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A "Direct" Estimation of Surface Solar Fluxes from CERES

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Outline

- Background
- Method
- Validation data sets
  - CERES (CAVE) & MODIS data
- Validation Results
  - surface solar net flux from MODIS atmosphere
  - surface solar net flux from CAVE atmosphere

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 have large uncertainty 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 direct relationship can be used to estimate ASR when absorbed SW radiation at TOA is known.

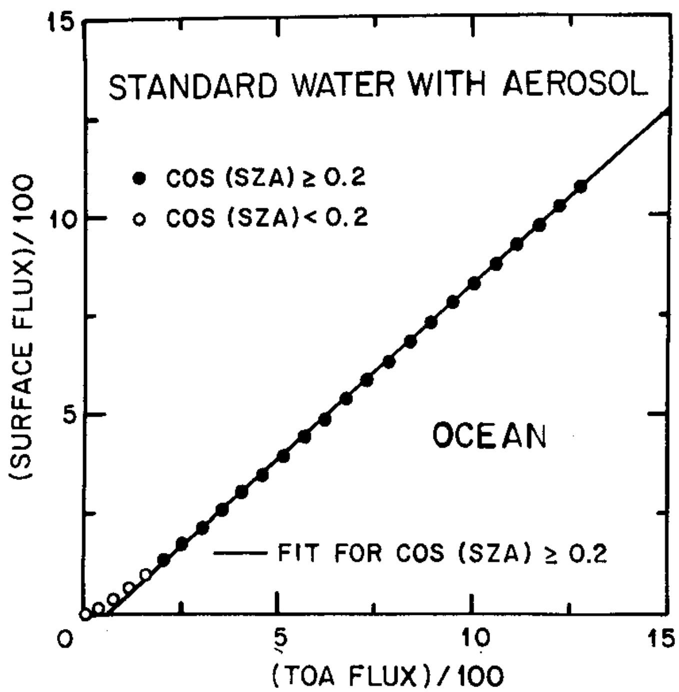


Illustration of the relationship between ASR (surface flux) and TOA absorbed radiation (TOA flux). (*Cess and Vulis*, 1989, Fig 12)

ASR Retrieval Method (3)

- The direct relationship is established and ASR is estimated in one of two ways:
  - » Statistical algorithm
    - – the relationship between surface and TOA solar absorption is established from a regression of absorbed radiation at the surface and at TOA
      - the relationship is a function of
        - – solar zenith angle
        - – total column amount of precipitable water

ASR Retrieval Method (4)

» Physical algorithm
  – the relationship between surface and TOA solar absorption is established directly from reflectance (*R*) and transmittance (*T*) of the surface-atmosphere as calculated from RT
    – estimates ASR using inputs of atmosphere (gases, aerosol and cloud optical properties)

ASR Physical Algorithm (1)

- From energy conservation of surface-atmosphere:

$$n_{SRF} = n_{TOA} - n_{ATM}, \text{ where } n = \frac{\text{energy absorbed}}{S_0 \cos\vartheta_0 \frac{d_0^2}{d^2}} \quad (1)$$

Solar irradiance at TOA

  - n is the fraction of solar energy absorbed at the surface (SRF), by the atmosphere (ATM), and at the top of atmosphere (TOA)
  - d and d_0 are the actual and mean Sun-Earth distances, respectively.
  - S_0 is the solar “constant”, ϑ_0 is the solar zenith angle.

ASR Physical Algorithm (2)

- Using the adding equations of RT one can express n_{TOA}-n_{ATM} as a function of atmospheric composition and n_{TOA} (*Laszlo and Pinker*,1994, 2002)
- Adding equations of RT (*Chandrasekhar*, 1960):

$$R(\vartheta_0) = R^0(\vartheta_0) + r\tilde{T} \quad (2a)$$

$$T(\vartheta_0) = T^0(\vartheta_0) + r\tilde{R} \quad (2b)$$

surface contribution transmitted to TOA

surface contribution back-reflected by atmosphere

atmospheric reflectance and transmittance (no surface)

accounts for multiple reflection between atmosphere and surface

$$\text{where} \quad r = \left[a(\vartheta_0)T^0(\vartheta_0)\right]\left[1 - a(\vartheta_0)\tilde{R}\right]^{-1}$$

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. a is the surface albedo.

ASR Physical Algorithm (3)

- Expressing $T(\vartheta_0)$ and a from (2) and using the relationships

$$n_{SRF} = T(\vartheta_0)[1 - a(\vartheta_0)] \text{ and } n_{TOA} = 1 - R(\vartheta_0)$$

$$n_{SRF} = A + B\, n_{TOA}, \qquad (3)$$

$$\text{where } B = (1 - \tilde{R})/\tilde{T}, \text{ and } A = T^0(\vartheta_0) - B[1 - R^0(\vartheta_0)]$$

- B is ONLY a function of the atmosphere
- A is a function of the atmosphere AND solar angle
- Eq. 3 does NOT explicitly depend on the surface albedo
- When A and B are constants (or vary little) Eq. 3 describes a linear relationship.

ASR Physical Algorithm (4)

- Using the relationship $n_{TOA} = 1 - R(\vartheta_0)$ in (3):

$$n_{SRF} = A^* - B\,R(\vartheta_0), \qquad (4)$$

where $A^* = T^0(\vartheta_0) + B\,R^0(\vartheta_0)$, and B is as before.

$$\text{Then } ASR = n_{SRF}\; S_0 \cos\vartheta_0 \frac{d_0^2}{d^2} \qquad (5)$$

Solar irradiance at TOA ($S_0 \cos\vartheta_0 \frac{d_0^2}{d^2}$)

Fraction of TOA solar irradiance absorbed at surface (n_{SRF})

- $R^0, T^0, \tilde{R}$, and $\tilde{T}$ are calculated from LUT knowing the gas amounts, aerosol and cloud properties; and R is determined from observations.

ASR Physical Algorithm (5)

- Surface downward flux can also be obtained without an explicit surface albedo

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

- Error in *T* (ΔT) and n_{SRF} (Δn_{SRF}) due to error in *R* (ΔR):

$$\Delta T = \frac{\tilde{R}}{\tilde{T}}\Delta R, \qquad \Delta n_{SRF} = \frac{(1-\tilde{R})}{\tilde{T}}\Delta R$$

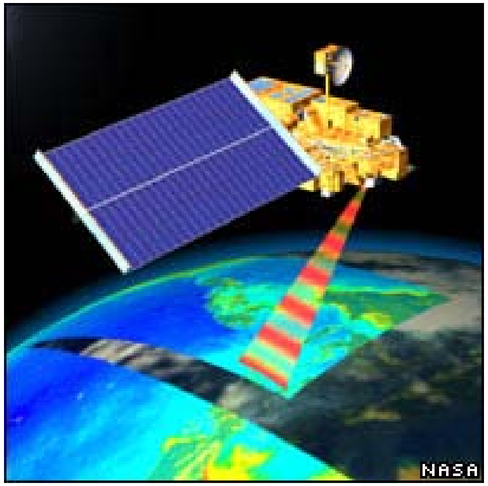
ASR "Direct" Retrieval

- *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)

EVALUATION

Data

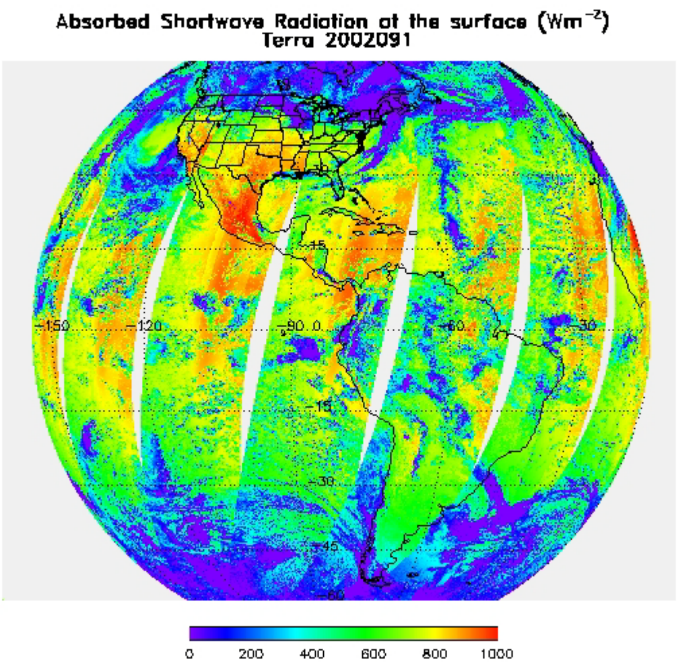
- *TOA albedo*: **CERES** TOA albedo (25-km footprint) from CAVE
- *Atmosphere*: Gases, aerosol and cloud are from Moderate Resolution Imaging Spectroradiometer (**MODIS**) **atmospheric** products (within 25-km square box centered on stations) (from MOD/MYD021KM)
- **Only clear and overcast CERES scenes** 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



Spatial scale for this study: 25 km

MODIS Atmosphere Inputs

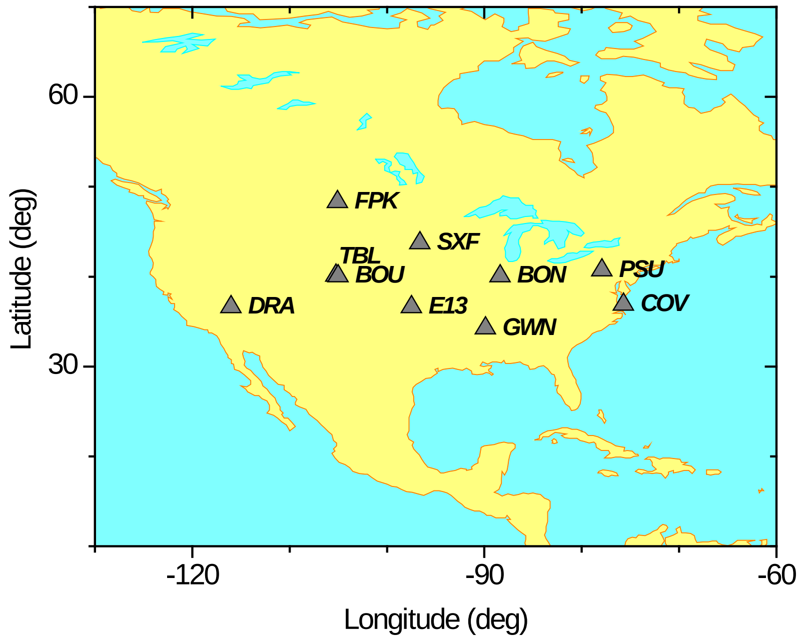
- Geometry (from MOD/MYD03)
- Surface elevation (from MOD/MYD03)
- Cloud mask (from MOD/MYD35)
- Cloud optical depth/size/height/phase (from MOD/MYD06)
- Aerosol optical depth (from MOD/MYD04)
- Aerosol model (characterized by a constant (0.95) single scattering albedo in current evaluation)
- Ozone (from MOD/MYD07, TOMS/OMI)
- Total Precipitable Water (from MOD/MYD07, CERES/CAVE, NCEP Reanalysis)



The ASR from MODIS atmosphere and MODIS-based TOA albedo on day 91 in 2002

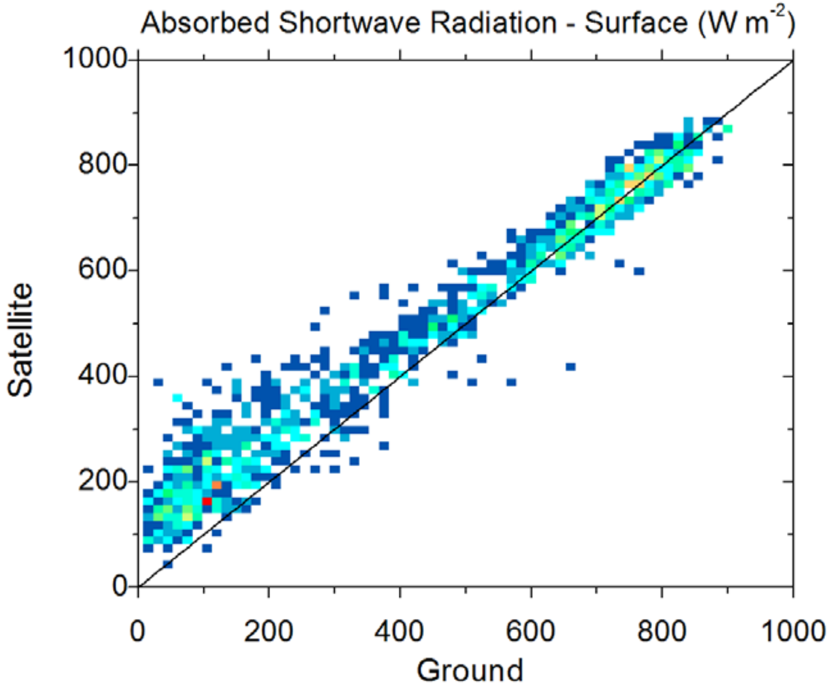
Reference Data

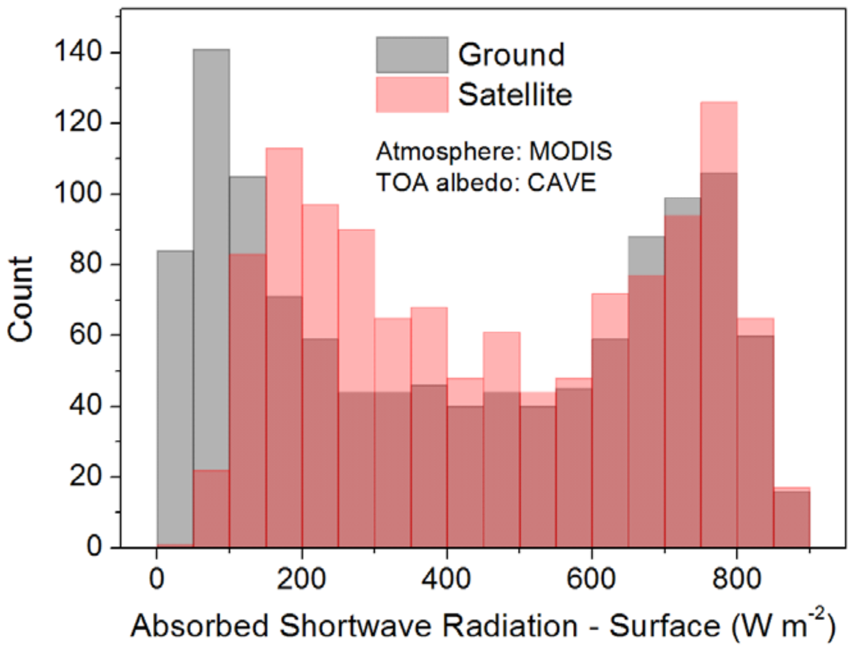
- 10 sites within current GOES domain:
  - BON, DRA, FPK, GWN, PSU, SXF, TBL (SURFRAD)
  - COV (COVE)
  - E13 (ARM)
  - BOU (CMDL)
- Time Period:
  - 2000.03 – 2009.12 (Terra);
    2002.07 – 2009.12 (Aqua)
    for SURFRAD and COVE stations;
  - 2000.03 – 2006.06 (Terra);
    2002.07 – 2005.02 (Aqua)
    for ARM and CMDL stations.



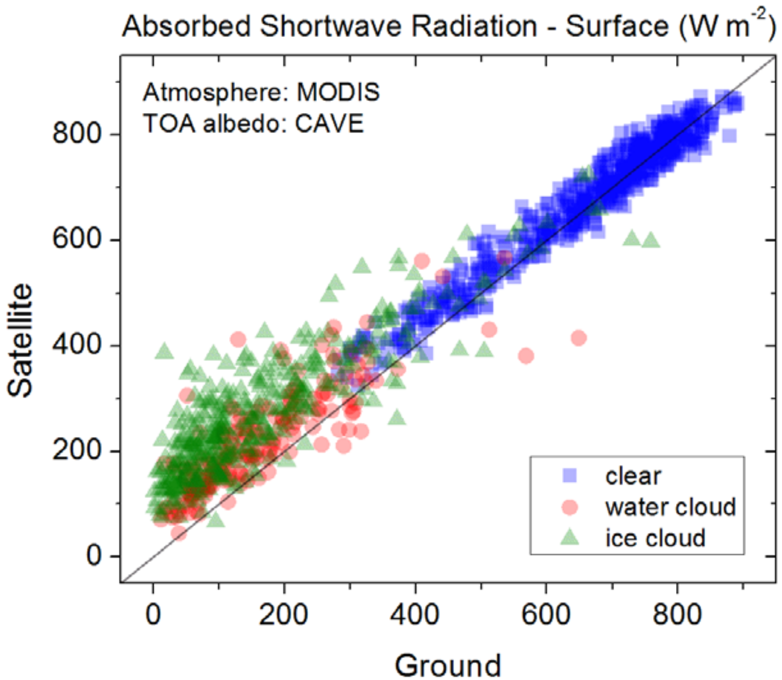
- CERES/CAVE: 15-min averages before 06/2006 (Terra) and 02/2005 (Aqua)
- SURFRAD and COVE data: 30-min average centered on the satellite overpass time after 06/2006 (Terra) and 02/2005 (Aqua)

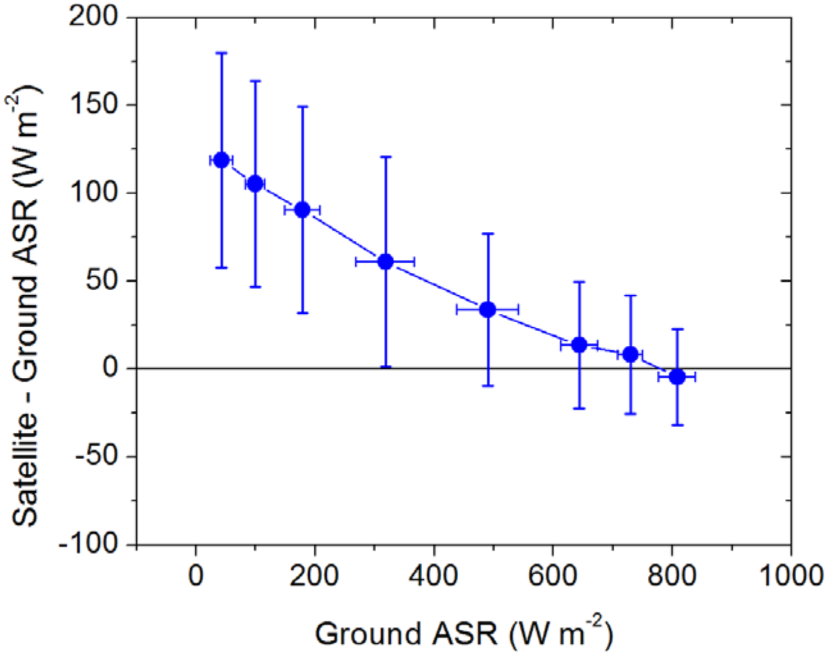
ASR from MODIS atm (1)





ASR from MODIS atm (2)

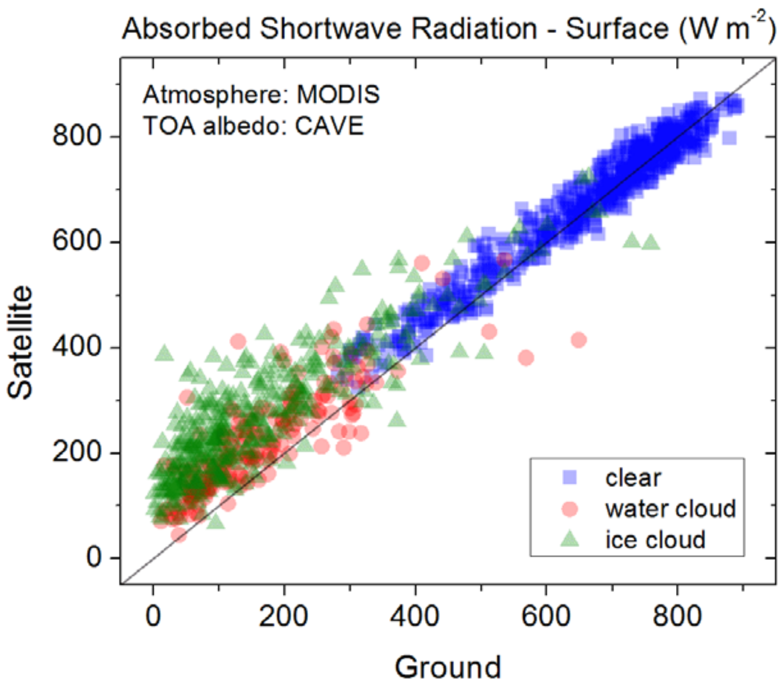


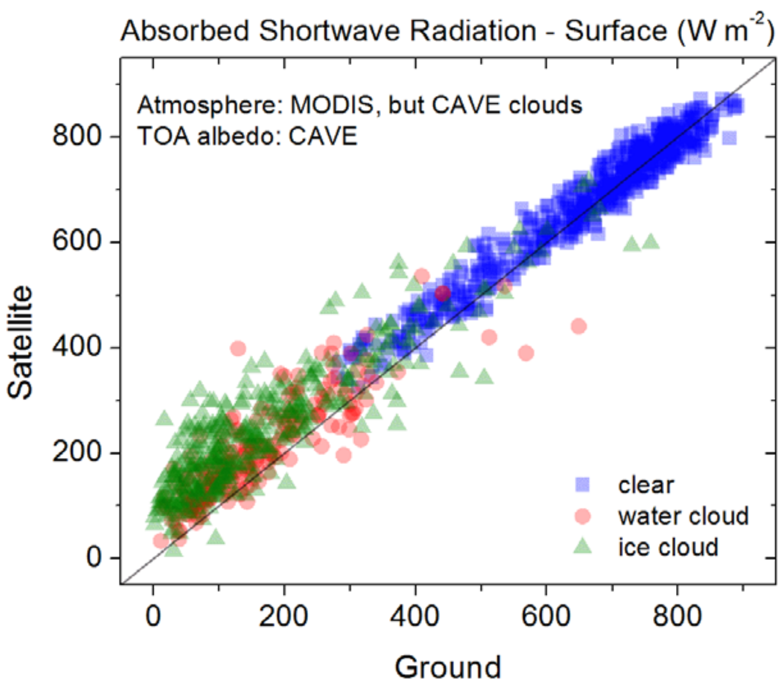


	clear	water cloud	ice cloud	all
Satellite (bias)	667 (2%)	226 (36%)	273 (65%)	467 (13%)
Ground	651	166	165	414

- Large overestimation at low ASR associated with cloudy (mostly ice) scenes
- MODIS cloud is less consistent with CAVE albedo?

MODIS atm with CAVE cloud

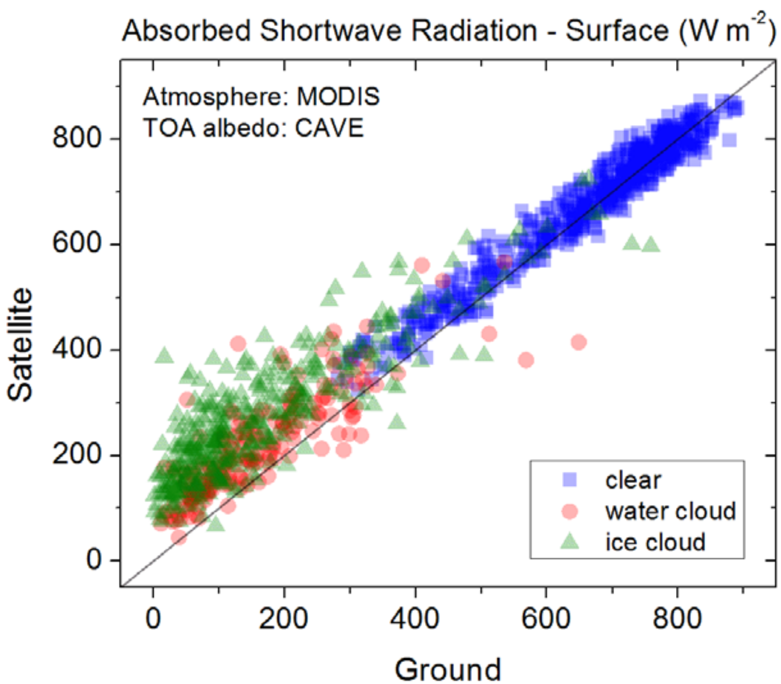


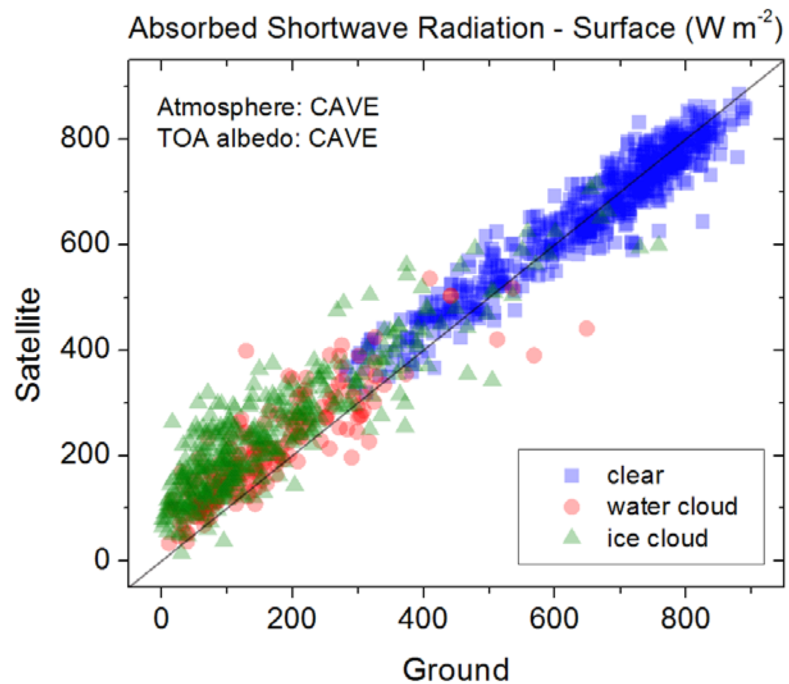


	clear	water cloud	ice cloud	all
Satellite (bias)	667 (2%)	226 (36%)	273 (65%)	467 (13%)
Ground	651	166	165	414

	clear	water cloud	ice cloud	all
Satellite (bias)	667 (2%)	212 (27%)	245 (46%)	458 (10%)
Ground	651	167	168	418

ASR from CAVE atm (1)

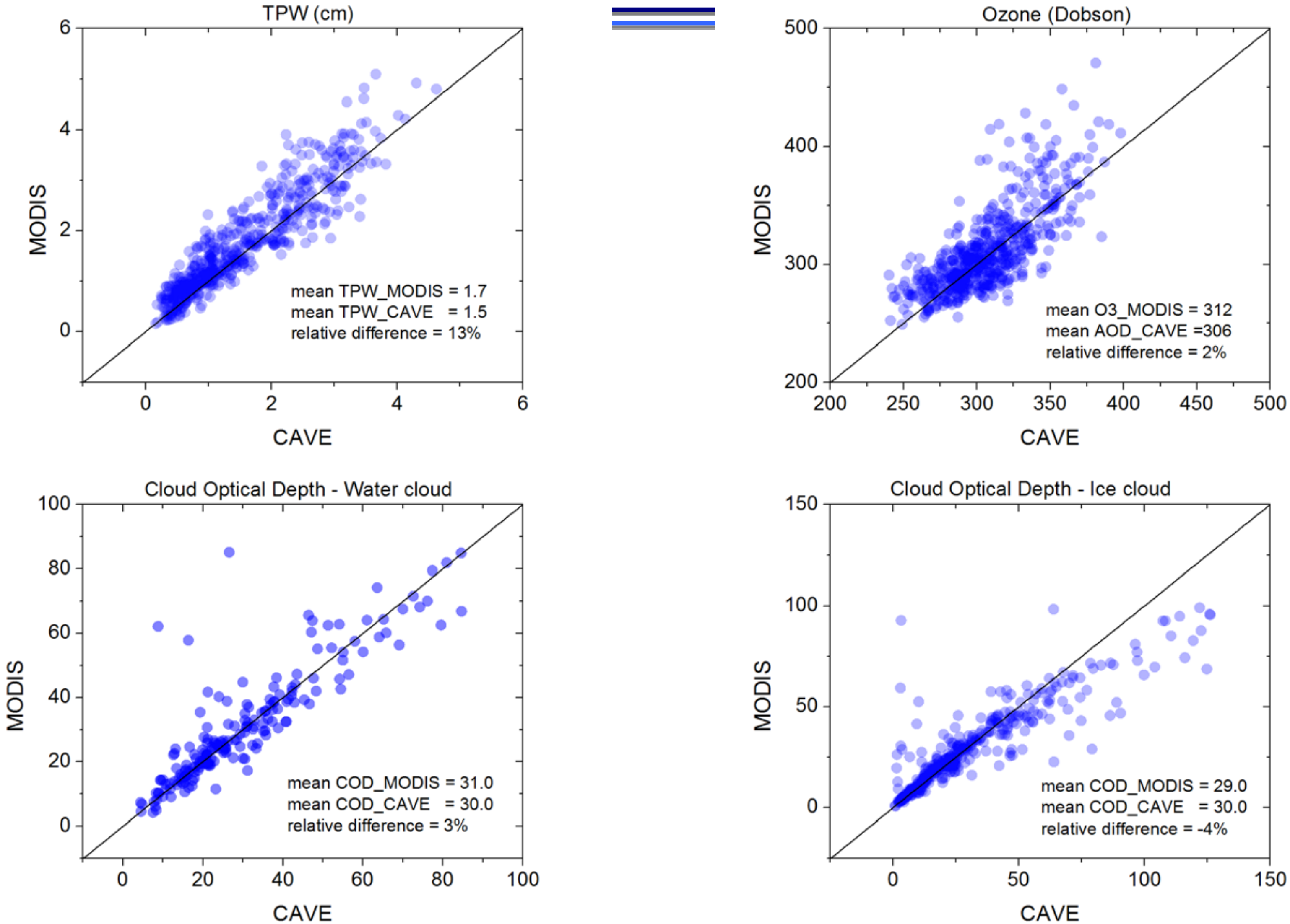




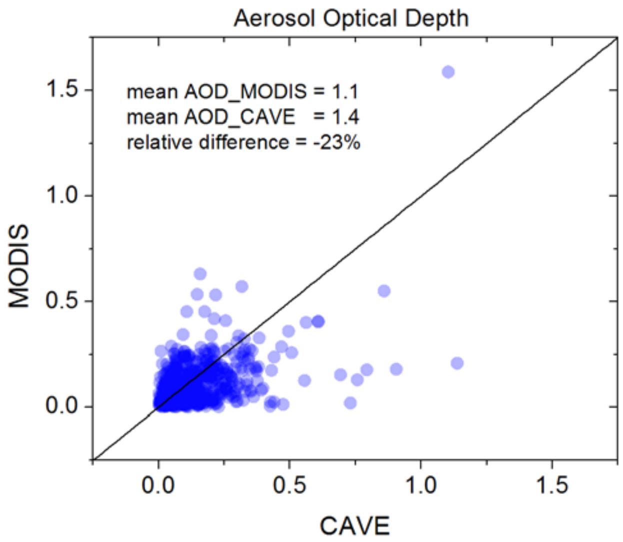
	clear	water cloud	ice cloud	all
Satellite (bias)	667 (2%)	226 (36%)	273 (65%)	467 (13%)
Ground	651	166	165	414

	clear	water cloud	ice cloud	all
Satellite (bias)	656 (1%)	211 (27%)	242 (47%)	449 (8%)
Ground	651	166	165	414

MODIS vs. CAVE atmosphere

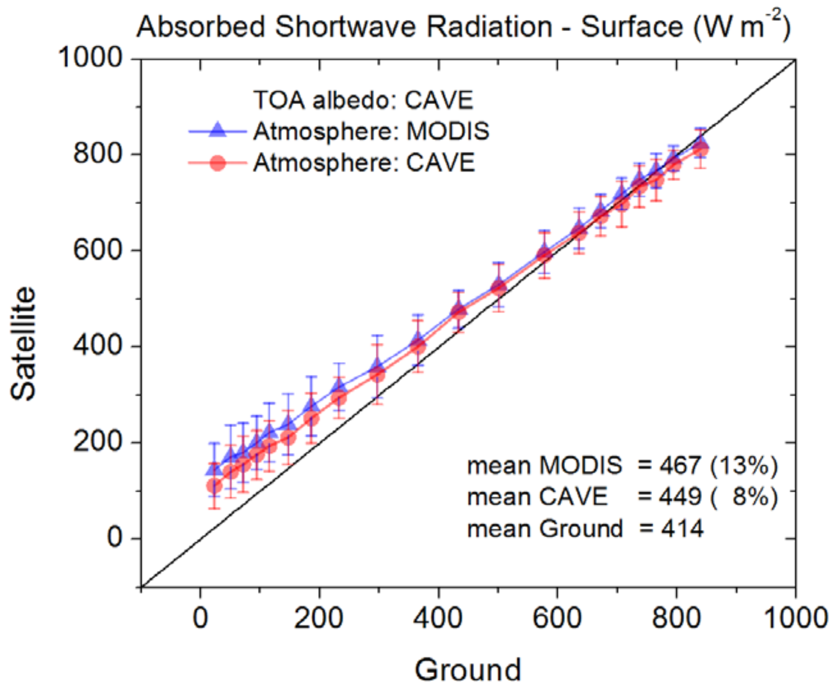


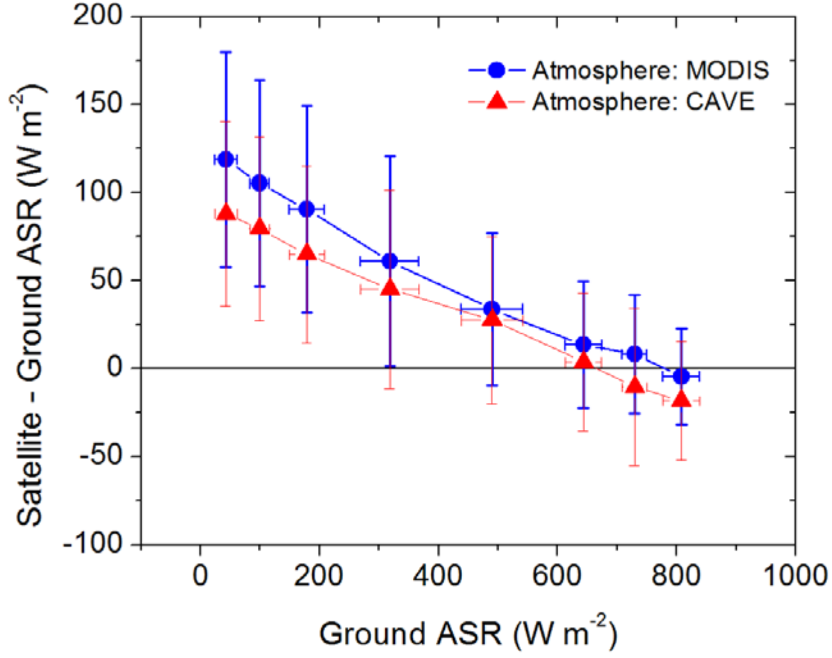
MODIS vs. CAVE atmosphere



- Large scatter in MODIS vs. CAVE atmosphere
- Mean differences are, however, relatively small
- Largest relative differences in TPW and AOD

ASR from CAVE atm (2)

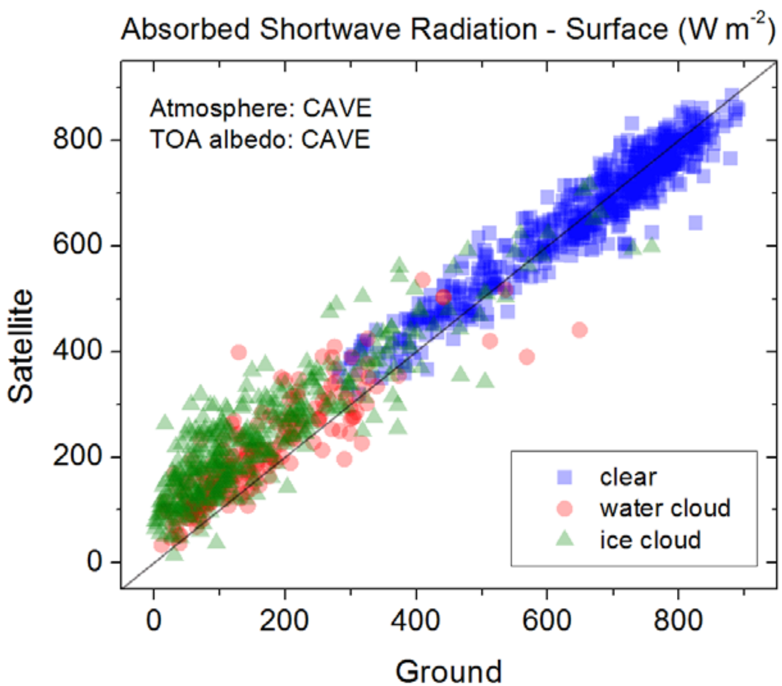


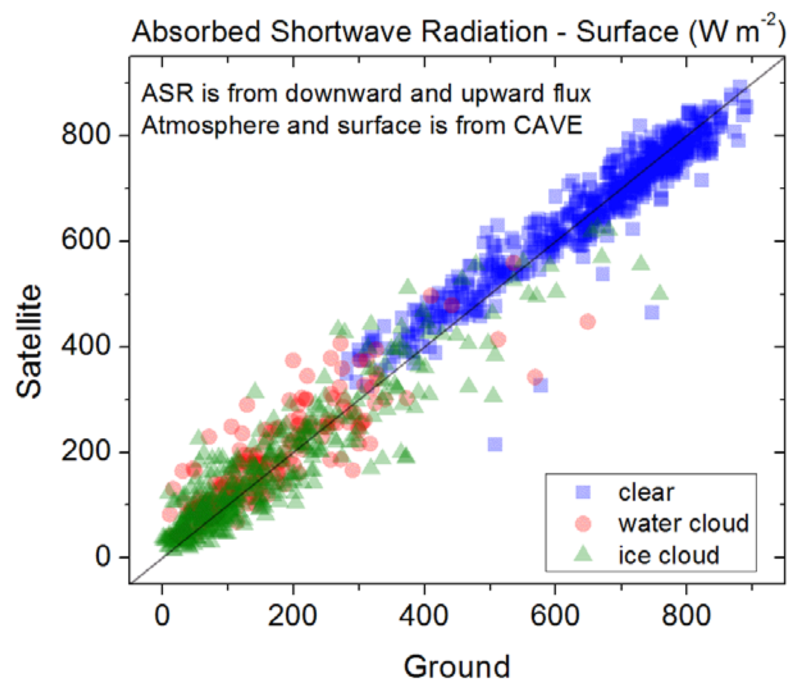


Summary

- ASR is retrieved from CERES (CAVE) TOA albedo without the need for estimating upward and downward fluxes at surface
- Using CAVE atmosphere results in better agreement with ground than using MODIS atmosphere
  - Atmosphere in CAVE data is more consistent with CERES (CAVE) TOA albedo then atmosphere from MODIS data.
- Still large bias for cloudy scenes.

ASR from up & down fluxes





	clear	water cloud	ice cloud	all
Satellite (bias)	656 (1%)	211 (27%)	242 (47%)	449 (8%)
Ground	651	166	165	414

	clear	water cloud	ice cloud	all
Satellite (bias)	658 (1%)	187 (13%)	170 (3%)	423 (2%)
Ground	651	166	165	414