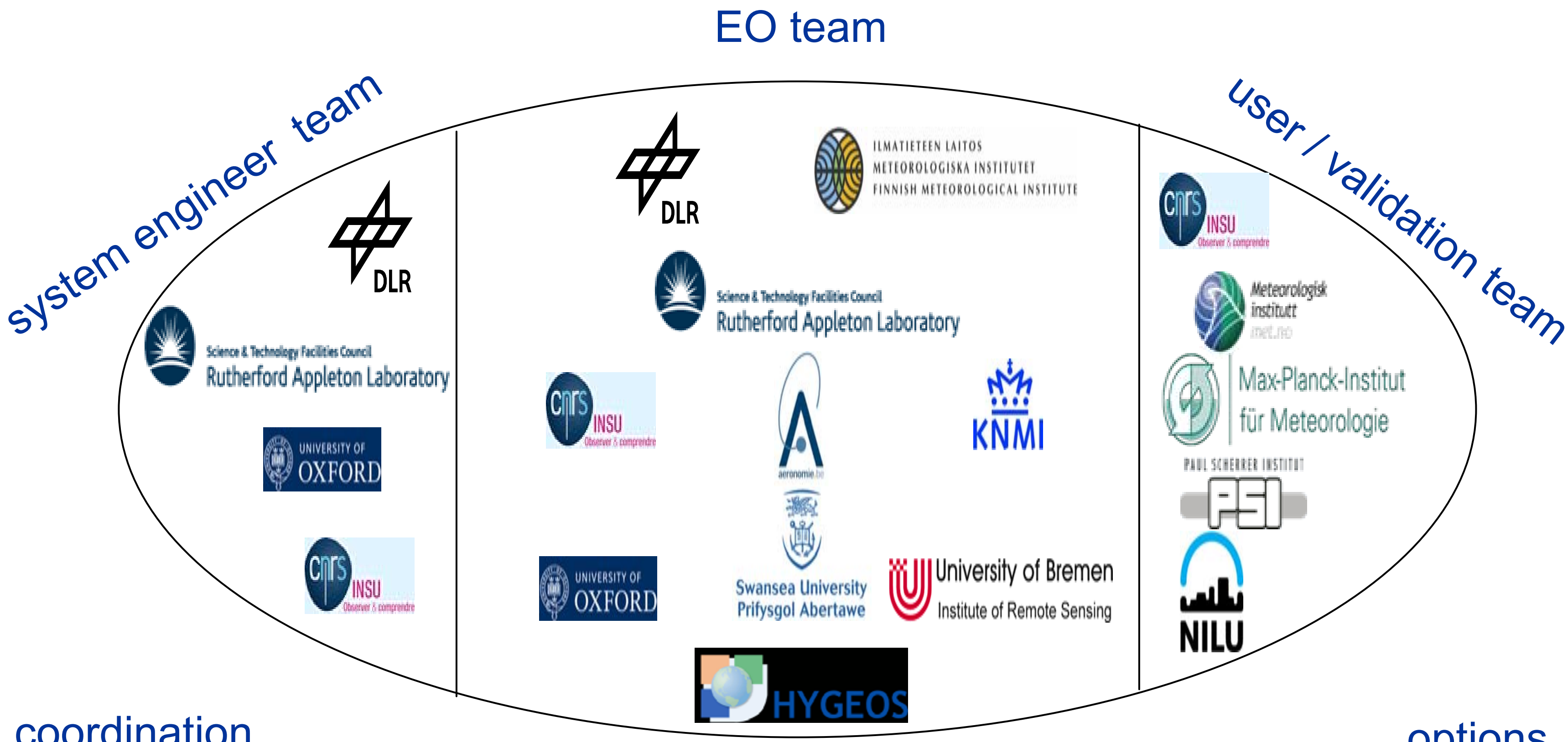
Extensive aerosol retrieval algorithm evaluation within ESA aerosol_cci project

Thomas Holzer-Popp (DLR), Gerrit de Leeuw (FMI)
& the Aerosol_cci team

aerosol_cci team



coordination

DLR

Ilmatieteen laitos
Meteorologiska institutet
Finnish Meteorological Institute

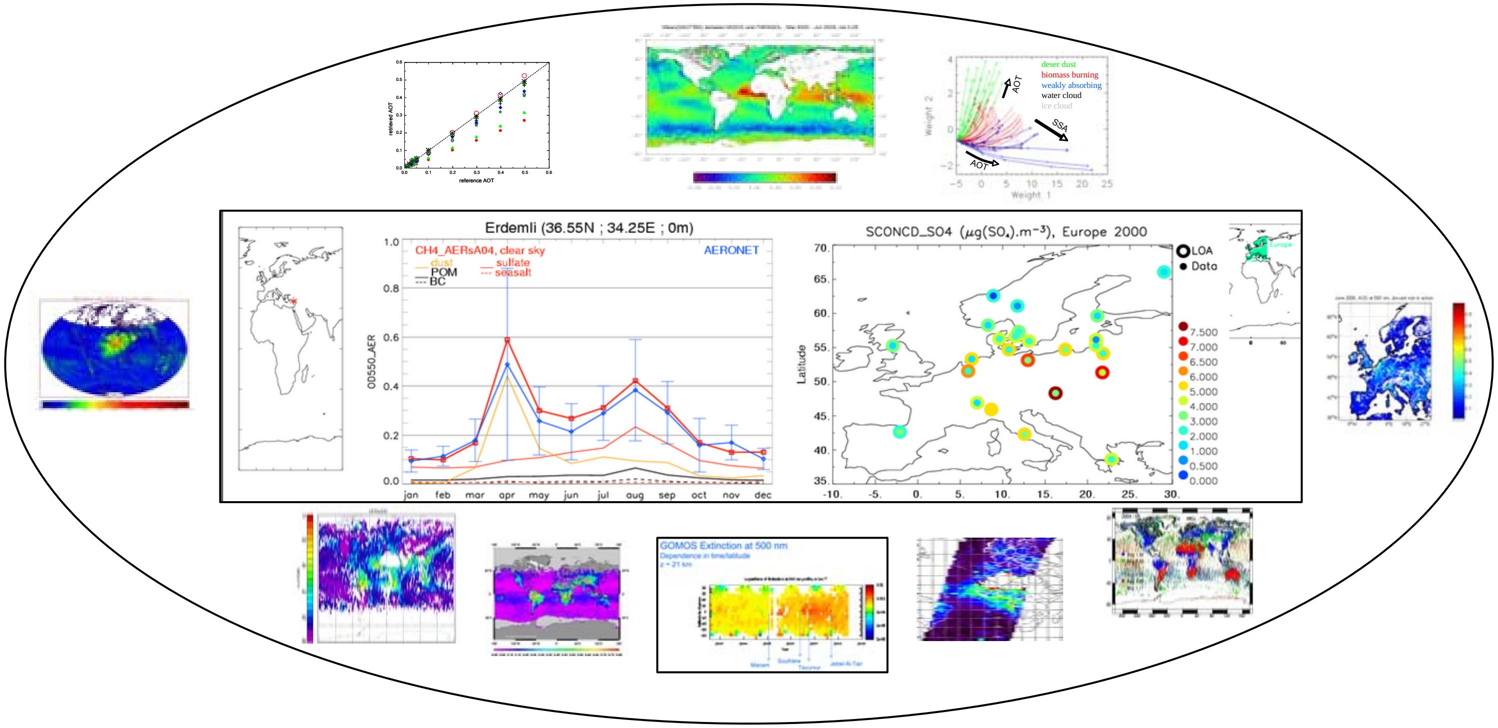
options

Freie Universität Berlin

aerosol_cci concept

understand differences
of various products

integrate major
European EO teams



work with AEROCOM
user community

focus on ENVISAT
and European sensors

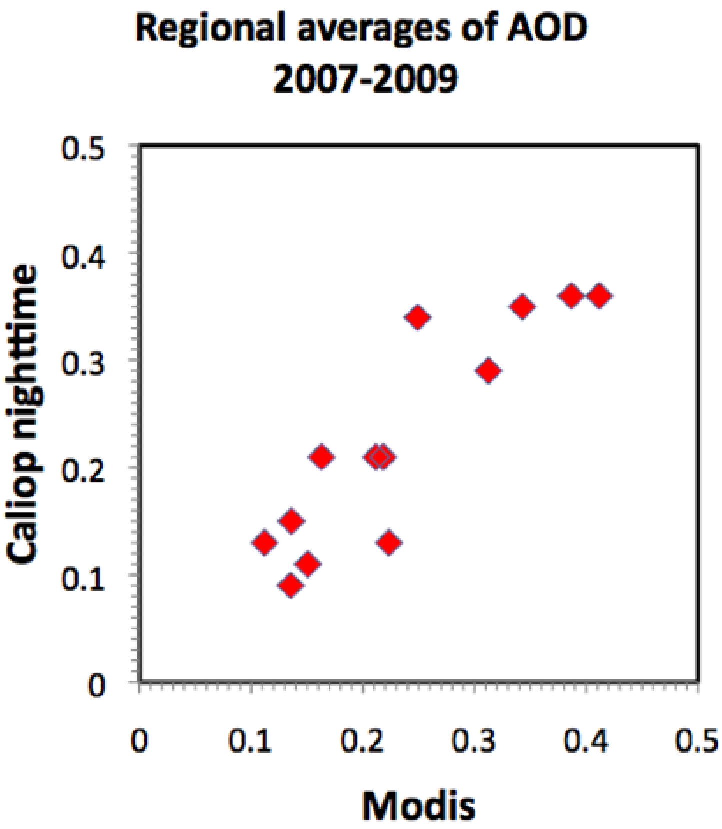
User requirements

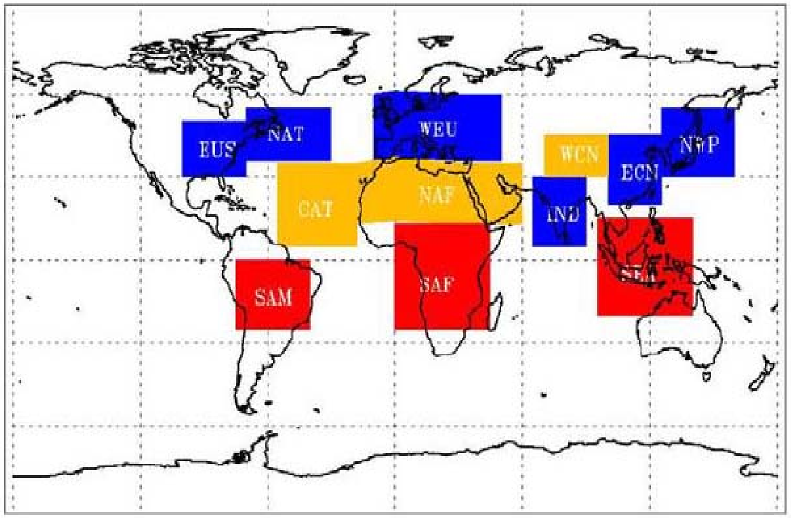
- GCOS as baseline, elaborated by AEROCOM (model development, trend monitoring) and MACC (assimilation for re-analysis)

- overall user needs: easy availability (netCDF), proven and documented quality, aerosol species linked to source categories, observation of long-term trends (many years) for regions and globally, prepare for easy and complete re-processing with new versions

- Level2 products for data assimilation:
    - AOD at 4 wavelengths (440, 550, 670, 870 nm) and several layers
    - 500 (1000) observations per hour
    - with pixel level uncertainty (random + systematic)
    - consistent with clouds and fire
- Level3 products for model comparison
    - Angstrom coefficient (440-870), fine mode fraction (D<1µm), dust fraction
    - Absorption aerosol optical depth (or single scattering albedo)
    - Aerosol vertical extinction / AOD profile (any information is valuable)
    - Accuracy: combined absolute (low AOD) and relative (high AOD)
    - Error characteristics

User requirements





derived stability need

regional AOD range (0.1 – 0.5) * 5% trend detection -> 0.005

User requirements

Satellite variable (reference dataset)	required RMS at superpixel level of 10x10 km^2	required RMS at climate model grid level of 1°x1°	required RMS at regional level of 1000x1000 km^2
Aerosol optical depth at 550nm and other wavelengths (Aeronet global dataset daily mean)	20% or 0.05	10% or 0.02	0.02
Fine mode fraction (Aeronet global dataset daily mean)	20% or 0.1	20% or 0.1	0.1
Dust fraction (Coarse fraction from Aeronet global dataset in known dusty conditions daily mean)	30% or 0.2	30% or 0.2	30% or 0.2
Absorption optical depth (Absorption optical depth computed from SSA and size of Aeronet daily mean)	20% or 0.05	20% or 0.02	0.02

Product specification

<table>
<tr><th>Product name</th><th>Parameter(s)</th><th>sensors</th><th>level</th><th>comment</th></tr>
<tr><td colspan="5">Tropospheric / total column products</td></tr>
<tr><td>Single-sensor
AOD / type</td><td>Multi-spectral AOD
Aerosol type probability
Fine mode AOD</td><td>ATSR-2 / AATSR
MERIS

POLDER</td><td>Level2,3</td><td rowspan="4">Multi-spectral AOD depending on instrument capabilities.

Ångstrom coefficient can be derived from multi-spectral AOD.
Aerosol type may include information on fine / coarse mode fraction and chemical components, which together best describe the observations</td></tr>
<tr><td>Synergetic
AOD / type</td><td>Multi-spectral AOD
Aerosol type probability</td><td>AATSR/SCIAMACHY
ATSR-2/GOME
AVHRR/GOME-2</td><td>Level2,3</td></tr>
<tr><td>AAI</td><td>Absorbing aerosol index
averaging kernel</td><td>OMI
SCIAMACHY
GOME</td><td>Level2,3</td></tr>
<tr><td>Merged AOD / type</td><td>Multi-spectral AOD
Aerosol type probability</td><td>Combining several level2 with appropriate wighting</td><td>Level3</td></tr>
<tr><td>Aerosol type
“climatology”</td><td>Aerosol type probability / dominant aerosol type</td><td>All AOD products</td><td>Level3</td><td>Based on one year of data</td></tr>
<tr><td colspan="5">Stratospheric products</td></tr>
<tr><td>Extinction</td><td>Gridded extinction profile</td><td>GOMOS
(SCIAMACHY)</td><td>Level3</td><td></td></tr>
</table>

Aerosol optical properties

- define common small set of components for inter-comparisons
- mixing by fine mode fraction, coarse (salt or dust), fine mode absorption
- test AEROCOM median a priori
- test retrievals with fixed a priori and free selection of properties

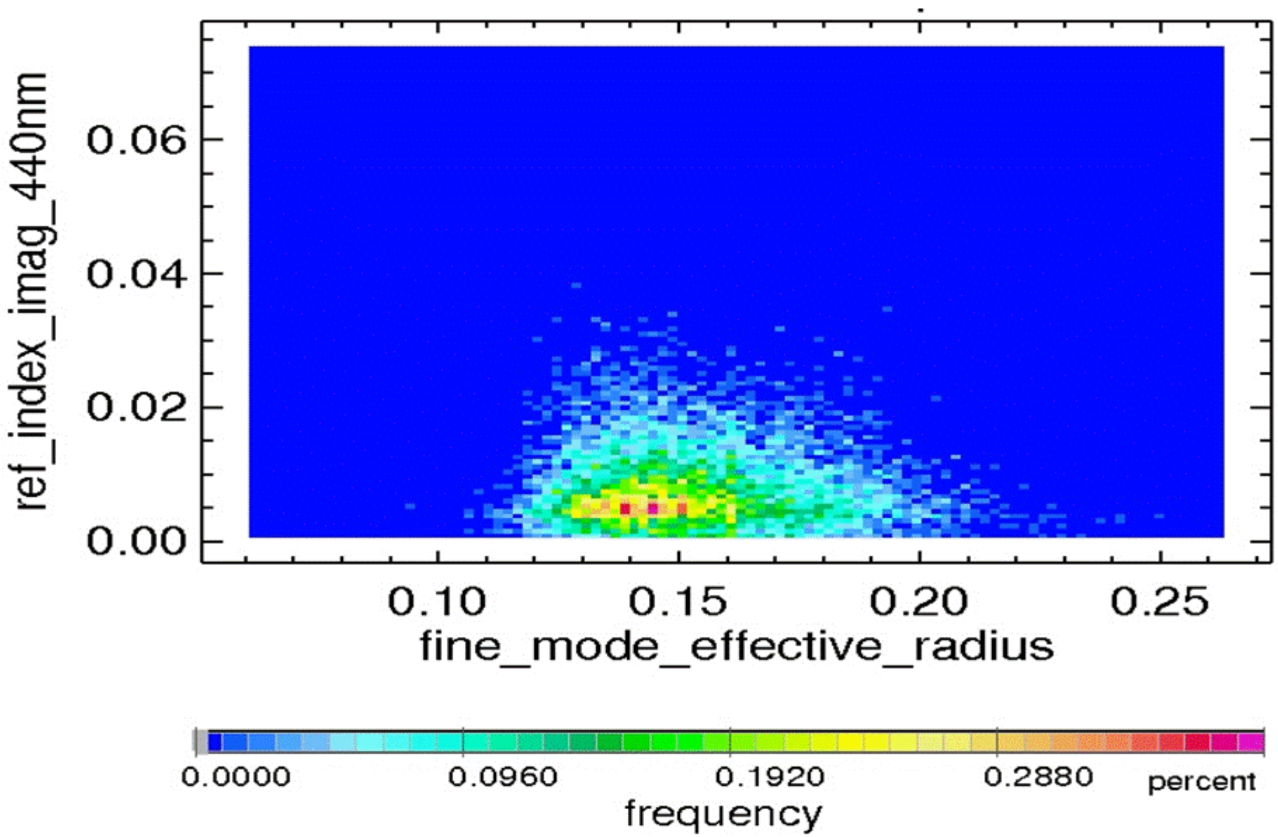
Aerosol Component	Real part Refr. Index (550 nm)	Im. Part Refr. Index (550 nm)	Reff* (μm)	Geom. stdv	Geometric mean radius (μm)	Comments	Aerosol layer height
Dust§	1.56 (varies with wavelength)§	0.0018 (varies with wavelength)§	1.8	1.82	0.79	Non-spherical	Fixed hgt at 2-4km
Sea salt	1.4	0	1.82	1.7	0.9	AOD threshold constraint#	0-1 km
Fine mode very weak-abs	1.4	0.003	0.142	1.7	0.07	(ssa at 500 nm: 0.98)	0-2 km
Fine mode strong-abs	1.5	0.025	0.142	1.7	0.07	(ssa at 500 nm: 0.80)	0-2 km

see poster by Gerrit de Leeuw et al.

Aerosol optical properties

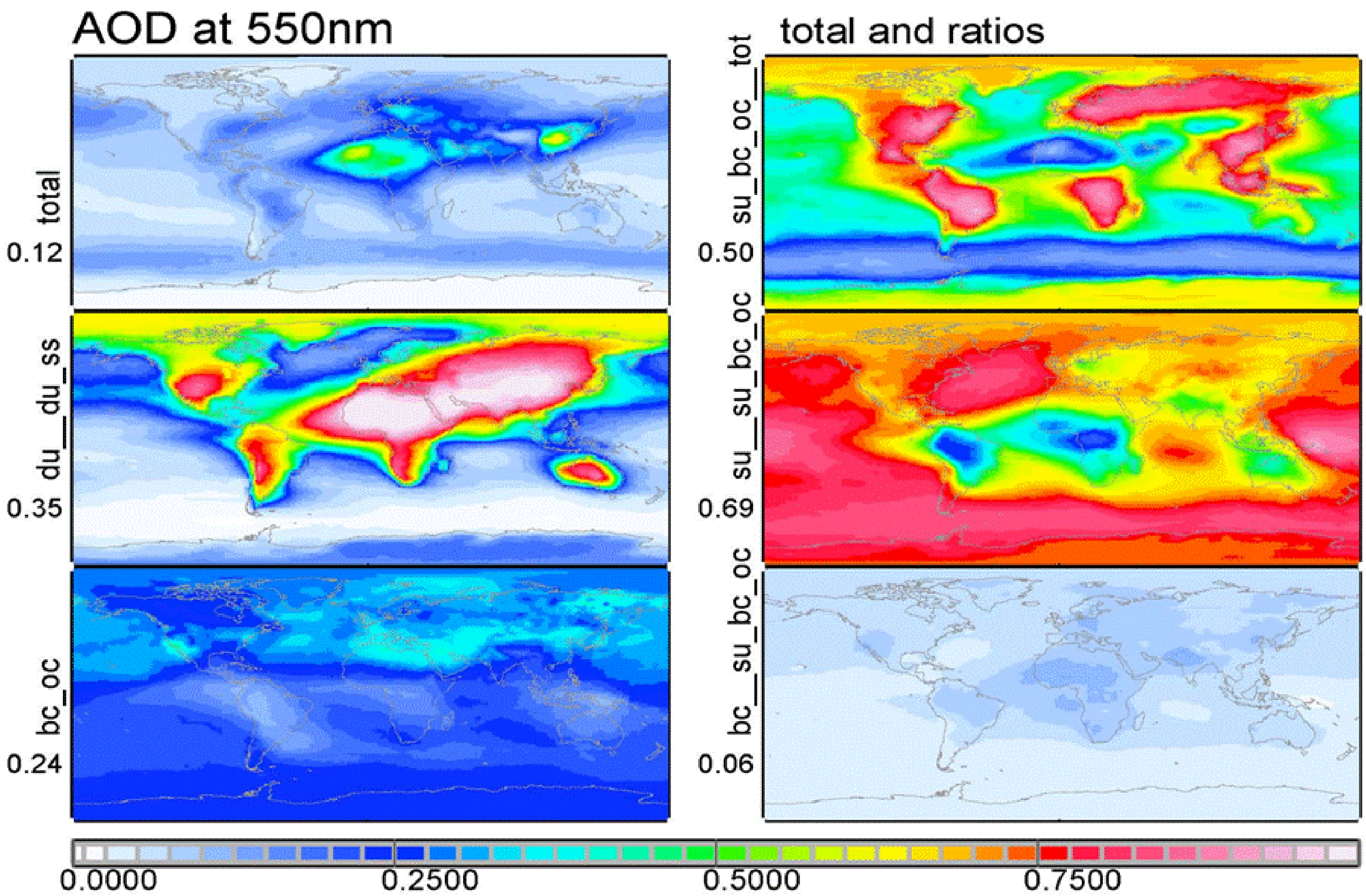
- define common small set of components for inter-comparisons
- mixing by fine mode fraction, coarse (salt or dust), fine mode absorption
- test AEROCOM median a priori
- test retrievals with fixed a priori and free selection of properties

Aerosol Component	Aerosol layer height
Dust§	Fixed hgt at 2-4km
Sea salt	0-1 km
Fine mode weak-abs	0-2 km
Fine mode strong-abs	0-2 km



de Leeuw et al.

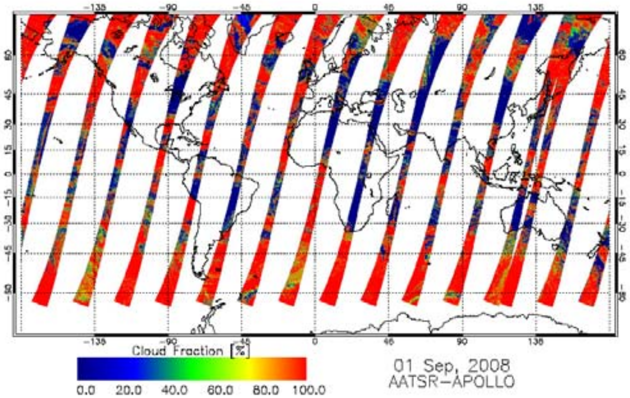
Aerosol optical properties

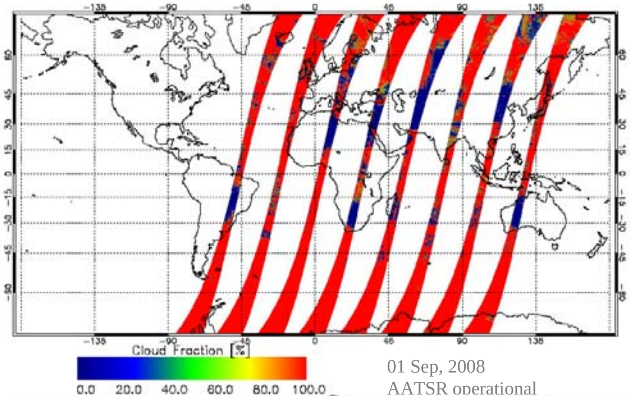


AEROCOM a priori

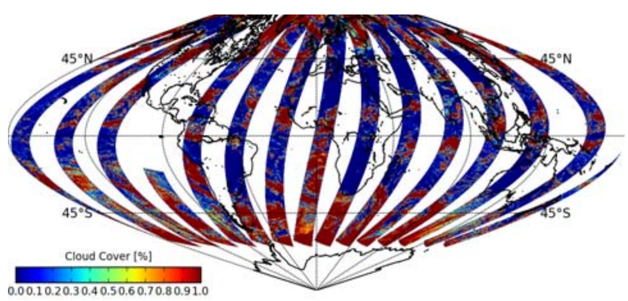
Cloud masking

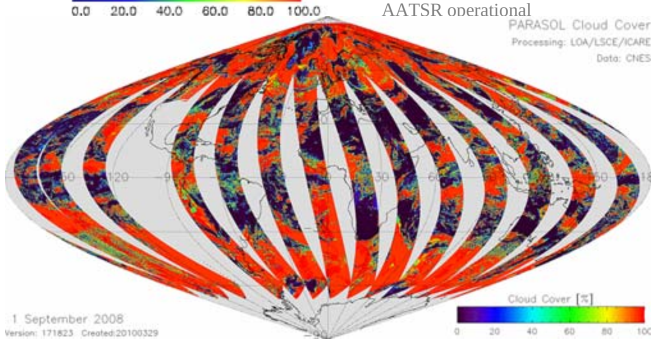
- compare different cloud masks
  - various AATSR algorithms / AATSR versus MERIS / versus PARASOL
- transfer to larger spectrometer pixels
- prepare common cloud mask for selected inter-comparison
- compare to external reference datasets (SYNOP, MODIS/CALIPSO)





ENVISAT.MERIS





Surface treatment

- analyse different approaches (multi-angle, multi-spectral, polarisation)
- over ocean use common auxiliary datasets and modules

  (e.g. white caps / ECMWF ERA interim)
- analyse critically independence from other retrieval results (e.g. Globcolour)
- over land compare with external reference reflectance (e.g. MODIS AERONET corrected)
- test use of common surface reflectance and BRDF dataset (MODIS, POLDER)

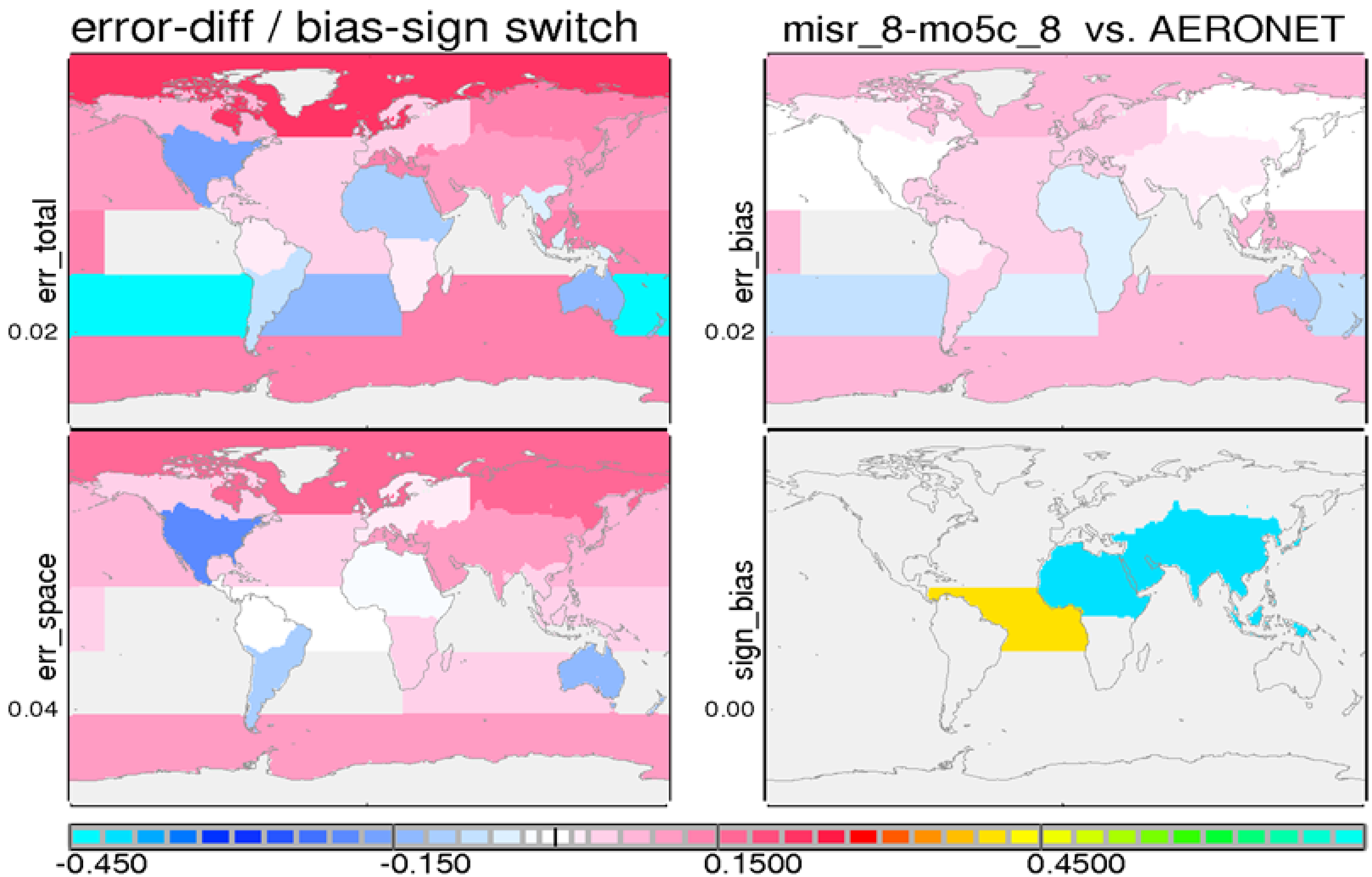
Analysis tools

- MPI scoring (level2)
  - spatial patterns, bias, noise
  - versus AERONET

- ICARE statistical inter-comparison (level2, level3)
  - envelope criterium
  - versus AERONET, MACC forecasts
  - versus other satellites (MODIS, POLDER, CALIPSO, OMI, SEVIRI)

- AEROCOM model inter-comparison (level3)
  - versus model median

MPI tools



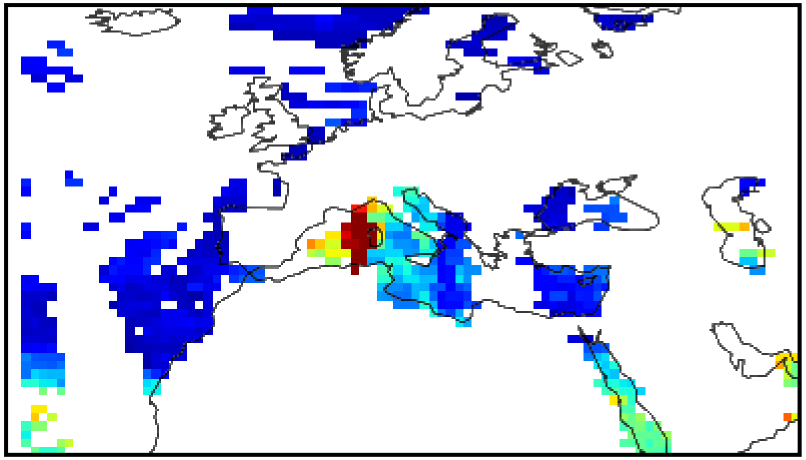
error-diff / bias-sign switch
misr_8-mo5c_8 vs. AERONET
err_total
0.02
err_bias
0.02
err_space
0.04
sign_bias
0.00
-0.450
-0.150
0.1500
0.4500

MPI tools

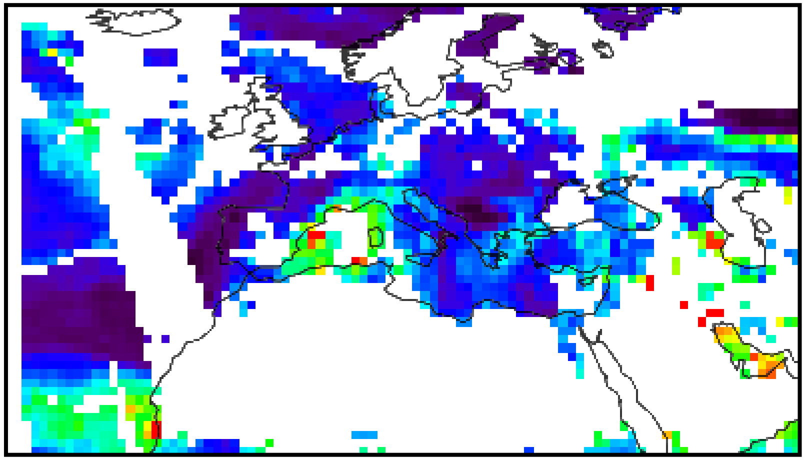
rank	**total**	seaso	bias	space	**data**	**refer**	error	bias	**data-set**
1	**-0.772**	0.936	-.888	0.929	**0.166**	**0.157**	0.24	0.030	**_sky_8**
2	**0.656**	0.934	0.844	0.832	**0.172**	**0.159**	0.42	0.14	**mo5a_8**
3	**0.640**	0.938	0.827	0.825	**0.175**	**0.157**	0.46	0.18	**mo5t_8**
4	**0.607**	0.889	0.830	0.823	**0.177**	**0.155**	0.44	0.19	**mo5c_8**
5	**0.587**	0.928	0.812	0.779	**0.170**	**0.152**	0.47	0.23	**misr_8**
6	**0.569**	0.843	0.802	0.842	**0.143**	**0.153**	0.48	0.059	**clim_8**
7	**0.557**	0.835	0.795	0.838	**0.145**	**0.153**	0.49	0.070	**median**

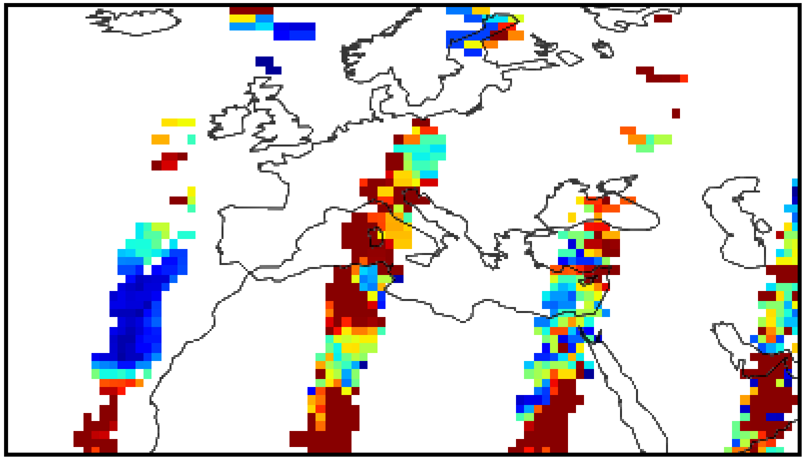
ICARE tools

PARASOL CCI (fine mode)

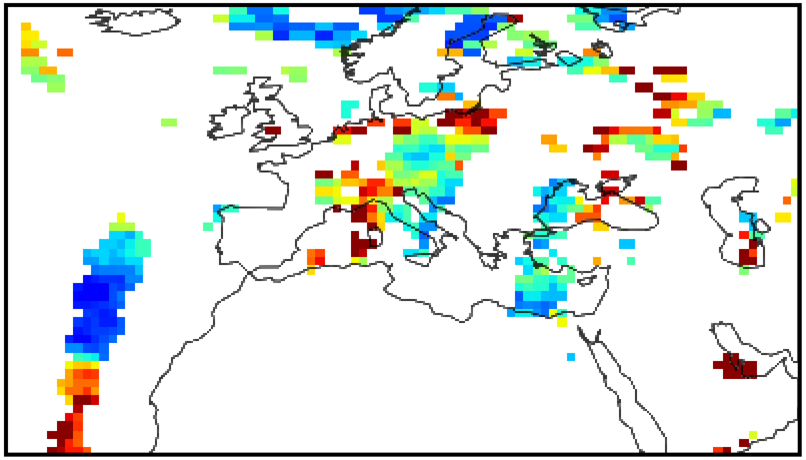


MODIS AQUA





ORAC AATSR CCI

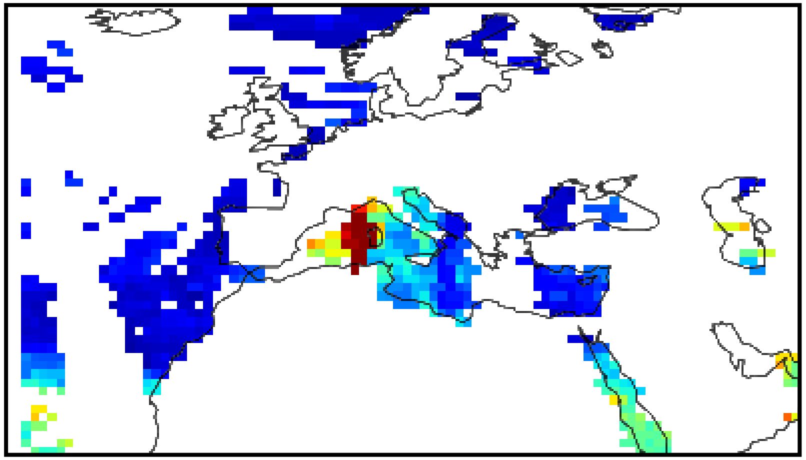


MERIS standard CCI

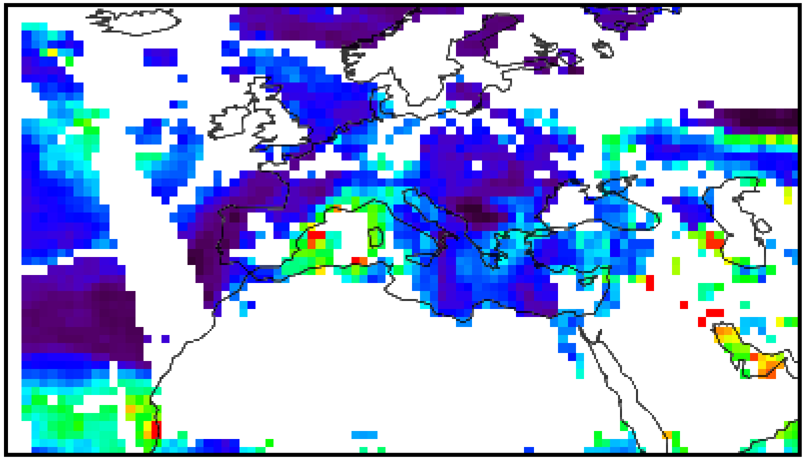
10 September 2008

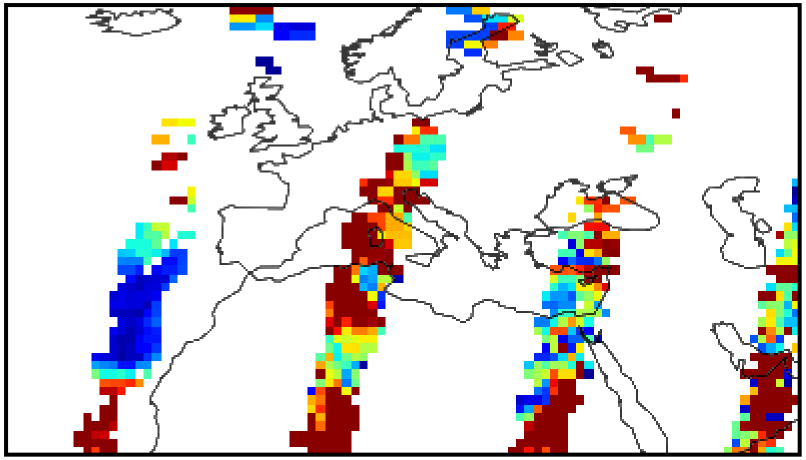
ICARE tools

PARASOL CCI (fine mode)

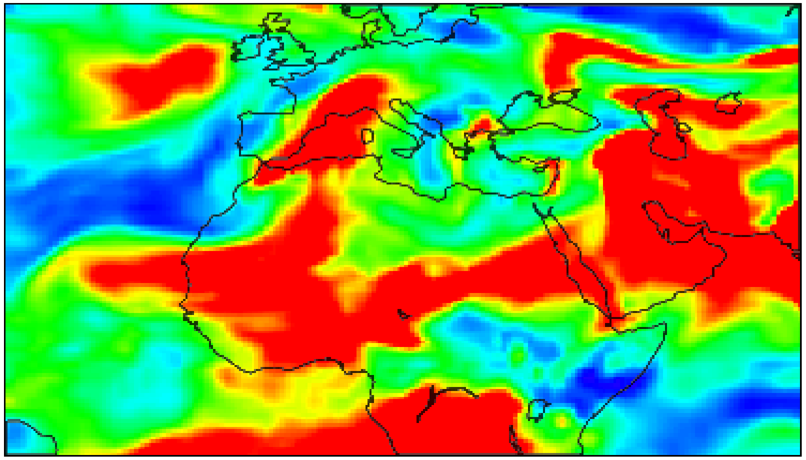


MODIS AQUA





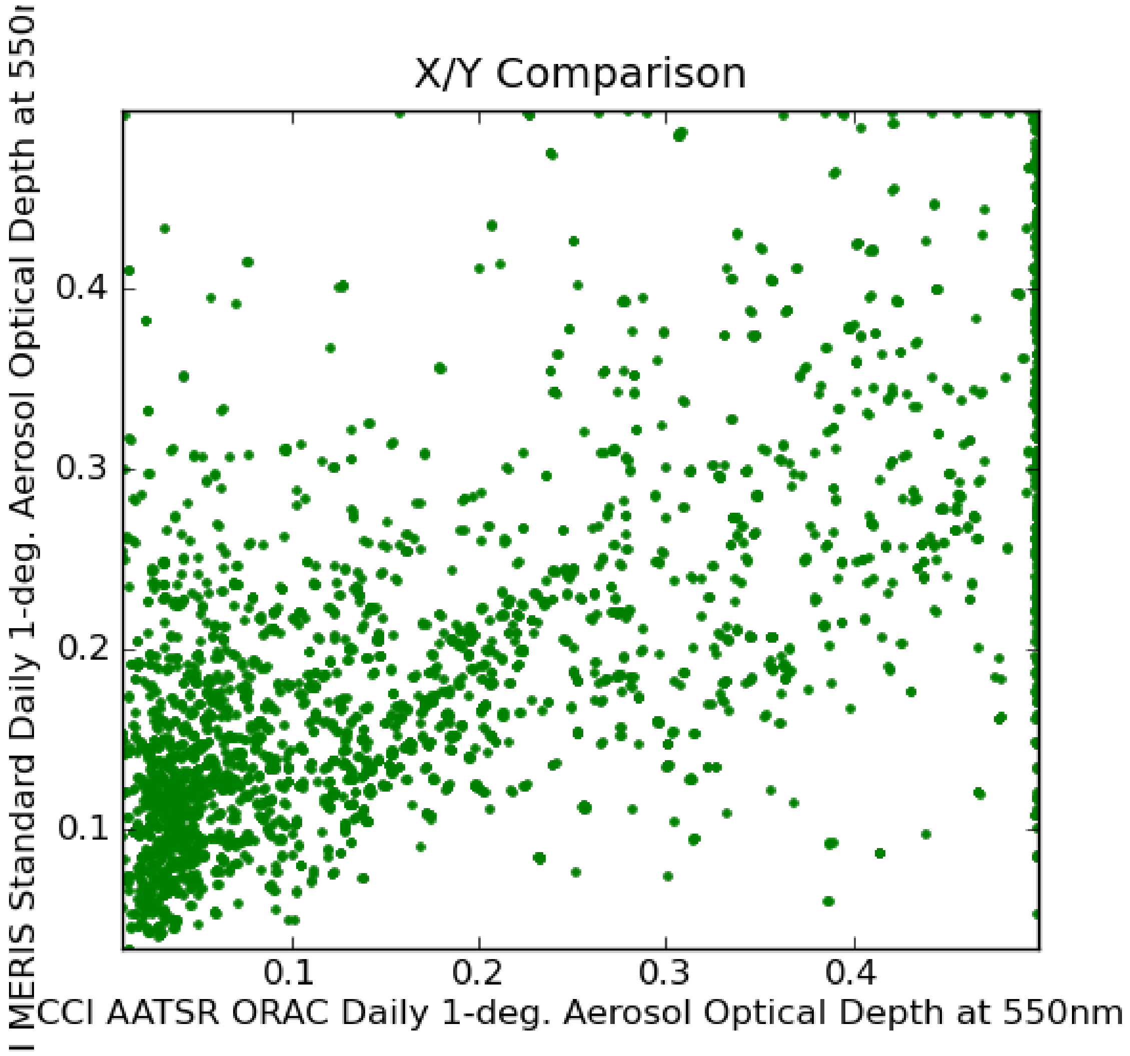
ORAC AATSR CCI



MACC forecast

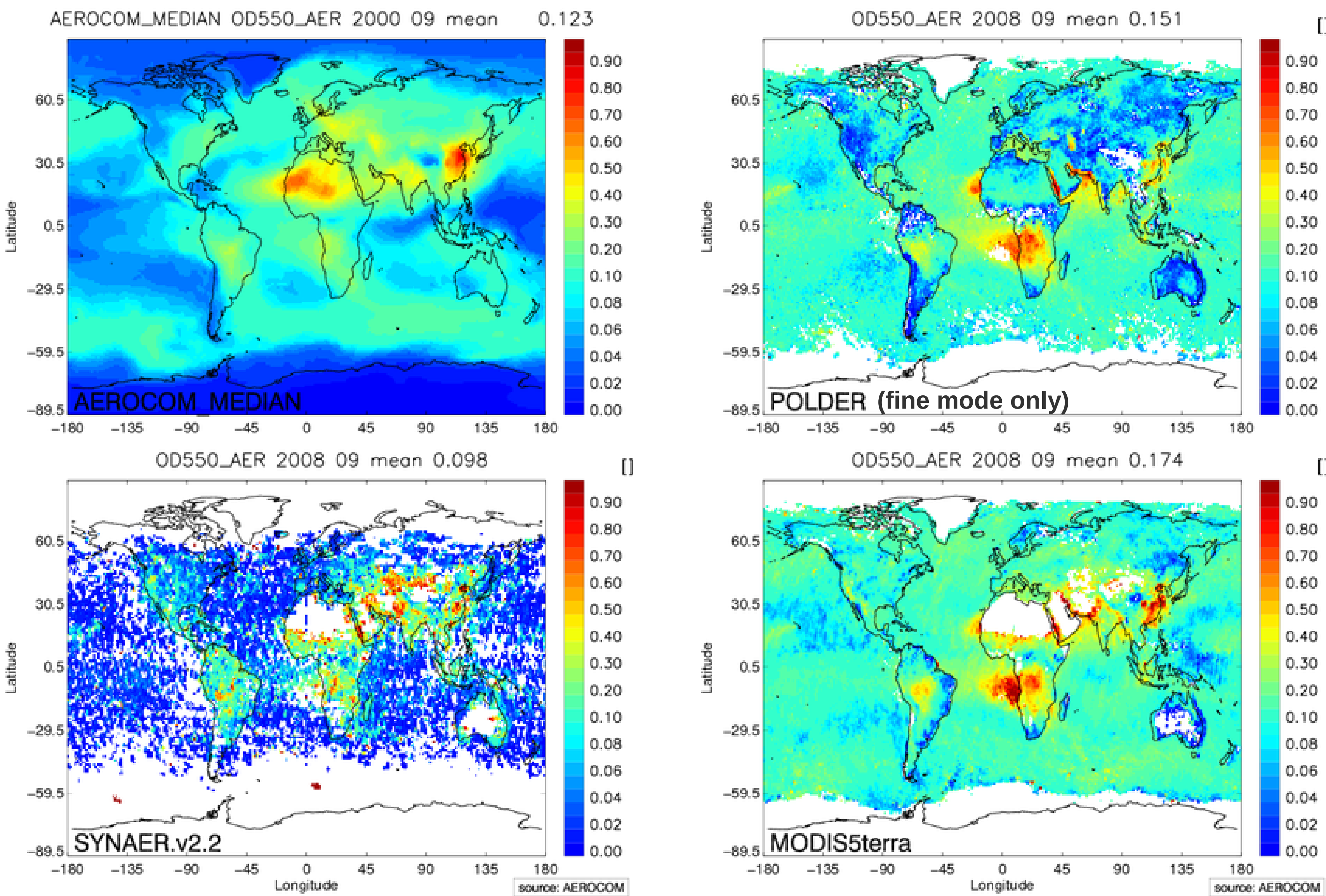
10 September 2008

ICARE tools

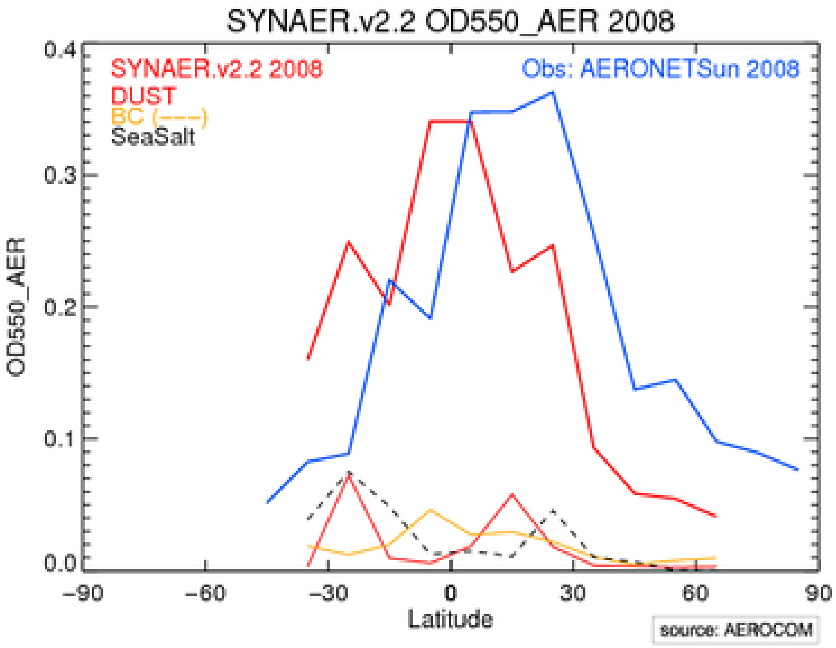


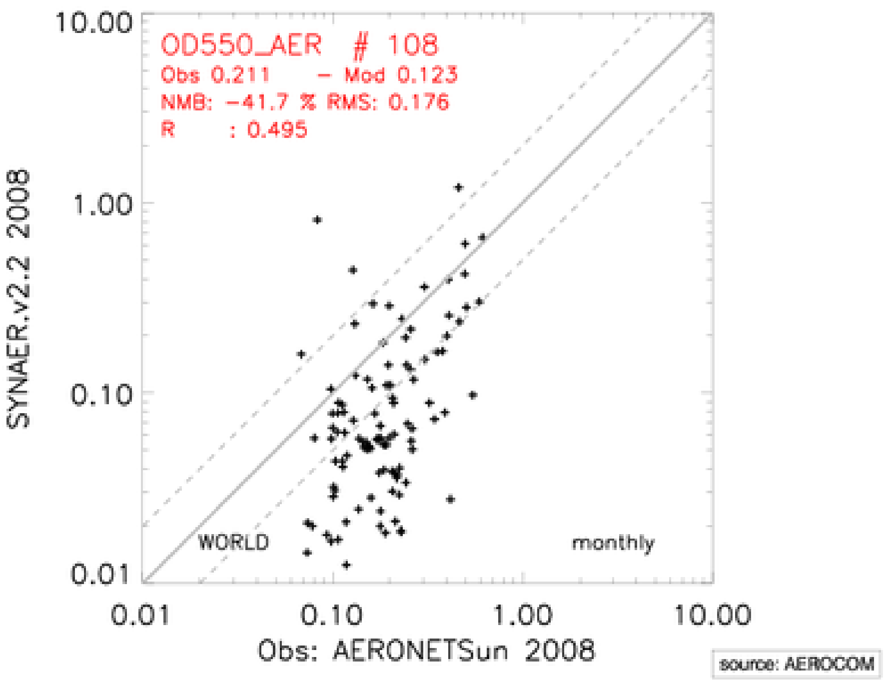
X/Y Comparison
0.1
0.2
0.3
0.4
0.1
0.2
0.3
0.4
CCI AATSR ORAC Daily 1-deg. Aerosol Optical Depth at 550nm
MERIS Standard Daily 1-deg. Aerosol Optical Depth at 550

AEROCOM tools



AEROCOM tools





Conclusion

- phase 1 (summer 2011) analysis of various retrieval versions
    - test dataset global September 2008
    - 8 tropospheric algorithms

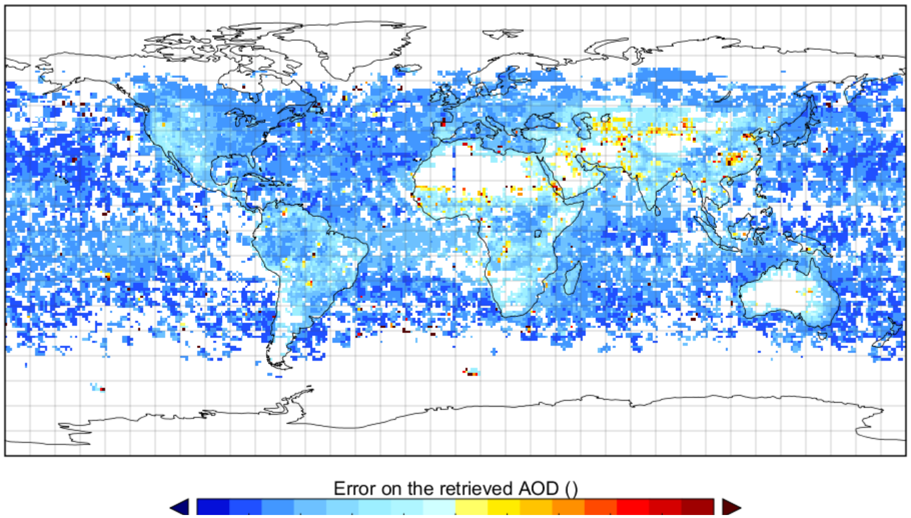
- phase 2 (autumn 2011) round robin
    - dataset global March, June, September, December 2008
    - 8 tropospheric algorithms

- phase 3 (autumn 2012)
    - ECV production global all 2008
    - 5 tropospheric algorithms + merged dataset(s)

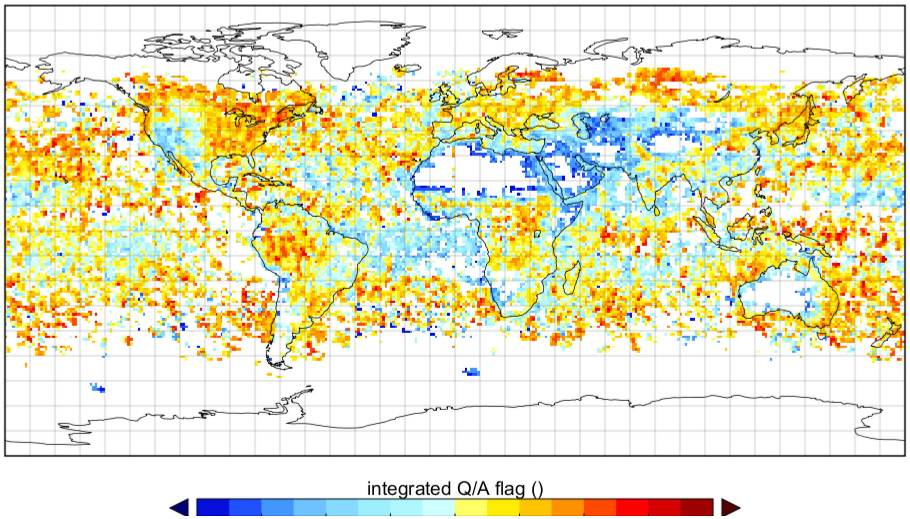
- validation with established tools in all stages
- evaluation by AEROCOM (MACC)
- further analysis: synthetic case studies, information content analysis

Product uncertainties

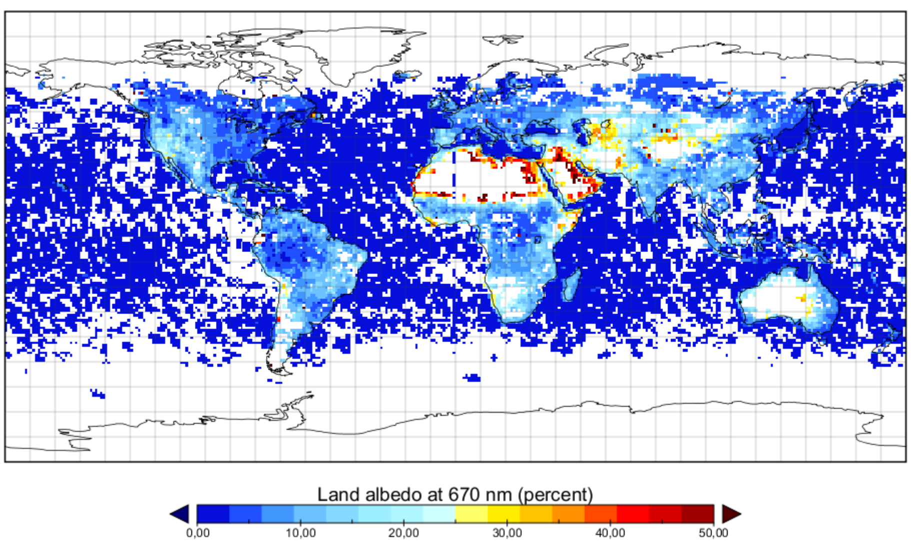
Error on the retrieved AOD



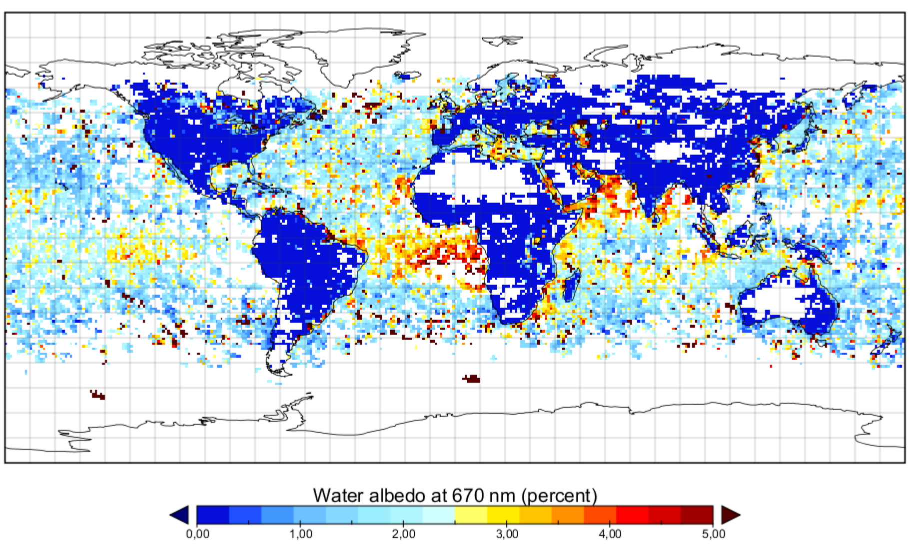
integrated Q/A flag



Land albedo at 670 nm



Water albedo at 670 nm



Product uncertainties

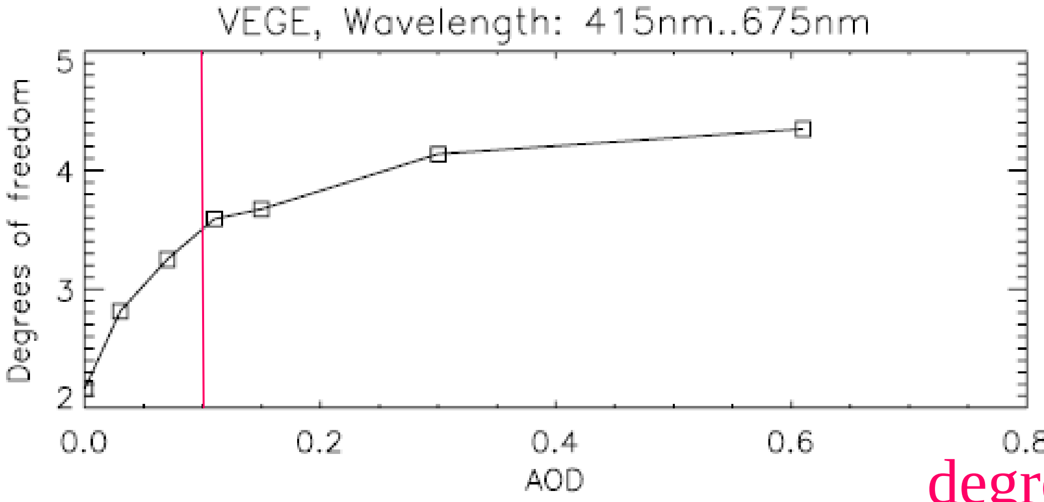
An example: synergetic retrieval algorithm (first estimation based on validation results)

Error source	Absolute error contribution	comment
calibration	TBD	Can be critical
Radiative transfer	negligible	Error due to Mie calculations for dust TBD
Noise due to pixel size	0.05	Varies for different continents
Cloud fraction	TBD	Validation showed that pixels up to cloud fraction of 35% can be exploited for the retrieval
Surface reflectance	Land: 0.05 – 0.15 (for visible surface reflectance from 0 – 0.25) Ocean: 0.03 – 0.1 (for visible surface reflectance from 0 – 0.05)	
Choice of wrong aerosol type (spectral extinction, absorption, phase function)	0 – 0.2 for AOD550 0. – 1.	Is estimated for each pixel by identifying ambiguous aerosol types through comparing quality of fit with difference between aerosol types with similar spectra)

Information content

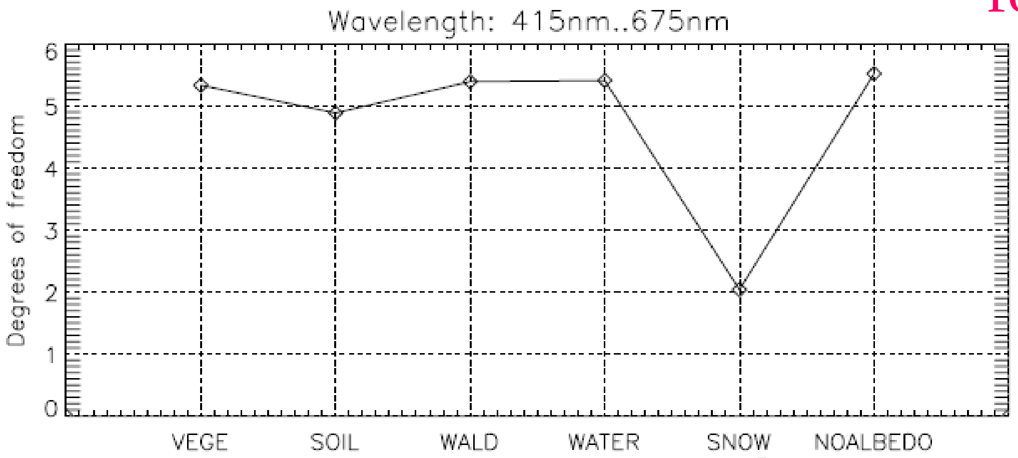
SYNAER: analyzed information content of spectrometer

with AOD



more than 2 degrees of freedom for aerosol, type

with surface type



Holzer-Popp et al., ACP, 2008

GCOS requirements

- Aerosol optical depth

	goal	threshold
• accuracy	0.01	0.02
• stability	0.005 / decade	N/A
• resolution	1 km / daily	10 km / weekly

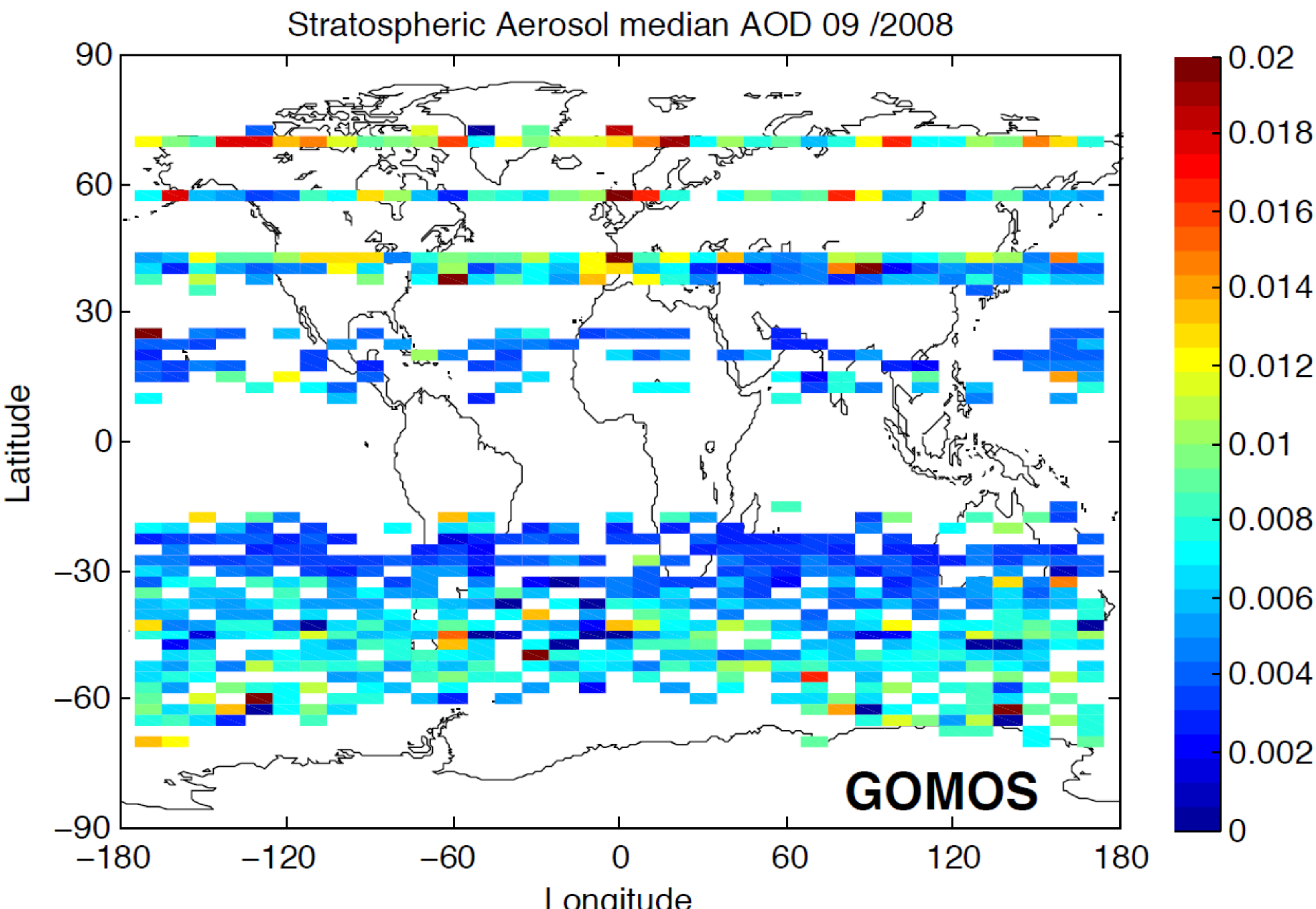
- Other aerosol properties
  - to supplement AOD
  - e.g. single scattering albedo

• accuracy	0.02
• stability	0.015 / decade

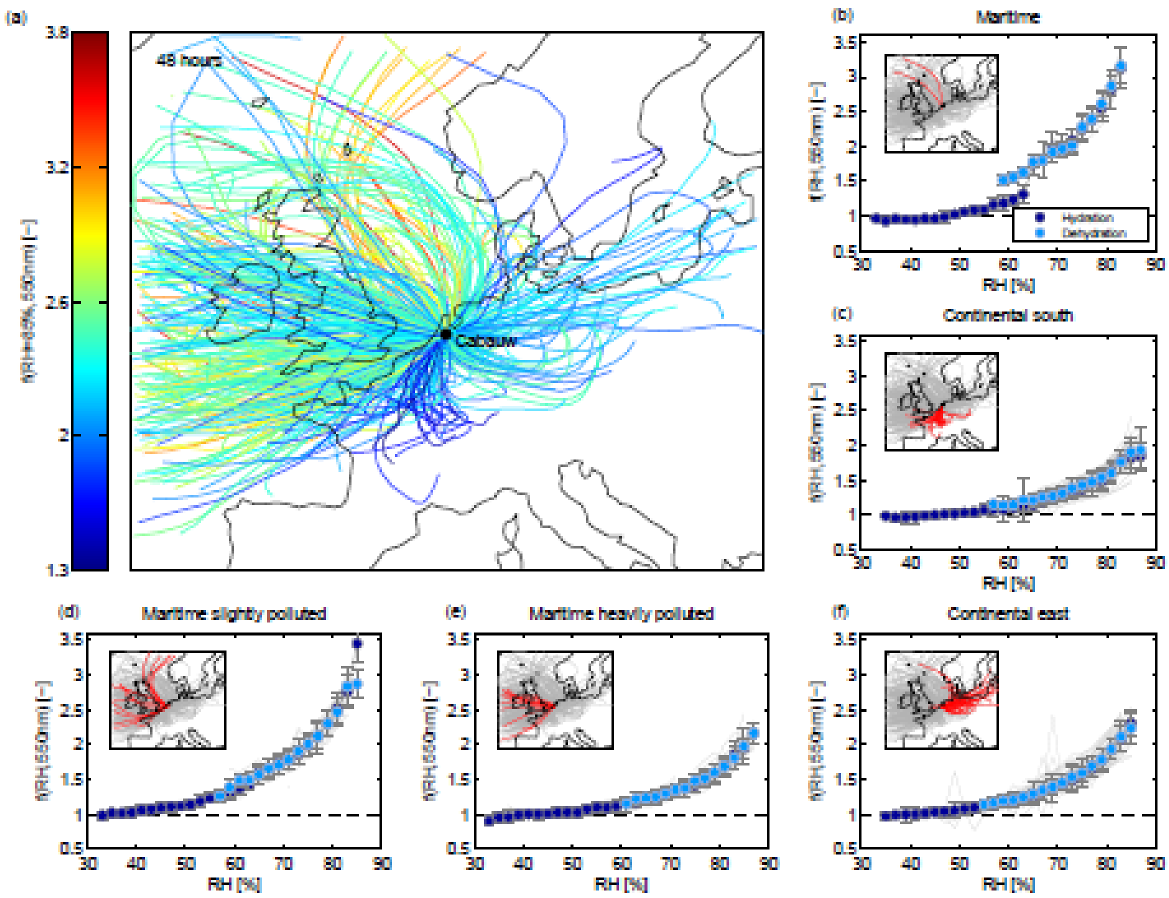
- Comprehensive ground-based independent validation

-> can not be met (per pixel) by any satellite product

Stratospheric aerosol



Use of in situ data



Zieger et al., Comparison of ambient aerosol extinction coefficients obtained from in-situ, MAX-DOAS and LIDAR measurements at Cabauw, ACP, 11, 2603–2624, 2011

aerosol scientific issues

- joint definition of **micro-physical / optical aerosol types**
  -> consistent inter-comparisons between different algorithms / use for all prototype ECVs

- **cloud masking** comparison and optimization between 4 ATSR and AVHRR/3 algorithms
  -> reference for sensors with lower resolution or smaller spectral coverage

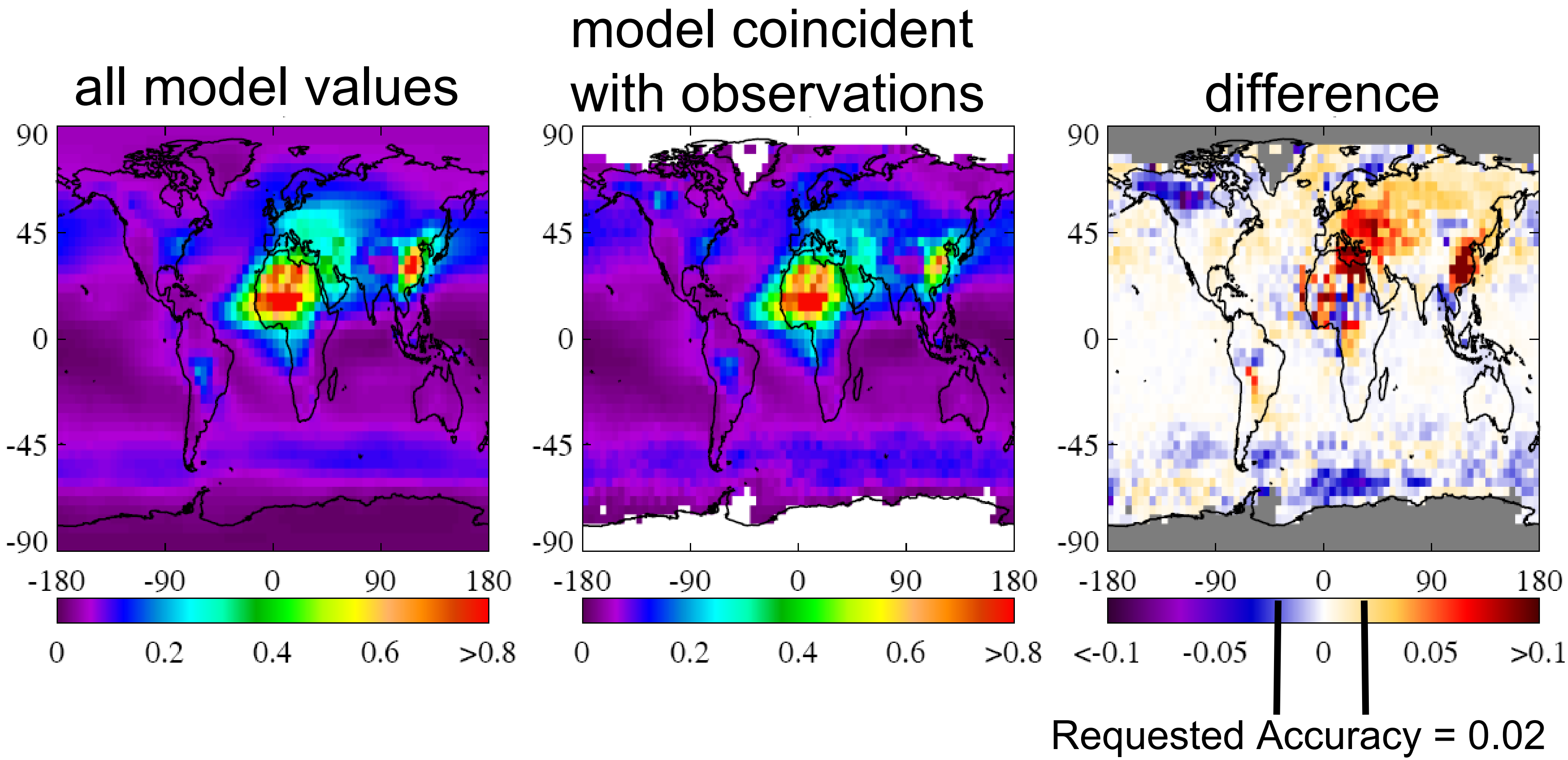
- inter-comparison of different approaches for **treatment of surface reflectance and BRDF**
  -> optimal / combined solutions identified for ATSR, MERIS, POLDER instruments

- inter-comparison of **auxiliary data** used by the different retrievals
  -> harmonized datasets (elevation, land cover, ocean reflectance, BRDF, humidity, …)

- investigate **merging of datasets and pixel selection** / outlier screening
  -> proper error weighting for merging different AOD from complementary sensors

- **improve stratospheric limb products** (longitudinal dependance)
  -> correction of nadir products for volcanic cases

Sampling impact



Sayer et al: Some implications of sampling choices on comparisons between satellite and model aerosol optical depth fields, ACPD, 10, 17789-17814, 2010.