Surface Net Fluxes from Broadband and Narrowband Observations: CERES and GOES-R/ABI

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Outline

- Background
  - GOES-R & the Advanced Baseline Imager
- Algorithms/Methods
  - CERES & MODIS in algorithm development
- Validation data sets
  - CERES & MODIS in evaluation
- Validation Results
  - surface solar net flux from MODIS
  - surface solar net flux from CERES

Background: GOES-R & ABI

- **Geostationary Operational Environmental Satellite-R Series (GOES-R)**
  - follow-on satellite system to the existing GOES-I/M and NOP series satellites
  - 3-axis stabilized with on-orbit lifetime of 15 years (5 years of storage and 10 years of operational)
  - two spacecraft (75W and 137W)
  - launch date: 2015 (planned)
- **Advanced Baseline Imager (ABI)**
  - 16-band, two-axis scanning passive radiometer with star sensing
  - measures emitted and solar reflected radiance simultaneously in all spectral bands
  - **first imager with onboard calibration of solar reflective channels on a US geostationary platform!**

ABI channels

Channel ID	Wavelength Microns	Hor. Res.	Upper and lower 50% response points (in microns)	Noise @ Ref.	Max. Level
1	0.47	1km	0.45±0.01 - 0.49±0.01	300/1	100 %
2	0.64	0.5km	0.59±0.01 - 0.69±0.01	300/1	100 %
3	0.865	1km	0.8455±0.01 - 0.8845±0.01	300/1	100 %
4	1.378	2km	1.3705±0.005 -1.3855±0.005	300/1	100 %
5	1.61	1km	1.58±0.01 - 1.64±0.01	300/1	100 %
6	2.25	2km	2.225±0.01 - 2.275±0.01	300/1	100 %
7	3.90	2km	3.80±0.05 - 4.00±0.05	0.1 K	400 K
8	6.185	2km	5.77±0.03 - 6.6±0.03	0.1 K	300 K
9	6.95	2km	6.75±0.03 - 7.15±0.03	0.1 K	300 K
10	7.34	2km	7.24±0.02 - 7.44±0.02	0.1 K	320 K
11	8.5	2km	8.3±0.03 - 8.7±0.03	0.1 K	330 K
12	9.61	2km	9.42±0.02 - 9.8±0.03	0.1 K	300 K
13	10.35	2km	10.1±0.1 - 10.6±0.1	0.1 K	330 K
14	11.2	2km	10.8±0.1 - 11.6±0.1	0.1 K	330 K
15	12.3	2km	11.8±0.1 - 12.8±0.1	0.1 K	330 K
16	13.3	2km	13.0±0.06 - 13.6±0.06	0.3 K	305 K

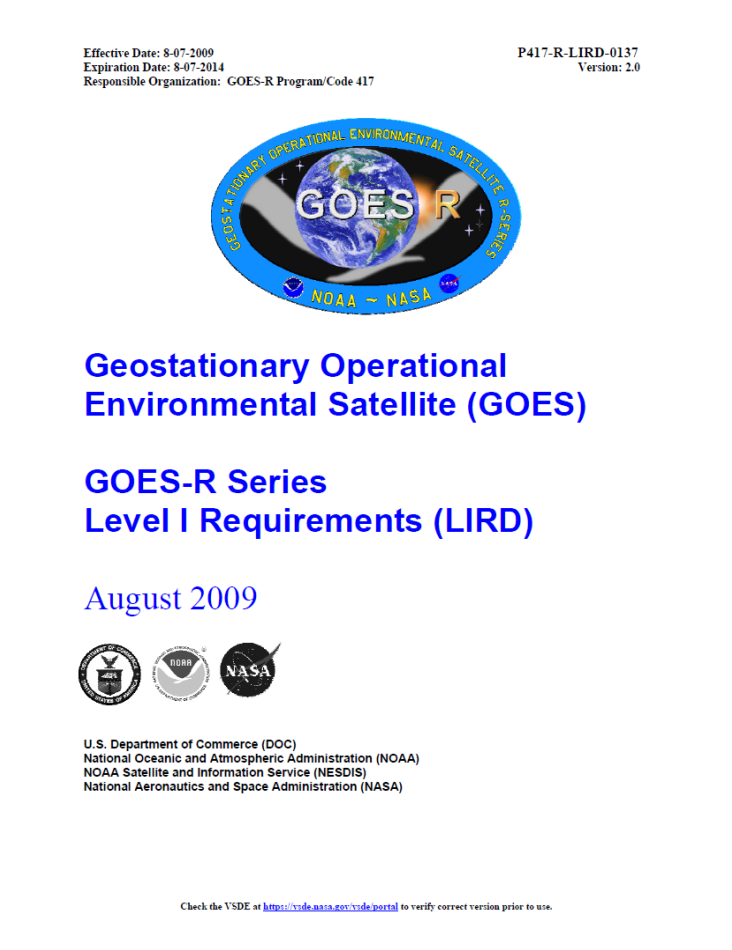
DRAFT

Background: RB Products

Radiation Products:

1. Downward SW Radiation: Surface (DSR)
2. Reflected SW Radiation: TOA (RSR)
3. Absorbed SW Radiation: Surface (ASR)
4. Upward LW Radiation: TOA
5. Downward LW Radiation: Surface
6. Upward LW Radiation: Surface

Only ASR is discussed in this presentation



Effective Date: 8-07-2009
Expiration Date: 8-07-2014
Responsible Organization: GOES-R Program/Code 417

P417-R-LIRD-0137
Version: 2.0

Geostationary Operational Environmental Satellite (GOES)

GOES-R Series
Level I Requirements (LIRD)

August 2009

U.S. Department of Commerce (DOC)
National Oceanic and Atmospheric Administration (NOAA)
NOAA Satellite and Information Service (NESDIS)
National Aeronautics and Space Administration (NASA)

Check the VSDE at https://vsde.nasa.gov/vsde/portal to verify correct version prior to use.

ASR Retrieval Methods

- ASR from the difference of downward and upward SW fluxes at the surface (*direct path*)
  - similar to CERES SARB
    - upward flux may have large uncertainty due to errors in surface albedo
- Directly from TOA ASR
  - from RT (*physical method*)
    - avoid potentially uncertain upward flux (surface albedo)

ASR Physical Algorithm (1)

- From energy conservation of surface-atmosphere:

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

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

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

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

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

- 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

Fraction of TOA solar irradiance absorbed at surface

- $R^0, T^0, \tilde{R}$, 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)

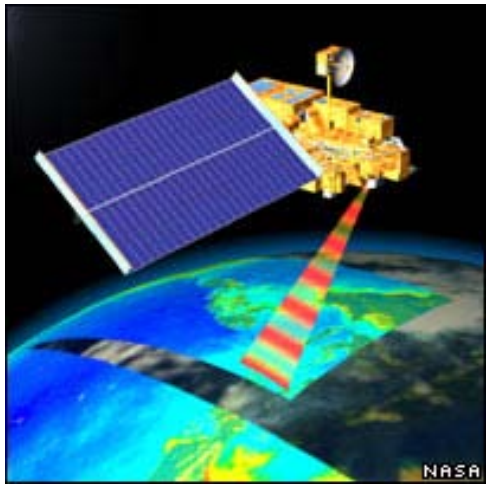
Compared to Direct Path:

- *Advantages*
  - **No need for upward flux (albedo) at surface**
  - Improvements in input TOA albedo should lead to improvement of ASR
- *Disadvantages*
  - Needs broadband TOA albedo that for ABI requires spectral and angular corrections, which introduce (additional) uncertainties
  - For optimal performance atmosphere inputs and TOA albedo must be consistent (closure)

EVALUATION

Proxy Data

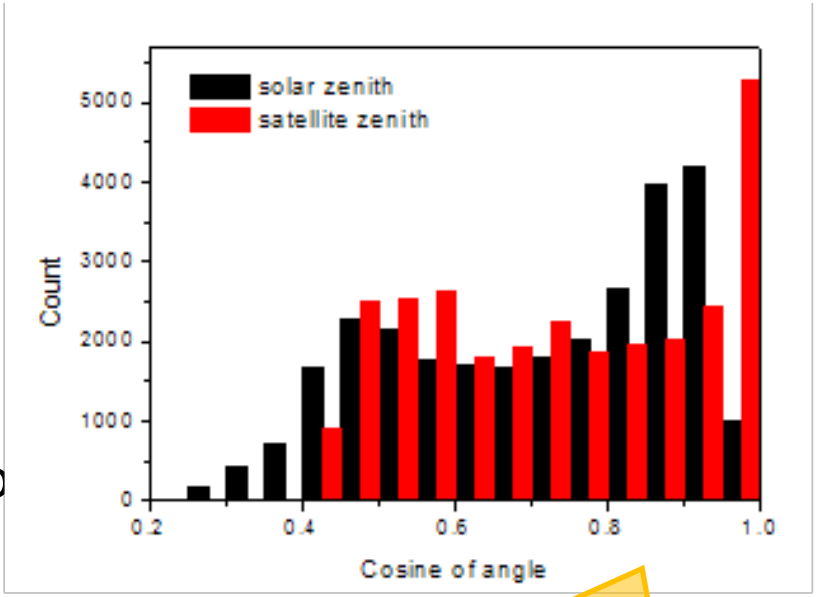
- **CERES** TOA albedo (25-km footprint)
- Moderate Resolution Imaging Spectroradiometer (**MODIS**) reflectances (within 25-km square box centered on stations) (from MOD/MYD021KM)
- **Only clear and overcast CERES scenes** are used (based on MODIS cloud fraction within the CERES footprint) in this presentation due to
  - algorithm requirement for separate clear- & cloudy-scene albedos
  - CERES data are all-sky



Spatial scale for this study: 25 km

Proxy Data – Other 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)



Large range of solar and view angles

TOA Broadband Albedo

1. Narrowband reflectances in 3 MODIS channels (0.47, 0.64, 0.86 μm) $R_{n,i}$ are converted into broadband BRDF R_b

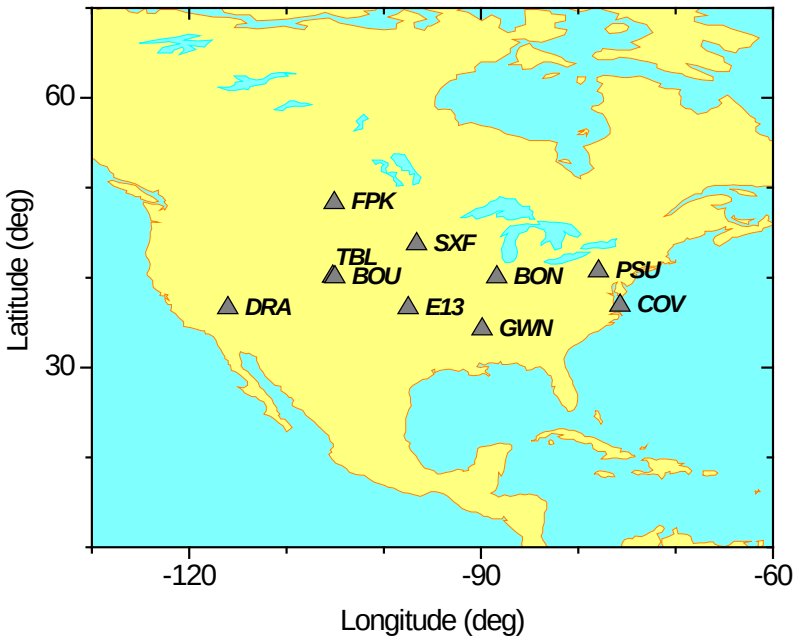
$$R_b = c_0 + \sum_{i=1}^{3} c_i R_{n,i}$$

   Coefficients c_i are obtained for discrete solar zenith angle bins from regression of simulated (MODTRAN, *Berk et al.,* 1985) narrowband and broadband BRDF.

2. CERES on TRMM (*Loeb et al.,* 2003; *Kato and Loeb*, 2005) ADM is applied to R_b to get broadband TOA albedo.

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.



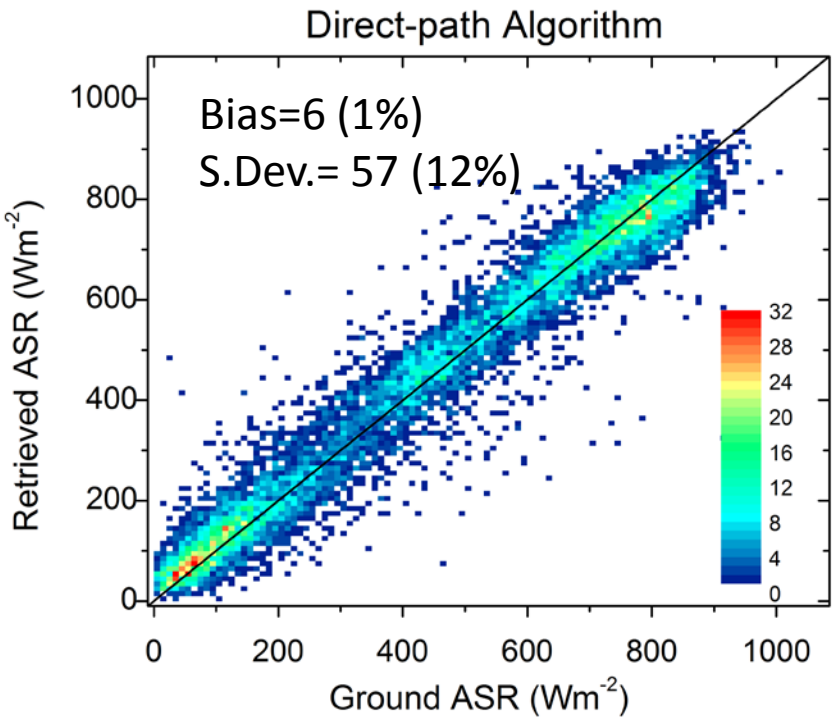
- CERES/CAVE: 15-min averages before 06/2006 (Terra) and 02/2005 (Aqua)
- SURFRAD and COVE data: 30-min average centered on the satellite overpass time after 06/2006 (Terra) and 02/2005 (Aqua)

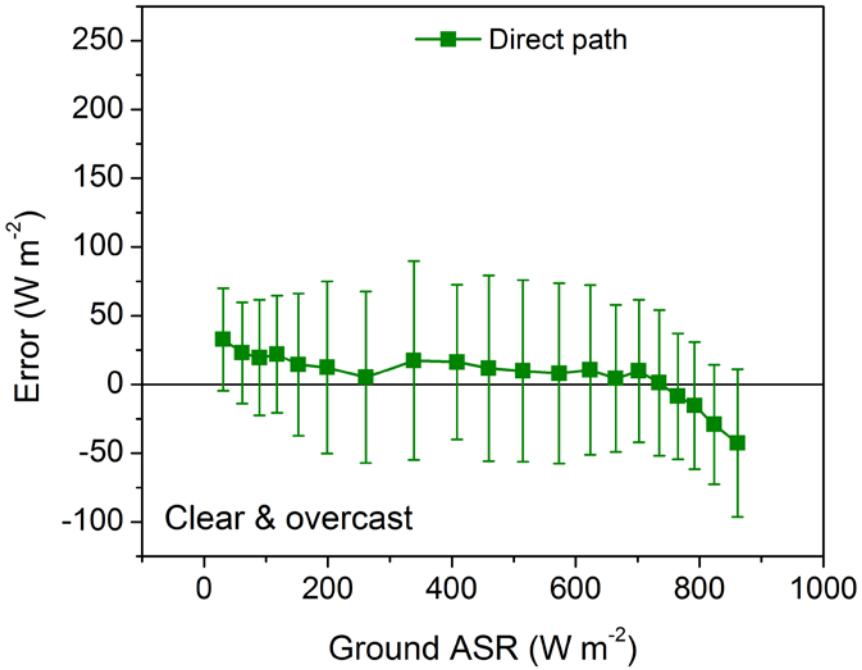
ASR Retrievals

ASR is retrieved by

- **direct path algorithm**
  - from MODIS atmosphere and surface data – **direct path**
- **physical algorithm**
  - from MODIS atmosphere data and MODIS-based broadband TOA albedo – **physical (MODIS albedo)**
  - from MODIS atmosphere and CERES TOA albedo – **physical (CERES albedo)**

Retrieval vs. Reference Direct Path





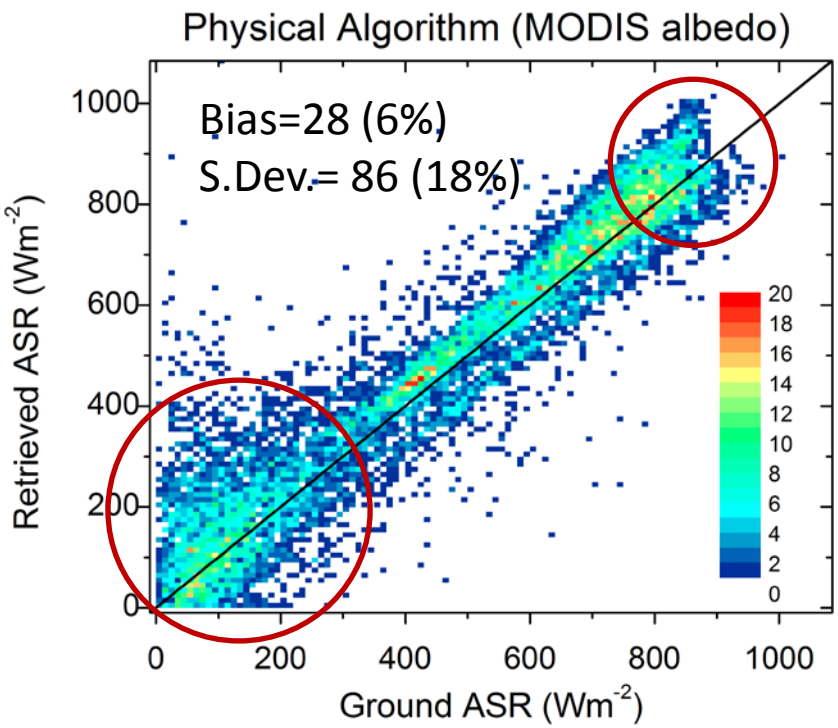
Only clear and overcast scenes used.

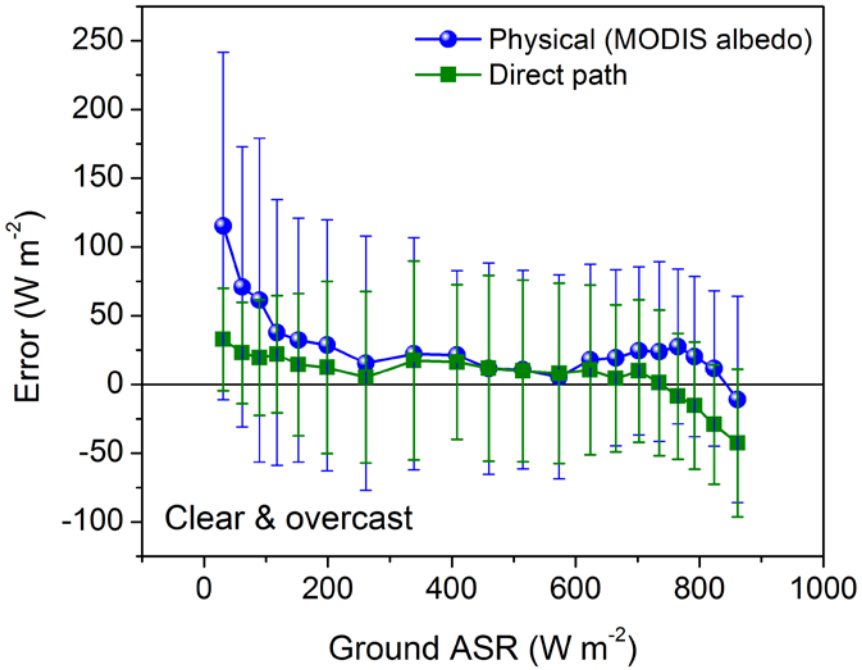
Data are binned according to ground data.

symbol: bias in bin

vertical line: standard deviation of biases

Retrieval vs. Reference Physical (MODIS)





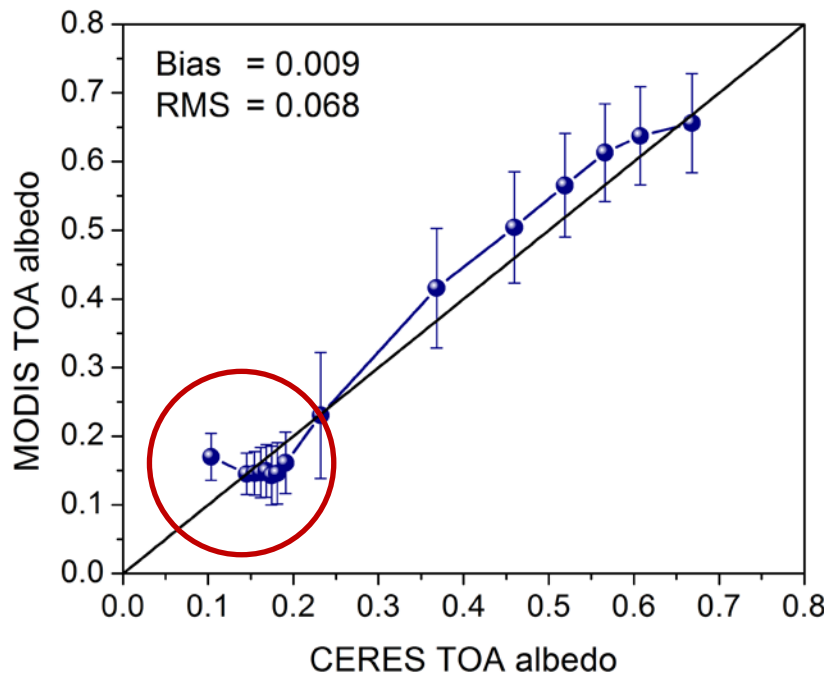
Larger scatter than for Direct path.

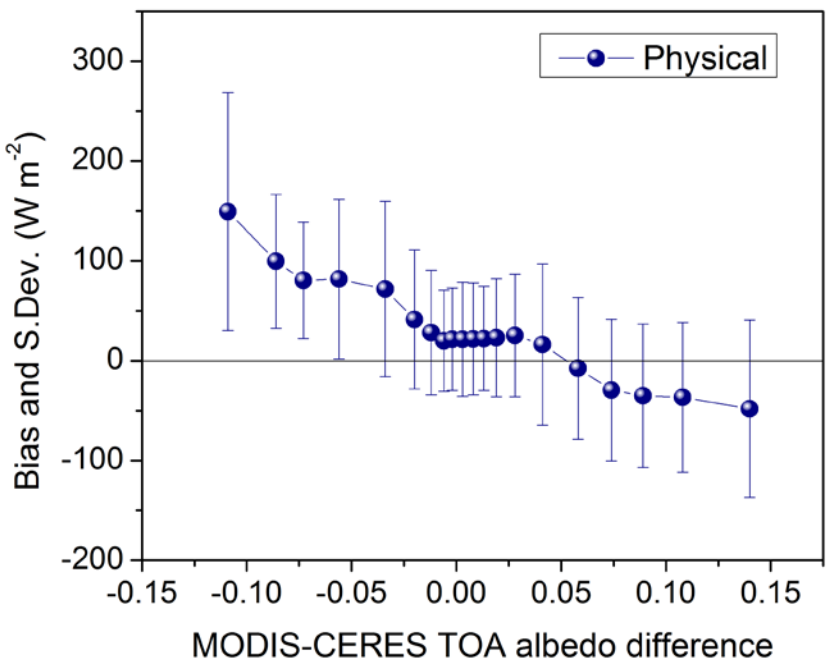
Larger errors at low and high ASR.

Not what was expected.

TOA albedo is bad?

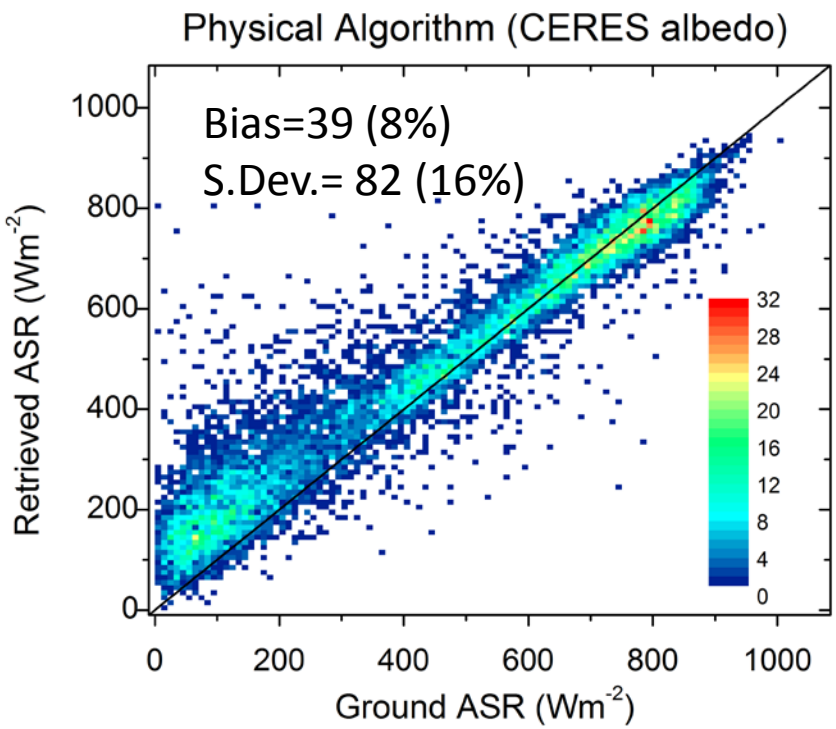
Dependence of Error on TOA Albedo Error

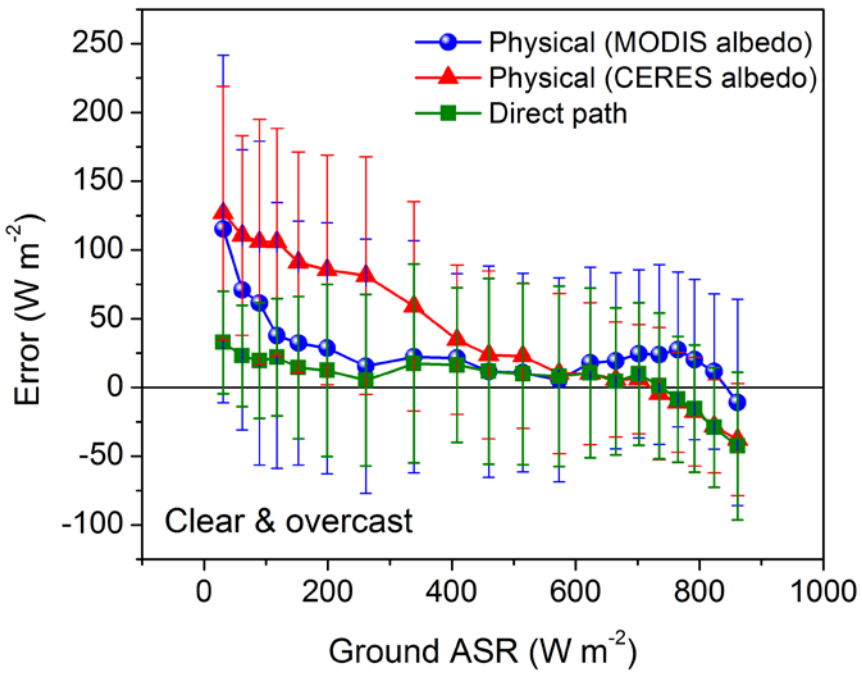




Indeed, TOA albedo from MODIS has large errors, especially at low values (clear sky). Let's use a better (CERES) TOA albedo.

Retrieval vs. Reference Physical (CERES)

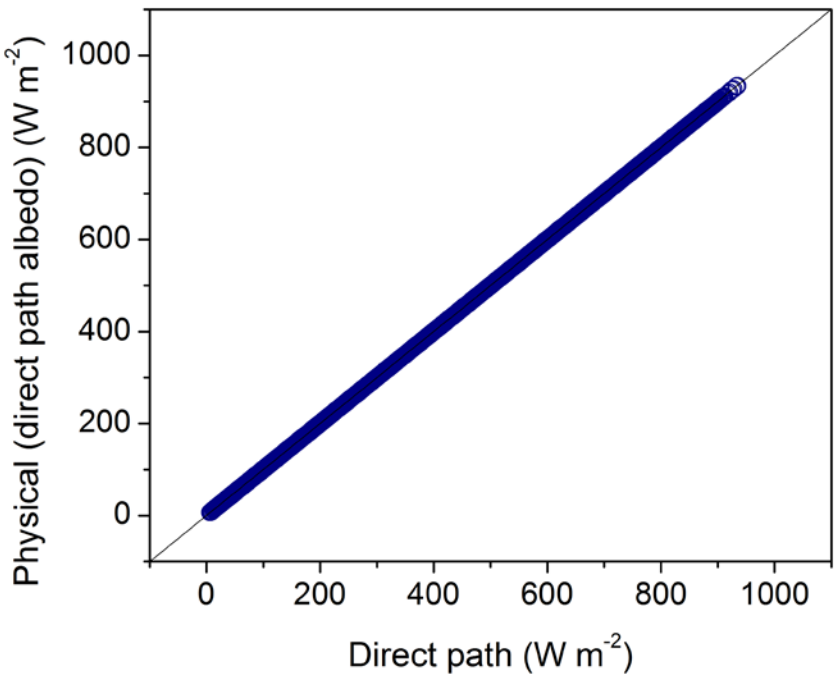


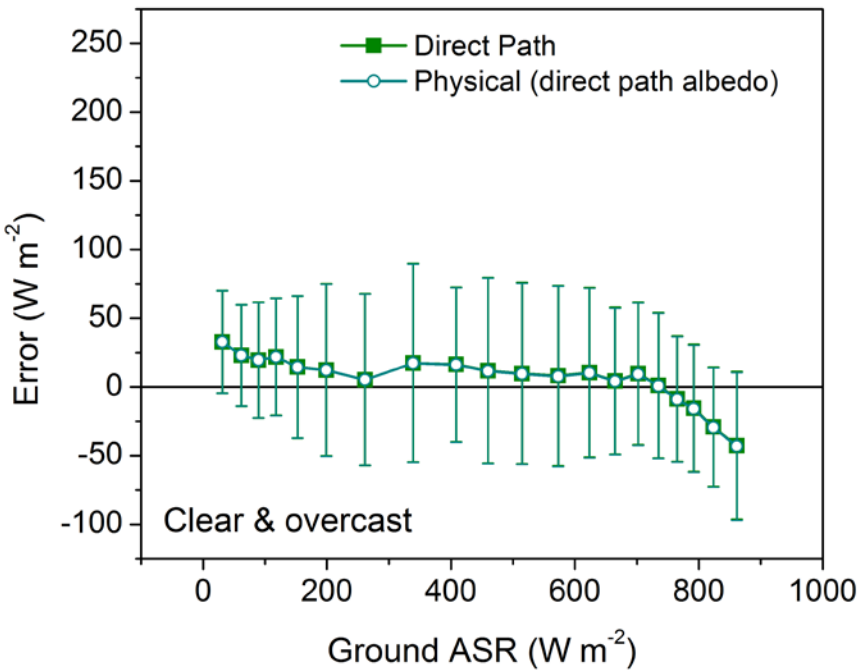


Looks better at high ASR.

Even worse than Physical (MODIS) at low ASR.

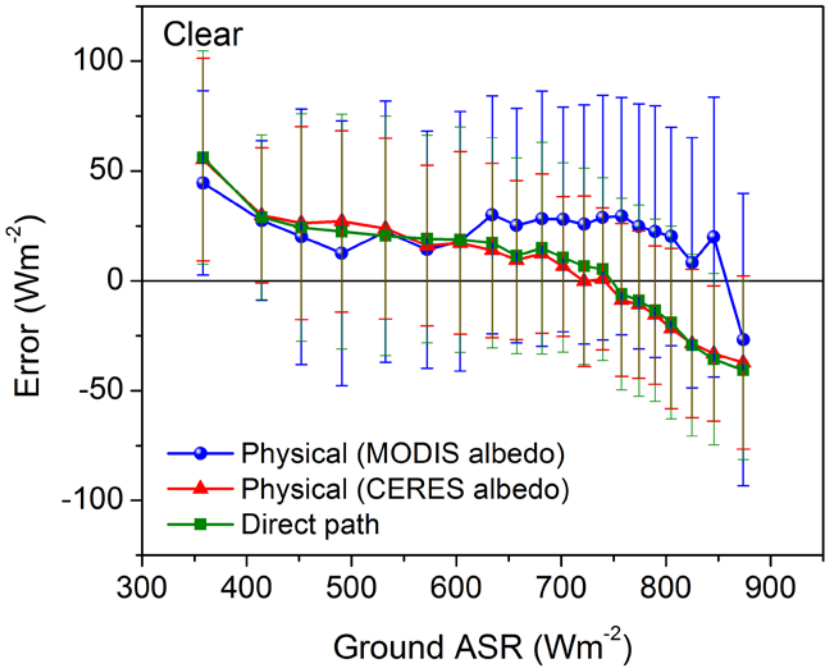
Concept & Implementation Check

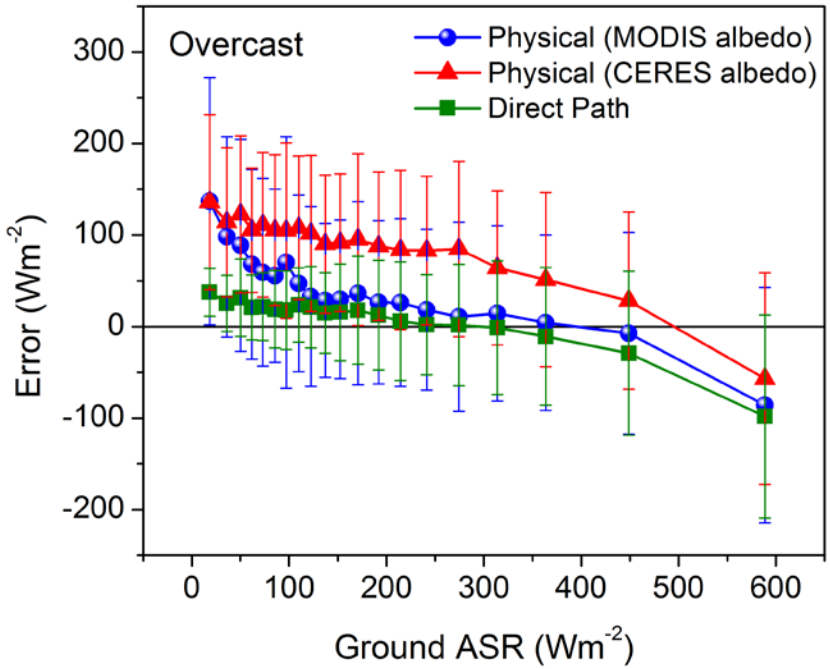




- Both *Direct path* and *Physical* algorithms use the same atmosphere input. With TOA albedos consistent with atmosphere and surface inputs *Direct path* and *Physical* algorithms should result in the same ASR.
- Atmosphere data and TOA albedo calculated in the Direct path algorithm provides such consistent inputs.

Clear- & Overcast-sky Results





Error Statistics

Clear & overcast sky			
N=10,348	Physical (MODIS)	Physical (CERES)	Direct path
Bias	28	39	6
S.Dev.	86	82	57

Clear sky			
N=5,913	Physical (MODIS)	Physical (CERES)	Direct path
Bias	21	4	5
S.Dev.	57	44	51

Overcast sky			
N=4,435	Physical (MODIS)	Physical (CERES)	Direct path
Bias	38	86	8
S.Dev.	113	96	65

Summary

- Two algorithms ("direct path" and "physical") for retrieving ASR were evaluated.
  - The "direct path" outperformed the "physical" algorithm due mainly to errors in the input (MODIS-based) broadband TOA albedo used in the "physical" algorithm.
- Better TOA albedo (CERES) improved retrieval from the "physical" algorithm for clear sky, but not for overcast sky.
  - The MODIS cloud product is less consistent with the CERES TOA albedo (?)