GOES-R AWG Radiation Budget Team: Absorbed Shortwave Radiation at surface (ASR) algorithm

June 9, 2010

Presented By: Istvan Laszlo
NOAA/NESDIS/STAR

ASR Team

- **Radiation Budget AT chair:** Istvan Laszlo
- **ASR Team**
  - » Istvan Laszlo (Lead)
  - » Hye-Yun Kim
  - » Hongqing Liu
  - » Ellsworth G. Dutton, John A. Augustine
- **Others**
  - » Aiwu Li

Outline

- Executive Summary
- Requirements
- Algorithm Description
- Examples of Product Output
- Validation Approach
- Validation Results
- Summary

Executive Summary

- The ABI Absorbed Shortwave Radiation at surface (ASR) algorithm generates the Option 2 product of solar radiation absorbed at the surface.
- Version 3 was delivered in May 2010. ATBD (80%) and test datasets are scheduled to be delivered in Sept. 2010.
- The algorithm uses TOA broadband albedo and combines physical and statistical approaches to estimate ASR.
- Validation & Development Datasets: CERES/ARM Validation Experiment (CAVE), SEVIRI, and MODIS data.
- Validation of retrievals with ground observations the algorithm meets requirements.

Requirements

Product	Horizontal resolution	Accuracy	Precision	Latency
Absorbed Shortwave Radiation: Surface (ASR)	Mesoscale: 5 km	• 90 Wm-2 at low value (100 Wm^{-2}); • 45 Wm^{-2} at mid value (400 Wm^{-2}); • 55 Wm-2 at high value (800 Wm^{-2})	• 75 Wm^{-2} at low and high values (100 and 800 Wm^{-2} and • 95 Wm^{-2} at mid values (400 Wm^{-}2)	60 min

Qualifiers:

- Daytime
- Solar zenith angle < 70 degrees
- Quantitative for Local Zenith Angle < 70 degrees, qualitative beyond

Algorithm Description

Absorbed SW Radiation at surface (ASR) Algorithm

- **ASR is the difference between the downward and upward solar radiative fluxes at the surface – used e.g., in hydrological and in surface energy budget models**
- **For the retrieval of ASR a hybrid algorithm is developed that combines the merits of physical and statistical algorithms**
  - » when all inputs needed to drive it, the STAR physical algorithm is used
  - » when one or more inputs needed for the physical algorithm is missing ASR is estimated using the statistical algorithm
- **Selection rationale:**
  - » Estimation of ASR from the physical algorithm provides consistency with ABI products; while the statistical algorithm permits ASR retrieval even when ABI-derived AOD is not available (over bright surfaces)

Absorbed SW Radiation at surface (ASR) Algorithm: Key Features

- **Physical algorithm:**
  - » Physically-based retrieval by using a LUT representation of RT calculations
  - » ABI products (AOD, COD, cloud fraction, etc.) and ABI reflectances in multiple channels are the inputs; more consistent with other ABI products
  - » No need for upward flux (albedo) at surface
  - » Improvements in input (ABI atmosphere products and TOA albedo) should lead to improvement of ASR
- **Statistical algorithm:**
  - » Regression-based retrieval between surface and TOA absorption
  - » ABI reflectances and ABI-derived water vapor as inputs
  - » No need for upward flux (albedo) at surface
  - » Straightforward computation with low latency and variants of the method have been tested (e.g., CERES)

ASR Retrieval Strategy (1)

- Absorbed SW radiation at surface retrieval
  - » uses ABI products and/or ABI reflectances
  - » performed for daytime only
  - » based on radiative transfer calculations
- Radiative transfer
  - » Look-up table (LUT) approach
    - – Separate LUT for clear and cloudy (water and ice) scenes
    - – LUT are created in 18 narrow bands using the modified NASA/LaRC Fu-Liou code (4-stream delta-Eddington code) (*Fu*, 1996) and 35 vertical levels
    - – Atmospheric absorption is calculated using the correlated-k distribution method (*Kato et al.*, 1997)
    - – Lambertian narrowband surface albedos are assumed

ASR Retrieval Strategy (2)

- TOA albedo is determined from ABI reflectances applying spectral and angular transformations
- When all needed input ABI products are available
  - » reflectance and transmittance needed to calculate ASR in the physical algorithm are determined from LUT
- When one or more needed input ABI products are missing
  - » ASR is estimated from established relationship between ASR and TOA albedo in the statistical algorithm
- ASR is determined separately for clear and for water and ice cloud scenes in the physical algorithm, and the output is the scene-fraction weighted average of clear and cloudy estimates
- ASR is determined for combined clear and cloudy scenes in the statistical algorithm

ASR Algorithm: Physical Basis (1)

- A direct relationship between TOA albedo and ASR 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 calculated from RT
      - the relationship is a function of
        - solar zenith angle
        - total column amount of precipitable water
    - estimates ASR from the pre-established relationship between surface and TOA solar absorption using inputs of
      - view and solar angles
      - ABI SW reflectances
      - total column amount of precipitable water

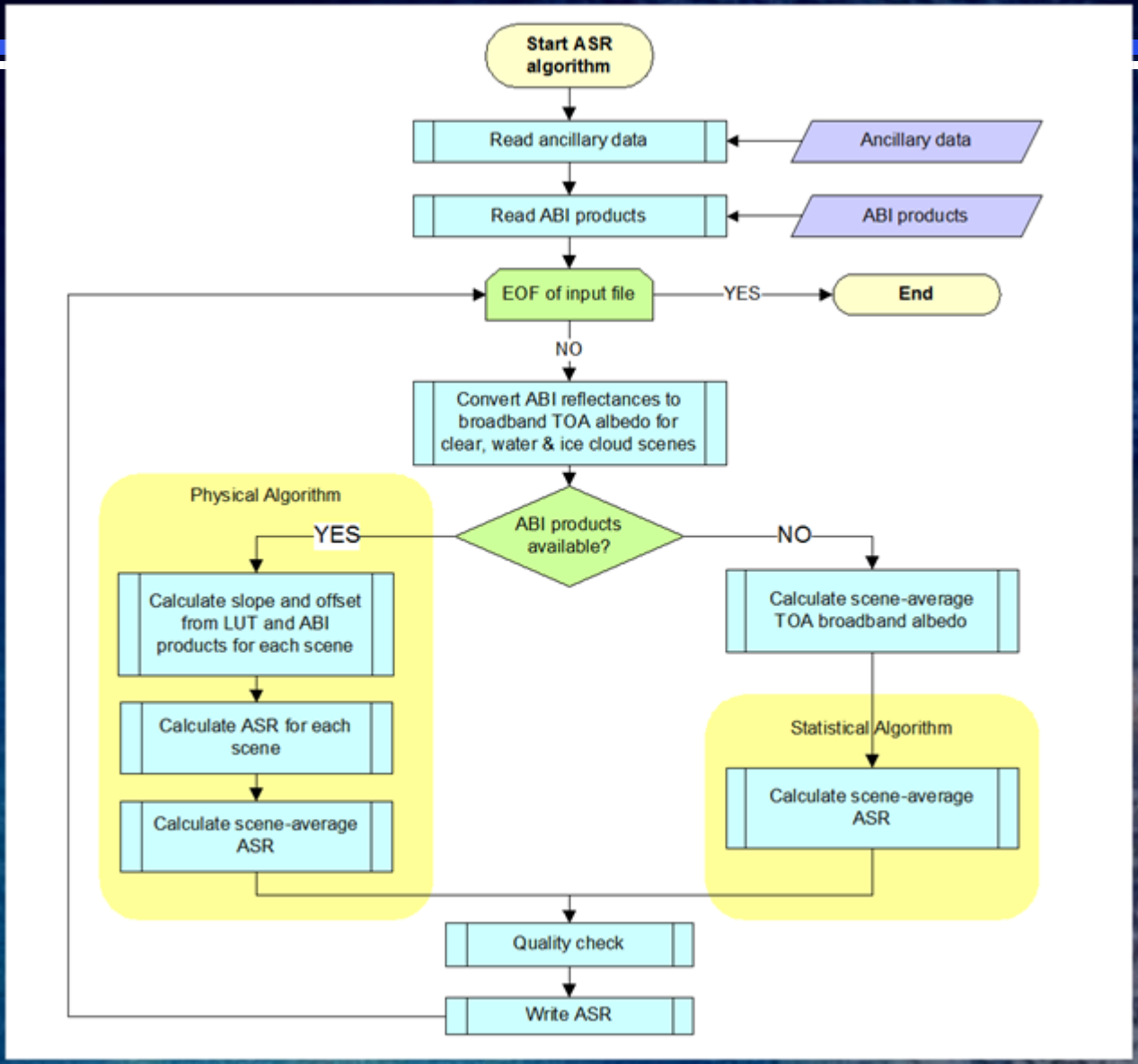
      from ABI products/observations

ASR Algorithm: Physical Basis (2)

- 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 and represented by LUT
  - estimates ASR using inputs of
    - view and solar angles
    - ABI SW reflectances
    - total column amount of precipitable water
    - total column amount of ozone
    - aerosol optical depth, single scattering albedo and model
    - cloud (water/ice) optical depth and effective radius
    - cloud height
    - cloud fraction
    - surface height

    from ABI products/observations

Absorbed SW Radiation Algorithm Processing Outline



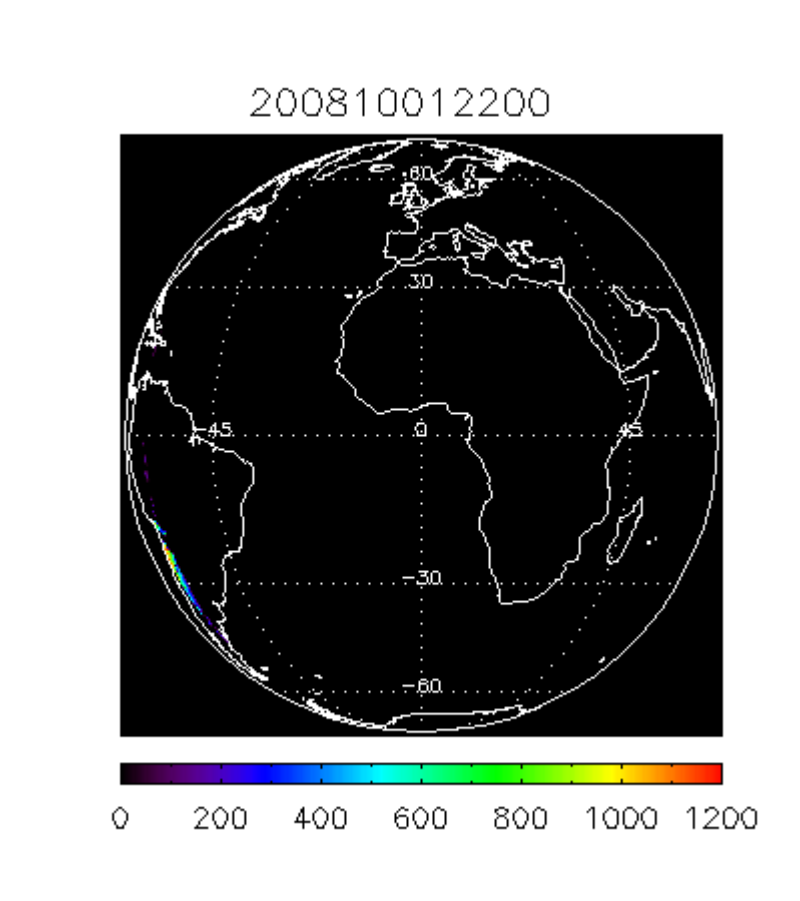
Algorithm Summary

- **The ABI ASR algorithm uses two sub-algorithms depending on availability of ABI products:**
  - » **When the full description of the atmosphere are available from ABI the transmittance and reflectance (and thus the atmospheric absorption) are estimated from the LUT directly (physical algorithm)**
  - » **When one of the ABI product inputs is missing ASR is estimated from a linear fit (statistical algorithm)**
  - » **Both algorithms require the TOA broadband albedo, which is obtained from the narrowband ABI reflectances using spectral and angular transformations**
- **Retrievals are performed only daytime**

Examples of Product Output

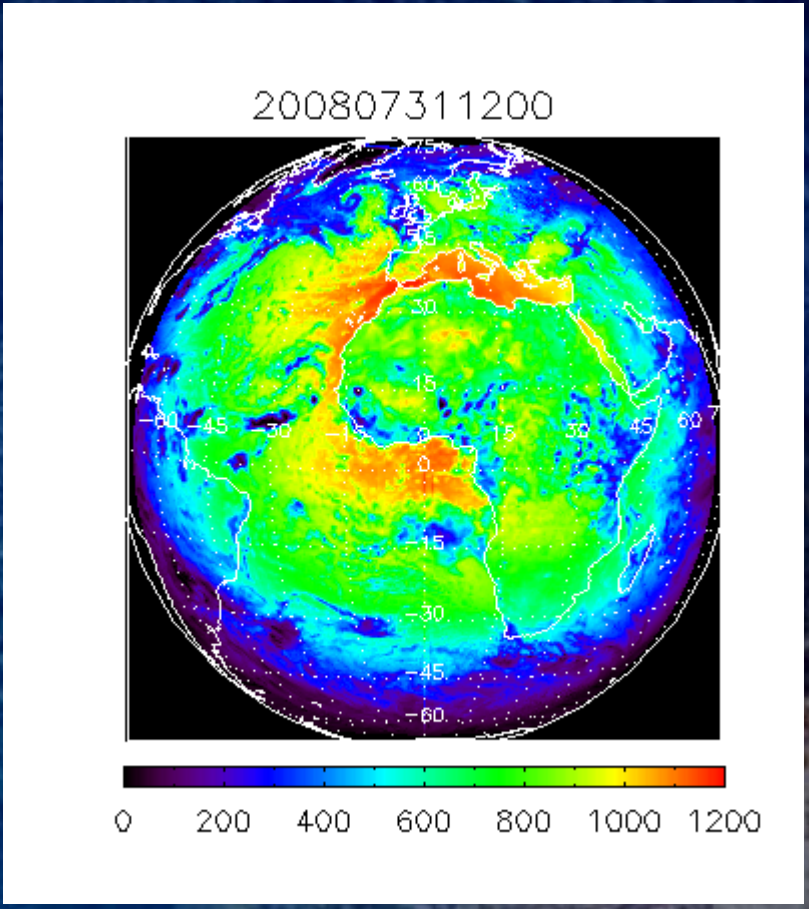
ABI ASR Product Output

- Statistical algorithm
- ASR on Oct. 1st, 2008
  - » 02:00h – 22:00h
- Inputs:
  - » TOA albedo from SEVIRI
    - – SEVIRI observations from two SW channels (0.63 and 0.86 µm).
    - – Narrow-to-broadband and angular transformation were applied.
  - » TPW from NCEP Reanalysis II



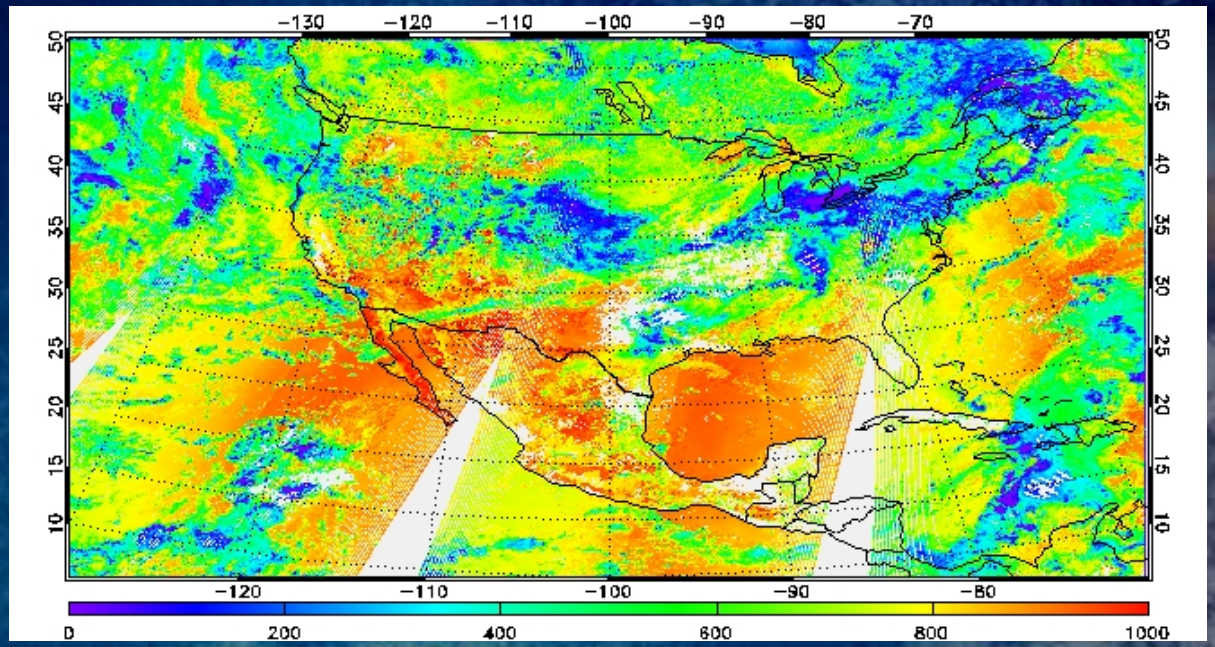
ABI ASR Product Output

- Physical algorithm
- ASR at noon in July 2008
- Inputs:
  - » TOA albedo from SEVIRI
    - – two SEVIRI SW channels (0.63 and 0.86 µm) with spectral and angular transformation
  - » cloud fraction from SEVIRI
  - » cloud height and droplet size from ISCCP monthly mean
  - » aerosol and cloud optical depth climatology from baseline indirect path
  - » TPW from NCEP Reanalysis II



ABI ASR Product Output

- Hybrid algorithm
- ASR at 5-km resolution on June 11, 2009
- MODIS inputs: SW narrowband reflectance, location, elevation, geometry, aerosol optical depth, cloud properties, TPW and ozone, cloud and snow mask



Validation Approach

Validation approach: Datasets (1)

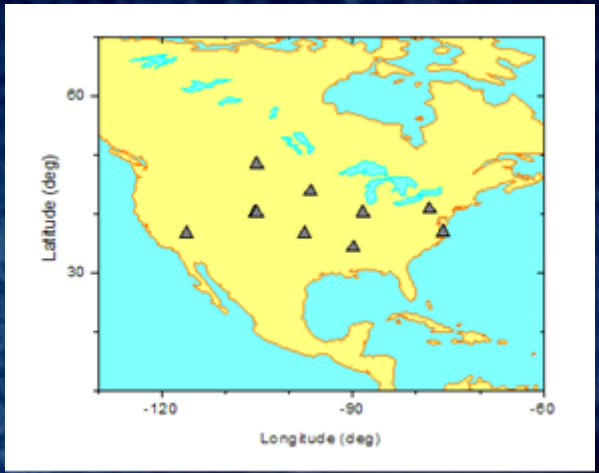
- Collocated satellite and model data taken from CERES/ARM Validation Experiment (CAVE) website over SURFRAD, ARM, BSRN stations for the period of 03/2000 – 06/2006 are used to evaluate the physical & statistical algorithms separately
  - » Cloud optical depth, phase, particle size, height retrieved from TRMM/MODIS imager data
  - » Aerosol optical depth and single scattering albedo retrieved from TRMM/MODIS imager data or MATCH model
  - » Total precipitable water from GEOS assimilation products
  - » Total column ozone are taken from TOMS retrievals
  - » CERES absorbed SW radiation at surface (Model B)

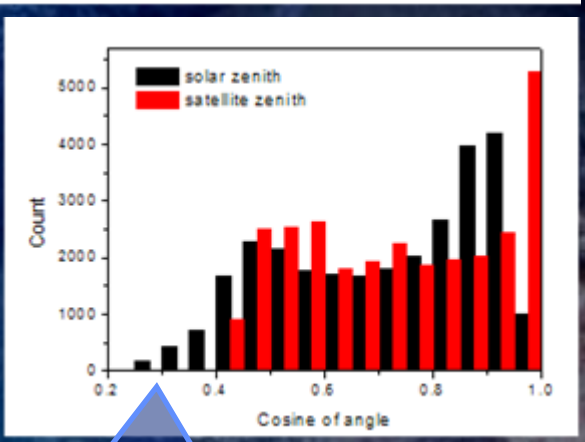
Validation approach: Datasets (2)

- Hourly SEVIRI data for four seasonal months: Jan, Apr, Jul, Oct, 2006 and 2008
  - » Image-based Cloud Mask (CLM) product from EUMETSAT (http://archive.eumetsat.org/umarf).
  - » Snow detection follows threshold tests of ABI Snow Cover and Snow Depth algorithm
  - » L1B SEVIRI radiances are averaged into ½ degree equal-angle grids
  - » No atmospheric products of optical properties – aerosol properties from *indirect path* and cloud properties from *climatology (ISCCP data)*
- Compared retrieved ASR to:
  - » Ground measurement of ASR from two BSRN sites

Validation approach: Datasets (3)

- **MODIS-based dataset:**
  - » Centered on10 sites
  - » ~ 7 years (03/2000 – 06/2006)
  - » Inputs from MODIS (Terra, Aqua) granule
    - – SW narrowband reflectance at 1KM resolution (MOD021KM)
    - – Location, surface height, geometry (MOD03)
    - – Aerosol optical depth (MOD04)
    - – Cloud optical depth, size, phase, height (MOD06)
    - – Total precipitable water, ozone (MOD07)
    - – Cloud and snow mask (MOD35)
  - » TOA albedo input is derived from MODIS reflectances using narrow-to-broadband (NTB) conversions and angular models (ADM)
  - » Even though this is the best dataset currently available, the estimated TOA albedo may have large errors, and may not be fully consistent with the MODIS atmosphere products
- **Compared retrieved ASR to:**
  - » Ground measurement of surface flux at 10 sites (SURFRAD, ARM, CMDL, COVE)





Large range of angles, but, low-end of geo angles are not covered

Absorbed SW radation at surface (ASR): Validation Approach

- Derive ASR using test datasets
- Collocate (in space and time) derived ASR with satellite and ground truths
  - » compare ASR from CAVE with that from CAVE (32 sites)
  - » compare ASR from SEVIRI with that from BSRN (2 sites)
  - » compare ASR from MODIS with that from SURFRAD and CMDL (10 sites)
- Generate comparative statistics
  - » accuracy and precision
  - » histogram

Validation Results

ASR Algorithm performance estimate with CAVE data

- From 251,370 retrievals for three F&PS ranges (mid, low, high)

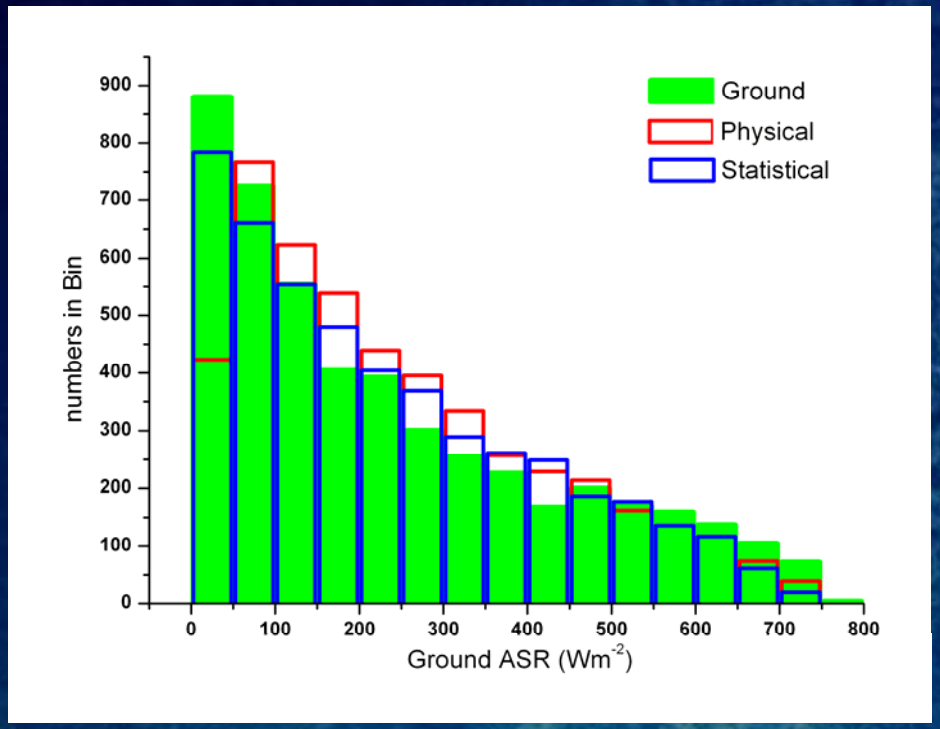
Accuracy	F&PS	Physical	Statistical	Direct	Indirect	Model B
low	90	81	49	43	72	95
mid	45	42	10	38	46	34
high	55	-43	-34	-34	-28	-56

Precision	F&PS	Physical	Statistical	Direct	Indirect	Model B
low	75	68	70	67	65	66
mid	95	76	85	85	78	80
high	75	65	58	68	61	54

- The ABI algorithms (Physical and Statistical) with CAVE inputs meet the requirements
  - » The baseline (direct) also meets the requirements
  - » Except for mid-value ASR accuracy of Model-B algorithm is worse than any of the other algorithms tested
  - » Accuracy is best in statistical and baseline direct path algorithms
  - » Precisions are similar

ASR Algorithm performance estimate with SEVIRI data

- SEVIRI data of four seasonal months in two years (Jan, Apr, Aug, Oct in 2006 and 2008) for two BSRN sites (total 5023 retrievals)
- *Not enough number of comparisons to evaluate high ASR retrieval



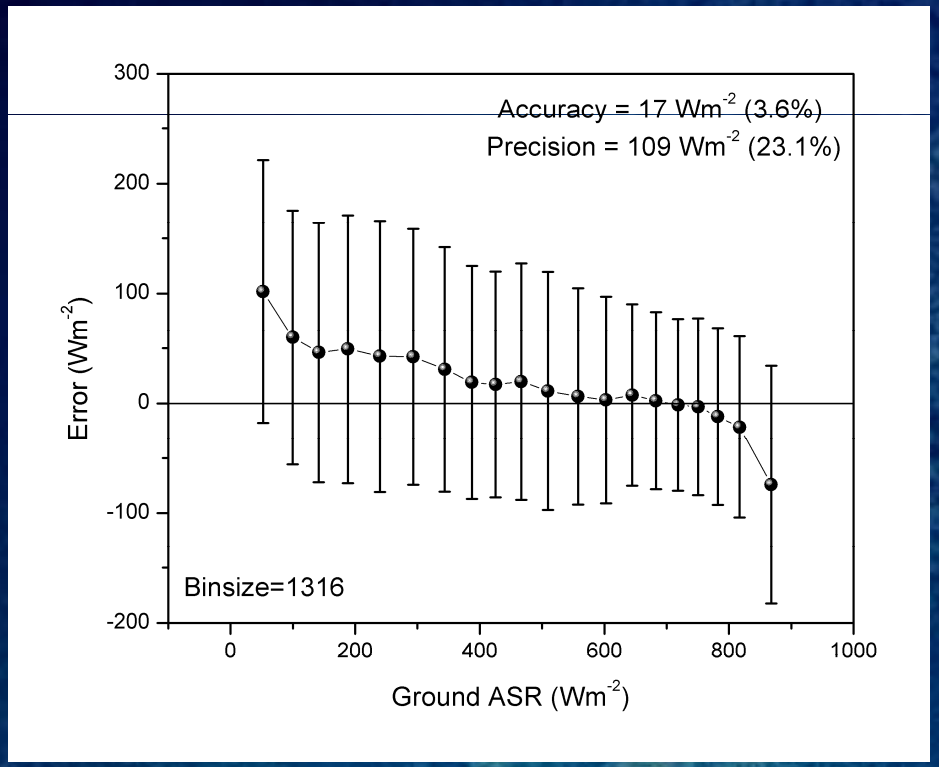
Accuracy	F&PS	phys	stat
low (100)	90	52	36
mid (400)	45	-24	-35
high (800)	55	*	*

Precision	F&PS	phys	stat
low (100)	75	93	97
mid (400)	95	110	110
high (800)	75	*	*

With SEVIRI input spec is met for accuracy but NOT for precision.

ASR Algorithm performance estimate with MODIS data

- Over/under estimation at low/high end of ASR
- Overall accuracy and precision of hybrid algorithm : 17 and 109 Wm^{-2}
- 30% of total of 26,309 retrievals are estimated by statistical algorithm



Accuracy	F&PS	ABI retrieval
Low (100)	90	60
Mid (400)	45	19
High (800)	55	-12

Precision	F&PS	ABI retrieval
Low (100)	75	116
Mid (400)	95	106
High (800)	75	81

With MODIS input spec is met for accuracy but NOT for precision.

Next steps to reach 100%

- The ABI ASR algorithm already meets the requirement for accuracy. It also meets the requirement for precision when high quality input RSR is used.
- The ABI ASR algorithm accounts for all known physical processes determining availability of solar radiation for absorption at the surface.
- For 100% compliance for precision with MODIS and SEVIRI data the quality of inputs must be improved.
- Specifically, need to improve narrow-to-broadband transformation to estimate RSR from MODIS and SEVIRI (and eventually, from ABI).
- Better matching of satellite and ground data in space and time should also improve the statistics.

Summary

- A hybrid algorithm was developed that combines physical and statistical retrievals of ASR
- ASR retrievals from ABI proxy data (CERES, SEVIRI, MODIS) were compared to independent satellite-derived (CERES) and ground-observed (CAVE, SURFRAD) data.
- The algorithm meets the requirement for accuracy with all three types of inputs
- The algorithm does not meet the requirement for precision with SEVIRI and MODIS inputs
  - » likely cause: TOA albedo is not accurate enough and/or inconsistent with other atmospheric inputs – need to improve narrow-to-broadband transformation