Evaluation of "Direct" Estimation of Surface Solar Net Flux with CERES data

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Outline

- Background
- Method
- Limitation
- Evaluation
  - Input data
  - Reference data sets
  - Results
    - For all scenes
    - For four surface types

ASR Retrieval Methods (1)

- Absorbed Solar Radiation (ASR) at surface from the difference of downward and upward SW fluxes at the surface
  - upward flux may be uncertain due to uncertainty in surface albedo
- Directly from TOA ASR
  - avoids potentially uncertain upward flux (surface albedo)

ASR Retrieval Method (2)

- Model simulations and measurements indicate a near-linear relationship between surface solar absorption and surface-atmosphere solar absorption (*Ramanathan*, 1986; *Cess and Vulis*, 1989).
- This relationship can be used to estimate ASR when absorbed SW radiation at TOA is known.

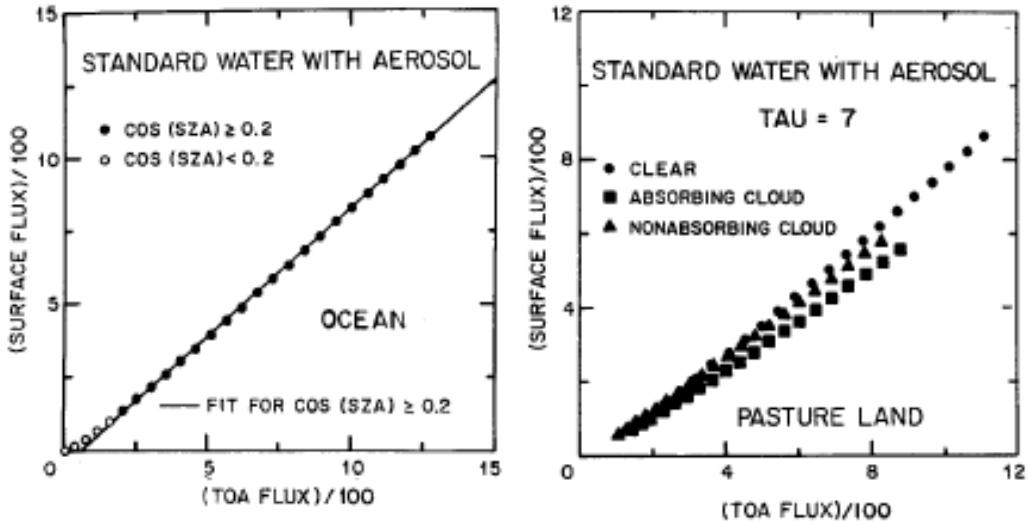
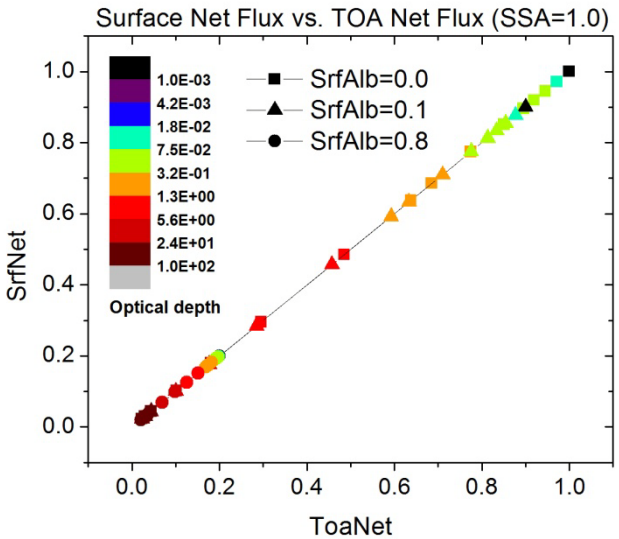
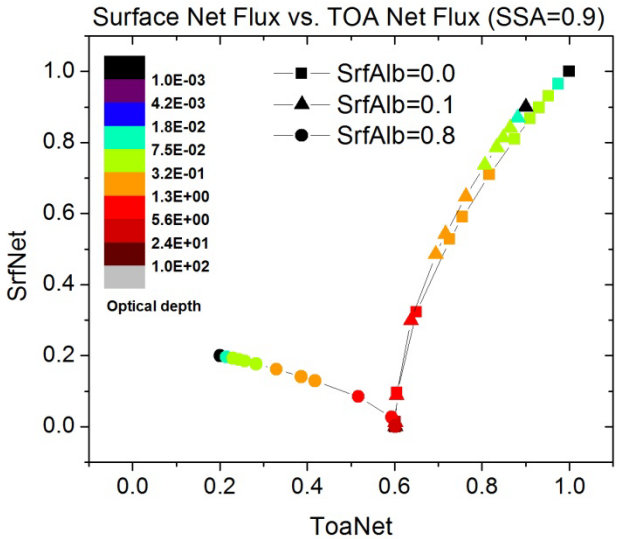


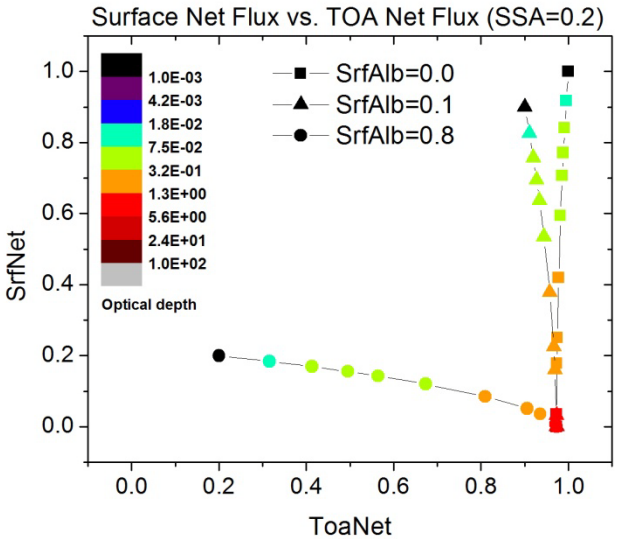
Illustration of the relationship between ASR (surface flux) and TOA absorbed radiation (TOA flux). (*Cess and Vulis*, 1989, Figs 12 and 23)

Solar zenith angle varies mostly.

Surface vs. TOA Net Flux







What if the optical depth varies the most?

- DISORT results
  - Single homogeneous layer
  - H-G phase function, g=0.5
  - Solar zenith angle cosine = 0.5
  - **Optical depth: 0-100**
  - **SSA: 1.0, 0.9, 0.2**
  - **Surface albedo: 0.0, 0.1, 0.8**

"Direct" Retrieval of ASR

- Relationship between surface and TOA solar absorption has the form
  - $n_{\mathrm{SRF}} = f\,(n_{\mathrm{TOA}}) = A + B * n_{\mathrm{TOA}}$ $\qquad n = \dfrac{\text{energy absorbed}}{\text{TOA solar irradiance}}$
  - *A* and *B* **must account for variability in the atmosphere**
  - Conservation of energy

$$n_{SRF} = n_{TOA} - n_{ATM}$$

  - n_{TOA} is "measured", n_{ATM} is calculated when atmosphere is known.
  - Both are affected by surface albedo. **Find expression for n_{ATM} that does not explicitly depend on surface albedo.**

"Direct" relationship from RT

- Based on the adding equation of RT (*Chandrasekhar*, 1960) :

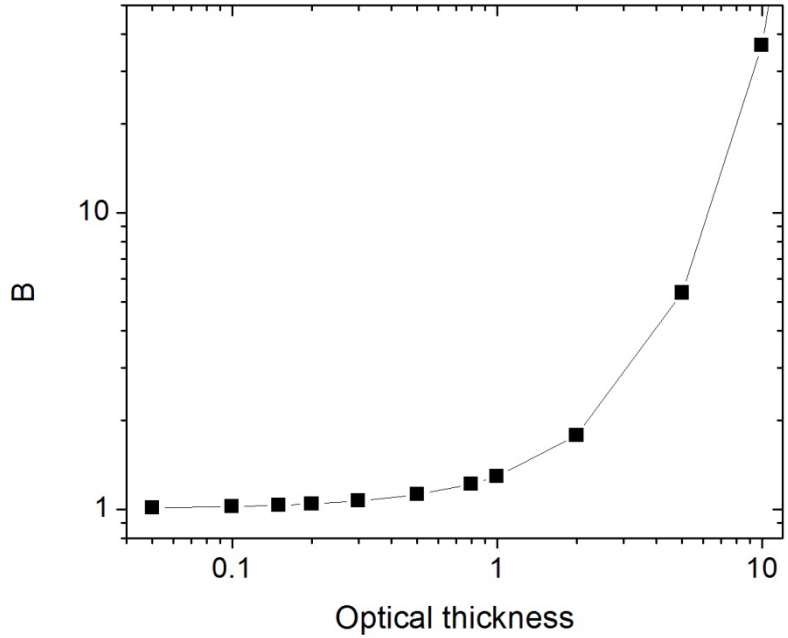
$$n_{SRF} = A + B\, n_{TOA}, \quad \text{where}$$
$$B = \left(1 - \tilde{R}\right)\tilde{T}^{-1}, \text{and } A = T^0\left(\vartheta_0\right) - B\left[1 - R^0\left(\vartheta_0\right)\right]$$

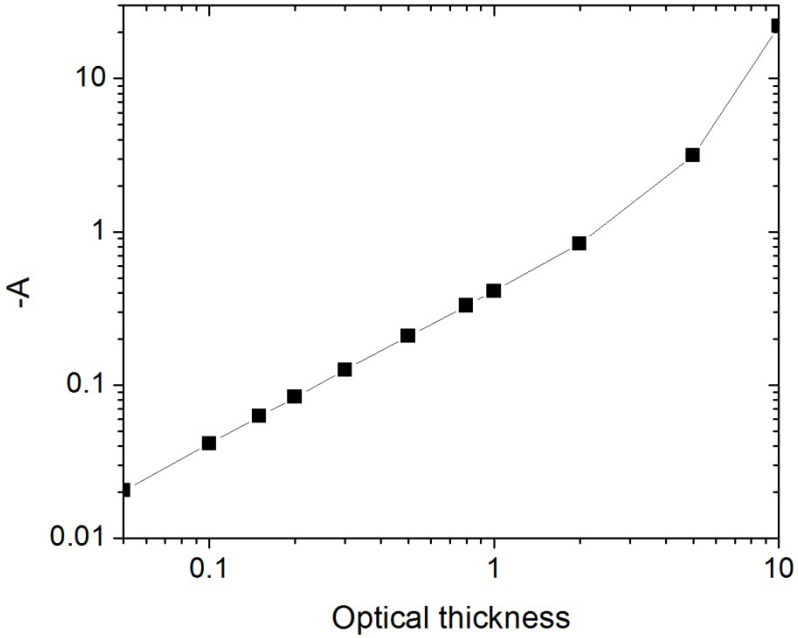
R^0 and T^0 are the reflectance and transmittance of the atmosphere, R and T are those of atmosphere-surface system, and $\tilde{R}$ and $\tilde{T}$ are the spherical reflectance and transmittance.

$$n_{SRF} = A^* - B\, R\left(\vartheta_0\right), \quad \text{where} \quad A^* = T^0\left(\vartheta_0\right) + B\, R^0\left(\vartheta_0\right)$$

- **No explicit dependence on surface albedo**
- Surface albedo is in n_{TOA}
- B is ONLY a function of the atmosphere
- A and A*are functions of the atmosphere AND solar angle ϑ_0

A and *B*





Example:

- *A* and *B* for test case (slide 5) from DISORT calculations
- Absolute values of *A* and *B* increase rapidly with optical depth
  —presents numerical problems at high optical depth that need to be dealt width

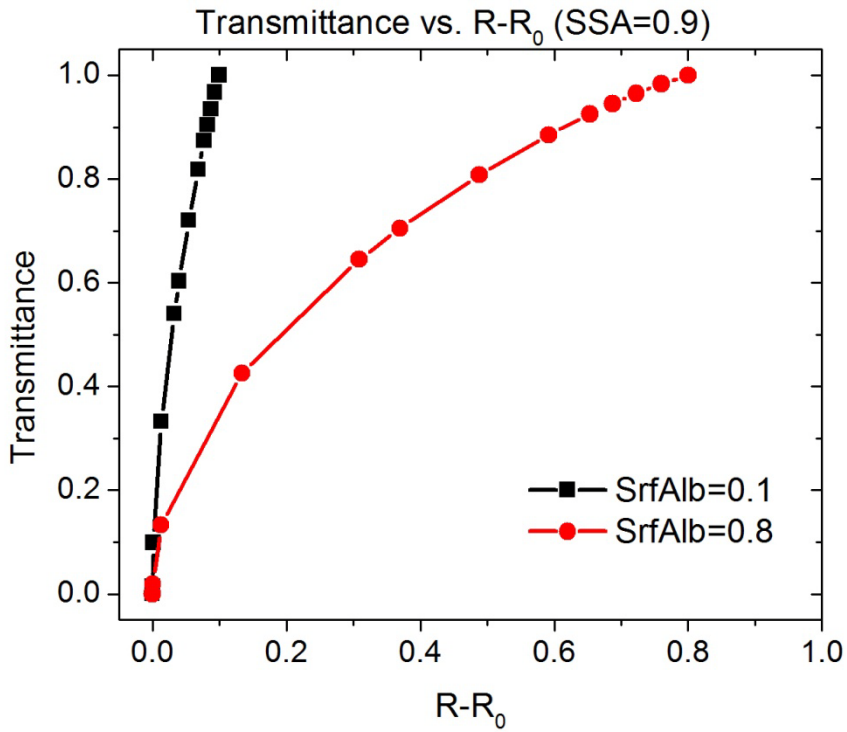
n_{SRF} Retrieval Limit

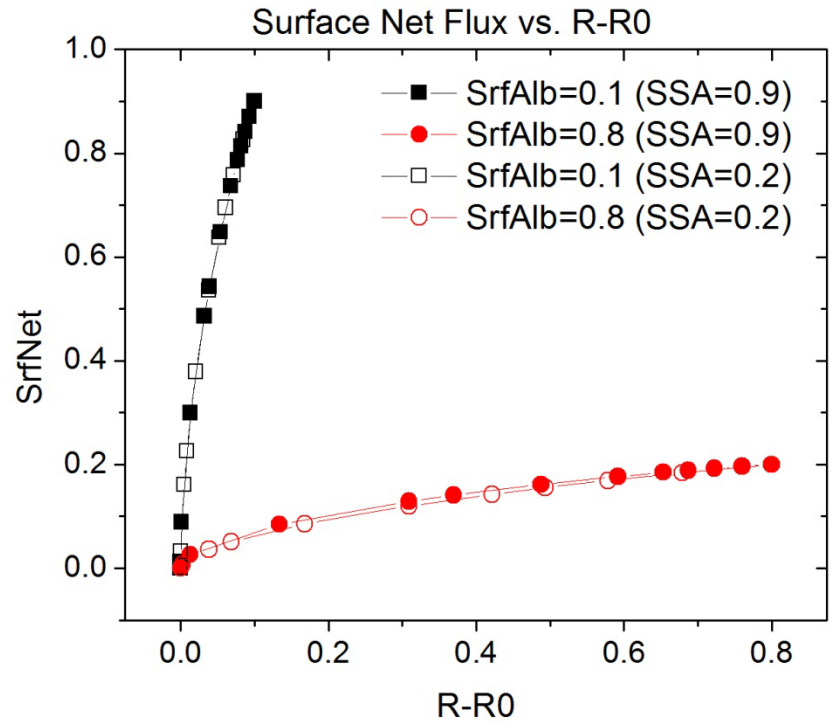
- Surface albedo contributes to *R*. Contribution may be small when R^0 or atmospheric absorption is large.
- A different form of the n_{SRF}-*R* relationship:

$$n_{SRF}(\vartheta_0) = T^0(\vartheta_0) - \frac{1-\tilde{R}}{\tilde{T}}\left[R(\vartheta_0) - R^0(\vartheta_0)\right]$$

- Surface signal in *R* decreases when optical depth increases, R-R^0 -> zero;
- When R-R^0 -> zero n_{SRF} -> T^0. T -> T^0. What is the value of T?

T, n_{SRF} vs. R-R_0





Both T and n_{SRF} approach zero as R-R_0 approaches zero

"Direct" Retrieval of ASR

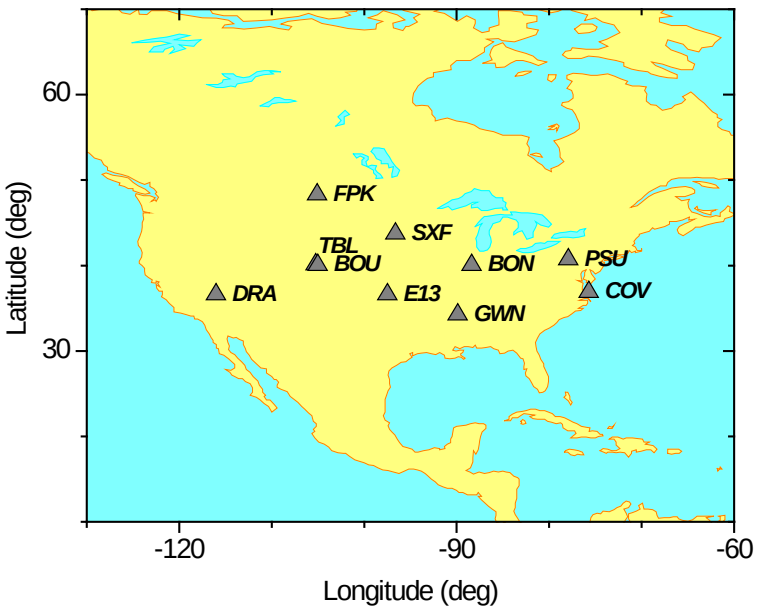
- *Implementation*: $R^0, T^0, \tilde{R}$, and $\tilde{T}$ are calculated from LUT knowing the gas amounts, aerosol and cloud properties; and R is determined from observations.
- *Advantages*
  - **No need for upward flux (albedo) at surface**
  - Improvements in input TOA albedo should lead to improvement of ASR
- *Caveats*
  - Needs broadband TOA albedo that for narrowband instruments requires spectral and angular corrections, which introduce (additional) uncertainties
  - For optimal performance atmosphere inputs and TOA albedo must be consistent (closure)
  - Atmospheric properties may have larger uncertainties when uncertainty in surface albedo is large (aerosol/cloud properties over very bright surface (e.g., snow)

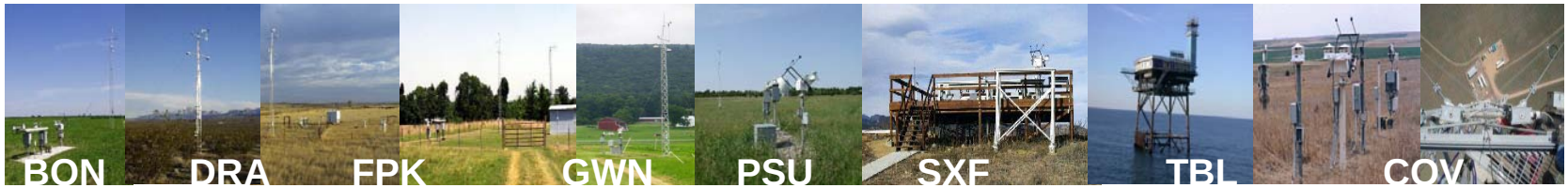
Data

- Time period
  - 2000.03 – 2009.12 (Terra) and 2002.07 – 2009.12 (Aqua)
- TOA albedo from CERES
- Tuned ("constrained") CERES/ARM Validation Experiment (CAVE) data for atmosphere
- Spatial scale: 25 km

Reference data

- 10 sites within current GOES domain
- Before 06/2006 (Terra) and 02/2005 (Aqua) from CERES/CAVE: 15-min averages
- Afterward from SUFRAD and COVE data: 30-min average centered on the satellite overpass time
- Surface type cleasses
  - Agricultural area: BON, PSU (SURFRAD)
  - Open shrub: DRA (SURFRAD)
  - Grass: FPK, GWN, SXF, TBL (SURFRAD), E13 (ARM), BOU (GMD)
  - Water: COV (COVE)



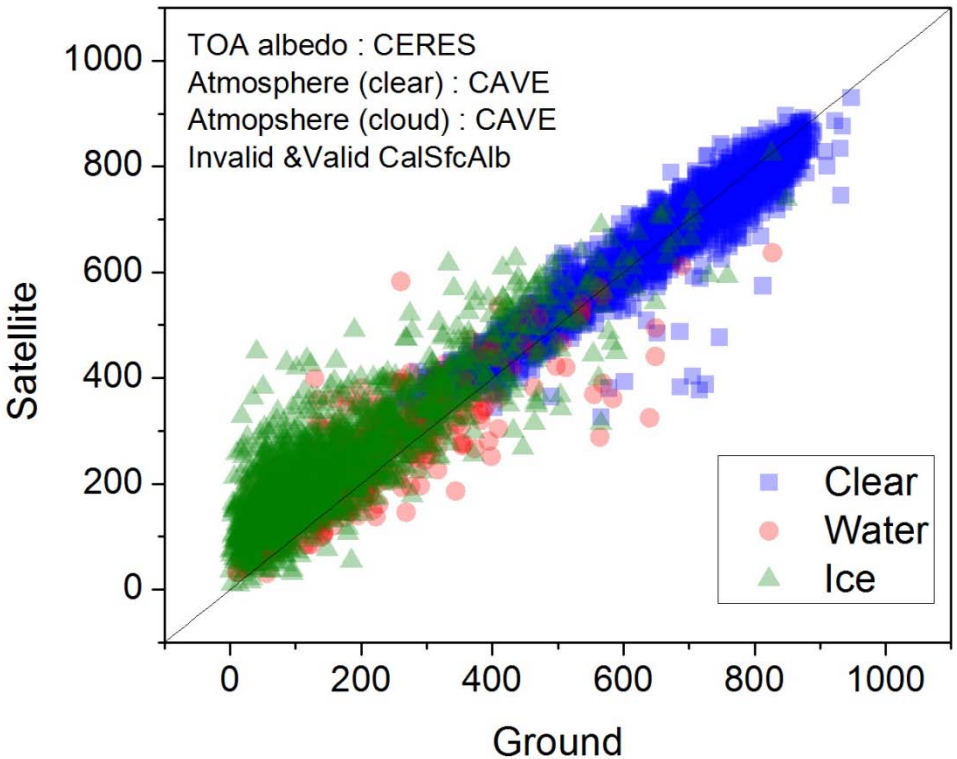


E13 BOU

ASR Retrievals

- CAVE Clouds & Radiation Swath (CRS) data
  - Difference between downwelling and upwelling tuned flux at surface
- Baseline algorithm (baseline)
  - Difference between downwelling and upwelling tuned flux at surface
  - CAVE atmosphere input and surface albedo (tuned)
- Direct ASR algorithm (direct)
  - CAVE atmosphere input
- **Only clear and overcast** CERES scenes are used (based on MODIS cloud fraction within the CERES footprint) due to
  - algorithm requirement for separate clear- & cloudy-scene albedos
  - CERES data are all-sky
  - To minimize spatial inconsistency between surface and satellite measurements

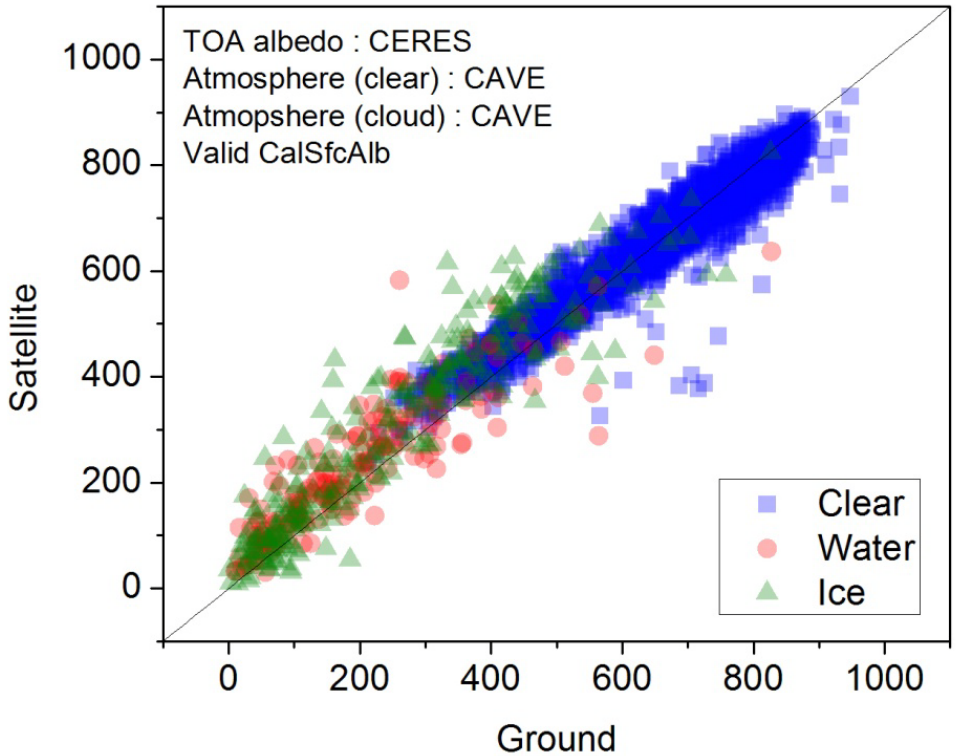
Direct Algorithm



All clear and overcast data

	Clear	Water cloud	Ice cloud	All
Satellite	656	204	239	449
Bias(%)	0	27	45	8
Ground	654	161	165	417

Direct Algorithm - Filtered



Analysis: some atmosphere inputs are inconsistent with TOA albedo input.

The largest inconsistent inputs are identified by unphysical surface albedos

$$a = \frac{R - R^0}{T^0 \tilde{T} + \tilde{R}\left(R - R^0\right)}$$

Data with such albedos are filtered out

Filtered data

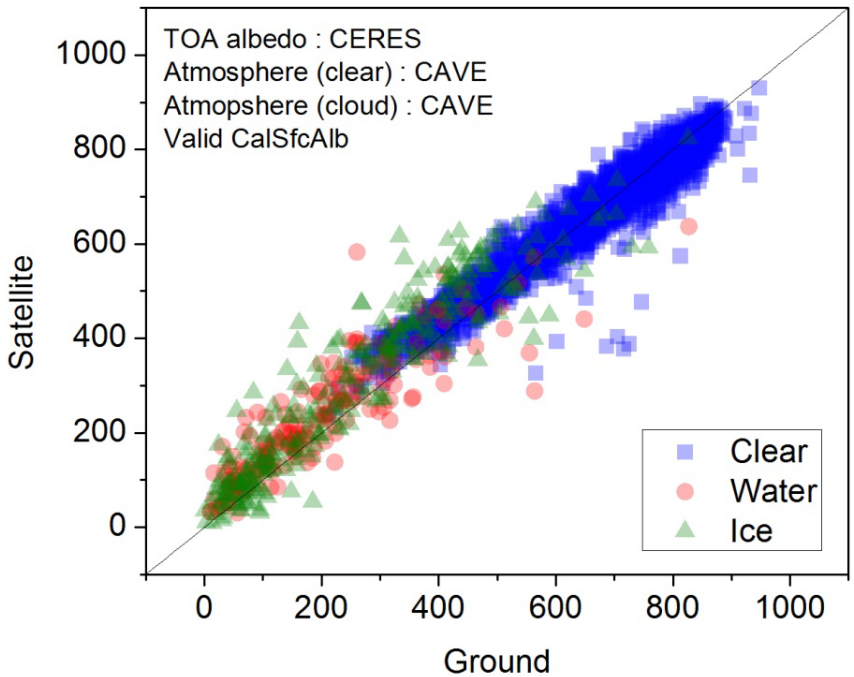
	Clear	Water cloud	Ice cloud	All
Satellite	656	235	316	596
Bias(%)	0	16	18	1
Ground	654	202	268	588

Unfiltered data

	Clear	Water cloud	Ice cloud	All
Satellite	656	204	239	449
Bias(%)	0	27	45	8
Ground	654	161	165	417

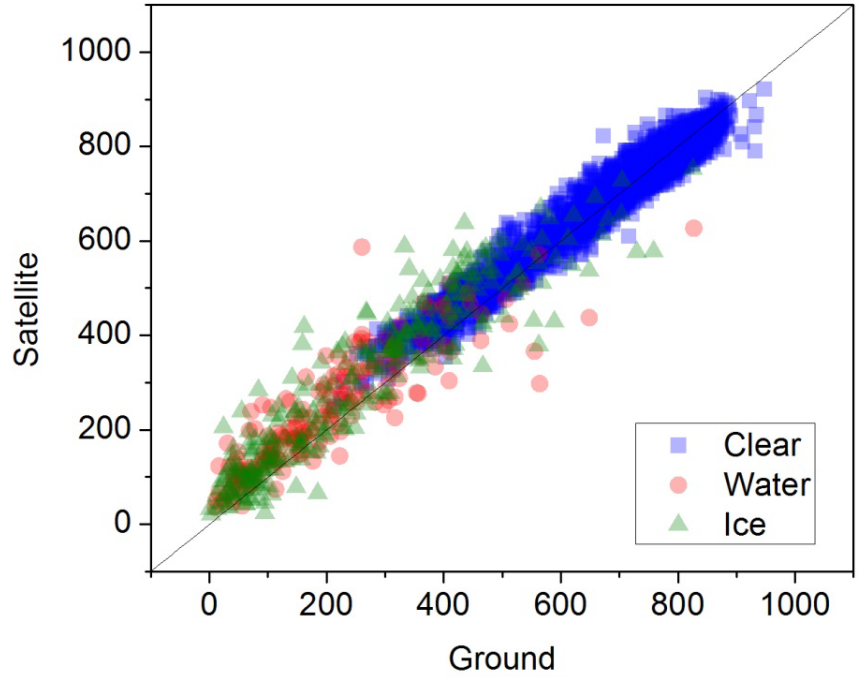
Direct vs. CRS data

Direct



	Clear	Water cloud	Ice cloud	All
Satellite	656	235	316	596
Bias(%)	0	16	18	1
Ground	654	202	268	588

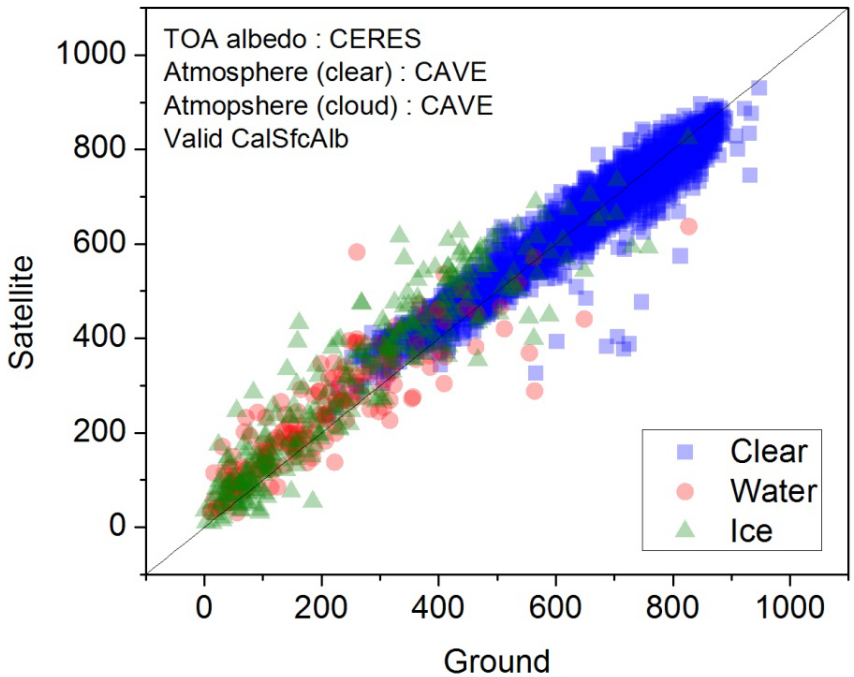
CRS



	Clear	Water cloud	Ice cloud	All
Satellite	666	239	310	605
Bias(%)	2	18	16	3
Ground	654	202	268	588

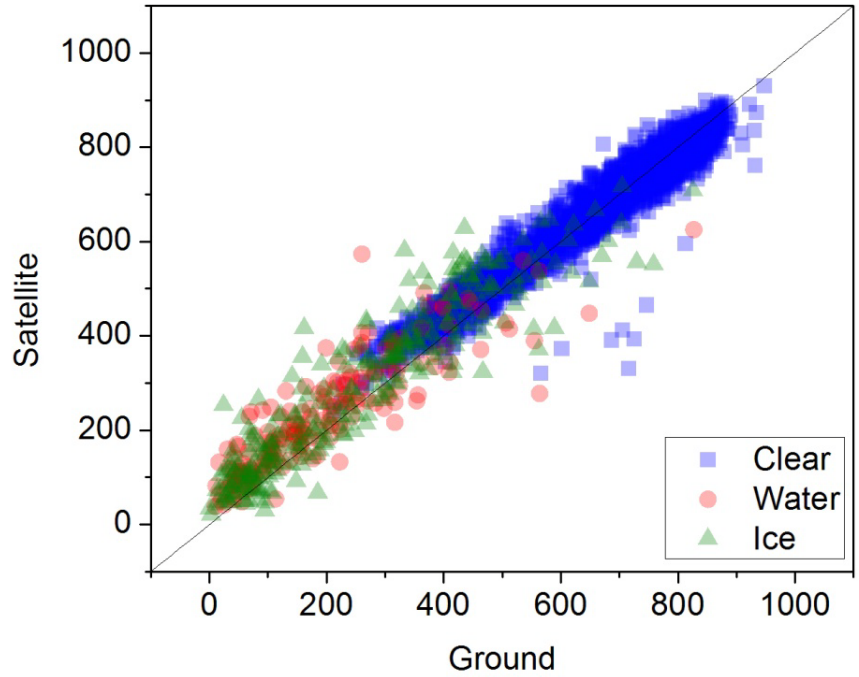
Direct vs. Baseline

Direct



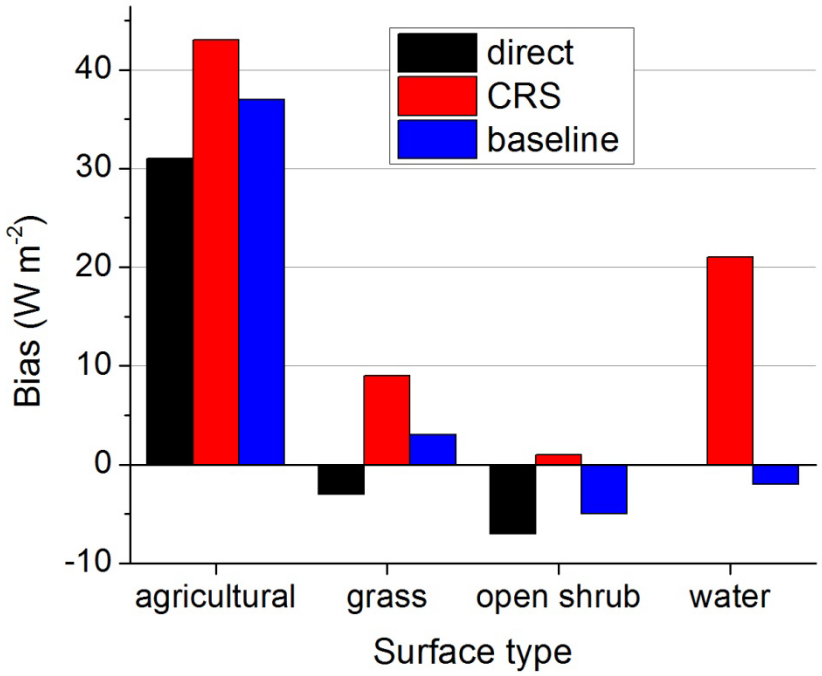
	Clear	Water cloud	Ice cloud	All
Satellite	656	235	316	596
Bias(%)	0	16	18	1
Ground	654	202	268	588

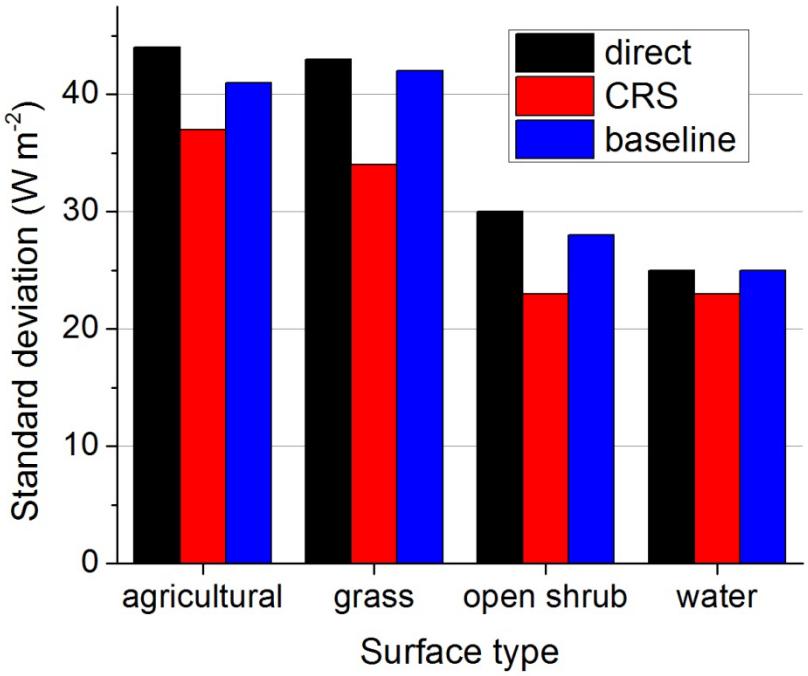
Baseline



	Clear	Water cloud	Ice cloud	All
Satellite	661	238	302	599
Bias(%)	1	18	13	2
Ground	654	202	268	588

Error vs. Surface Scene Type





Summary

- RT-based relationship of $n_{\mathrm{SRF}} = f\,(n_{\mathrm{TOA}})$ accounts for large range of variability in atmosphere
- Direct method can retrieve ASR even when the surface is not "seen"
- Significant improvement in cloudy cases when inconsistent atmosphere and TOA inputs are discarded.
- Direct, CRS and Baseline retrievals are comparable – CRS has somewhat less scatter