climate change initiative

→ AEROSOL

Benchmarking and use of improved Aerosol_cci+ data for climate monitoring

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27 May 2022 ESA Living Planet Symposium

aerosol cci

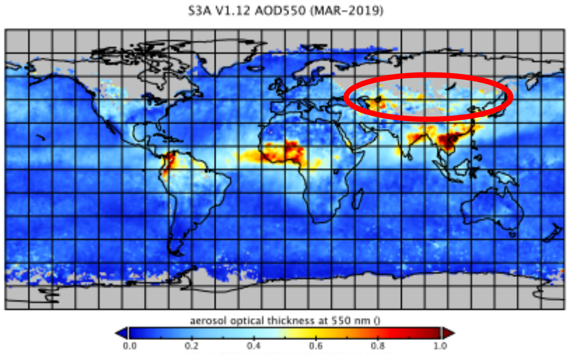
Aerosol_cci+ datasets

- evolve + qualify algorithms for **dual-view radiometer sensor line** (ATSR-2, AATSR, SLSTR-A, SLSTR-B)
  - Swansea: mature algorithm from Aerosol_cci2
    - reduce SLSTR AOD over-estimation
    - improve methodological consistency between (A)ATSR(-2) and SLSTR /3A and /3B
  - Rayference: innovative algorithm adapted from SEVIRI / optimal estimation method
    - demonstrate for SLSTR, evaluate and subsequently improve
    - works without a classical cloud mask
- apply systematic benchmarking of test datasets (A)ATSR(-2) (1998, 2008), SLSTR (2019, 2020)
  - Validation against AERONET, MAN: AOD, FM-AOD, u(AOD)
  - Inter-comparison to MODIS, MISR, POLDER
  - Evaluation from user perspective / 2 user case studies

Algorithm improvement

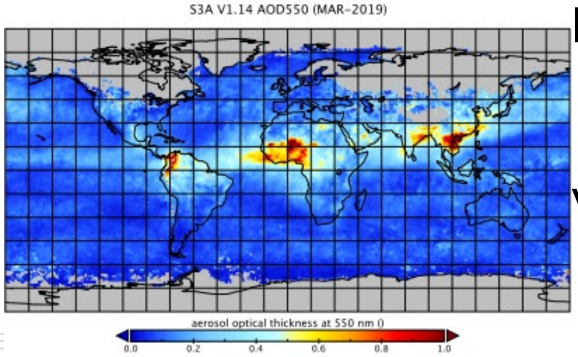
Mature SLSTR Swansea algorithm

Reduced bias over bright surfaces



v1.12

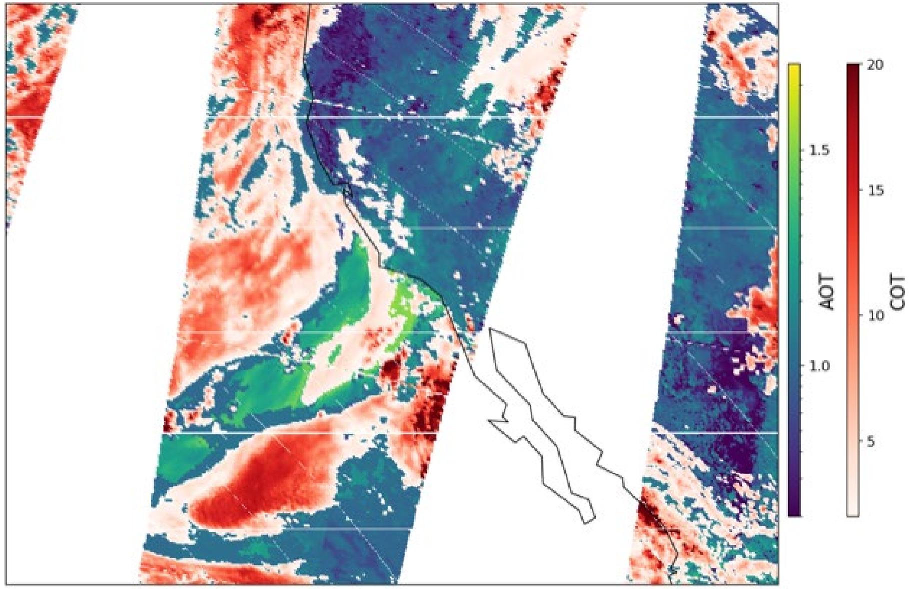
SLSTR / S3A
March 2019



v1.14

New SLSTR CISAR algorithm

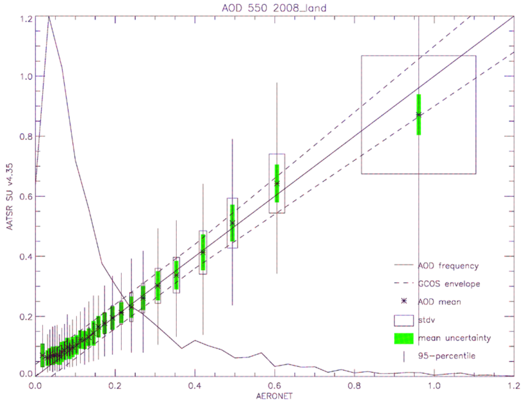
Joint aerosol and cloud retrieval

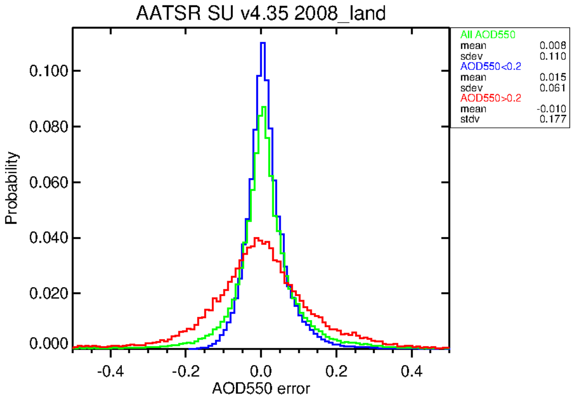


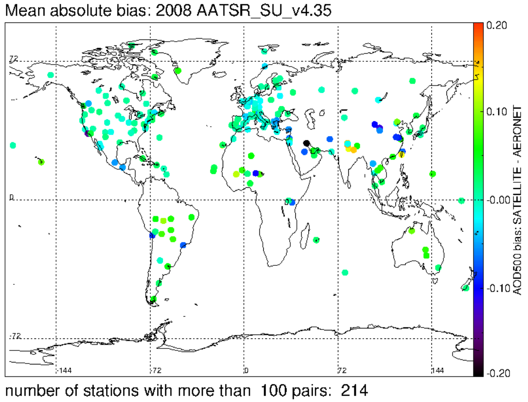
California 2020-08-20

Benchmarking SU algorithm

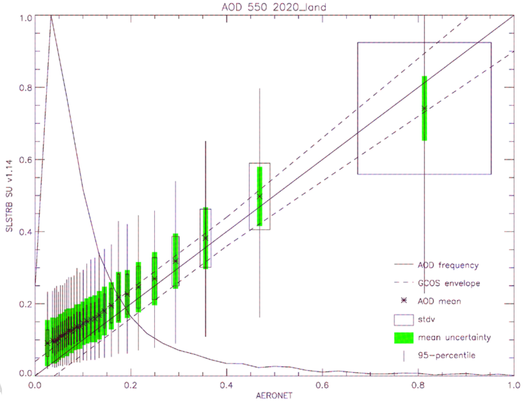
AATSR 2008

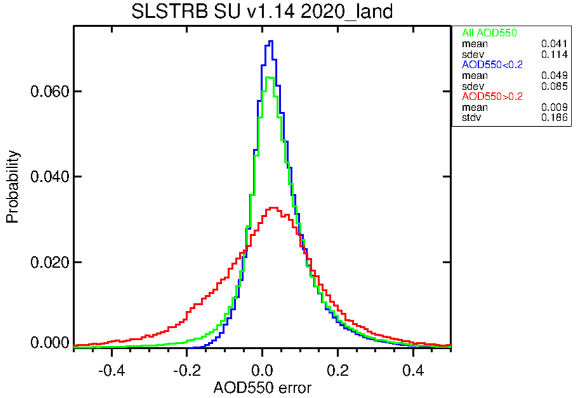


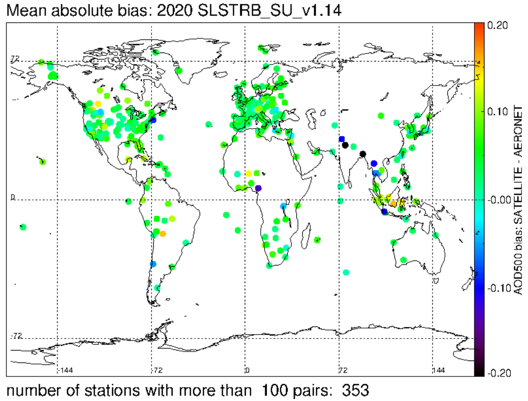




SLSTR/S3B 2020

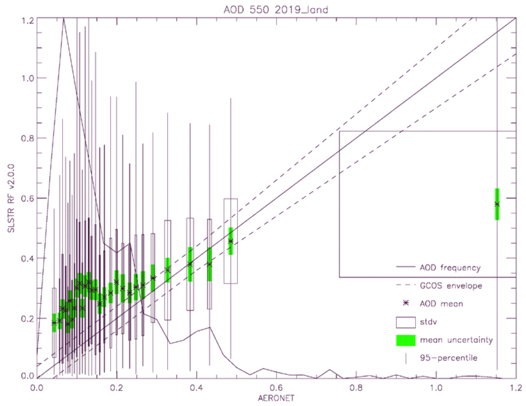


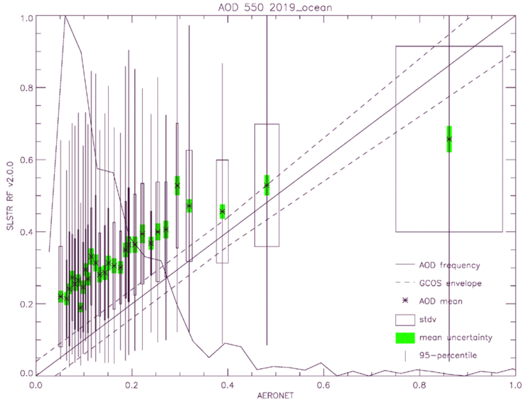




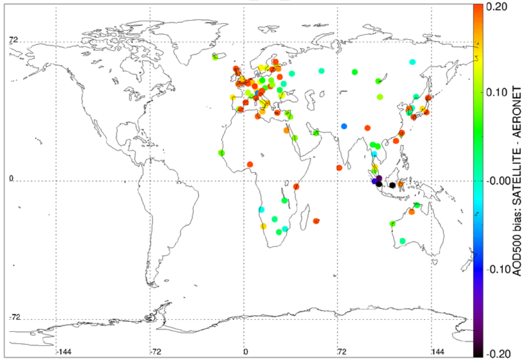
Benchmarking CISAR algorithm

V2.0.0
2019



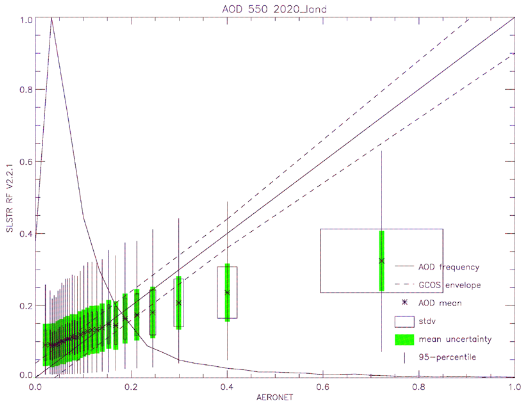


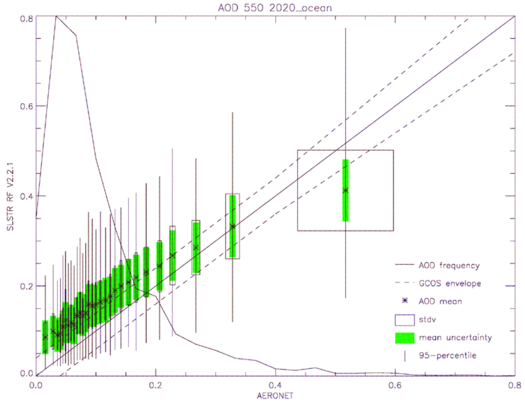
Mean absolute bias: 2019 SLSTR_RF_v2.0.0



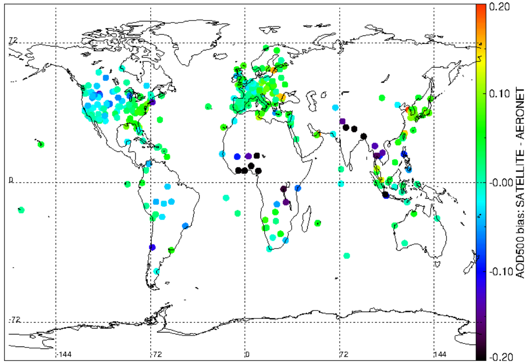
number of stations with more than 100 pairs: 100

V2.1.1
2020





Mean absolute bias: 2020 SLSTR_RF_V2.2.1



number of stations with more than 100 pairs: 346

Achieved improvements: AOD

year	sensor	algorithm version	area	bias	stdv	Pearson corr	GCOS fraction
2008	AATSR	SU_v4.32	land	0.02	0.11	0.89	52.3
2008	AATSR	SU_v4.35	land	0.01	0.11	0.87	54.0
2008	AATSR	SU_v4.32	ocean	0.03	0.11	0.84	57.0
2008	AATSR	SU_v4.35	ocean	0.02	0.07	0.89	61.3
2019	SLSTRA	SU_v1.11	land	0.05	0.15	0.73	35.2
2020	SLSTRA	SU_v1.14	land	0.03	0.12	0.80	42.7
2019	SLSTRA	SU_v1.11	ocean	0.05	0.08	0.86	40.3
2020	SLSTRA	SU_v1.14	ocean	0.04	0.08	0.83	52.4
2019	SLSTRA	RF_v2.0.0	land	0.08	0.41	0.17	23.0
2020	SLSTRA	RF_v2.1.1	land	0.00	0.14	0.45	38.6
2019	SLSTRA	RF_v2.0.0	ocean	0.14	0.35	0.28	19.0
2020	SLSTRA	RF_v2.1.1	ocean	0.05	0.11	0.59	38.7

AOD bias
(last version)
land / ocean

0.01 / 0.02

0.03 / 0.04

0.00 / 0.05

Achieved results: FM-AOD

year	sensor	algorithm version	area	bias	stdv	Pearson corr
1998	ATSR-2	SU_v4.35	land	0.04	0.11	0.72
1998	ATSR-2	SU_v4.35	ocean	0.05	0.07	0.84
2008	AATSR	SU_v4.35	land	0.03	0.09	0.82
2008	AATSR	SU_v4.35	ocean	0.05	0.11	0.58
2019	SLSTRA	SU_v1.14	land	0.05	0.12	0.70
2020	SLSTRA	SU_v1.14	ocean	0.05	0.08	0.71
2019	SLSTRB	SU_v1.14	land	0.05	0.11	0.70
2020	SLSTRB	SU_v1.14	ocean	0.06	0.08	0.73
2020	SLSTRA	RF_v2.1.1	land	0.00	0.12	0.36
2020	SLSTRA	RF_v2.1.1	ocean	0.03	0.09	0.60

FMAOD bias
(last version)
land / ocean

0.03 / 0.05

0.05 / 0.05

0.00 / 0.03

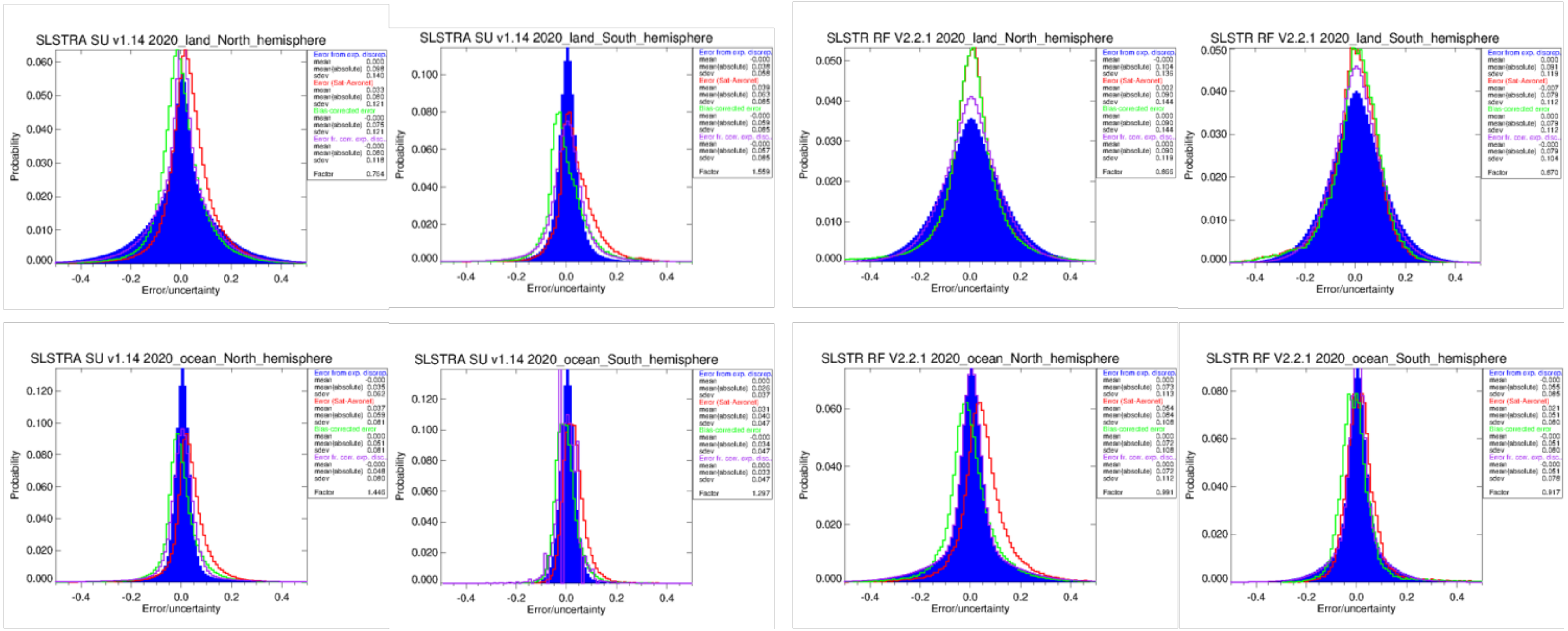
Evaluation of uncertainties

SLSTR / 3A

SU v1.14 | RF V2.2.1

North | South | North | South

land / ocean



Inter-comparison to other satellites

SLSTR / Swansea v1.14 (2019)

regions	Eur	Bor	AsN	AsW	AsE	ChinaSE	Aus	AfN	AfS	SA	NAW	NAE	Ind	Aod	Aob	InO	PO	Land	Ocean	Globe
March																				
S3A-S3B	-1,93	-1,37	-3,79	-0,73	-1,41	-1,23	0,05	1,85	0,23	-0,26	-1,20	-2,24	-0,66	1,37	-0,66	-0,19	-0,49	-0,64	-0,61	-0,61
S3A-MODIS	0,38	-1,72	-0,12	0,26	-0,71	-0,85	1,58	0,37	1,76	1,46	1,11	1,63	-0,38	-0,33	-0,57	-0,68	-0,78	0,75	-0,82	-0,47
S3A-MISR	0,68	1,37	1,79	1,57	2,04	1,61	0,61	0,48	0,89	2,43	0,94	1,84	1,08	0,24	0,99	0,64	0,59	1,48	0,31	0,54
S3B-MODIS	0,47	-1,37	0,24	0,65	-0,29	-0,44	1,86	0,20	2,06	1,44	1,44	1,08	0,00	-0,07	-0,21	-0,38	-0,45	0,90	-0,47	-0,16
S3B-MISR	0,78	1,72	2,14	1,93	2,44	2,01	0,90	0,31	1,21	2,40	1,27	1,30	1,46	0,49	1,34	0,94	0,92	1,63	0,66	0,85
June																				
S3A-S3B	-0,19	-1,58	-0,07	0,34	0,02	0,00	-0,45	1,20	-0,37	-0,24	-0,26	-0,31	-0,71	-0,80	-0,47	-0,59	-0,49	-0,24	-0,59	-0,49
S3A-MODIS	0,85	-0,45	1,06	1,57	0,84	0,49	0,75	2,24	1,14	0,94	0,40	1,11	-0,99	-0,93	-0,61	-0,78	-0,71	0,97	-0,71	-0,12
S3A-MISR	1,98	1,06	1,25	1,53	1,98	2,43	0,64	0,52	2,64	1,77	0,71	1,20	1,04	1,30	1,27	0,12	0,35	1,39	0,54	0,87
S3B-MODIS	0,97	-0,21	1,08	1,71	0,63	0,27	0,87	2,21	1,22	1,04	0,28	1,13	-0,49	-0,43	-0,35	-0,33	-0,35	1,06	-0,31	0,14
S3B-MISR	2,10	1,30	1,27	1,67	1,79	2,22	0,75	0,49	2,71	1,86	0,59	1,23	1,53	1,81	1,53	0,57	0,71	1,48	0,94	1,13
September																				
S3A-S3B	-0,54	0,14	-1,51	0,26	-0,96	-0,99	0,38	2,50	0,07	0,07	-0,35	-0,31	-0,02	-0,49	-0,34	-0,38	-0,52	0,07	-0,54	-0,38
S3A-MODIS	-0,12	-1,13	0,75	1,53	0,22	-0,04	1,60	1,15	2,15	1,08	0,54	1,74	-1,31	-0,64	-1,35	-0,68	-0,73	0,78	-0,90	-0,45
S3A-MISR	0,66	0,19	1,15	2,52	1,98	2,12	0,38	0,31	1,89	1,77	1,44	2,10	2,02	0,87	2,40	0,92	0,52	1,30	0,57	0,78
S3B-MODIS	0,09	-1,13	0,87	1,69	0,80	0,58	1,53	0,62	1,85	0,75	0,78	2,00	-1,53	-0,49	-1,31	-0,47	-0,40	0,73	-0,57	-0,21
S3B-MISR	0,87	0,19	1,27	2,67	2,51	2,68	0,31	-0,23	1,59	1,44	1,67	2,36	1,81	1,01	2,44	1,13	0,85	1,25	0,90	1,01
December																				
S3A-S3B	-0,28	NaN	-1,04	-0,71	-0,97	-1,08	0,16	-1,44	-0,35	-0,71	-0,21	-0,61	-0,54	-0,59	-0,59	-0,54	-0,52	-0,68	-0,52	-0,54
S3A-MODIS	-0,52	NaN	0,80	-1,72	-1,23	-1,70	3,04	-0,47	2,43	2,99	0,59	1,25	-0,28	0,00	-0,42	-0,85	-0,82	1,11	-0,97	-0,54
S3A-MISR	0,52	NaN	1,15	0,02	0,66	0,73	0,94	-0,12	1,60	2,88	1,27	1,63	1,18	1,30	0,90	0,54	0,47	1,37	0,28	0,49
S3B-MODIS	-0,45	NaN	1,51	-1,60	-0,57	-0,85	3,09	-0,59	2,73	3,25	0,54	1,34	-0,12	0,31	-0,09	-0,52	-0,54	1,30	-0,66	-0,26
S3B-MISR	0,59	NaN	1,86	0,14	1,32	1,58	0,99	-0,24	1,91	3,13	1,23	1,72	1,34	1,60	1,23	0,87	0,75	1,56	0,59	0,78

RD	<-2.0	<-1.5	<-1.0		>1.0	>1.5	>2.0
Group	Ng3	Ng2	Ng1		Pg1	Pg2	Pg3

$$RD = \frac{AOD_1 - AOD_2}{AD}$$

$$AD = \sqrt{ae_1^2 + ae_2^2}$$

$$ae_i = max(0.03, 0.1 * AOD)$$

Radiative forcing / decadal steps

- at 1x1deg lat/lon, monthly
- apply AOD and AODf satellite data
- use fine and coarse mode properties of the MAC climatology
- use vertical distribution by mode from modeling
- use the anthropogenic model attribution (via a fine mode fraction)
- use ISCCP cloud (high mid, low cloud cover, COT)
- MODIS surface land VIS / n-IR albedo, ocean albedo
- 2-stream radiative transfer (multiple sun-elevations)
  - ***impacts of total, direct (anthropogenic), indirect (Twomey) effects***
  - ***investigations at TOA (climate) SUR (processes) and ATM (dynamic)***

- Comparison to other satellites and model climatology shows significant differences
- Value in satellite datasets: systematic evolution over 2-3 decades

Radiative forcing / decadal steps

Radiative forcing

anthropogenic

direct + indirect

surface

ATSR-2: 1998

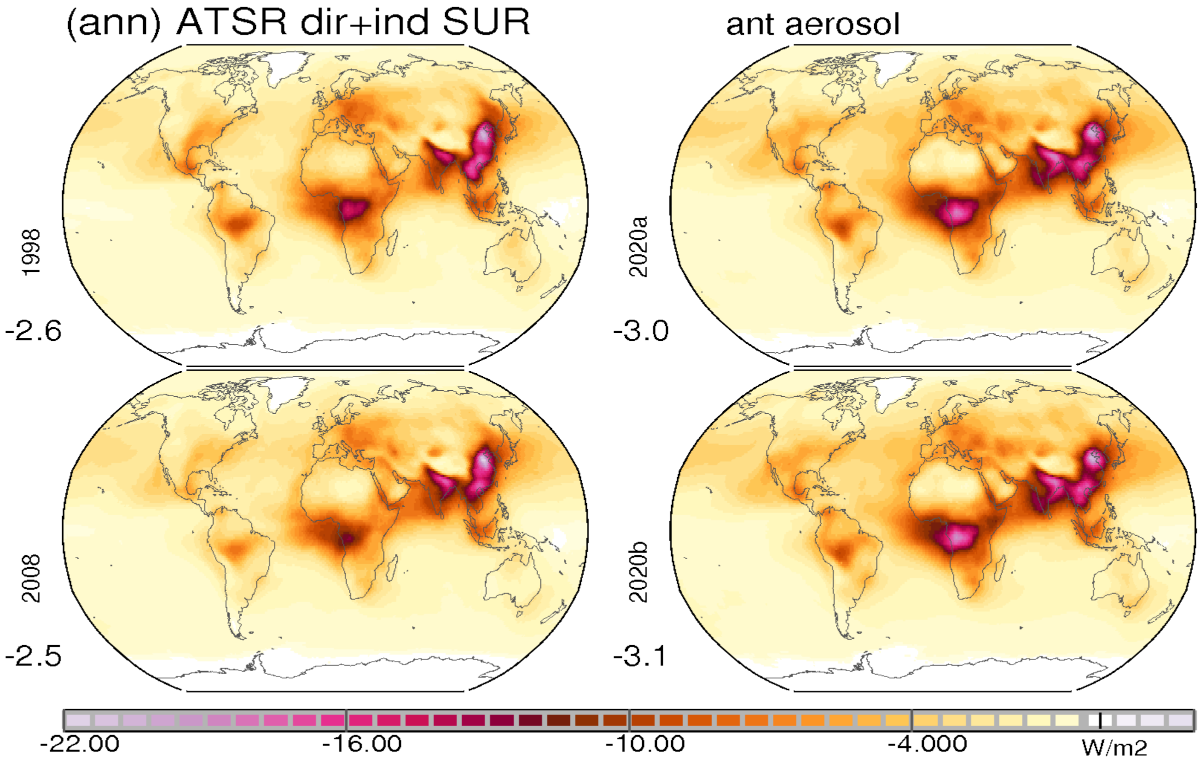
AATSR: 2008

SLSTR/3A: 2020

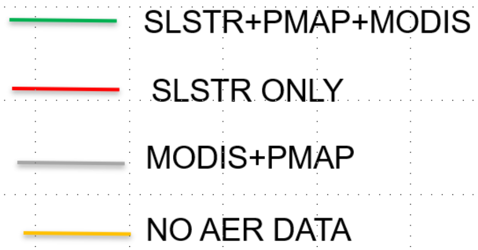
SLSTR/3B: 2020

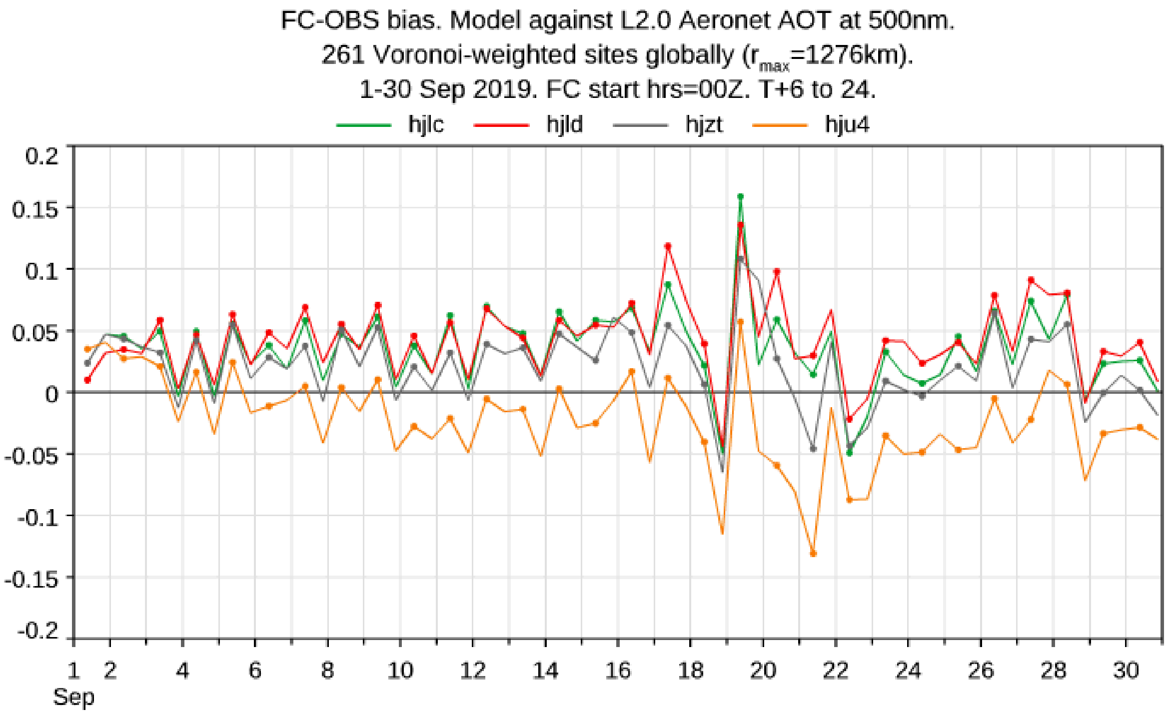
impact of SLSTR bias

impact of FMF bias vs. other data



SLSTR data assimilation into CAMS





- Positive bias w/ SLSTR no thinning or varBC
- higher than experiment with MODIS+PMAP

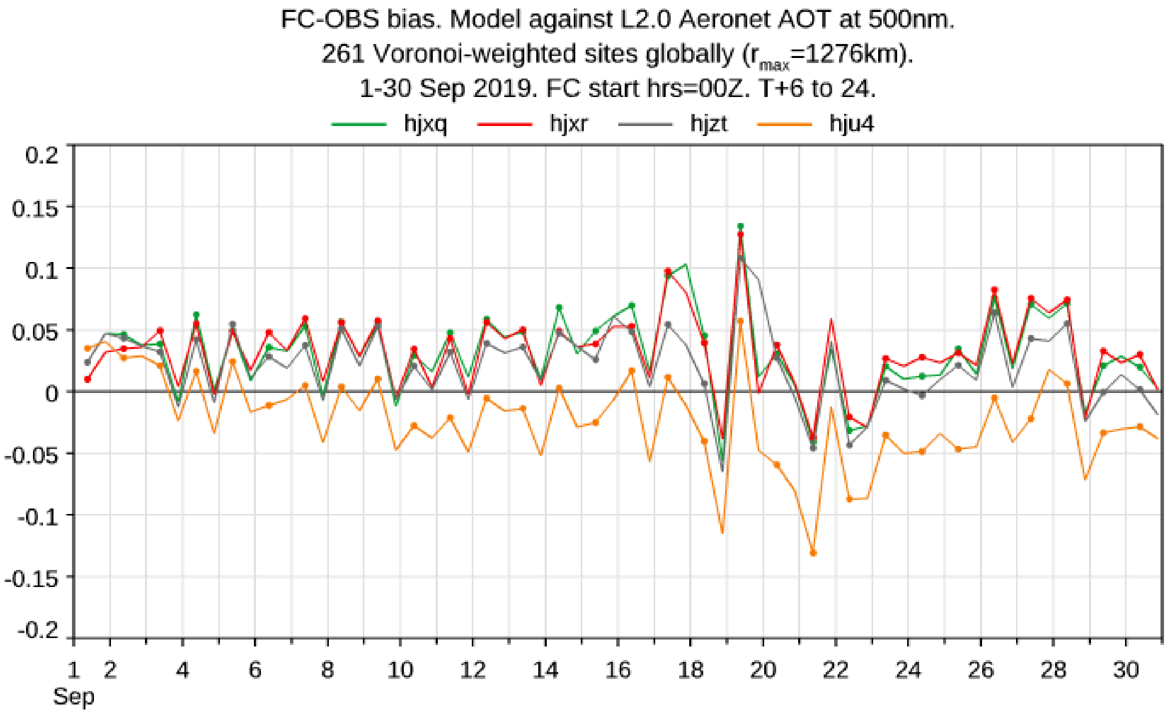
SLSTR data assimilation into CAMS

SLSTR+PMAP+MODIS

SLSTR ONLY

MODIS+PMAP

NO AER DATA



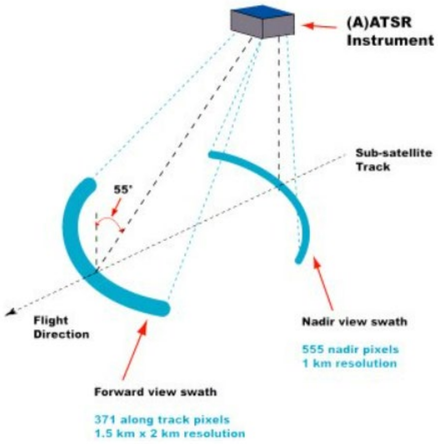
- Positive bias slightly reduced with thinning + varBC
- Closer to experiment with MODIS+PMAP (CAMS operational configuration)

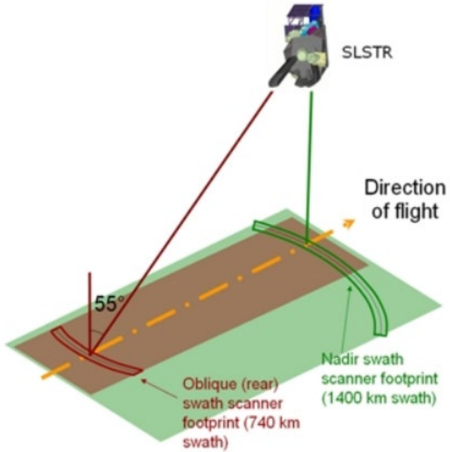
Conclusions

- Based on benchmarking and user case studies

- Swansea algorithm needs
  - further reduction of SLSTR bias
    - despite major efforts for consistency
  - overall reduction of Fine Mode fraction
    - adaptation of dust properties?

- CISAR algorithm needs
  - improvement for high AOD / cloud discrimination
  - better coverage of main seasonal / regional patterns

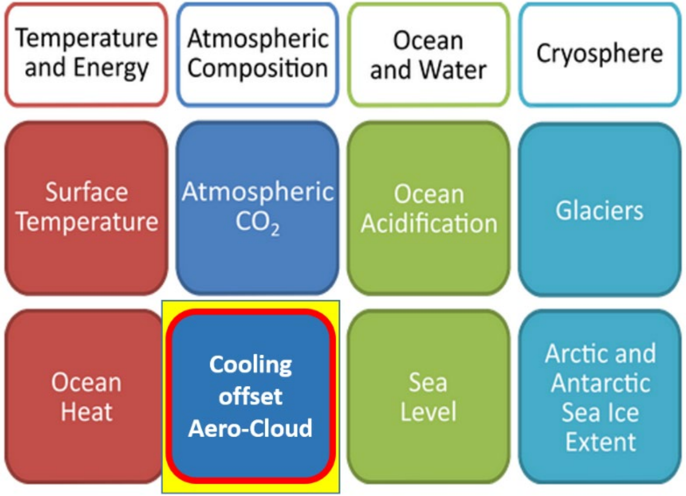




Outlook

- Aerosol_cci+ Phase 2 (2022 – 2024)
  - currently under preparation
  - improve identified deficiencies of both algorithms
  - benchmark / evaluate new version test datasets

- ESA CLIMATE-SPACE program (2024 -)
  - Cross-ECV study with Cloud_cci proposed
    - new satellite-based climate indicator
    - analyse aerosol-cloud associations



WMO climate indicators

Community framework

- AEROSAT – International Satellite Aerosol Science Network https://aero-sat.org/
- Coodinated by Aerosol_cci+ and NASA
- Unfunded discussion forum of aerosol retrieval experts and (model) users
  - Understand the strenghts and limitations of satellite retrievals
  - Match their capabilities with user needs
  - AEROSAT experiments to compare and test the use of satellite retrievals
- Cooperation with AEROCOM, ICAP, CEOS-VC-AC
- Next meeting (with AEROCOM): Oslo, 10-14 October 2022

Clean background evaluation

Clean sites, where AOD(AERONET) 70%-percentile (monthly mean) < 0.1 and h < 150 m					
year	**sensor**	**alg_version**	**bias**	**stdv**	**AERONET mean AOD**
2020	SLSTRA	SU_v1.14	0.01	0.03	0.062
2020	SLSTRB	SU_v1.14	0.01	0.04	0.066
2020	SLSTRA	RF_V2.2.1	-0.01	0.04	0.058
2008	AATSR	SU_v4.35	0.05	0.06	0.027
MAN colocations					
2020	SLSTRA	SU_v1.14	0.02	0.07	0.117
2020	SLSTRB	SU_v1.14	0.02	0.05	0.150
2020	SLSTRA	RF_V2.2.1	0.04	0.09	0.101

Relevant papers

Aerosol_cci+

- Stefan Kinne, Paul Ginoux, Peter North, Kevin Pearson, Rob Levy, Ralph Kahn, Thomas Popp, Aerosol radiative effects with MACv3 and satellites retrievals, in review (revision) at Atmospheric Physics and Chemistry, 2022.
- Angela Benedetti, Gianpaolo Balsamo, Souhail Boussetta, Francesca Di Giuseppe, Antje Inness, Kenta Ochi, Patricia de Rosnay, Hao Zuo, Use of ESA Climate Change Initiative data in ECMWF's Earth system model, ECWMF science blog at https://www.ecmwf.int/en/newsletter/171/news/use-esa-climate-change-initiative-data-ecmwfs-earth-system-model, 2022.
- Thomas Popp, Johnathan Mittaz, Systematic propagation of AVHRR AOD uncertainties - a case study to demonstrate the FIDUCEO approach, Remote Sensing, 14, 875, https://doi.org/10.3390/rs14040875, 2022.

AEROSAT

- Sogacheva Larisa, Thomas Popp, Andrew M. Sayer, Oleg Dubovik, Michael J. Garay, Andreas Heckel, N. Christina Hsu, Hiren Jethva, Ralph A. Kahn, Pekka Kolmonen, Miriam Kosmale, Gerrit de Leeuw, Robert C. Levy, Pavel Litvinov, Alexei Lyapustin, Peter North, Omar Torres and Antti Arola, Merging regional and global aerosol optical depth records from major available satellite products, Atmospheric Chemistry and Physics, 20, 2031 – 2056, https://doi.org/10.5194/acp-20-2031-2020, 2020.
- Sayer, A. M., Govaerts, Y., Kolmonen, P., Lipponen, A., Luffarelli, M., Mielonen, T., Patadia, F., Popp, T., Povey, A. C., Stebel, K., and Witek, M. L.: A review and framework for the evaluation of pixel-level uncertainty estimates in satellite aerosol remote sensing, Atmospheric Measurements and Techniques, 13, 373–404, https://doi.org/10.5194/amt-13-373-2020, 2020.
- Schutgens, N., Sayer, A. M., Heckel, A., Hsu, C., Jethva, H., de Leeuw, G., Leonard, P. J. T., Levy, R. C., Lipponen, A., Lyapustin, A., North, P., Popp, T., Poulsen, C., Sawyer, V., Sogacheva, L., Thomas, G., Torres, O., Wang, Y., Kinne, S., Schulz, M., and Stier, P.: An AeroCom–AeroSat study: intercomparison of satellite AOD datasets for aerosol model evaluation, Atmos. Chem. Phys., 20, 12431–12457, https://doi.org/10.5194/acp-20-12431-2020, 2020.
- Schutgens, N., Dubovik, O., Hasekamp, O., Torres, O., Jethva, H., Leonard, P. J. T., Litvinov, P., Redemann, J., Shinozuka, Y., de Leeuw, G., Kinne, S., Popp, T., Schulz, M., and Stier, P.: AEROCOM and AEROSAT AAOD and SSA study – Part 1: Evaluation and intercomparison of satellite measurements, Atmos. Chem. Phys., 21, 6895–6917, https://doi.org/10.5194/acp-21-6895-2021, 2021.
- Jonas Gliß, Augustin Mortier, Michael Schulz, Elisabeth Andrews, Yves Balkanski, Susanne E. Bauer, Anna M. K. Benedictow, Huisheng Bian, Ramiro Checa-Garcia, Mian Chin, Paul Ginoux, Jan J. Griesfeller, Andreas Heckel, Zak Kipling, Alf Kirkevåg, Harri Kokkola, Paolo Laj, Philippe Le Sager, Marianne Tronstad Lund, Cathrine Lund Myhre, Hitoshi Matsui, Gunnar Myhre, David Neubauer, Twan van Noije, Peter North, Dirk J. L. Olivié, Samuel Rémy, Larisa Sogacheva, Toshihiko Takemura, Kostas Tsigaridis, and Svetlana G. Tsyro, Atmos. Chem. Phys., 21, 87–128, https://doi.org/10.5194/acp-21-87-2021,https://doi.org/10.5194/acp-21-87-2021, 2021.