GRASP and PFR sun photometry synergy

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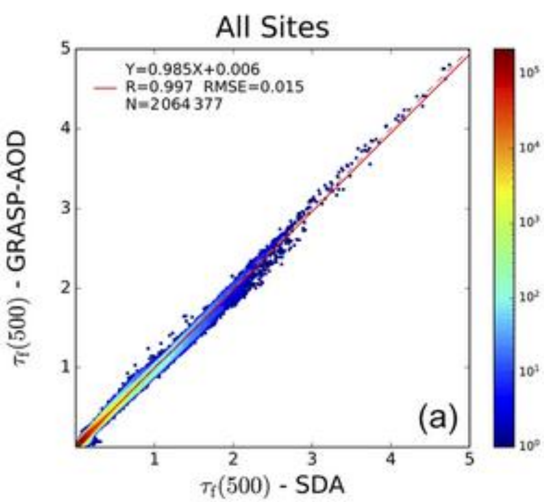
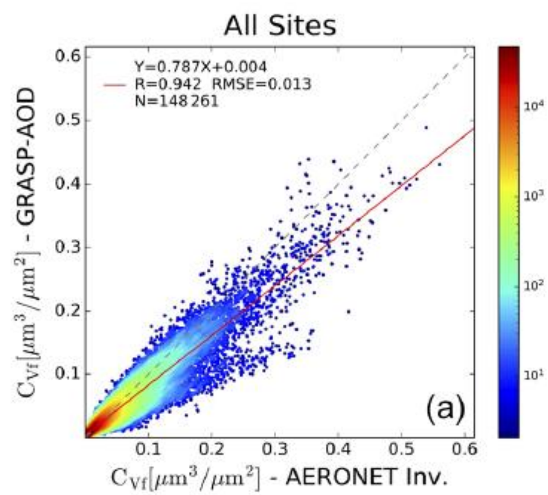
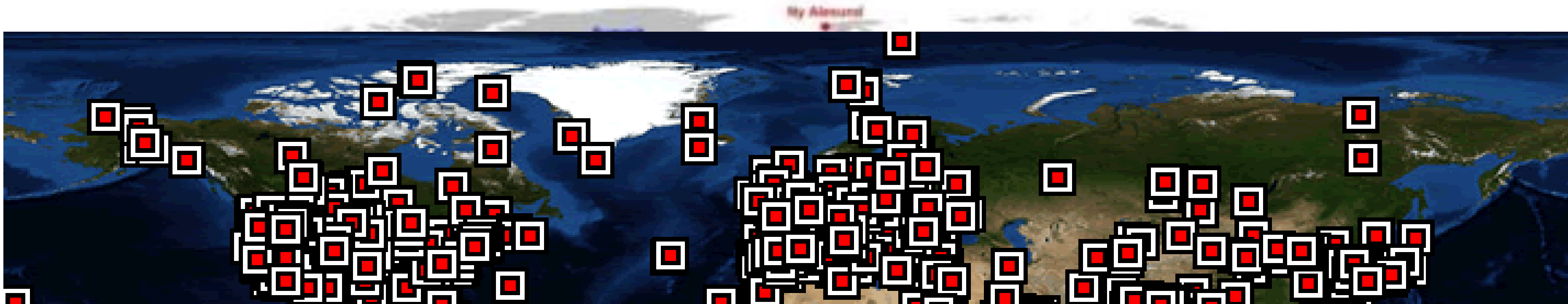
Motivation

- Sky radiance inversions: low temporal resolution, specific SZAs, scattered clouds-> low data availability [Dubovik & King 2000, Sinyuk et al. 2020]
- Aerosol properties only from AOD: Much higher availability during the day and night.
- Linear Estimation Techniques [Kazadzis et al 2014]
- Multi-term LET GRASP-AOD application on CIMEL [Torres et al. 2017,Torres & Fuertes 2021]
- Products: τ_f,τ_c, C_T, C_f, C_c , r_{eff}, r_f and r_c





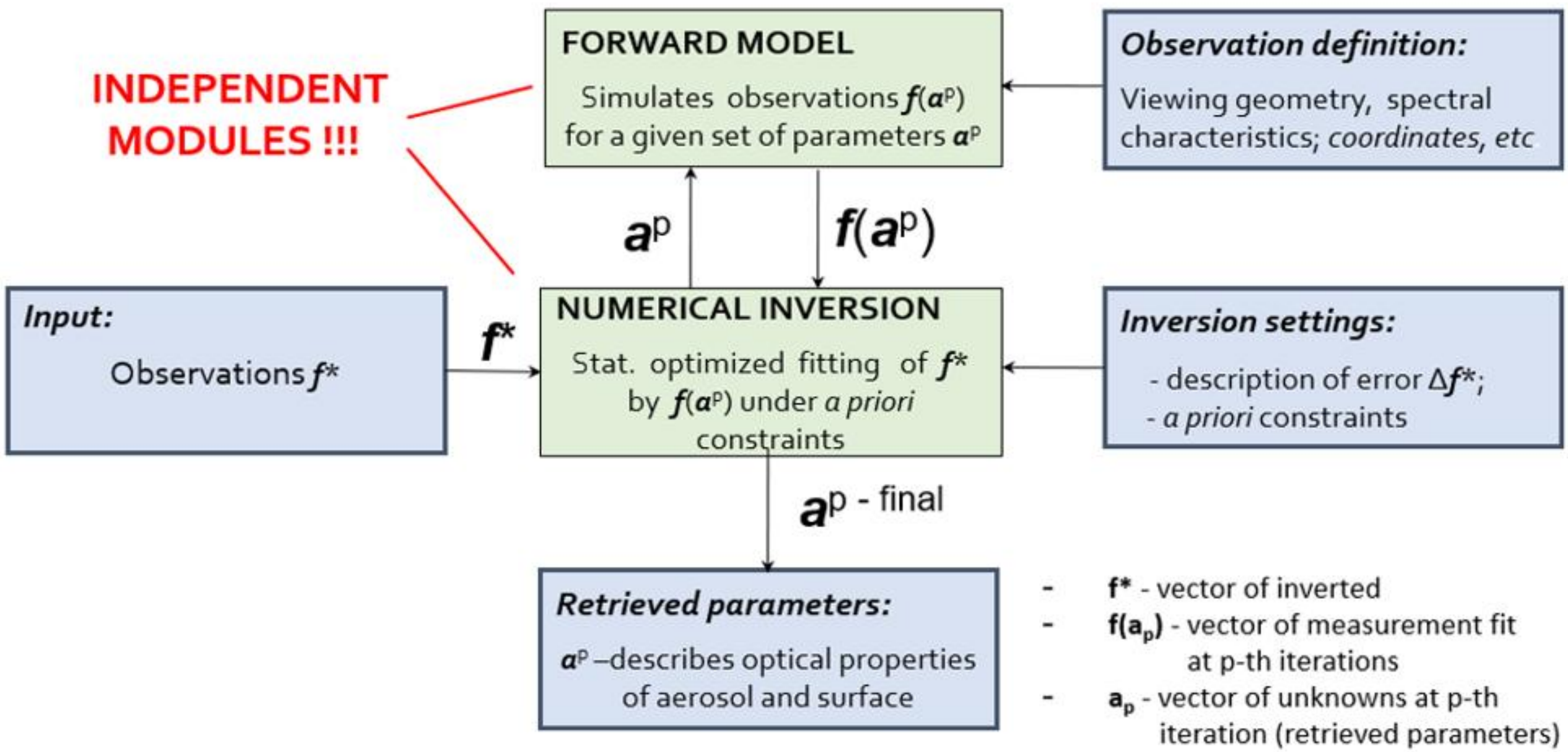
The instrument networks



Scientific question

- Which aerosol properties can we add as product to the GAW-PFR network?

Methodology



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GRASP-AOD modelling

- Forward model
  - Input: Aerosol properties (C_f, C_c , r_f , r_c, σ_c, σ_f, m and k)
  - Output: Aerosol Optical Depth (AOD) at any wavelengths
- Inversion
  - Input: AOD, m, k and initial guesses of C_f, C_c , r_f , r_c , σ_c, σ_f
  - Output: C_f, C_c , r_f , r_c, σ_c, σ_f, AOD recalculation, AOD_f, AOD_c, residuals

Initial guesses

Forward model run

Matches the observations?

Yes

Good, we' re lucky... or prophets! (hopefully)

No

Iterations

Best solution (hopefully)

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pmod wrc

Settings

- Running GRASP for retrievals only from AOD:
  - Sdata file -> wavelengths, AODs and other standard inputs like SZA, time.
  - Settings file:
    1. 'Technical-mathematical settings' (mode of inversion, input, output, Lagrange multipliers, maximum number of iterations, number of modes etc.)
    2. Assumed required parameters (sphericity and refractive index)
    3. Initial guess of retrieved parameters (C_f, C_c , r_f , r_c, σ_c, σ_f)
  - Run settings file

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Self consistency

- The forward model and the inversions have to be self-consistent.
- Tests with synthetic data:
  1. Choose aerosol size properties and get the AOD from a forward model run.
  2. Use that AOD as input for the inversions to get the chosen aerosol properties.
- Ideally:
  - ➢Input AOD to inversion and calculated AOD from the forward model are the same (serves as criterion for inversion quality check).
  - ➢Selected size distribution parameters and retrieved should be the same.

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PFR Validation

PFR – AERONET comparison at 4 sites

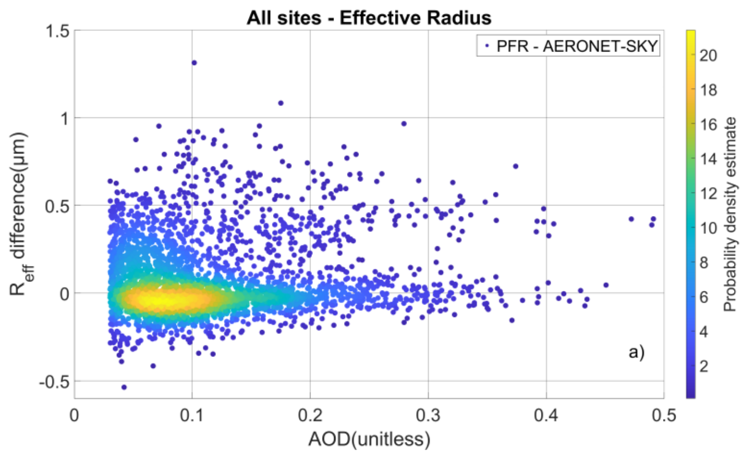
All sites Differences CIMEL-PFR AOD>0.03

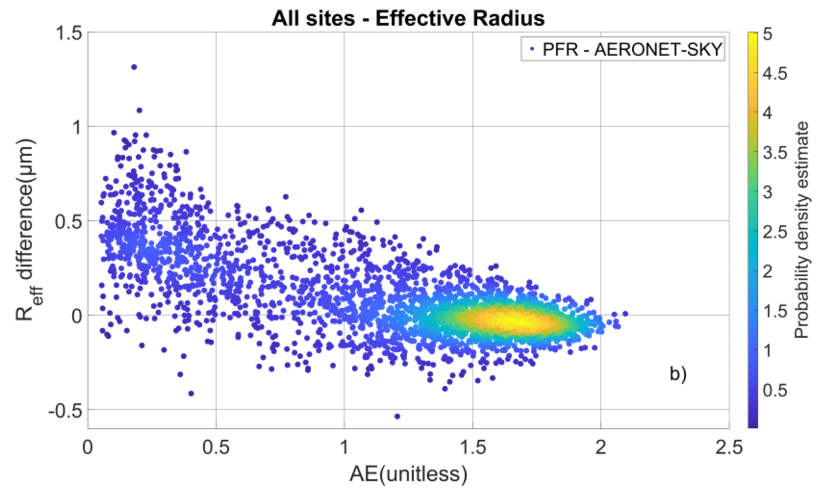
$AOD_{f/c}$>0.02 , AE>0.3 for fine mode AE<1.8 for coarse mode

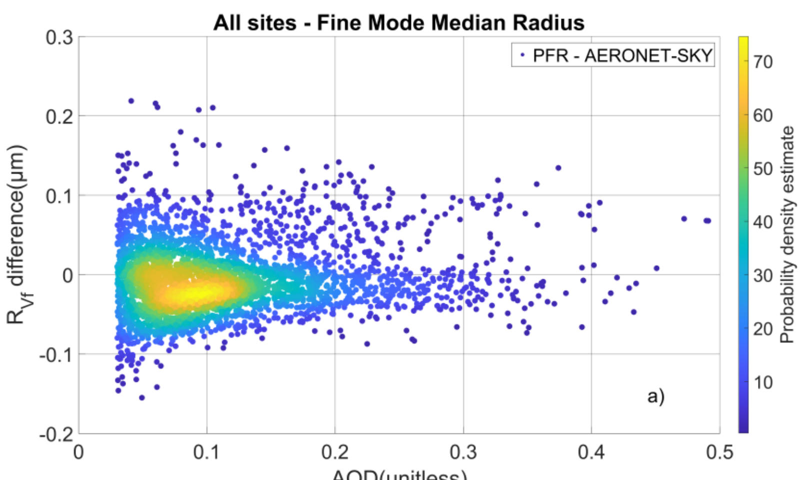
Parameter	median diff.	St.Dev.	R^2	median AERONET	N
τ_f 500 nm	**-0.001**	**0.011**	**0.97**	**0.070**	**2872**
τ_c 500 nm	**-0.003**	**0.007**	**0.99**	**0.042**	**1084**
C_T ($\mu m^3/\mu m^2$)	-0.006	0.012	0.91	0.029	3131
C_f ($\mu m^3/\mu m^2$)	-0.001	0.006	0.77	0.011	2872
C_c ($\mu m^3/\mu m^2$)	-0.010	0.015	0.92	0.036	1084
R_{eff} (µm)	-0.012	0.213	0.71	0.319	3131
R_f (µm)	0.014	0.038	0.16	0.168	2872
R_c (µm)	**-0.281**	**0.503**	**0.22**	**1.835**	**1084**

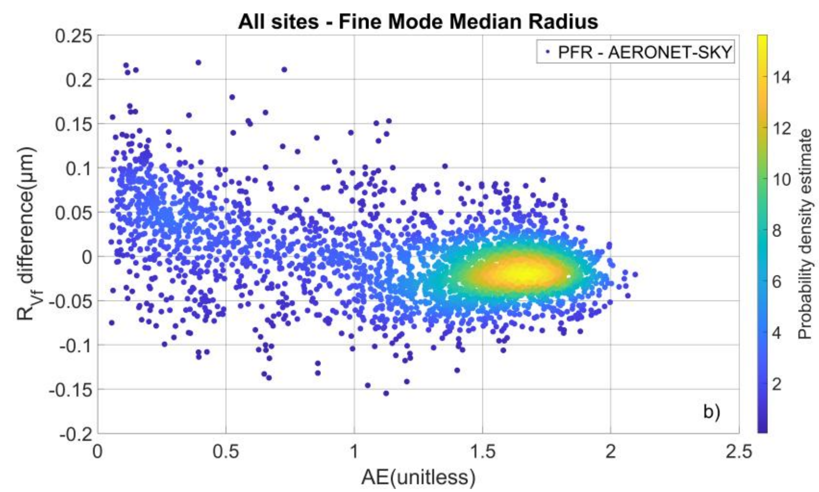
PFR Validation

PFR – AERONET comparison at 4 sites









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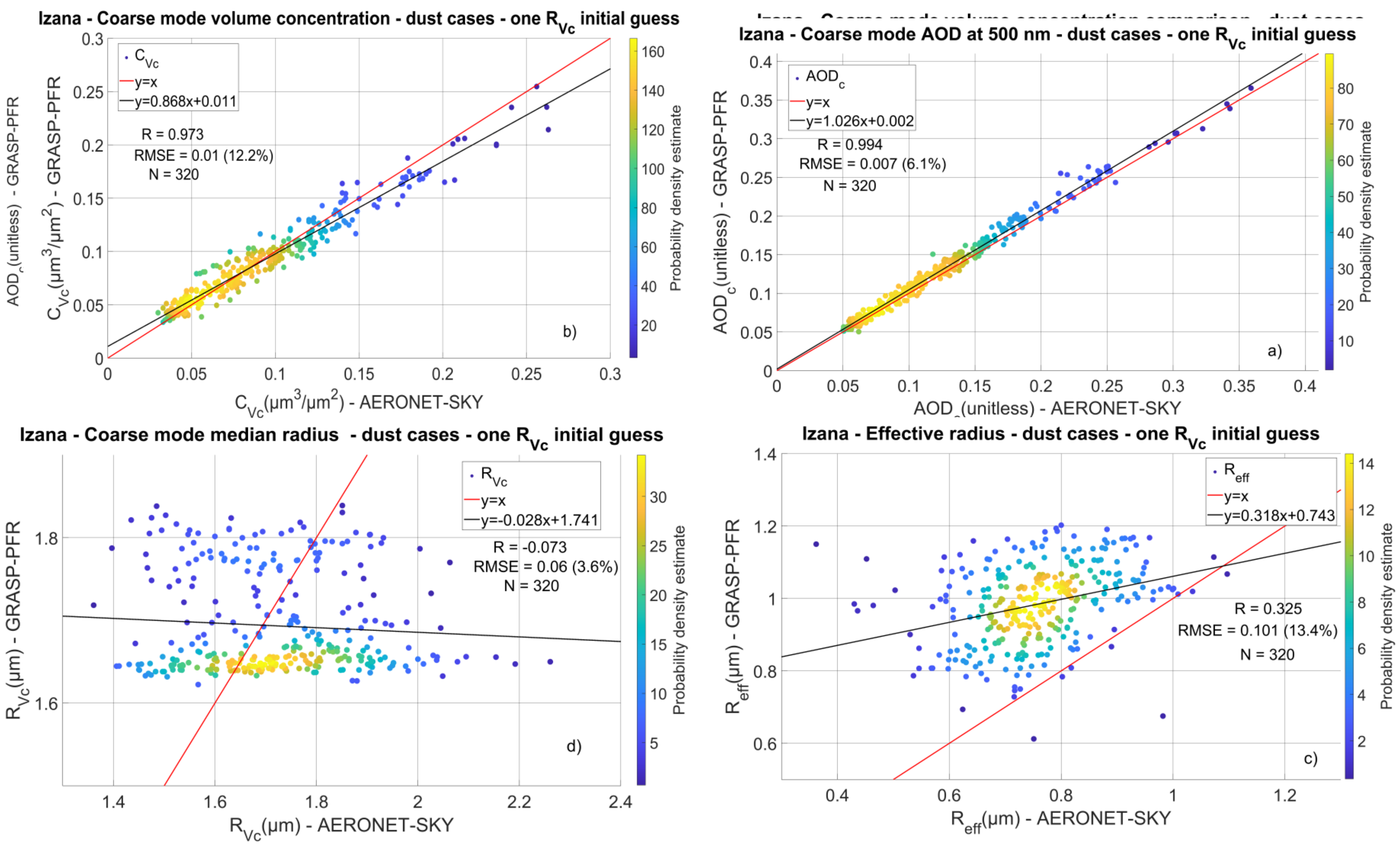
Dust

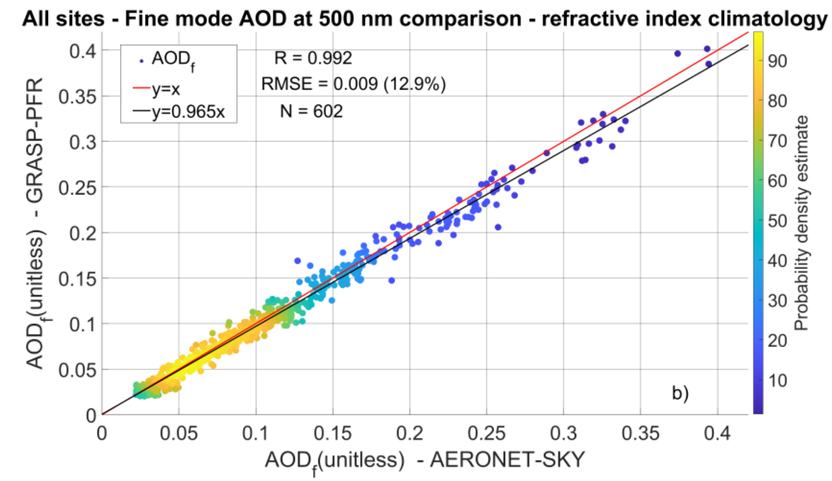
PFR – CIMEL GRASP inversions at Izana for:

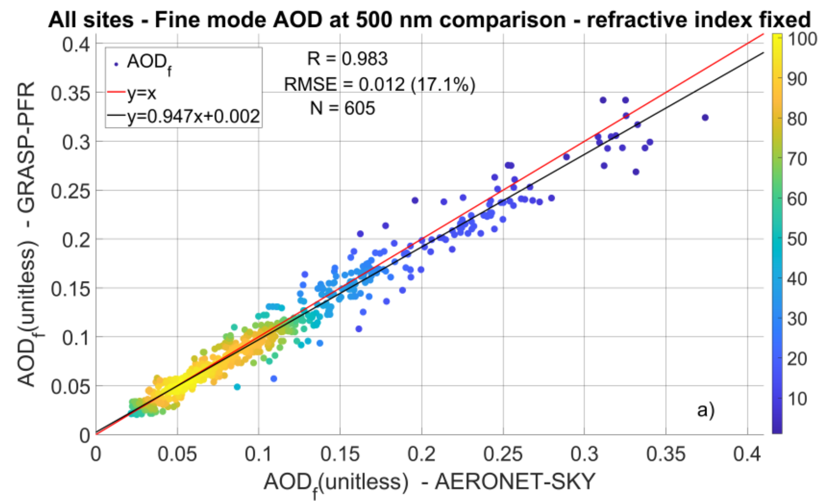
AE<0.5, AOD_c>0.05 and FMF<0.35

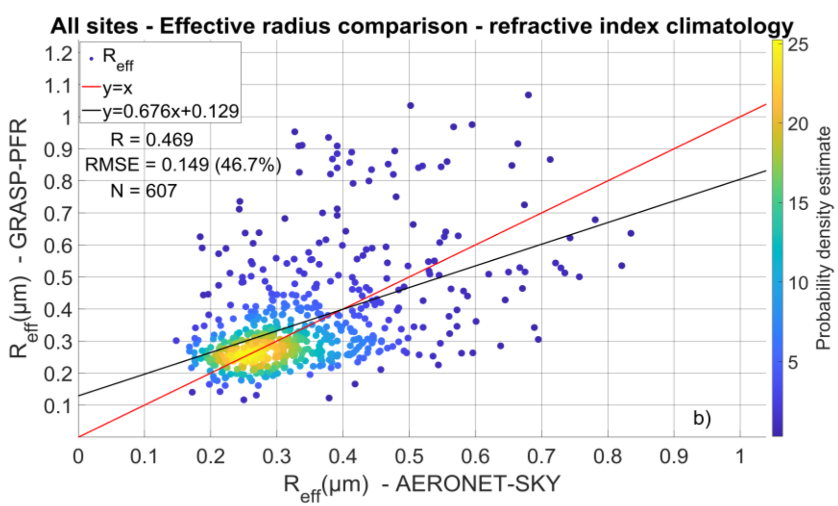


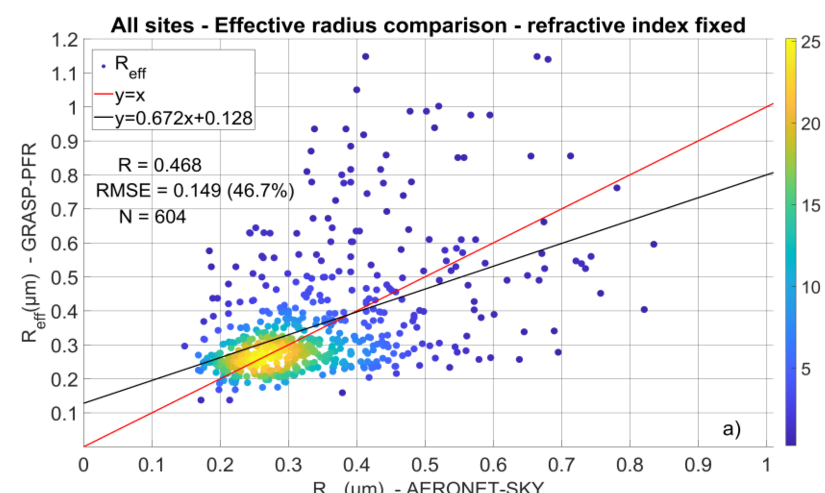
Effect of the refractive index

PFR – CIMEL GRASP inversions comparison at 4 sites









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Conclusions and outlook

- ✓ AOD modal separation: shows good agreement with AERONET standard products.
- ✓ Concentration: Lower than AOD separation, but still good agreement with AERONET standard products.
- Radii: Lower accuracy. Improvement for fine mode and effective radius at higher AODs and AEs.
- Coarse mode radius: 1 initial guess close to reality reduces the bias of R_{Vc} and R_{eff}.

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Thank you!!!
Questions???

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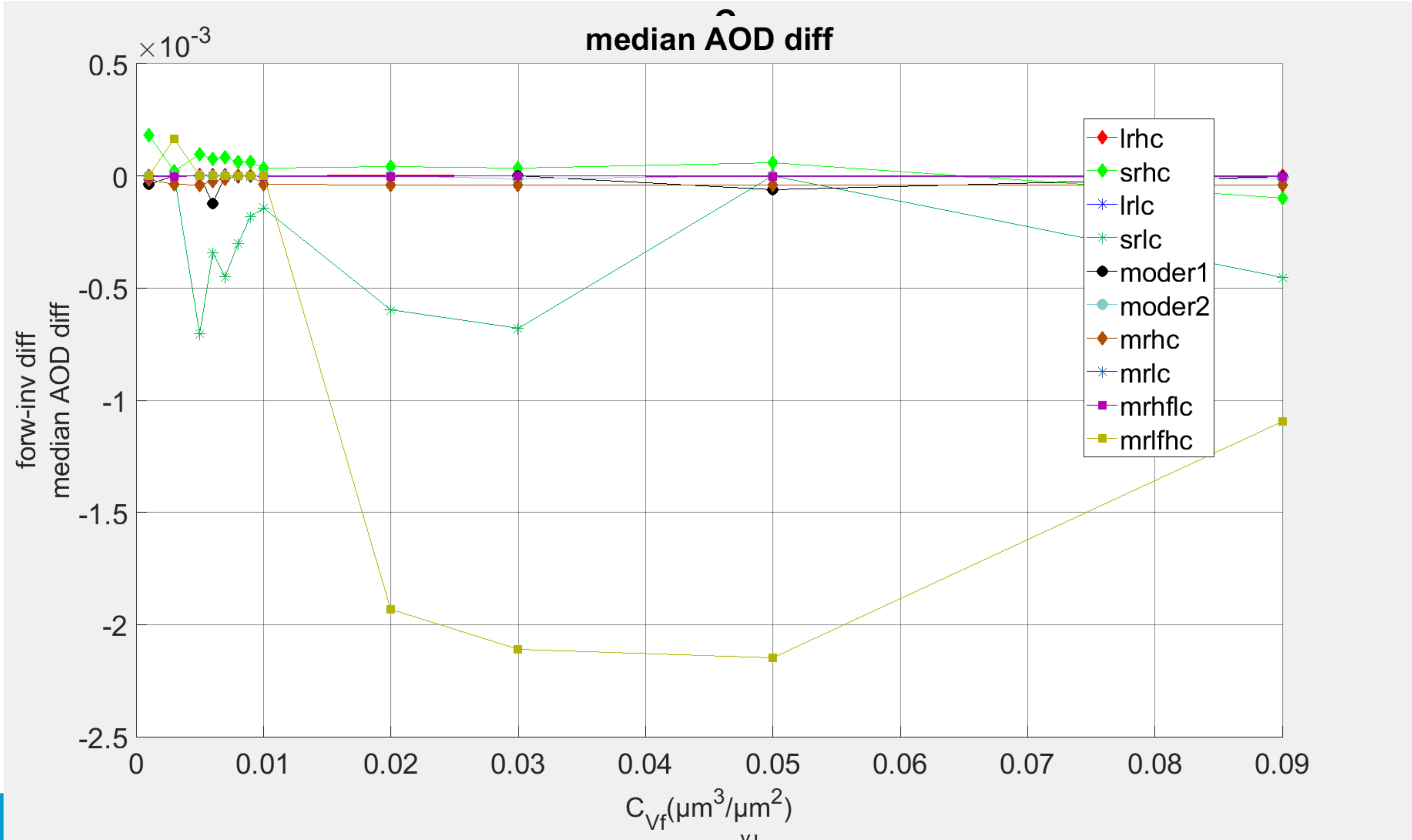
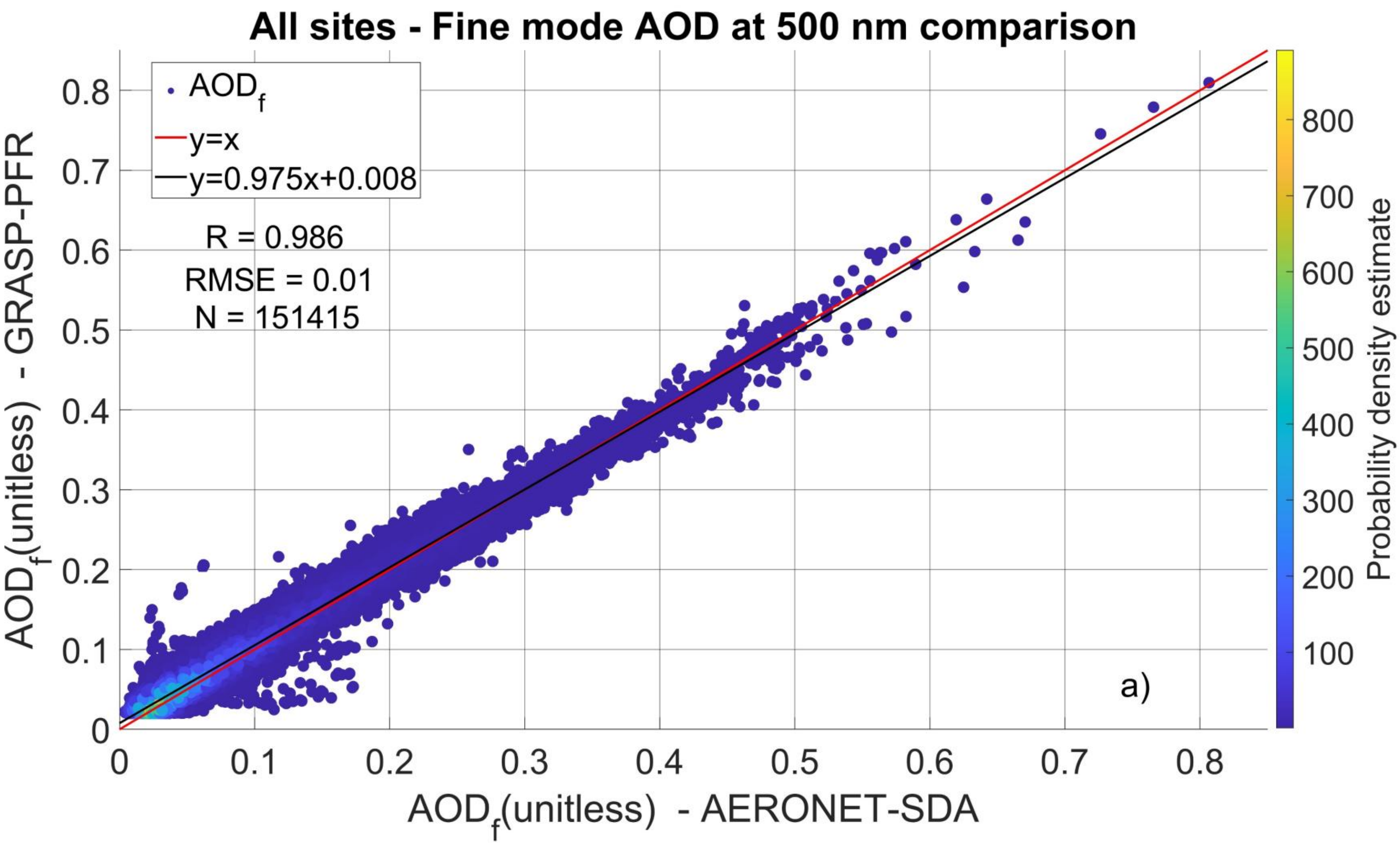
Self consistency tests



Location	Median difference	St.d.	P95-P5	median AOD PFR	Number of measurements
PFR - AER-SKY					
Davos	0.002	0.005	0.015	0.068	266
Hohenpeissenberg	0.007	0.006	0.018	0.098	960
Izana	0.000	0.005	0.017	0.073	895
Lindenberg	0.001	0.008	0.024	0.119	1010
PFR – AER-DIR					
Davos	0.001	0.005	0.016	0.053	49904
Hohenpeissenberg	0.006	0.006	0.019	0.077	36753
Izana	0.002	0.004	0.012	0.036	96236
Lindenberg	0.002	0.007	0.021	0.120	31522


All sites - Fine mode AOD at 500 nm comparison
AODf
y=x
y=0.975x+0.008
R = 0.986
RMSE = 0.01
N = 151415
a)
AODf(unitless) - GRASP-PFR
AODf(unitless) - AERONET-SDA
Probability density estimate
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
100
200
300
400
500
600
700
800

AOD_f unc ~0.01
AOD_c unc ~0.006

R_{Vf} unc ~0.01 µm
R_{Vc} unc ~0.1 µm

All sites Differences CIMEL-PFR AOD>0.1

Parameter	median diff.	St.Dev.	P95-P5	R^2	median AERONET	N
τ_f 500 nm	-0.002	0.013	0.040	0.96	0.131	1170
τ_c 500 nm	-0.003	0.007	0.022	0.99	0.114	356
C_T ($\mu m^3/\mu m^2$)	-0.006	0.015	0.047	0.89	0.047	1500
C_f ($\mu m^3/\mu m^2$)	-0.002	0.007	0.022	0.63	0.021	1170
C_c ($\mu m^3/\mu m^2$)	-0.019	0.018	0.057	0.87	0.082	356
R_{eff} (µm)	**-0.004**	0.225	0.722	**0.82**	0.306	1500
R_f (µm)	**0.019**	0.023	0.075	**0.51**	0.174	1170
R_c (µm)	-0.304	0.337	1.109	0.01	1.750	356

Climatology for refractive index

Parameter	mean	median	St.d.	P95-P5	R^2	median of the parameter AERONET	Number of measurements
AOD 500 nm	0.000	0.000	0.008	0.024	0.99	0.109	607
AOD_f 500 nm	0.003	0.003	0.009	0.029	0.98	0.093	602
AOD_c 500 nm	-0.005	-0.005	0.006	0.020	0.96	0.031	156
C_{VT}	-0.007	-0.006	0.010	0.032	0.84	0.033	607
C_{Vf}	-0.001	-0.001	0.006	0.015	0.78	0.014	602
C_{Vc}	-0.009	-0.008	0.012	0.036	0.80	0.033	156
R_{eff}	-0.020	-0.002	0.154	0.547	0.22	0.308	607
R_{Vf}	0.017	0.020	0.033	0.109	0.23	0.166	602
R_{Vc}	0.026	-0.053	0.593	1.858	0.21	2.510	156
σ_{Vf}	0.051	0.093	0.161	0.532	0.03	0.460	602
σ_{Vc}	-0.008	0.001	0.088	0.309	0.01	0.696	156

Refractive index:1.45 for the real part and 0.003 for the imaginary part

Parameter	mean	median	St.d.	P95-P5	R^2	median of the parameter AERONET	Number of measurements
AOD 500 nm	-0.001	0.000	0.013	0.040	0.97	0.109	604
AOD_f 500 nm	0.003	0.003	0.013	0.042	0.97	0.093	605
AOD_c 500 nm	-0.005	-0.005	0.007	0.022	0.94	0.031	159
C_{VT}	-0.007	-0.007	0.010	0.033	0.84	0.033	604
C_{Vf}	-0.001	-0.002	0.005	0.015	0.79	0.013	605
C_{Vc}	-0.009	-0.009	0.011	0.035	0.78	0.033	159
R_{eff}	-0.018	-0.004	0.154	0.539	0.22	0.308	604
R_{Vf}	0.012	0.016	0.034	0.121	0.2	0.165	605
R_{Vc}	0.048	-0.034	0.577	1.911	0.27	2.492	159
σ_{Vf}	0.066	0.090	0.136	0.435	0.03	0.460	605
σ_{Vc}	-0.006	0.003	0.087	0.308	0.05	0.698	159

Month	RRI				IRI			
	440 nm	675 nm	870 nm	1020 nm	440 nm	675 nm	870 nm	1020 nm
Davos								
Annual for all months	1.378	1.441	1.465	1.4621	0.0073	0.0026	0.0021	0.0018
Hohenpeissenberg								
Annual for all months	1.469	1.459	1.453	1.448	0.0032	0.0035	0.0038	0.0039
Izana								
1	1.476	1.472	1.448	1.436	0.0023	0.0006	0.0009	0.0012
2	1.476	1.472	1.448	1.436	0.0023	0.0006	0.0009	0.0012
3	1.476	1.472	1.448	1.436	0.0023	0.0006	0.0009	0.0012
4	1.484	1.477	1.454	1.442	0.0024	0.0007	0.0012	0.0016
5	1.484	1.477	1.454	1.442	0.0024	0.0007	0.0012	0.0016
6	1.484	1.477	1.454	1.442	0.0024	0.0007	0.0012	0.0016
7	1.480	1.475	1.452	1.440	0.0023	0.0006	0.0010	0.0013
8	1.480	1.475	1.452	1.440	0.0023	0.0006	0.0010	0.0013
9	1.475	1.473	1.449	1.438	0.0023	0.0005	0.0008	0.0010
10	1.475	1.473	1.449	1.438	0.0023	0.0005	0.0008	0.0010
11	1.475	1.473	1.449	1.438	0.0023	0.0005	0.0008	0.0010
12	1.476	1.472	1.448	1.436	0.0023	0.0006	0.0009	0.0012
Lindenberg								
1	1.489	1.474	1.469	1.461	0.0070	0.0068	0.0083	0.0090
2	1.489	1.474	1.469	1.461	0.0070	0.0068	0.0083	0.0090
3	1.469	1.462	1.461	1.456	0.0072	0.0070	0.0081	0.0086
4	1.469	1.462	1.461	1.456	0.0072	0.0070	0.0081	0.0086
5	1.453	1.453	1.453	1.450	0.0061	0.0057	0.0066	0.0069
6	1.471	1.461	1.457	1.450	0.0050	0.0048	0.0057	0.0060
7	1.457	1.451	1.449	1.444	0.0054	0.0056	0.0067	0.0071
8	1.461	1.453	1.451	1.445	0.0055	0.0059	0.0069	0.0073
9	1.449	1.446	1.446	1.442	0.0057	0.0063	0.0073	0.0077
10	1.470	1.461	1.459	1.453	0.0051	0.0053	0.0059	0.0060
11	1.470	1.461	1.459	1.453	0.0051	0.0053	0.0059	0.0060
12	1.479	1.467	1.464	1.457	0.0061	0.0061	0.0071	0.0075

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Aerosol scenarios

ATARI

- Runs of the forward model for different conditions to get AOD.

Aerosol scenarios k=0.009 m=1.49						
Scenario	conditions	C_{Vf}	C_{Vc}	R_{Vf}	R_{Vc}	AOD500
1	lrhc	0.1	0.12	0.4	4	0.722
2	srhc	0.1	0.12	0.1	1.5	0.626
3	lrlc	0.003	0.005	0.4	4	0.022
4	srlc	0.003	0.005	0.1	1.5	0.021
5	moder1	0.01	0.035	0.15	1.8	**0.114**
6	moder2	0.01	0.035	0.2	2.5	**0.112**
7	mrhc	0.1	0.12	0.15	2.5	0.398
8	mrlc	0.1	0.12	0.15	2.5	0.025
9	mrhflc	0.05	0.005	0.15	2.5	0.338
10	mrlfhc	0.003	0.07	0.15	2.5	0.085