Lessons Learned from 6 years of ESA Aerosol_cci work on Aerosol Climate Data Records

Thomas Popp, Gerrit de Leeuw, Simon Pinnock,
Miriam Kosmale, Larisa Sogacheva, Pekka Kolmonen, Gareth Thomas,
Adam Povey, Caroline Poulson, Peter North, Andreas Heckel,
Lars Klüser, Virginie Capelle, Lieven Clarisse, Sophie Vandenbussche,
Oleg Dubovik, Pavel Litvinov, Christine Bingen, Charles Robert,
Jacques Descloitres, Marco Vountas, Luca Lelli, Linlu Mei,
Stefan Kinne, Michael Schulz, Jan Griesfeller, Kerstin Stebel,
Christoph Brühl, David Neubauer, Pepijn Veefkind, Gijsbert Tilstra,
Yong Xue, Yves Govaert, Jürgen Fischer, Martin de Graaf

ESA CCI program

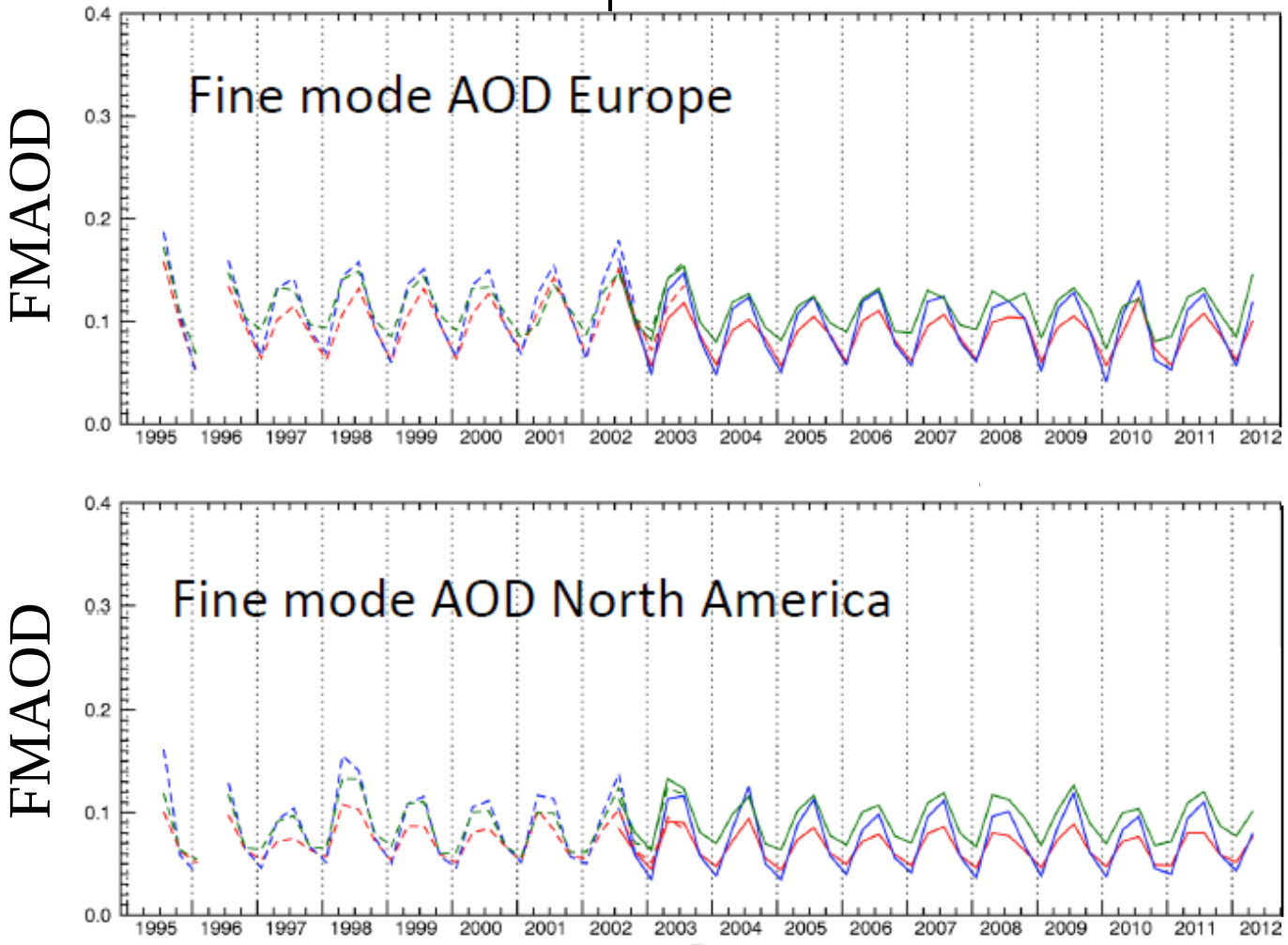
Hollmann, et al., BAMS 2013

Aerosol_cci Phase 2
Complementary products

Parameter	Sensor (Algorithms)	Coverage (planned) - status
AOD (4 λ) FM-AOD, Angström exponent	Dual view VIS-TIR **ATSR-2 + AATSR** (3 algorithms)	1995 – 2012 (2016 – 2030 SLSTR)
Dust AOD Round robin	Thermal IR spectrum **IASI** day+night (4 algorithms)	2013 (2006 – 2015) (- 2024 METOPs)
AOD, Angström exponent, SSA Quasi-reference	Polarisation / multi-angle multi-pixel VIS **PARASOL** (GRASP)	2008 (2006 – 2013) selected land regions (2020 – 3MI)
Stratospheric extinction, AOD, size	Star occultation VIS **GOMOS**	2002-2012
AAI	UV ratio index **Multi-sensor**	1978 - 2013

Fine Mode AOD time series

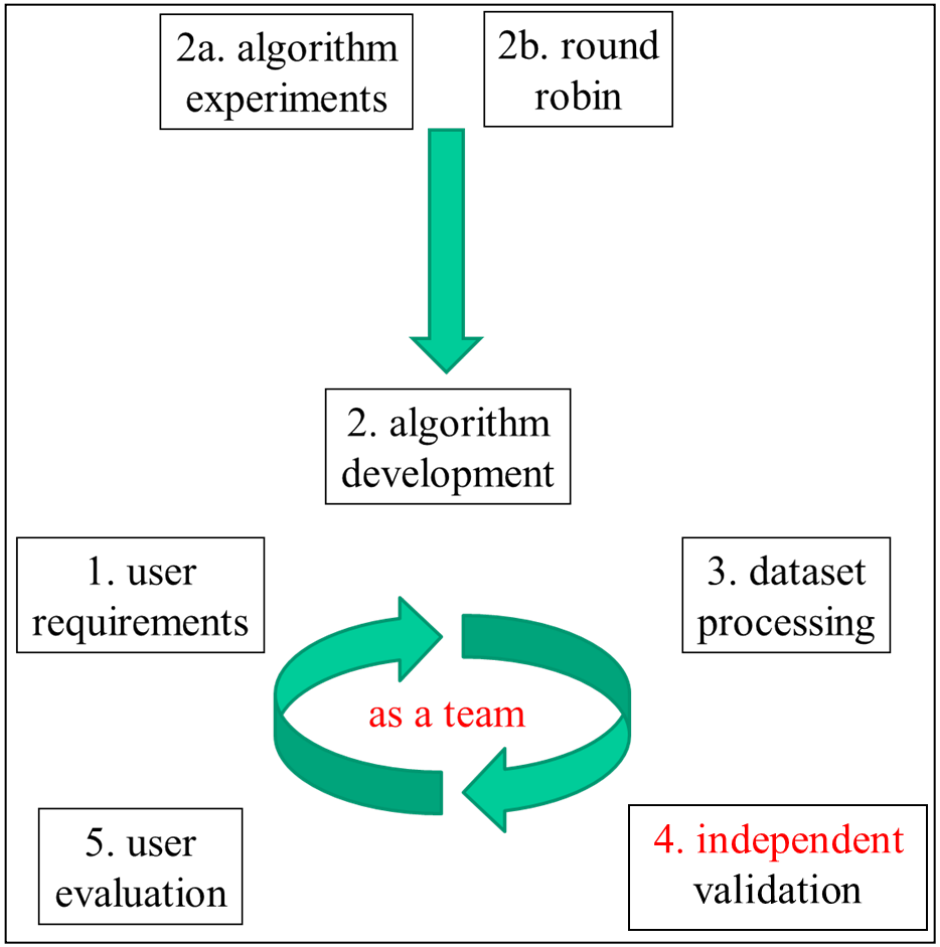
------ ATSR-2 ------ | ---------- AATSR ----------



ATSR ADV v2.30
ATSR SU v4.21
ATSR ORAC v3.02

regional consistent overlap biases ~0.02

Lessons learned
after 6 years



Popp, et al., RS 2016

- Iterative approach
- Early / full user involvement
- „Co-optition“ of teams

- Pixel-level uncertainties

- No algorithm is always best
- Algorithm ensembles

- Validation
  - Patterns, regions/seasons
  - Time series consistency
  - Sufficient reference data

Required aerosol data products

AEROCOM modelling needs

- AOD accuracy requirement: max (0.03; 10%)
- Extinction profile
- Layer height
- Absorption AOD / SSA

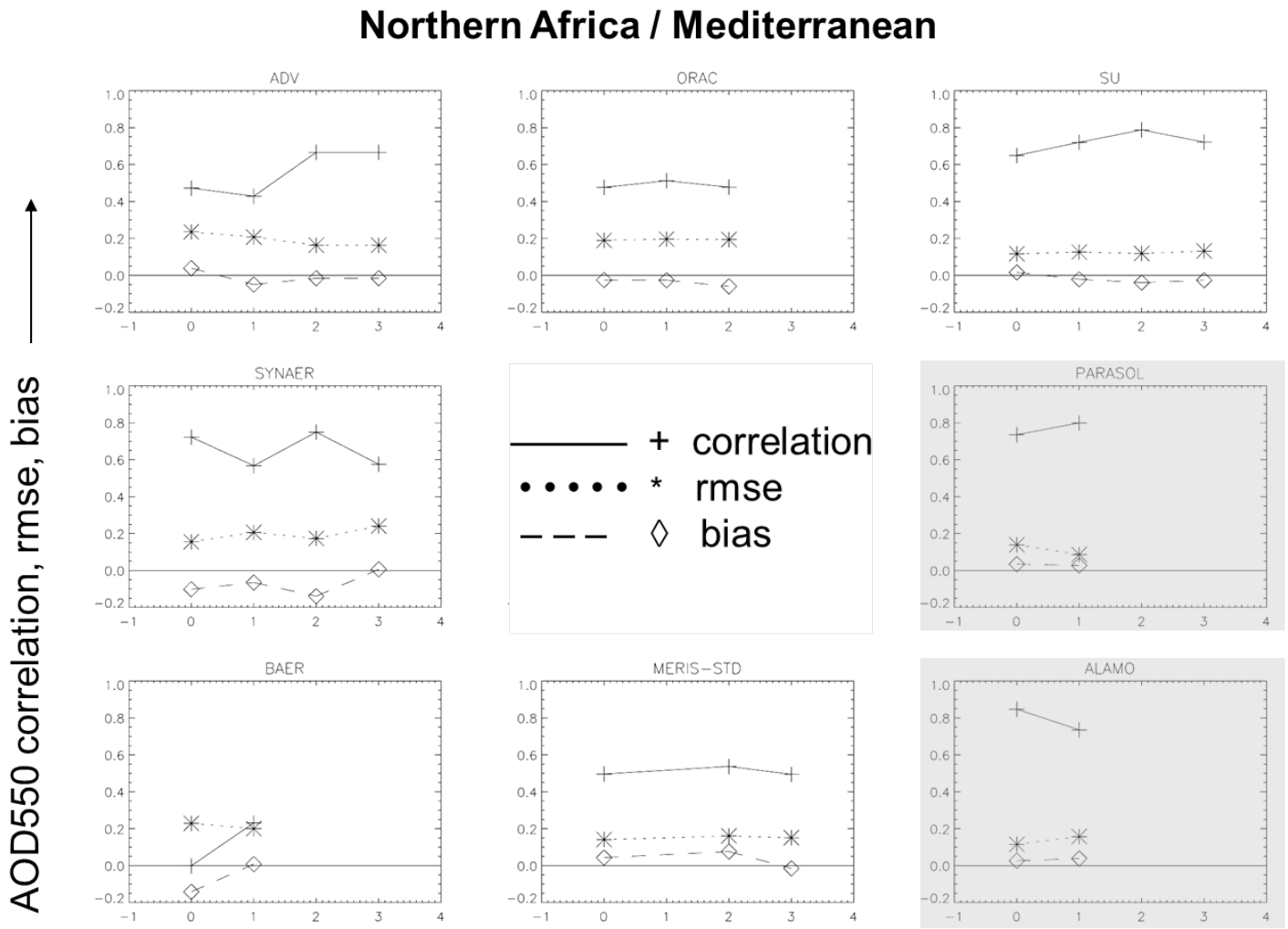
- **Model users (Aerosol_cci URD 2014)**
  - Fine mode AOD, dust AOD
  - Aerosol index (AOD * Angström exponent)

Required aerosol data products

AEROCOM modelling needs

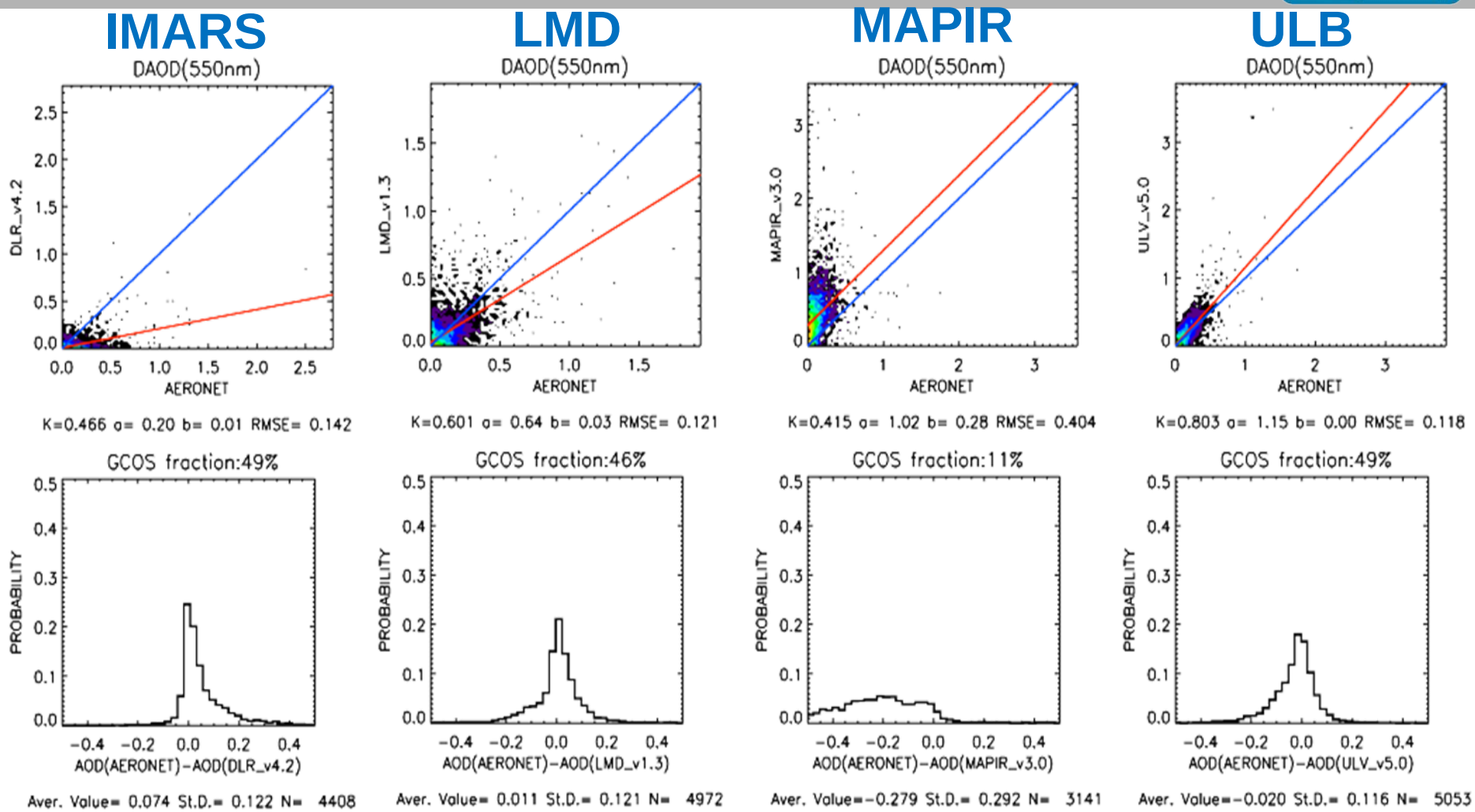
Total column properties					
Property **spatial resolution** **temporal resolution**	sat. product 0.1x0.1 degree 2 hours	model grid 1x1 degree daily	regional 10x10 degree monthly	inter-annual 10x10 degree seasonal	decadal 10x10 degree annual
AOD, 550nm	0.04	0.02	0.01	0.008	0.006
Fine mode AOD, 550nm	0.03	0.015	0.008	0.006	0.005
Absorbing AOD, 550nm	0.01	0.005	0.003	0.0025	0.002
Dust AOD, 550nm	0.03	0.015	0.008	0.006	0.005

Algorithm experiments to quantify sensitivities



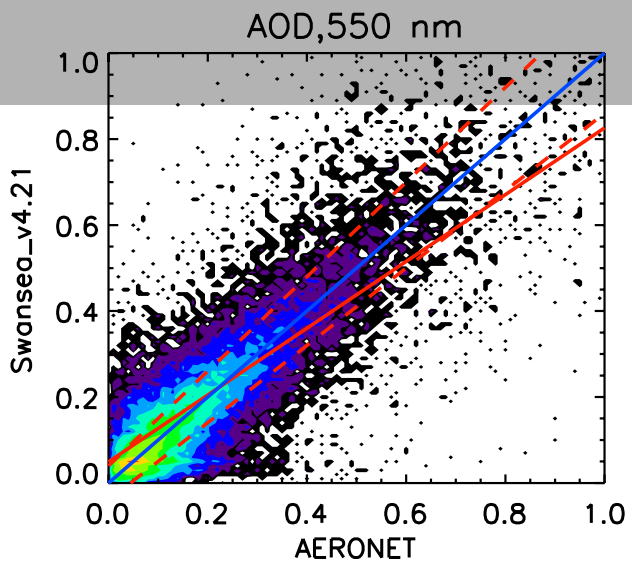
Holzer-Popp, et al., AMT 2013

IASI Dust AOD
Round roin exercise

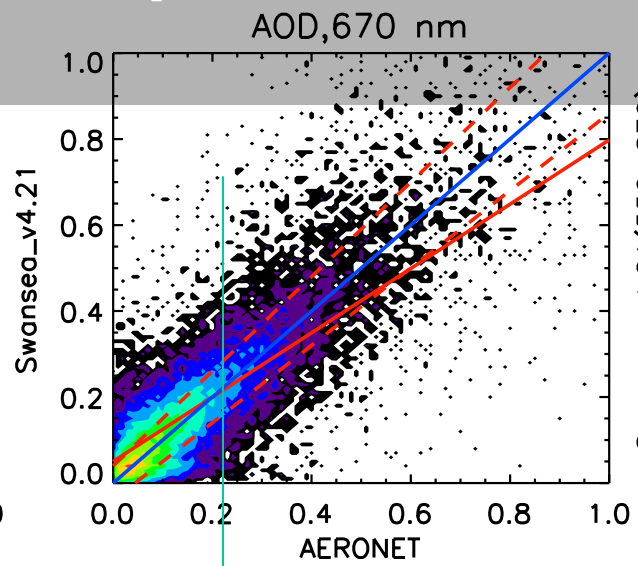


- validation complex: no 10µm reference, conversion to 550nm, different sampling
- IMARS: issues with input data / MAPIR: issues with apriori surface temperature

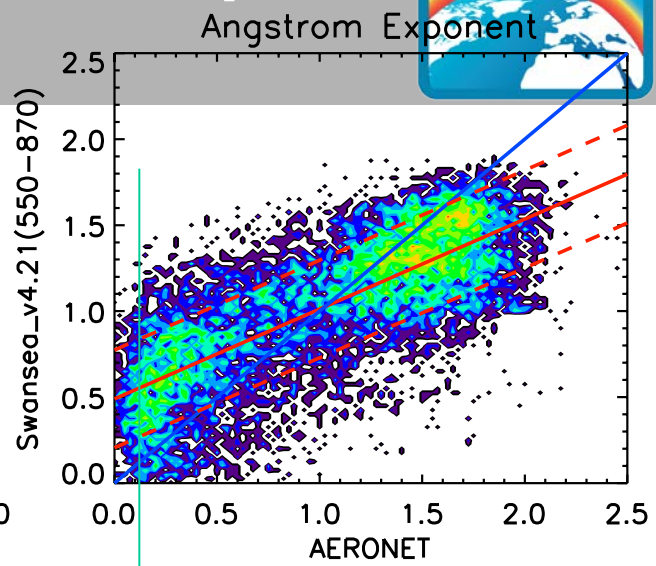
Validation with AERONET
SU v4.21 (L2, land, 2002-2012)



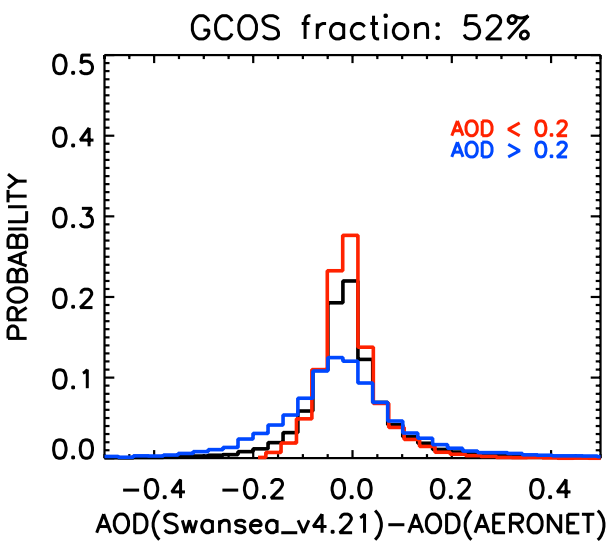
K=0.792 a= 0.78 b= 0.05 RMSE= 0.149



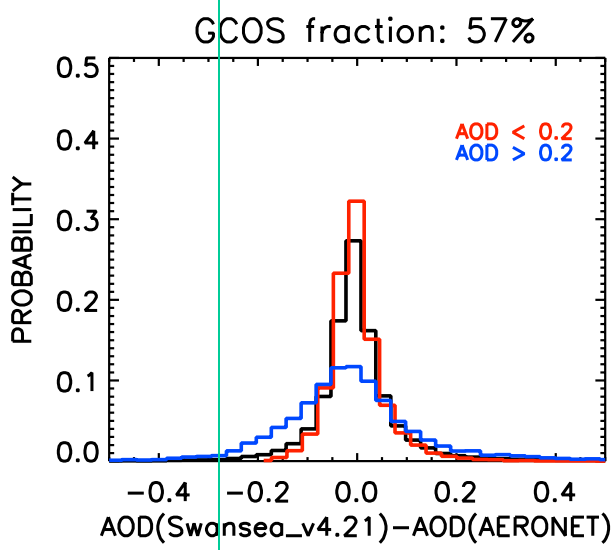
K=0.778 a= 0.75 b= 0.05 RMSE= 0.134



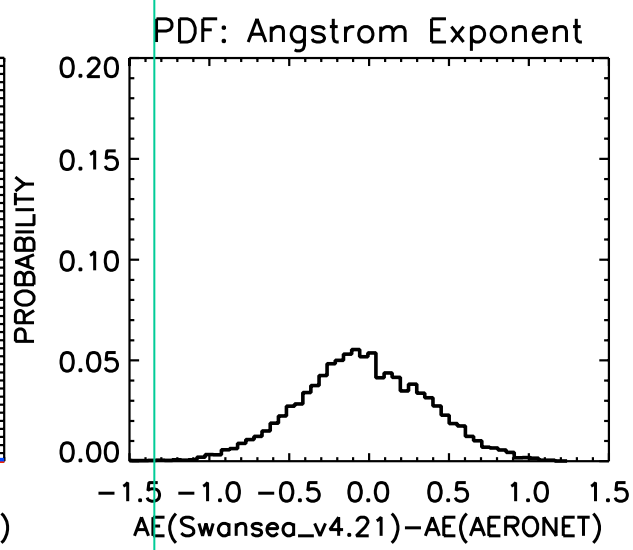
K=0.736 a= 0.52 b= 0.49 RMSE= 0.401



Aver. Value= 0.003 St.D.= 0.149 N=28123
Aver. Value= 0.012 St.D.= 0.068 N=18488
Aver. Value=−0.015 St.D.= 0.235 N=9635



Aver. Value= 0.009 St.D.= 0.134 N=28123
Aver. Value= 0.016 St.D.= 0.060 N=21121
Aver. Value=−0.013 St.D.= 0.246 N=7002



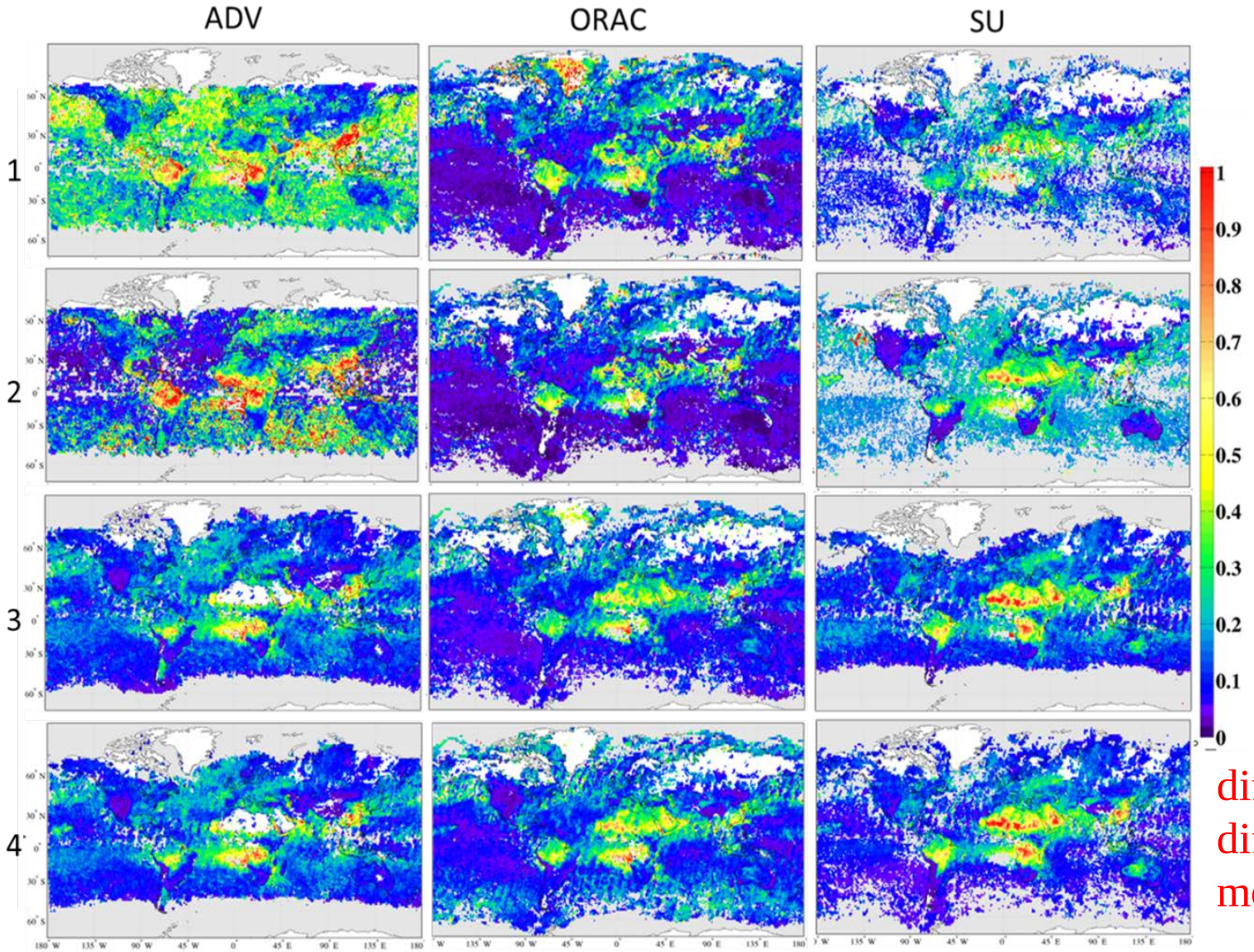
Aver. Value=−0.017 St.D.= 0.400 N=10063

Validation with AERONET
SU v4.21 (L2, land, 2002-2012)

metric	algorithm					
	ADV/ASV		ORAC		SU	
	V1.0	V2.3	V1.0	V3.02	V1.0	V4.21
over ocean						
number of points	75	64	65	102	13	52
bias	0.04	0.02	0.07	0.10	0.06	-0.002
RMSE	0.16	0.09	0.15	0.16	0.08	0.06
correlation	0.58	0.89	0.81	0.93	0.89	0.86
GCOS fraction (%)	17	66	46	31	15	58
over land						
number of points	306	185	262	262	138	343
bias	-0.005	-0.05	0.03	-0.002	-0.001	-0.01
RMSE	0.16	0.13	0.16	0.08	0.08	0.11
correlation	0.59	0.66	0.59	0.86	0.72	0.82
GCOS fraction (%)	37	54	40	51	46	62

De Leeuw, Holzer-Popp, et al., RSE 2015

Convergence of three AATSR algorithms (September 2008)



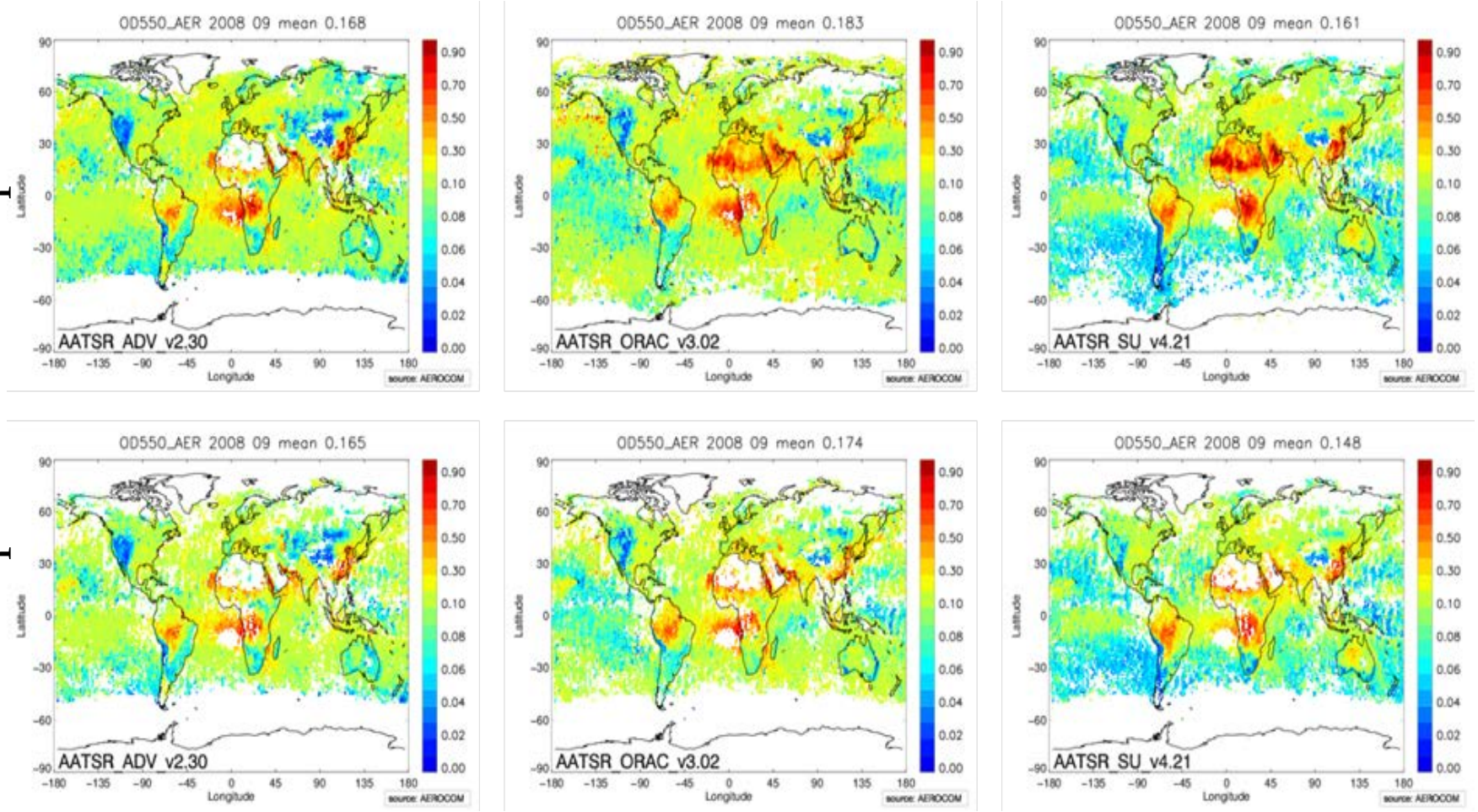
different principles
different Q/A
more consistent

Impact of filtering

(common points / no filtering – September 2008)

all points

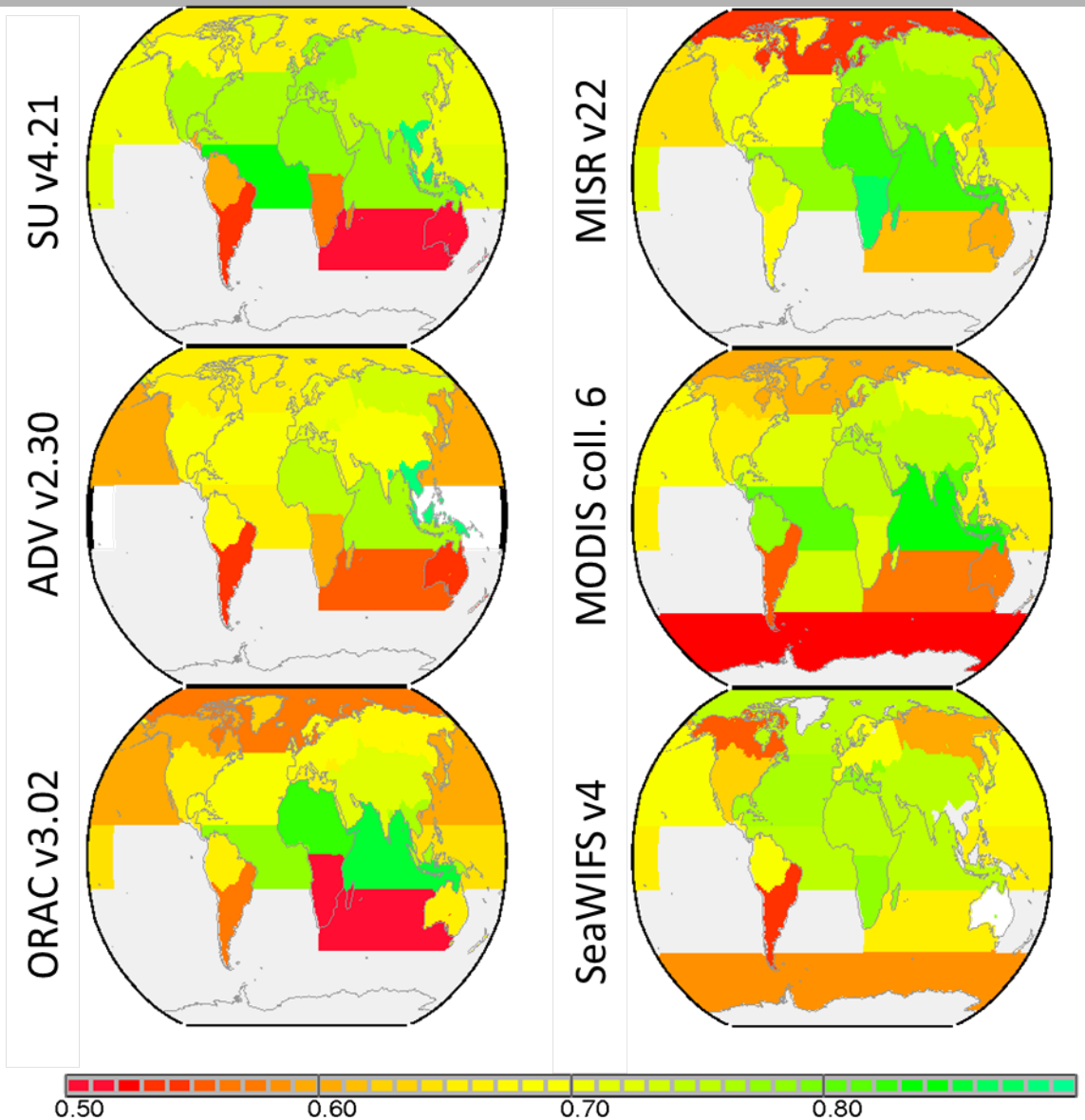
common points



filtering matters to assess trade-off between Q/A filtering and coverage in particular for areas with no AERONET stations

Evaluating patterns

(seasons, regions; 3 AATSR + NASA algorithms, 2008)



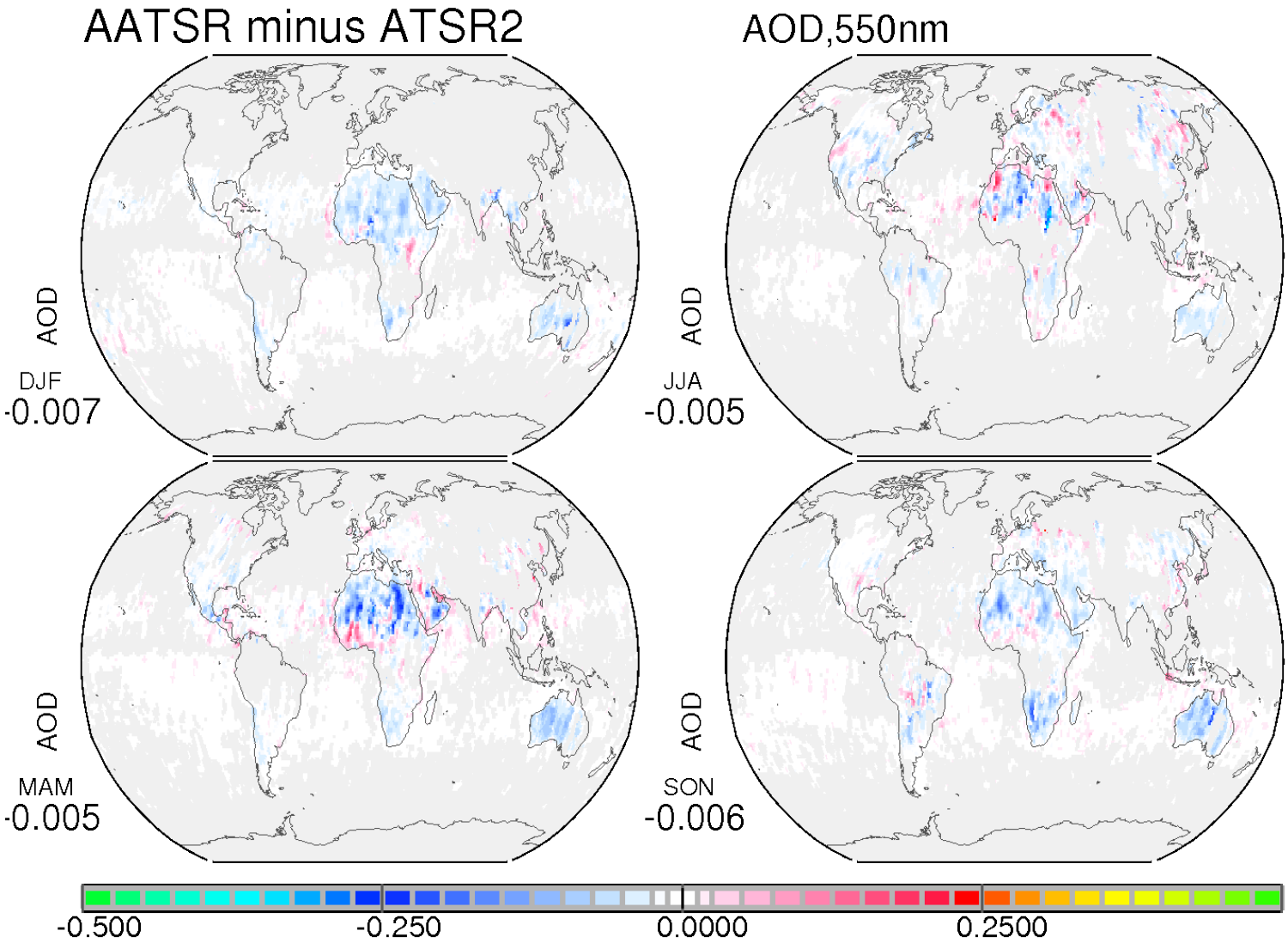
Score evaluates
spatial correlation
temporal correlation
bias

Requires

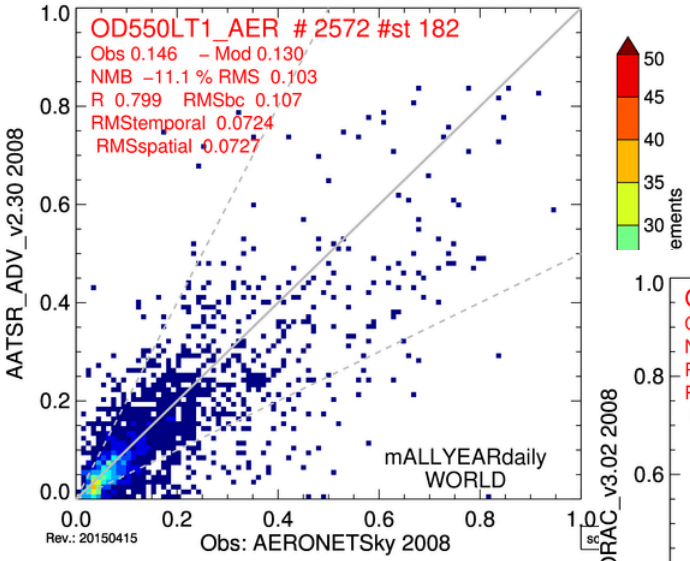
1 year of data

Regional analysis
No algorithm is
best everywhere

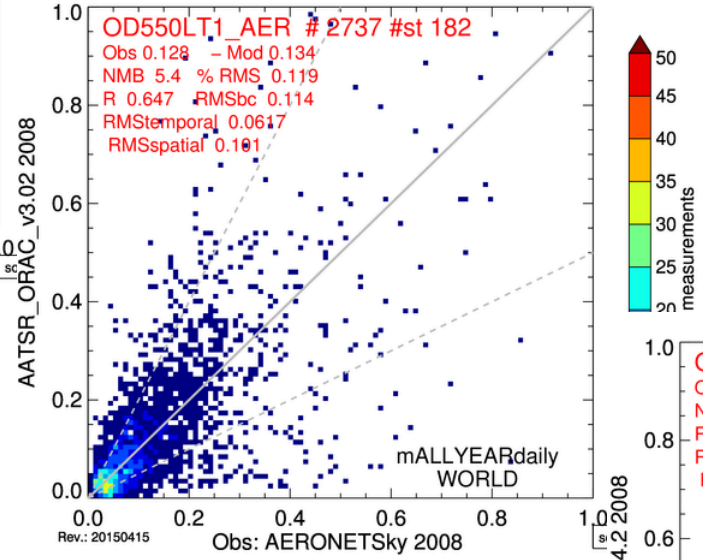
Overlap consistency
ATSR-2 / AATSR (SU 2002/3)



Growing confidence in
Fine mode AOD (land+ocean, 3x AATSR)

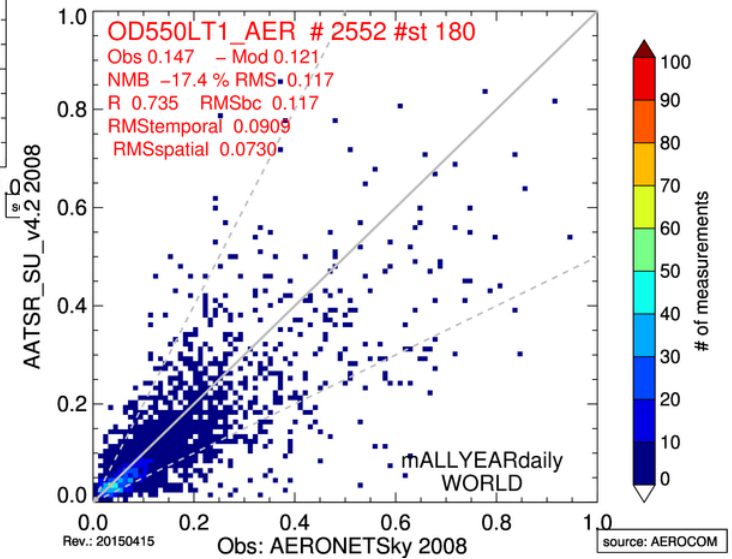


ADV



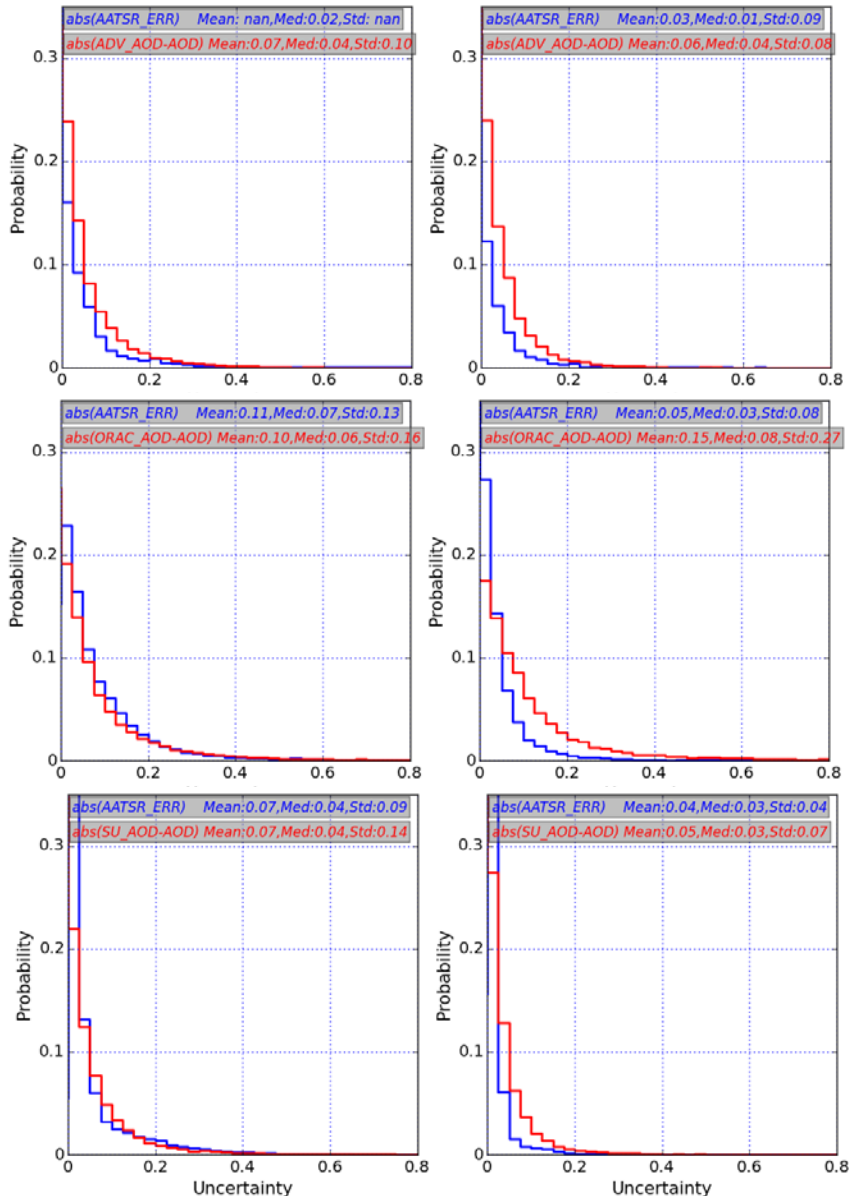
ORAC

SU



Uncertainties
AATSR (3 algorithms)

land ocean



ADV

ORAC

SU

uncertainty

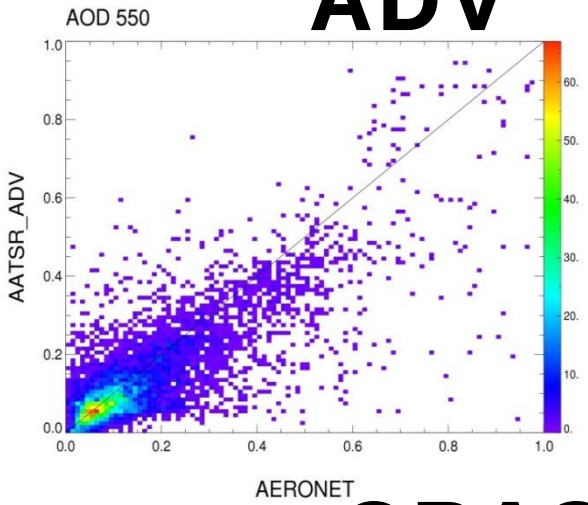
„true“ error

uncertainties feasable

cloud contamination cannot be considered

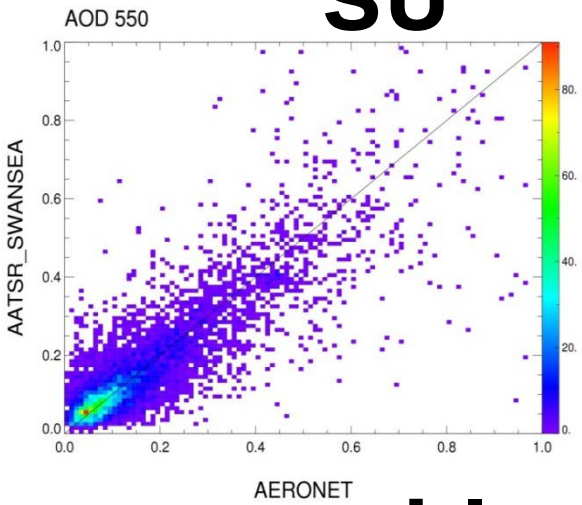
Uncertainty-weighted Ensemble (AATSR)

ADV



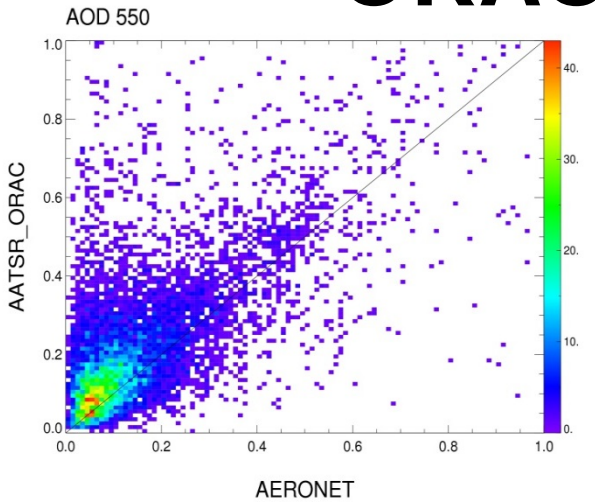
N:	6557
bias:	-0.02
rmse:	0.10
crmse:	0.10
pearson:	0.82
fit m:	0.76
fit offset:	0.02

SU



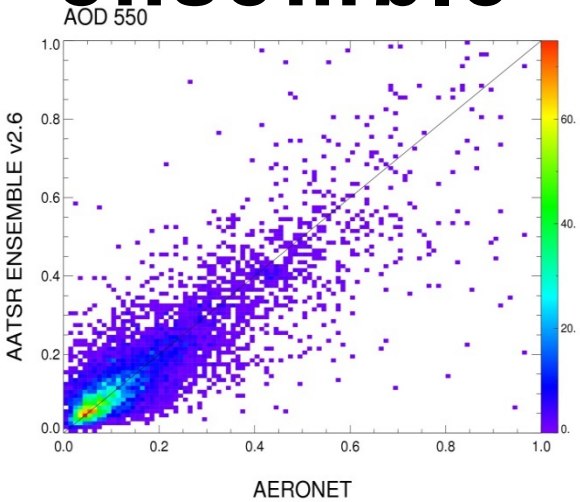
N:	6324
bias:	0.00
rmse:	0.11
crmse:	0.11
pearson:	0.82
fit m:	0.75
fit offset:	0.05

ORAC



N:	8532
bias:	0.07
rmse:	0.20
crmse:	0.18
pearson:	0.59
fit m:	0.74
fit offset:	0.12

ensemble



N:	6949
bias:	0.00
rmse:	0.10
crmse:	0.10
pearson:	0.85
fit m:	0.83
fit offset:	0.03

Uncertainty-weighted ensemble combines algorithm strengths

Uncertainty-weighted Ensemble (AATSR)

Validation with AERONET for 2011				
	ADV 2.30	SU 4.21	ORAC 3.02	Ensemble 2.6
N	6557	6324	8532	6949
BIAS	-0.02	0.00	0.07	0.00
RMSE	0.10	0.11	0.20	0.10
CRMSE	0.10	0.11	0.18	0.10
Pearson	0.82	0.82	0.59	0.85
fit m	0.76	0.75	0.74	0.83
fit offset	0.02	0.05	0.12	0.03

Uncertainty-weighted ensemble combines algorithm strengths

GCOS Climate Monitoring Principles

*Thus **satellite systems** for climate monitoring should adhere to the following specific principles:*

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.
12. A **suitable period of overlap** for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and **peer-reviewed new products** should be introduced as appropriate.
17. Data systems needed to **facilitate user access to climate products, metadata** and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.
19. **Complementary *in situ* baseline observations** for satellite measurements should be maintained through appropriate activities and cooperation.
20. **Random errors and time-dependent biases** in satellite observations and derived products should be identified.

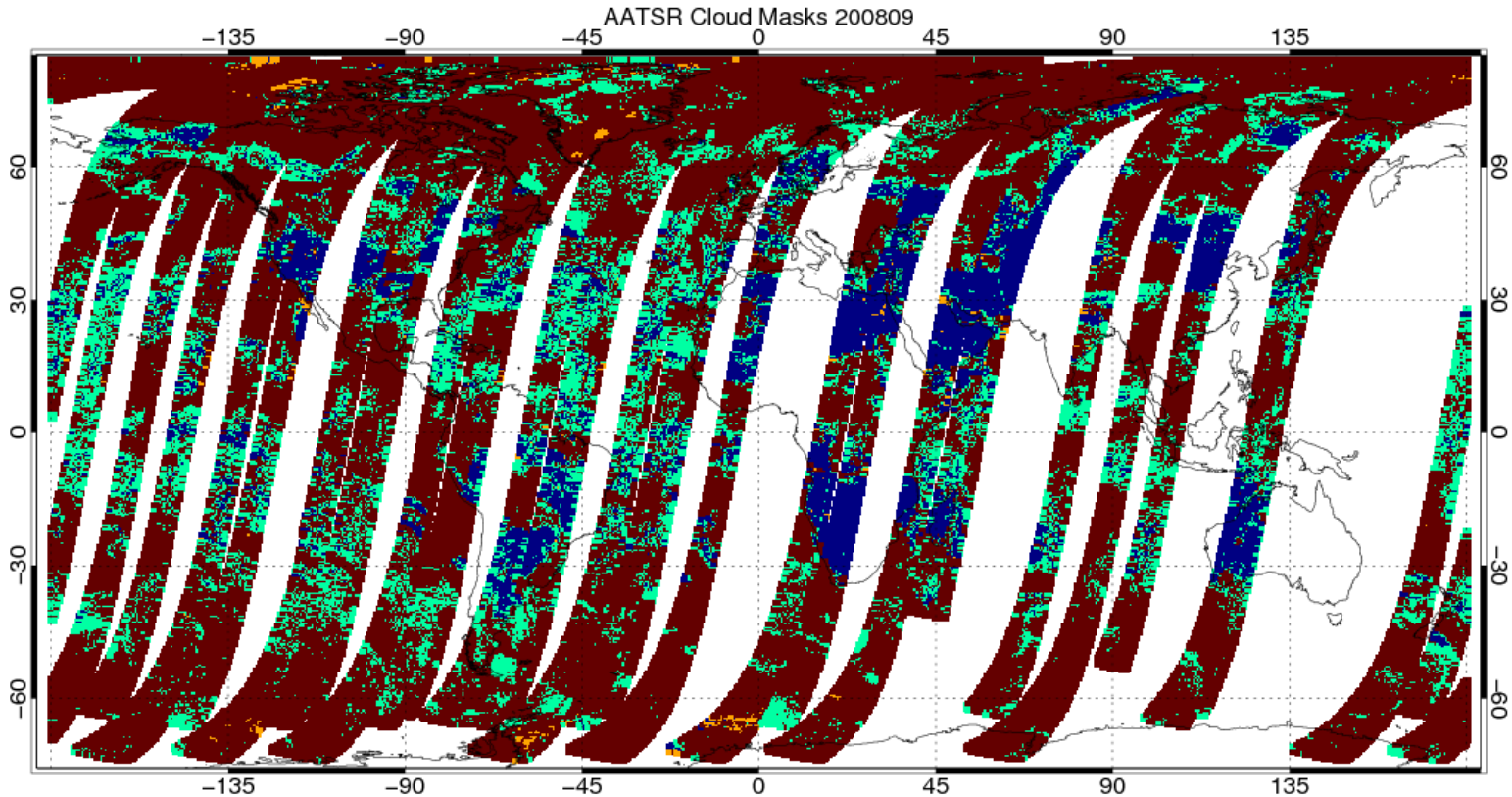
Conclusion & outlook

- Benefit from use of multi-sensor datasets
  - AOD with different retrieval principles in the Sahara

- Emerging tools: Pixel-level uncertainties / ensemble datasets

- Algorithm qualification / round robin exercise
  - Difficult comparison issue: quality filtering / sampling
  - Statistics to AERONET / MAN (global, land, ocean, regional)
  - Scoring temporal / spatial patterns
  - Maps to assess coverage / areas without AERONET stations
  - Common and all point filtering to assess algorithms
  - Time series stability
  - Consistency with other ECVs (e.g. cloud masks)

Consistency of cloud masks Aerosol_cci / Cloud_cci



5 selected days Sep 2008 – safety zone excluded by Aerosol_cci

APOLLO / Cloud_cci

12,4 %	21,1 %	0,5 %	66,0 %
No Cloud / No Cloud	Cloud / No Cloud	No Cloud / Cloud	Cloud / Cloud

References

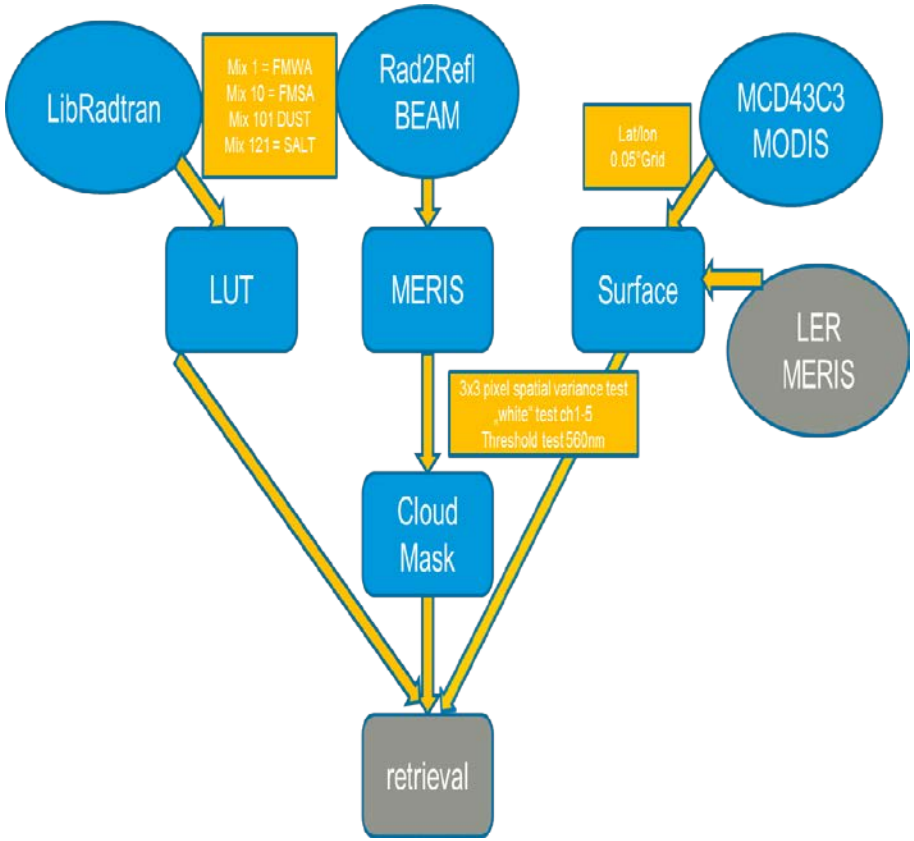
Hollmann R., C.J. Merchant, R. Saunders, C. Downy, M. Buchwitz, A. Cazenave, E. Chuvieco, P. Defourny, G. de Leeuw, R. Forsberg, T. Holzer-Popp, F. Paul,S. Sandven, S. Sathyendranath, M. van Roozendael, W. Wagner, **The ESA Climate Change Initiative: satellite data records for essential climate variables**, **Bulletin of the American Meteorological Society**, 11, online pre-release, doi: 10.1175/BAMS-D-11-00254.1, 2013

Holzer-Popp, T., de Leeuw, G., Martynenko, D., Klüser, L., Bevan, S., Davies, W., Ducos, F., Deuzé, J. L., Graigner, R. G., Heckel, A., von Hoyningen-Hüne, W., Kolmonen, P., Litvinov, P., North, P., Poulsen, C. A., Ramon, D., Siddans, R., Sogacheva, L., Tanre, D., Thomas, G. E., Vountas, M., Descloitres, J., Griesfeller, J., Kinne, S., Schulz, M., and Pinnock, S., **Aerosol retrieval experiments in the ESA Aerosol_cci project**, **Atmospheric Measurements and Techniques**, 6, 1919 - 1957, doi:10.5194/amt-6-1919-2013, 2013

de Leeuw, G., T. Holzer-Popp, S. Bevan, W. Davies, J. Descloitres, R.G. Grainger, J. Griesfeller, A. Heckel, S. Kinne, L. Klüser, P. Kolmonen, P. Litvinov, D. Martynenko, P.J.R. North, B. Ovigneur, N. Pascal, C. Poulsen, D. Ramon, M. Schulz, R.Siddans, L. Sogacheva, D. Tanré, G.E. Thomas, T.H. Virtanen, W. von Hoyningen Huene, M.Vountas, S. Pinnock, **Evaluation of seven European aerosol optical depth retrieval algorithms for climate analysis**, **Remote Sensing of Environment**, 162, 295-315, doi: 10.1016/j.rse.04.023, 2015

Thomas Popp, Gerrit de Leeuw, Christine Bingen, Christoph Brühl, Virginie Capelle, Alain Chedin, Lieven Clarisse, Oleg Dubovik, Roy Grainger, Jan Griesfeller, Andreas Heckel, Stefan Kinne, Lars Klüser, Miriam Kosmale, Pekka Kolmonen, Luca Lelli, Pavel Litvinov, Linlu Mei, Peter North, Simon Pinnock, Adam Povey, Charles Robert, Michael Schulz, Larisa Sogacheva, Kerstin Stebel, Deborah Stein Zweers, Gareth Thomas, Lieuwe Gijsbert Tilstra, Sophie Vandenbussche, Pepijn Veefkind, Marco Vountas, Yong Xue, **Development, Production and Evaluation of Aerosol Climate Data Records from European Satellite Observations (Aerosol_cci)**, **Remote Sensing**, accepted for publication, 2016

Aerosol retrieval challenge



- Aerosols are complex+variable
- Retrievals are ill-posed
- Information content varies
  - sensor, geometry, AOD, surface
- Algorithms need
  - smart use of apriori
  - Experimental iteration
  - Algorithm ensembles
  - Pixel-level uncertainties
- Observing complete aerosols
  - complementary sensors

Algorithm validation with growing data volums (SU AATSR)

4 months in 4 seasons can suffice

metric	Data volumes			
	Sep 2008	Mar, Jun, Sep, Dec 2008	All 2008	2002 - 2012
over ocean				
Number of points	52	235	716	5808
bias	-0.002	-0.002	-0.002	0.006
RMSE	0.06	0.07	0.07	0.08
correlation	0.86	0.93	0.91	0.87
GCOS fraction	58	64	66	62
over land				
Number of points	343	993	3313	28123
bias	-0.01	0.007	0.007	0.003
RMSE	0.11	0.12	0.14	0.15
correlation	0.82	0.86	0.81	0.79
GCOS fraction	62	56	51	52

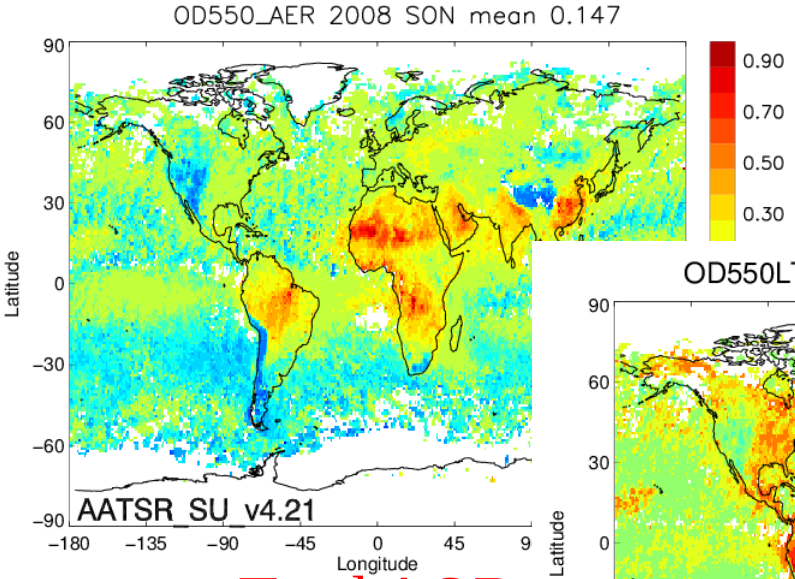
Level3 validation

(common points – September / all 2008)

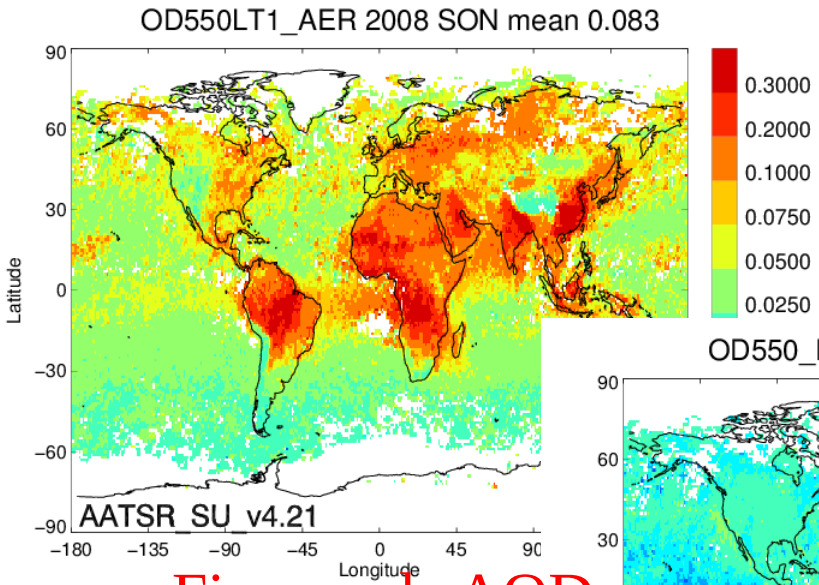
metric	Algorithm					
	ADV / ASV v2.30		ORAC v3.02		SU v4.21	
	Sep 2008	All 2008	Sep 2008	All 2008	Sep 2008	All 2008
Number of points	586	6072	586	6072	586	6072
bias	-0.048	-0.04	-0.001	-0.007	-0.025	-0.021
RMSE	0.12	0.11	0.11	0.11	0.11	0.10
correlation	0.71	0.80	0.74	0.79	0.80	0.83
GCOS fraction	53	52	50	49	60	59

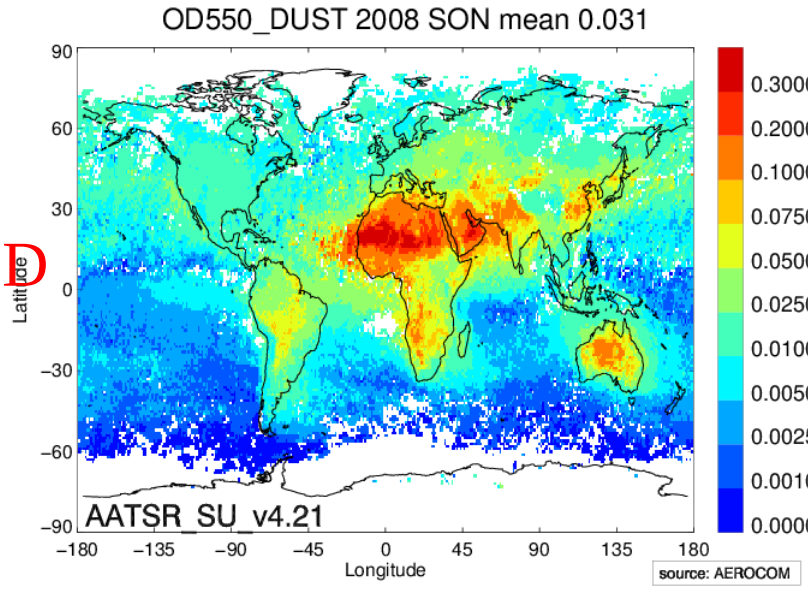
Lv2 and lv3 valdiation show similar algorithm comparisons

Growing confidence in
Fine mode AOD (land+ocean, SU AATSR)



Total AOD



Fine mode AOD

Dust AOD