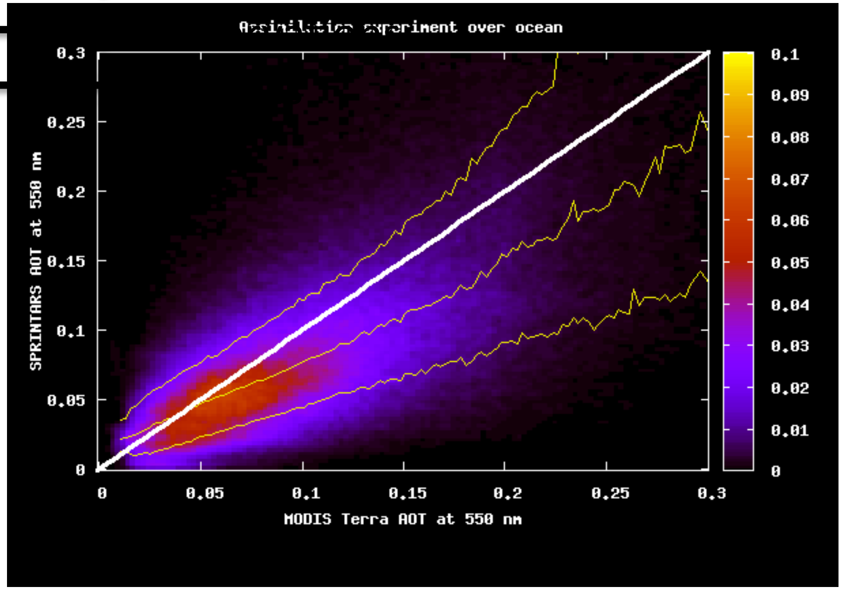
# Kalman smoother results

Assimilation of MODIS AOT over ocean and AERONET AOT & AE



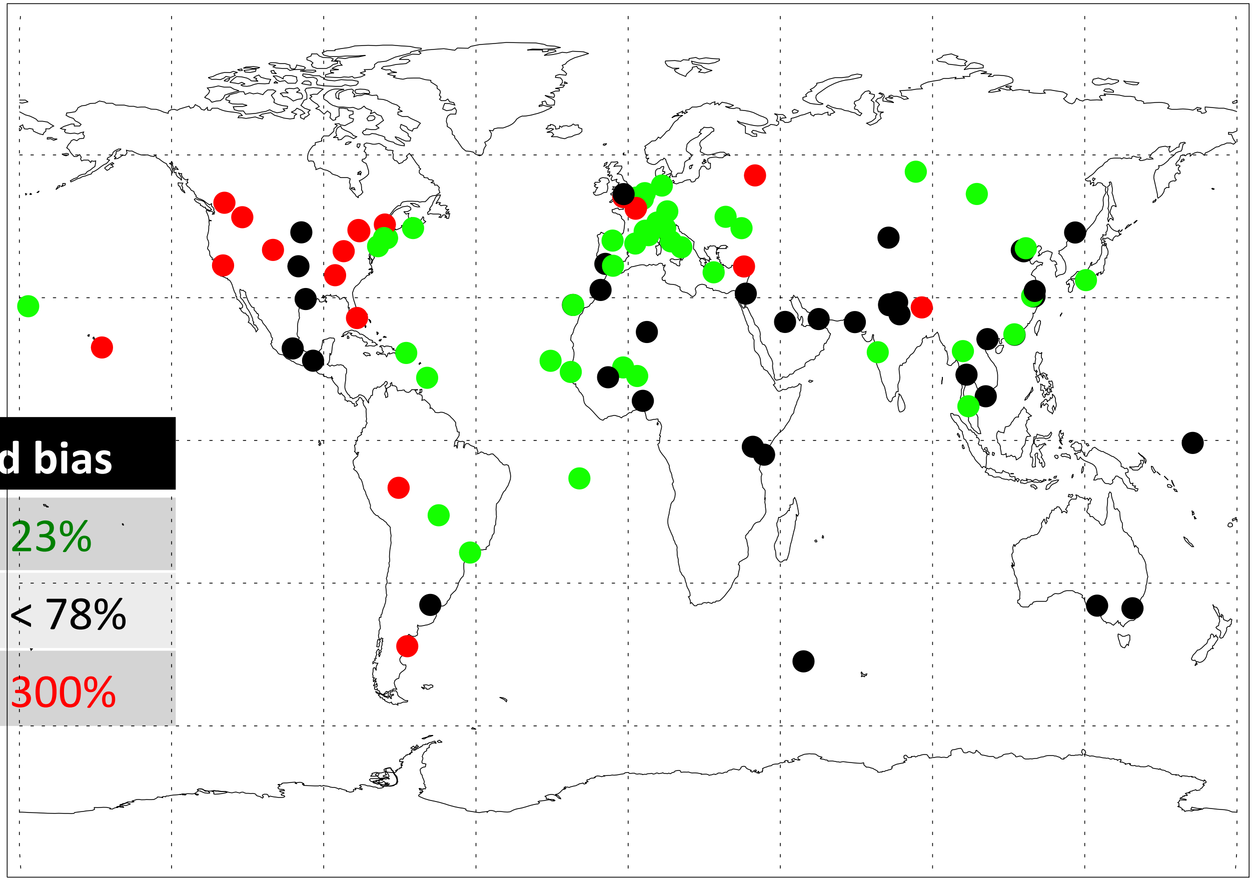

Analyzed variables:
Model parameters, e.g. emissions



# Kalman smoother results

Assimilation of MODIS AOT and AERONET AOT & AE



| Sites | New/old bias |
|---|---|
| Best 25% | 0 < R < 23% |
| Remainder | 23 % < R < 78% |
| Worst 25% | 78 < R < 300% |

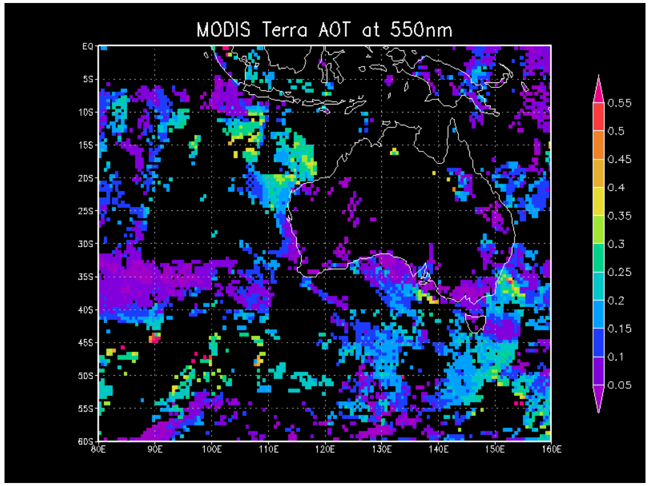
# Summary

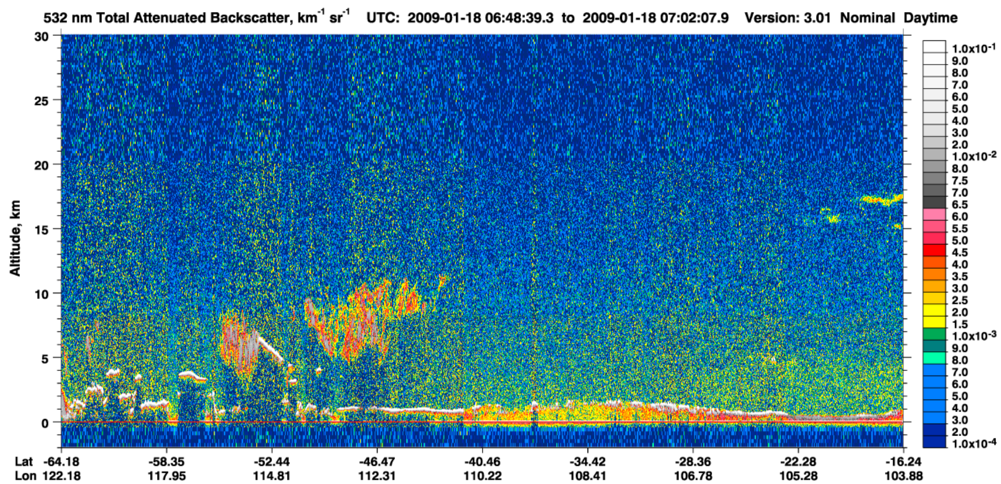
- Implemented and tested ensemble Kalman filter and smoother
  - Analyse mixing ratios or model parameters
- Support for OSSEs
- Support for various observations
  - MODIS
  - AERONET, SKYNET, CSHNET
  - CALIOP

# Kalman filter results

Observations during January 18 -22, 2009

Assimilated




For comparison