Modeling of TOA radiance measured by CERES over the East Antarctic Plateau

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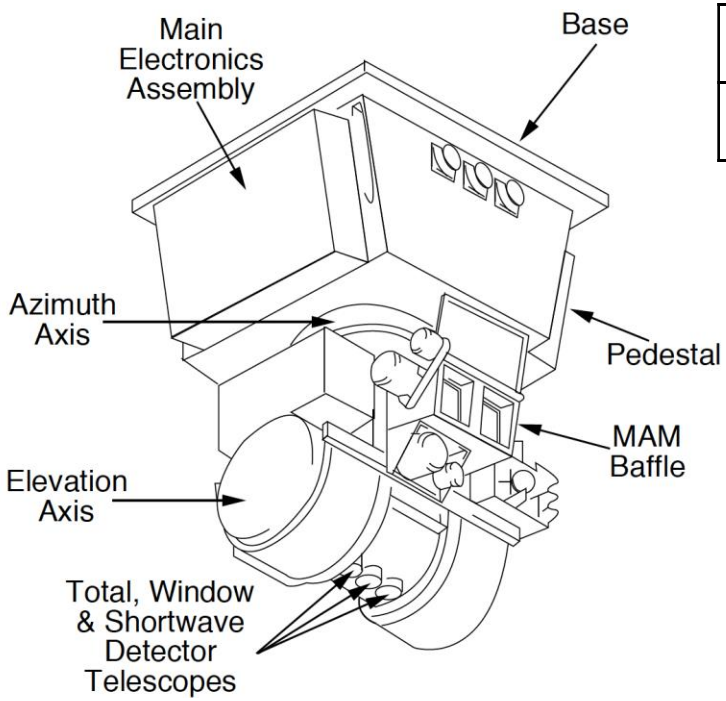
Photo: S. Hudson, 2004, Dome C, from 32 m tower

CERES instrument

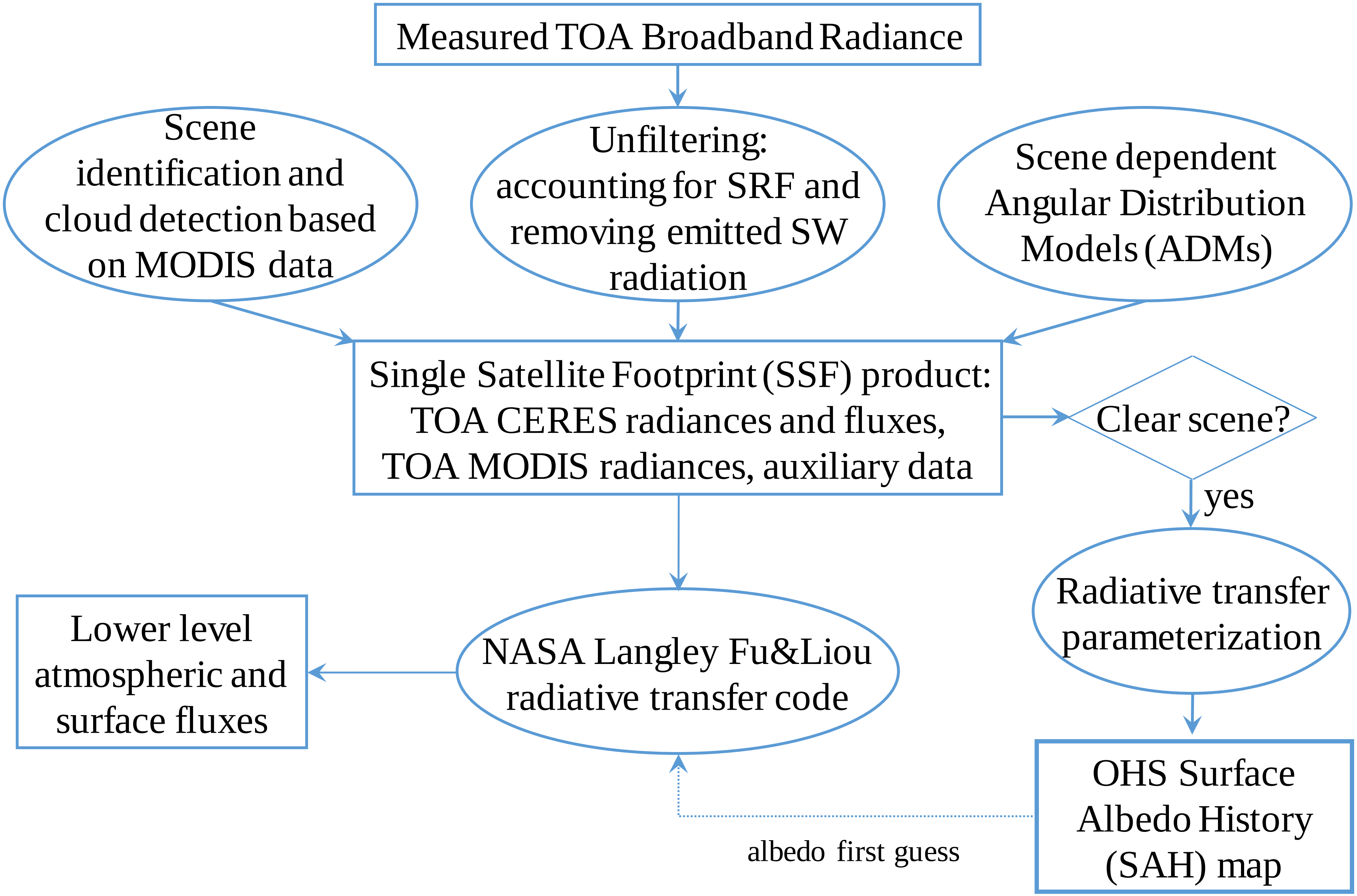
Platform	CERES Instruments	Orbit altitude, km	Equator crossing LST	Orbit repeat cycle, days
EOS Terra	FM-1, FM-2	~705	10:30	16
EOS Aqua	FM-3, FM-4	~705	13:30	16
NPP	FM-5	~825	13:30	16



Band	Shortwave	Window	Total
Range, µm	0.3 - 5.0	8.0 - 12.0	0.3 - 100.0

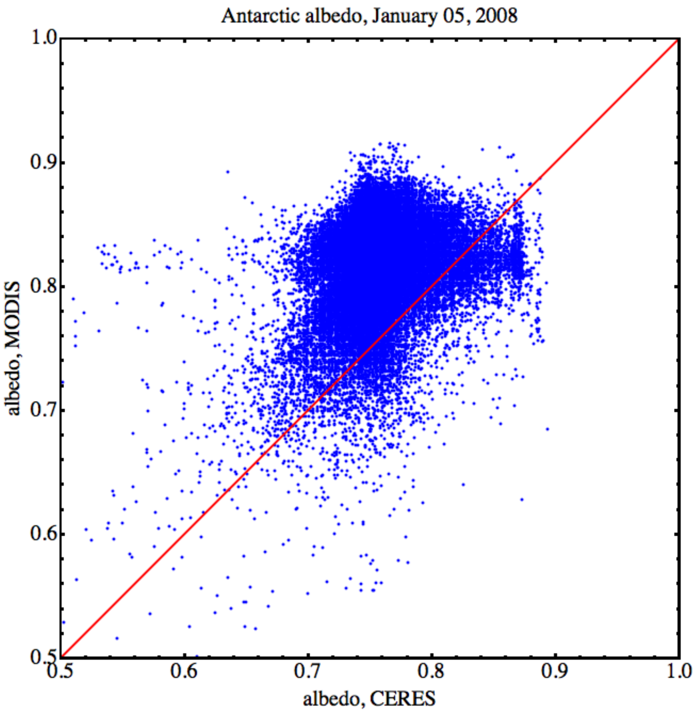
Until June 2005, one instrument on each EOS platform operated in a cross-track scanning mode and the other operated in a rotating azimuth scanning mode; now all are typically operating in the cross-track scanning mode. CERES on the NPP platform operates in the cross-track scanning mode.

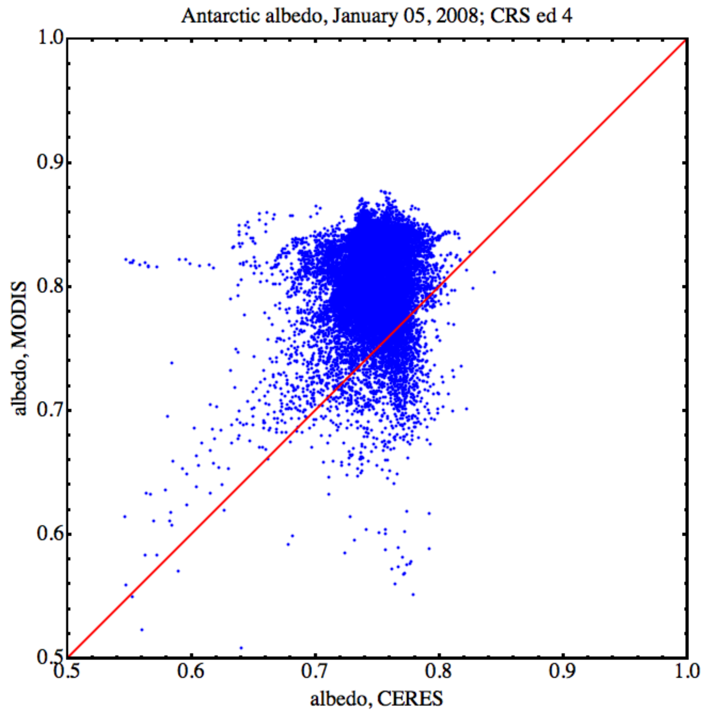
CERES Radiative Fluxes and Albedo



Motivation 1. CERES underestimates surface albedo over the Antarctic

CERES edition and SZA	N_{FOV}	Surface albedo ± standard deviation		linear fit slope: $a_M = b \times a_C$
		CERES	MODIS	
Ed. 2, all SZA	45496	0.758 ± 0.039	0.814 ± 0.042	1.0727
Ed. 2, SZA <70	26879	0.751 ± 0.025	0.806 ± 0.039	1.0724
Ed. 4, all SZA	18036	0.745 ± 0.026	0.800 ± 0.038	1.0719





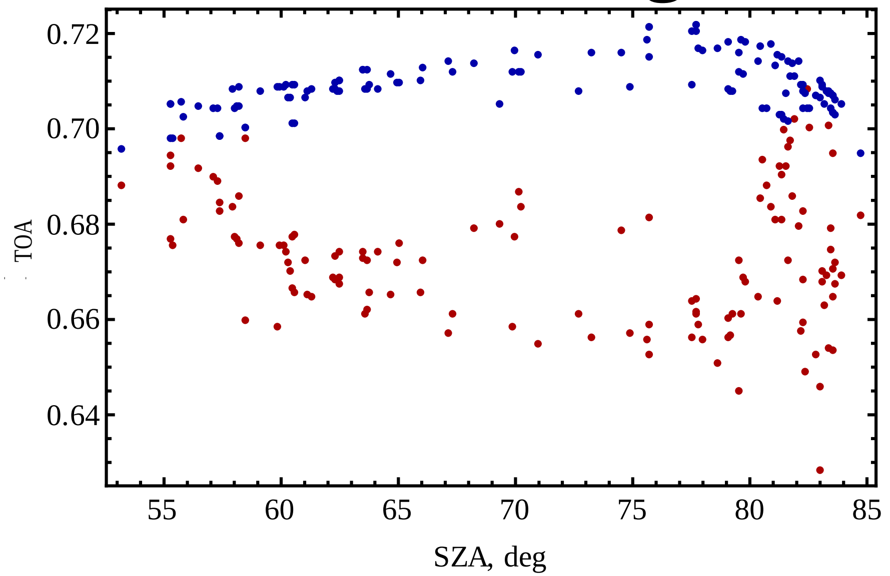
Is MODIS a benchmark? Probably not but it is closer to ground measurements under clear sky (Grenfel *et al.* JGR 1994):

SZA, degree	albedo
55	0.80
68	0.84
72	0.85

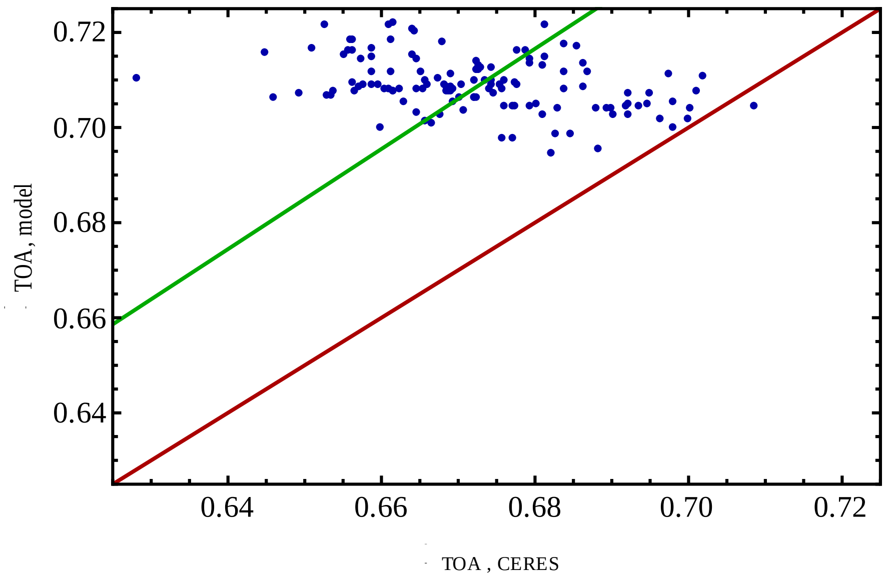
Possible reasons for the underestimation:

- Underestimation of TOA albedo over permanent snow/ice;
- Errors in RT calculations of surface albedo from TOA albedo.

Motivation 2. Modeled of TOA albedo greater than observed. Is Angular Distribution Model wrong?



TOA albedo as a function of sun zenith angle: red – CERES, blue – modeling.



TOA albedo: modeling vs. CERES retrievals.
Red line – 1:1 reference,
Green line – regression $\alpha_{model} = 1.054 \times \alpha_{CERES}$.

Radiative Transfer Model 1: general description

- 32 bands covering CERES SW band;
- monochromatic calculations performed by DISORT;
- accounts for Rayleigh scattering;
- gas absorption (correlated-*k*, HITRAN);
- clouds and aerosol scattering and absorption (if any);
- auxiliary data (surface pressure, O_3 and water vapour concentrations, and surface elevation) come from re-ananlysis used in CERES production – GEOS4 (2000 – 2007), GEOS5 (2008 – present);
- accounts for surface BRDF:

$$\rho(\theta_0,\theta_v,\varphi) = \frac{I_r(\theta_0,\theta_v,\varphi)}{F_0(\theta_0)} = \alpha(\theta_0) R(\theta_0,\theta_v,\varphi)/\pi$$

where $\alpha(\theta_0)$ – black sky albedo, cannot be measured due to Rayleigh scattering, has to be modeled; $R(\theta_0, \theta_v, \phi)$ – anisotropic reflection factor (ARF), measurable(?), an attempt to clean out directional distribution of the incident light

$$R(\theta_0,\theta_v,\varphi) = \frac{\pi I_r(\theta_0,\theta_v,\varphi)}{\int_0^{2\pi} d\varphi \int_0^{\pi/2} d\theta_v \sin\theta_v \cos\theta_v I_r(\theta_0,\theta_v,\varphi)}$$

Radiative Transfer Model 2:
ARF: measurements and analytical model

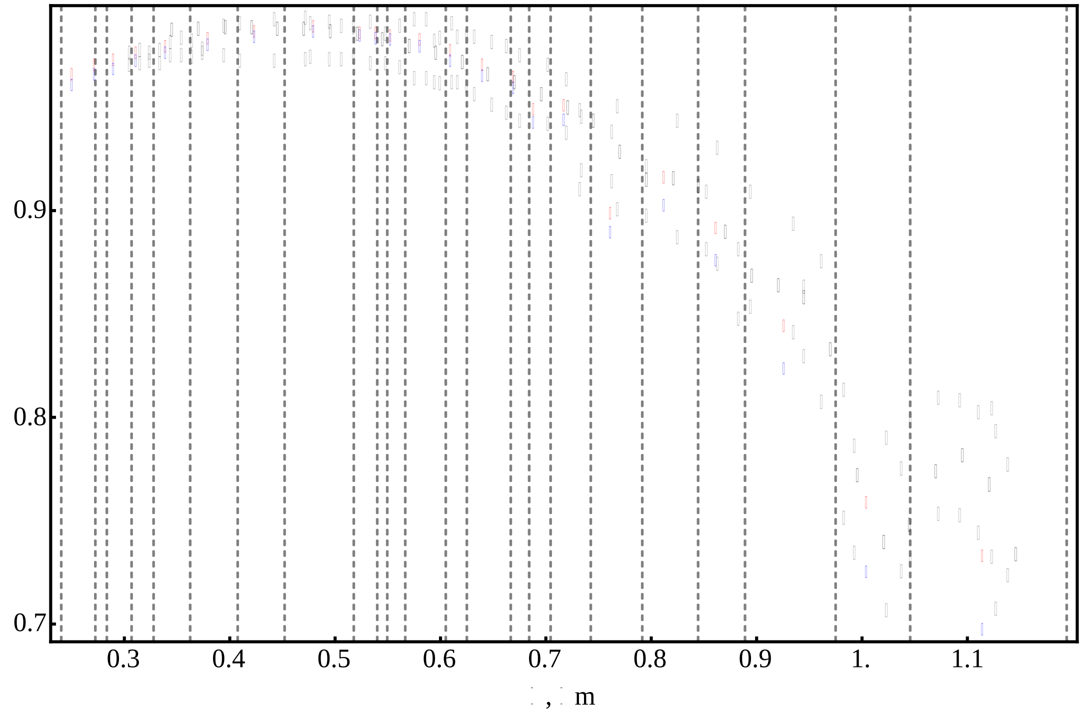
Reflected radiance and flux were measured at Dome C in austral summers of 2003 – 2004 and 2004 – 2005 (Hudson et al 2006 JGR). Measurements are done at θ_v = 7.5° , 22.5° , …, 82.5° and ϕ = 150° , 165° , …, 345° , 0° , 15° , 30° and wavelength 0.35 to 2.4 μm with a step of 0.025 μm.
Matrix of all measurements can be represented as

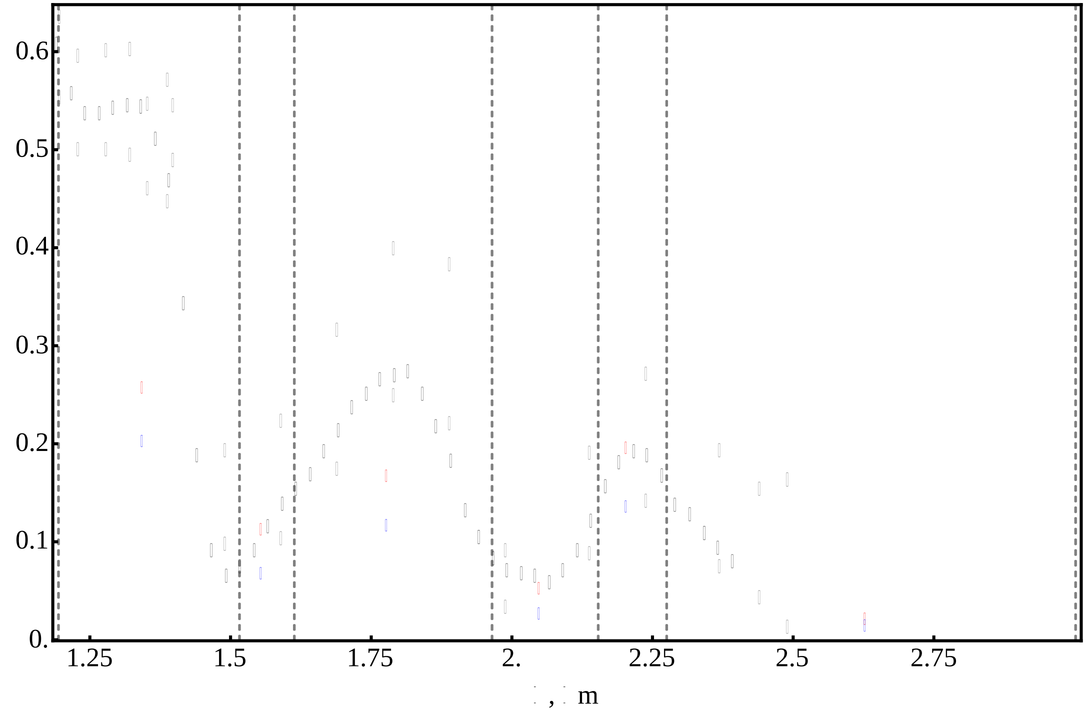
$$\mathbf{R} = \mathbf{1} + \mathbf{U}\Sigma\mathbf{V}^T$$

Where rows of R represent grid of SZA and RAZ while columns represent SZA values and wavelength. The representation above comes from EOF of the data. It was shown that variability of R can be described with first few columns of **U**, **Σ**, and **V**. Columns of V represent dependence on SZA and wavelength. These dependencies were parameterized.

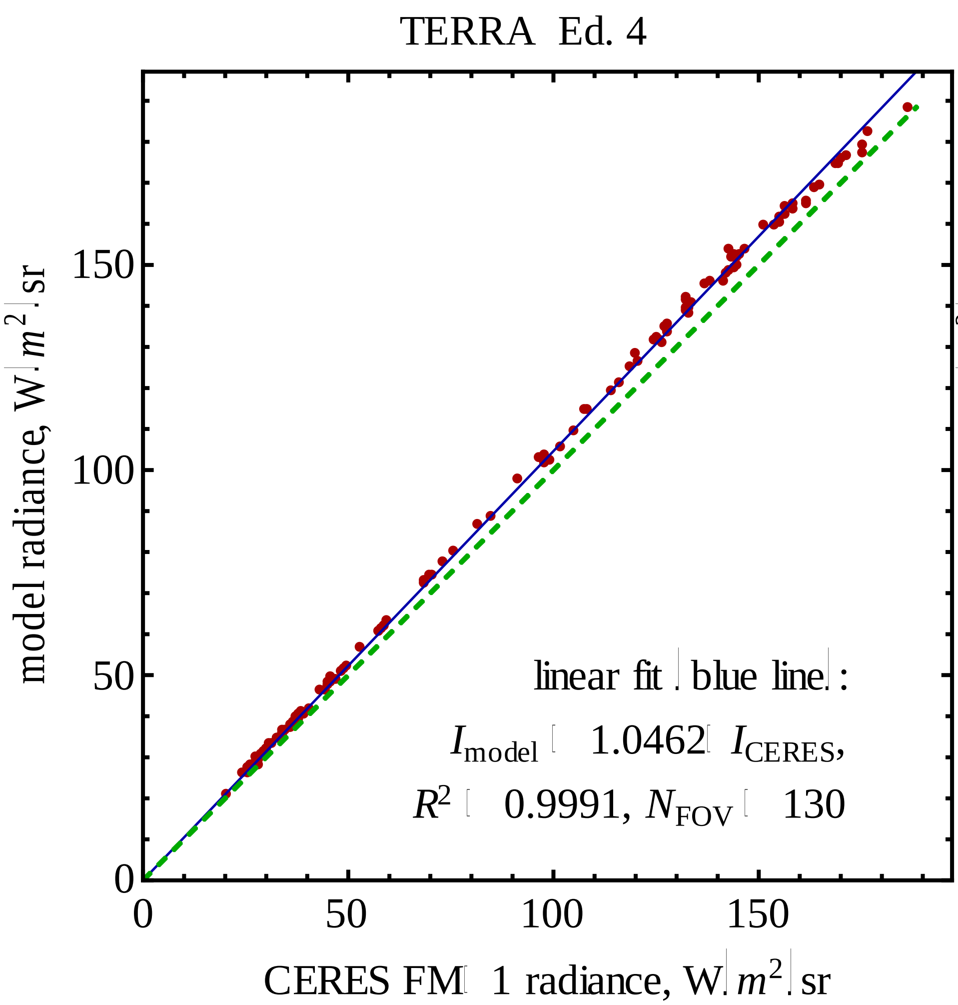
Radiative Transfer Model 3: black and white sky albedo of the snowpack

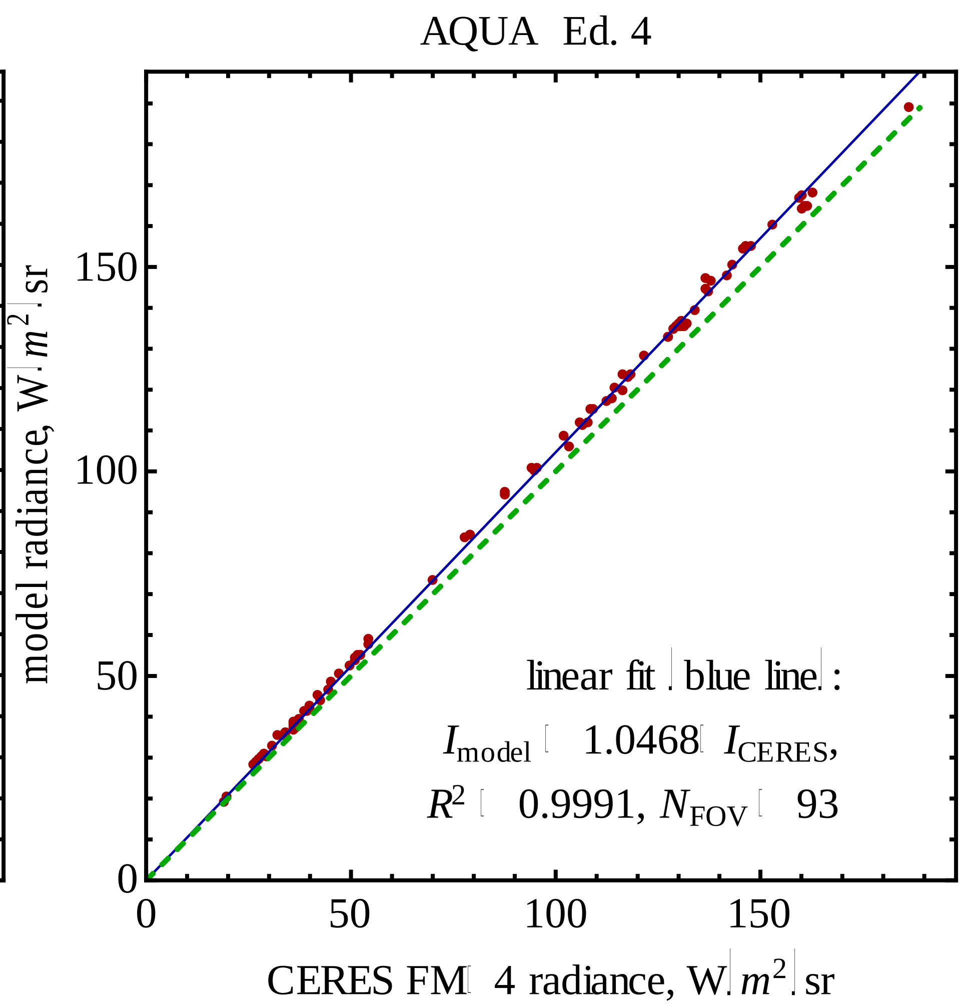
Comparison of white sky albedo for two models with actual measurements.
Red – 80/180 μm diameter model,
blue – 140/240 μm diameter model,
black dots – measurements by Hudson et *al*. (2006),
up and down triangles – 1σ confidence interval from Grenfell *et al*. (1994).
Gray vertical lines indicate spectral band boundaries of the radiative transfer model.





Broadband radiance: model vs CERES

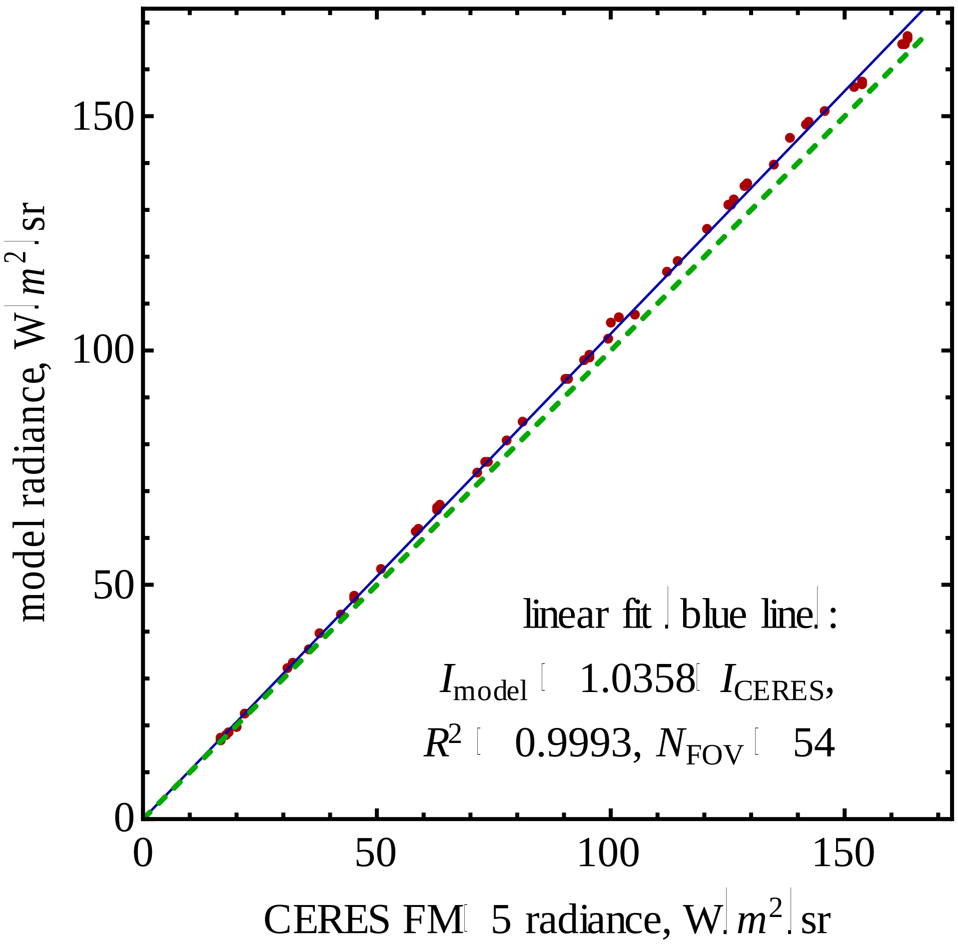




Ed. 3: $I_{\text{model}} = 1.0531 \times I_{\text{CERES}}$

Ed. 3: $I_{\text{model}} = 1.0451 \times I_{\text{CERES}}$

Broadband radiance: model vs CERES

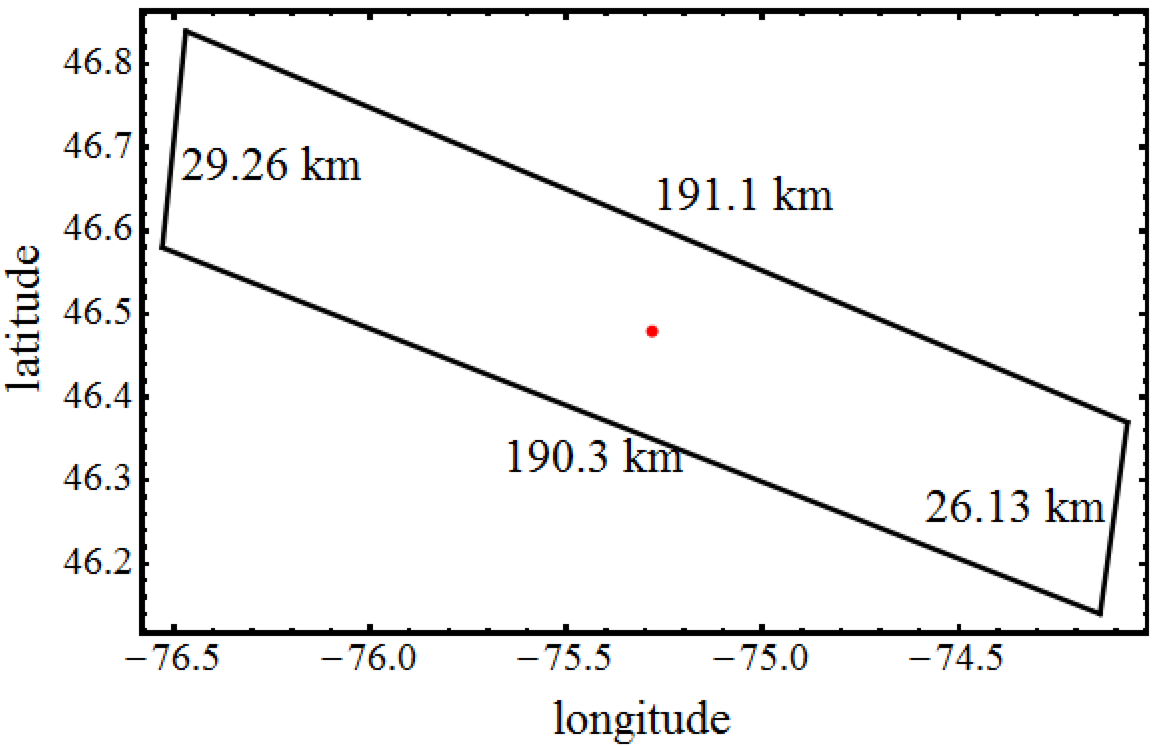


Modeling SCIAMACHY observations over the Antarctic 1

Instrument characteristics:

- Onboard of ENVISAT, altitude ~773 km
- Nadir observations* of the Earth reflected radiation
- Measurements of solar irradiance
- High spectral resolution, see table to the right
- Coarse spatial resolution, see figure below

Ch	Spectral Range (nm)	Resolution (nm)
1	214 - 334	0.24
2	300 - 412	0.26
3	383 - 628	0.44
4	595 – 812	0.48
5	773 – 1063	0.54
6	971 - 1773	1.48
7	1934 - 2044	0.22
8	2259 - 2386	0.26



Scheme of a SCIAMACHY footprint. Every record contains geolocations of the corners and the center of a footprint

* Viewing zenith angle varies from 0 to ~27°

Modeling SCIAMACHY observations over the Antarctic 2

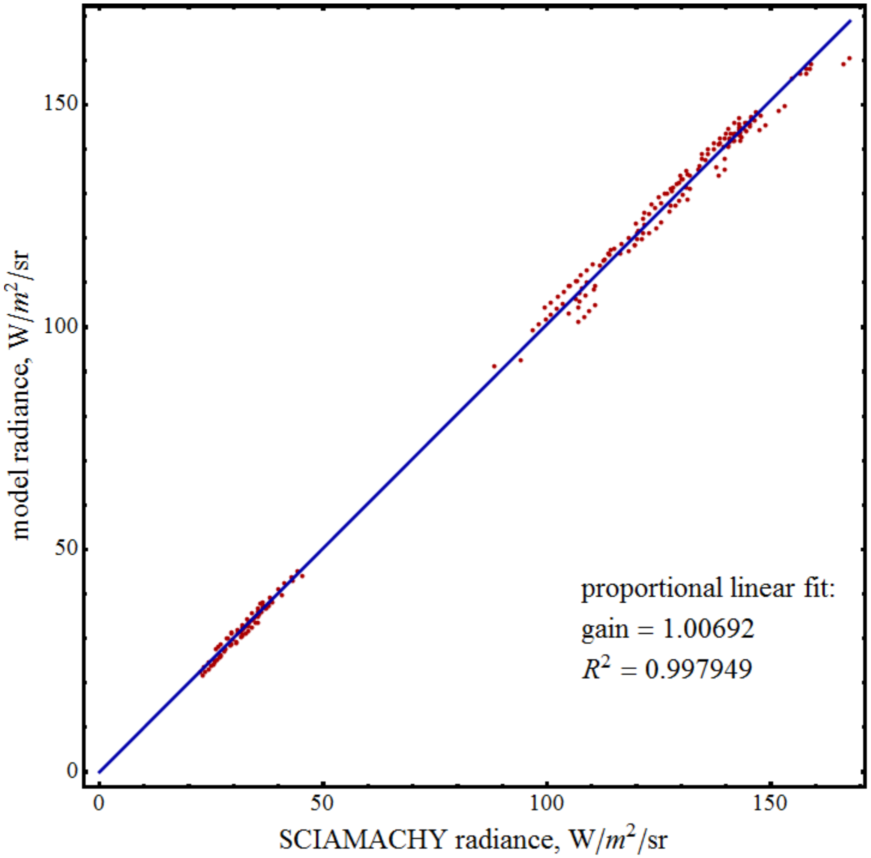
Footprint selection:

1) Distance from Dome C < 100 km;
2) All corners and the center of a footprint are marked as “clear”;
3) Sun zenith angle < 85°.

Spectral transformation:

SCIAMACHY channels 1 through 6 are used, channels 7 and 8 have known quality problems;
Computational model has 25 wide bands covering UV, VIS, and NIR spectral regions;
For each computational band SCIAMACHY spectral pixels are convolved with Gaussian filter with the following parameters:
$\sigma = \lambda_{max} - \lambda_{min}$,
integration domain $\lambda_c - 3\sigma < \lambda < \lambda_c + 3\sigma$,
where λ_{min}, λ_{max} are the limits of a model band, $\lambda_c = (\lambda_{max} + \lambda_{min})/2$.

Modeling SCIAMACHY observations over the Antarctic 3



BB radiance: model vs SCIAMACHY measurements; model overestimates measurements by ~0.7%

band	slope	R^2	mean SCIAMACHY solar constant, W/m^2	model solar constant, W/m^2
1	0.0381	0.6115	5.8657	4.0334
2	0.8130	0.7768	2.5804	2.2789
3	0.0476	0.7004	10.9362	11.6000
4	0.7143	0.9492	15.3368	15.4940
5	1.1569	0.9981	32.9280	35.2630
6	1.0288	0.9989	57.1746	54.1390
7	1.0185	0.9993	76.3972	78.7000
8	1.0300	0.9995	125.3785	128.6800
9	1.0189	0.9994	42.9738	41.7880
10	1.0281	0.9994	18.3937	17.7610
11	1.0311	0.9993	32.7232	31.6400
12	1.0343	0.9992	70.5513	69.6800
13	1.0330	0.9991	34.6681	34.3620
14	1.0354	0.9992	68.5400	66.8420
15	1.0361	0.9990	27.2995	26.5120
16	0.9809	0.9982	30.4300	29.1900
17	1.0658	0.9988	53.7005	51.3000
18	0.9624	0.9981	62.3042	59.7840
19	1.0547	0.9980	60.0832	57.9680
20	1.0472	0.9974	45.3251	43.3010
21	1.0173	0.9959	76.8515	74.2620
22	1.0330	0.9950	53.4770	51.5630
23	1.0567	0.9944	90.8475	86.3760
24	0.5373	0.9555	138.5433	123.4500
25	1.2278	0.7337	26.2114	26.0270

Conclusions and future work

1) Modeling of TOA shortwave radiance and albedo measured by CERES instrument onboard of Terra, Aqua, and NPP satellites was performed;
2) Significant discrepancy was found between CERES retrievals and the model. CERES underestimates TOA radiance by ~4.6% by instruments onboard of Terra and Aqua platforms and by 3.6% by the sensor on NPP;
3) At the same time, coefficient of determination is very high which means correction of the model can be done with one factor;
4) Comparison of the model with spectral SCIAMACHY data showed some discrepancy but the most contributing bands showed excellent correlation with observed radiance.

Future work is needed to localize the source of these differences:

- comparison of fluxes at the surface;
- sensitivity study:
  i. O_3 and water vapor concentrations;
  ii. refining spectral model of gas absorption (more bands, narrower width);
  iii. tuning model surface albedo in the range 0.9 μm through 1.4 μm.