Using CERES in Developing Shortwave Radiation Budget Algorithms from ABI on GOES-R

Istvan Laszlo, NOAA & UMD
Honqing Liu, DELL/QSS, Inc.
and
the GOES-R Algorithm Working Group
Radiation Budget Application Team

Algorithm Working Group (AWG) Radiation Budget Team Members

AWG RB Team Chair : Istvan Laszlo

- SW Radiation Budget Products
  - **Istvan Laszlo (NESDIS) (Lead)**
  - Hongqing Liu (DELL/QSS)
  - Fred G. Rose (NASA/LaRC)
  - Rachel T. Pinker (UMD/AOSC)
  - Hye-Yun Kim (IMSG)
- LW Radiation Budget Products
  - **Hai-Tien Lee (UMD/CICS) (Lead)**
  - Arnold Gruber (UMD/CICS)
- Validation (ground) data
  - **Ellsworth G. Dutton (OAR/ESRL) (Lead)**
  - John A. Augustine (OAR/ESRL)
- Software Development
  - Aiwu Li (was Peter Keehn) (IMSG)
- Independent Reviewers
  - P. Stackhouse (NASA/LaRC)
  - S-K. Yang (NOAA/NWS)
  - C-Z. Zou (NOAA/NESDIS)

Outline

- Background
  - GOES-R & the Advanced Baseline Imager
  - Products
  - Requirements
- Algorithms/Methods
  - CERES in algorithm development
- Validation data sets
  - CERES in evaluation
- Validation Results

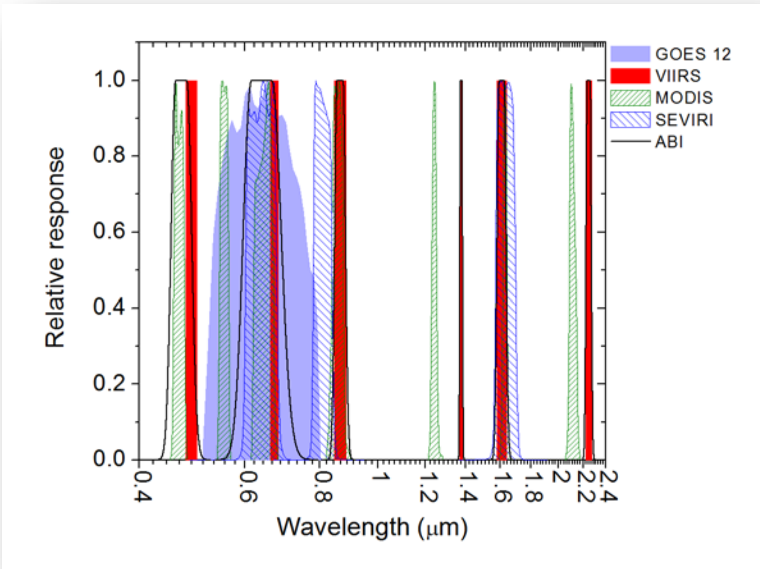
Background: GOES-R & ABI

- **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)
  - improved spacecraft and instrument technologies
  - 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

Background: GOES-R & ABI



- – 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

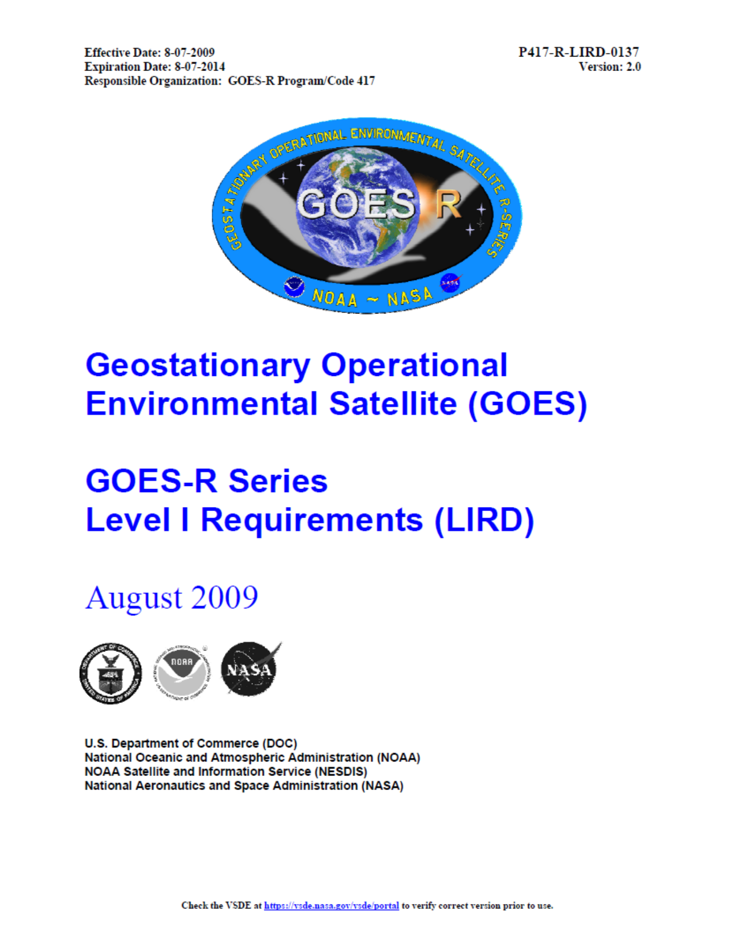
Channel ID	*Wavelength Microns*	*Hor. Res.*	*Upper and lower 50% response points (in microns)*	*Noise @ Ref.*	*Max. Level*
1	0.47	1km	0.45±0.01 - 0.49±0.01	300/1	100 %
2	0.64	0.5km	0.59±0.01 - 0.69±0.01	300/1	100 %
3	0.865	1km	0.8455±0.01 - 0.8845±0.01	300/1	100 %
4	1.378	2km	1.3705±0.005 -1.3855±0.005	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

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 DSR & RSR are 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.

Requirements - DSR

Name	Geographic Coverage	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Vendor Allocated Ground Latency	Product Measurement Precision
Downward Shortwave Radiation: Surface	M	5 km	1 km	0 – 1500 W/m^2	± 85 W/m^2 at high value (1000 W/m^2), ± 65 W/m^2 at mid value (350 W/m^2), and ±110 W/m^2 at low value (100 W/m^2)	60 min	3236 sec	100 W/m^2 for low and high values (100 and 1000 W/m^2) and 130 for mid values (350 W/m^2)
Downward Shortwave Radiation: Surface	C	25 km	2 km	0 – 1500 W/m^2	± 85 W/m^2 at high value (1000 W/m^2), ± 65 W/m^2 at mid value (350 W/m^2), and ±110 W/m^2 at low value (100 W/m^2)	60 min	3236 sec	100 W/m^2 for low and high values (100 and 1000 W/m^2) and 130 for mid values (350 W/m^2)
Downward Shortwave Radiation: Surface	FD	50 km	4 km	0 – 1500 W/m^2	± 85 W/m^2 at high value (1000 W/m^2), ± 65 W/m^2 at mid value (350 W/m^2), and ±110 W/m^2 at low value (100 W/m^2)	60 min	3236 sec	100 W/m^2 for low and high values (100 and 1000 W/m^2) and 130 for mid values (350 W/m^2)

M - Mesoscale   C – CONUS   FD – Full Disk

Requirements - RSR

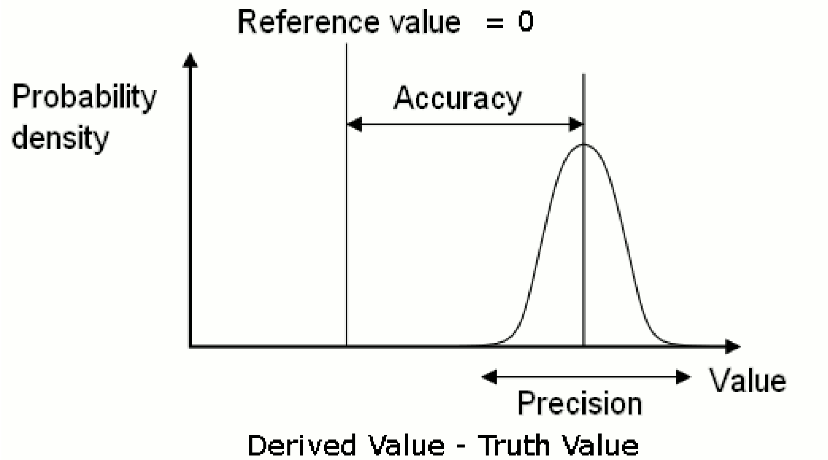
Name	Geographic Coverage	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Refresh Rate/Coverage Time Option (Mode 3)	Vendor Allocated Ground Latency	Product Measurement Precision
Reflected Shortwave Radiation: TOA	C	25 km	2 km	0 – 1300 W/m^2	55 W/m^2 at high value(>500 W/m^2); 45 W/m^2 at typical value/ midpoint (200-500 W/m^2); 25 W/m^2 at low end of range (<200 W/m^2)	60 min	3236 sec	65 W/m^2 at high value(>500 W/m^2); 65 W/m^2 at typical value/ midpoint (200-500 W/m^2); 35 W/m^2 at low end of range (<200 W/m^2)
Reflected Shortwave Radiation: TOA	FD	25 km	4 km	0 – 1300 W/m^2	55 W/m^2 at high value(>500 W/m^2); 45 W/m^2 at typical value/ midpoint (200-500 W/m^2); 25 W/m^2 at low end of range (<200 W/m^2)	60 min	3236 sec	65 W/m^2 at high value(>500 W/m^2); 65 W/m^2 at typical value/ midpoint (200-500 W/m^2); 35 W/m^2 at low end of range (<200 W/m^2)

C – CONUS FD – Full Disk

Product qualifiers: daytime with SZA ≤ 75^o; quantitative out to LZA =70^o and qualitative beyond

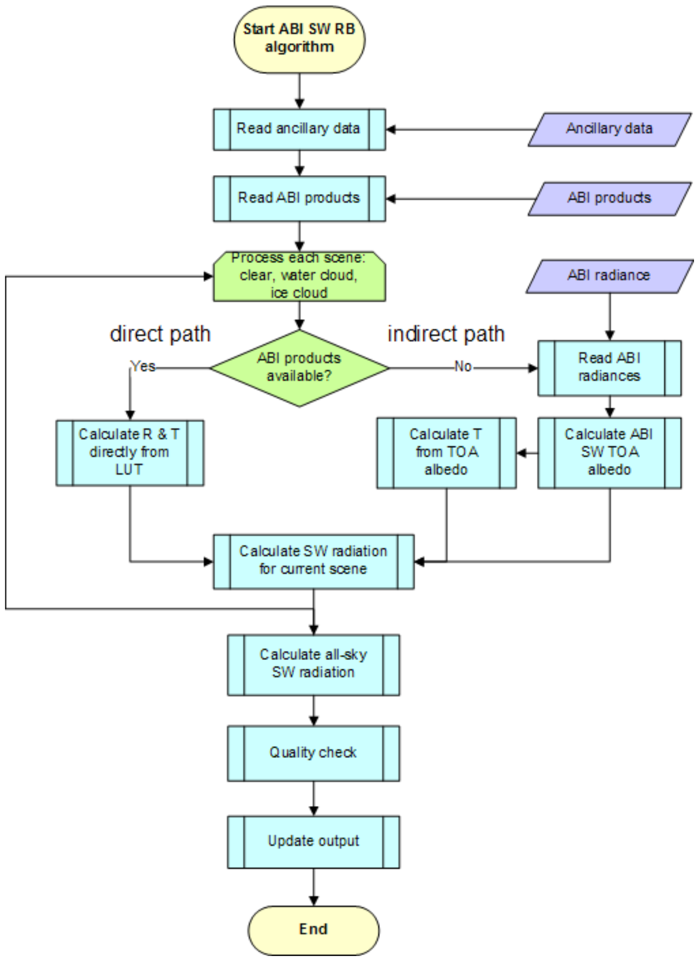
Accuracy and Precision
GOES-R AWG Definitions

- **GOES-R Series Ground Segment (GS) Project Functional and Performance Specification (F&PS) (ATTACHMENT 2 DG133E-09-CN-0094 Version 2.0 - Modification 0003, July 1, 2009):**
- **Product Measurement Accuracy** - defined as the systematic difference or bias between the derived parameter and truth.
  - It is determined by computing the absolute value of the average of differences between the derived parameter and truth over a statistically significant population of data such that the magnitude of the random error is negligible relative to the magnitude of the systematic error.
- **Product Measurement Precision** - the one-sigma standard deviation of the differences
  - between the derived parameters and their corresponding truth over the same population of data used to compute the product measurement accuracy.

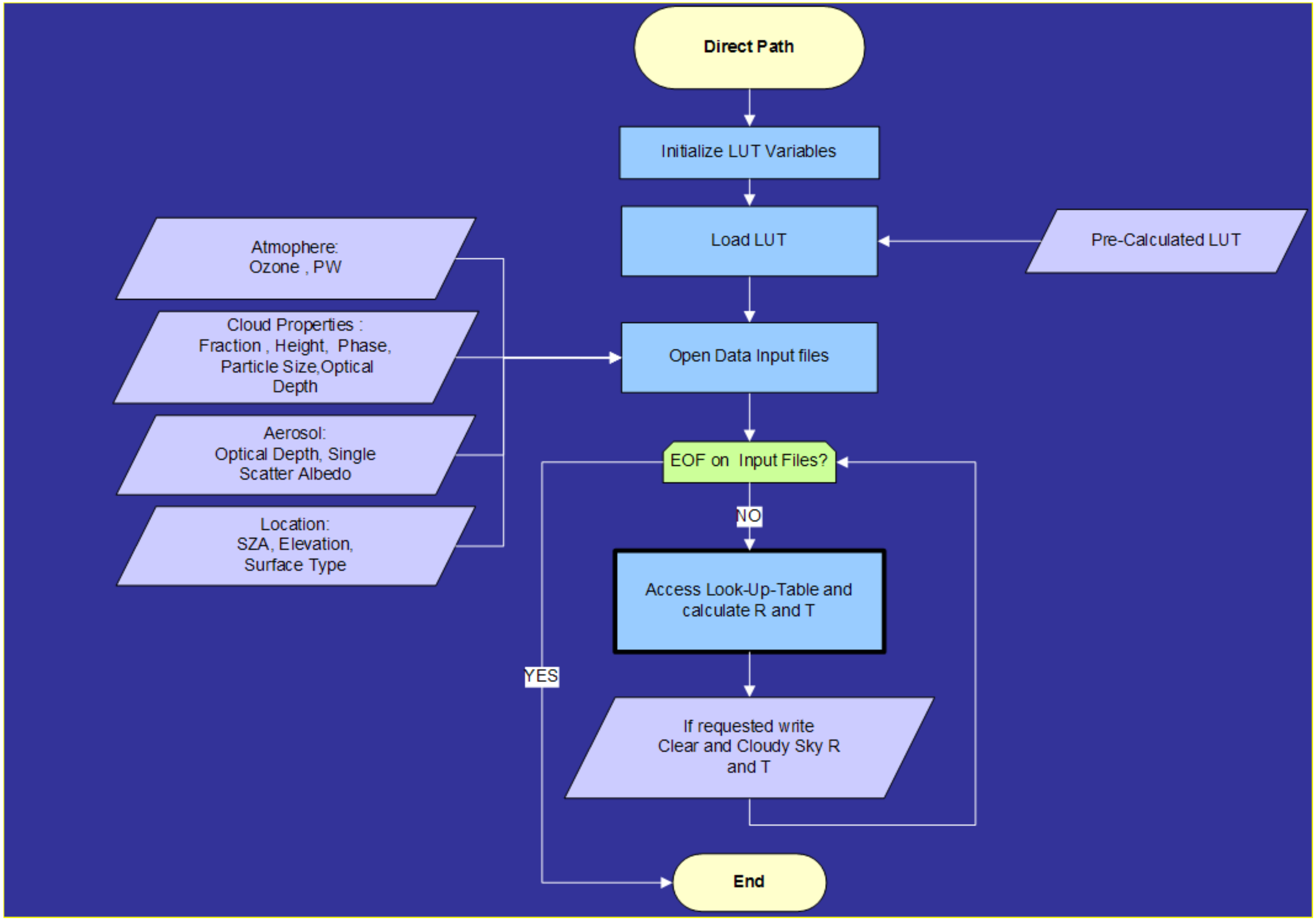


DSR & RSR Algorithm

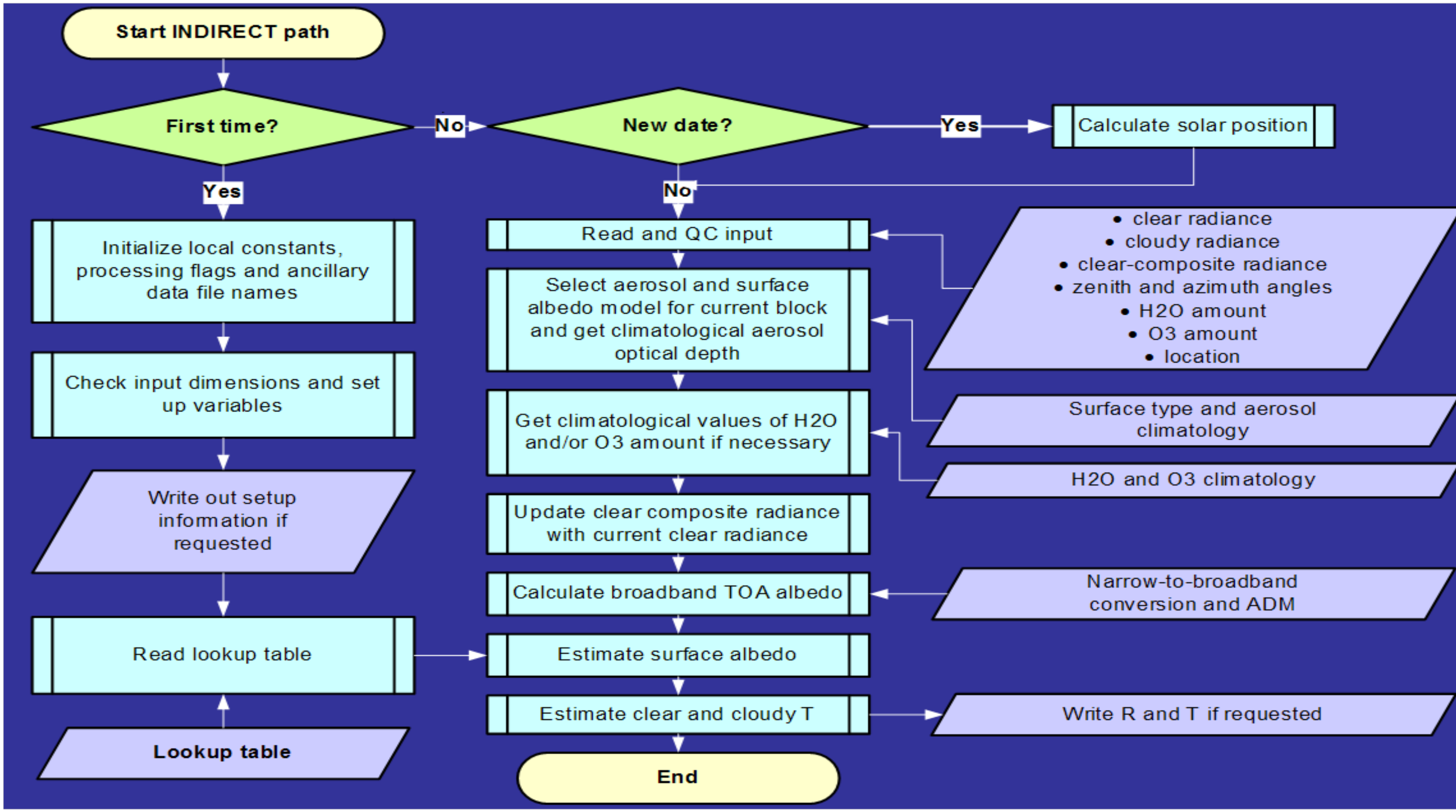
- Two independent algorithms performing physically-based retrieval of reflectances and transmittances by using LUT representation of RTM
- **Direct Path Algorithm (DPA)**
  - uses GOES-R products (AOD, COD, surface albedo, etc.) as inputs , and thus
  - more consistent with other ABI products
  - used when all atmospheric & surface inputs available
  - RTM version proven with CERES
  - straightforward computation with low latency
  - *Disadvantage*: some inputs (e.g., AOD over bright surface) are not available everywhere
- **Indirect Path Algorithm (IPA)**
  - uses ABI reflectances in multiple channels for RSR
  - estimates DSR & RSR by comparing satellite-estimated broadband TOA albedo to calculated ones
  - used when NOT all inputs needed in DPA available
  - proven in GEWEX/SRB and has been tested in an operational environment (NOAA/GSIP)
  - *Disadvantage*: broadband TOA albedo is not directly measured; it requires spectral and angular corrections, which introduce (additional) uncertainties



Direct Path Algorithm



Indirect Path Algorithm



Algorithm Validation: Test Data

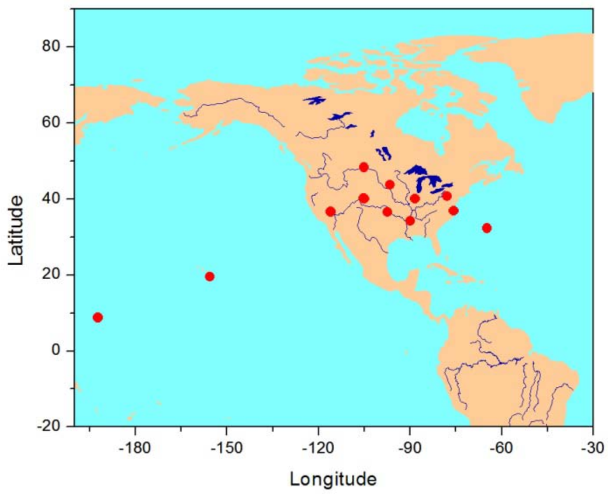
- **Collocated satellite and model data from CERES/ARM Validation Experiment (CAVE) over SURFRAD, ARM, BSRN stations**
  - CERES TOA upward SW radiation (RSR)
  - Cloud optical depth, phase, particle size, height retrieved from VIRS/MODIS imager data
  - Aerosol optical depth and single scattering albedo retrieved from VIRS/MODIS imager data or MATCH model
  - Total precipitable water from GEOS assimilation products
  - Surface albedo retrieved from CERES TOA SW data
  - Total column ozone are taken from TOMS retrievals
  - 15-minute average surface data
- **period: 01/1998-08/1998 and 03/2000-06/2006**
- used for evaluating direct & indirect path retrievals independently

- **Moderate Resolution Imaging Spectroradiometer (MODIS) measurements and retrievals over 13 (SURFRAD & CMDL) stations**
  - observation geometry (MOD/MYD03)
  - L1b SW narrowband reflectance at 1KM resolution (MOD/MYD021KM)
  - Location, surface height, geometry (MOD/MYD03)
  - L2 Aerosol optical depth (MOD/MYD04), single scatter albedo (0.95)
  - L2 Cloud optical depth, size, phase, height (MOD/MYD06)
  - L2 Total precipitable water, ozone (MOD/MYD07, CERES CRS, TOMS/OMI)
  - L2 Cloud and snow mask (MOD/MYD35)
  - L2 Surface albedo (MCD43, CERES)
- **period: 03/2000–06/2006 (Terra); 07/2002-02/2005 (Aqua)**
- used primarily for evaluating hybrid algorithm (combination of direct and indirect algorithms)

MODIS data "sites"

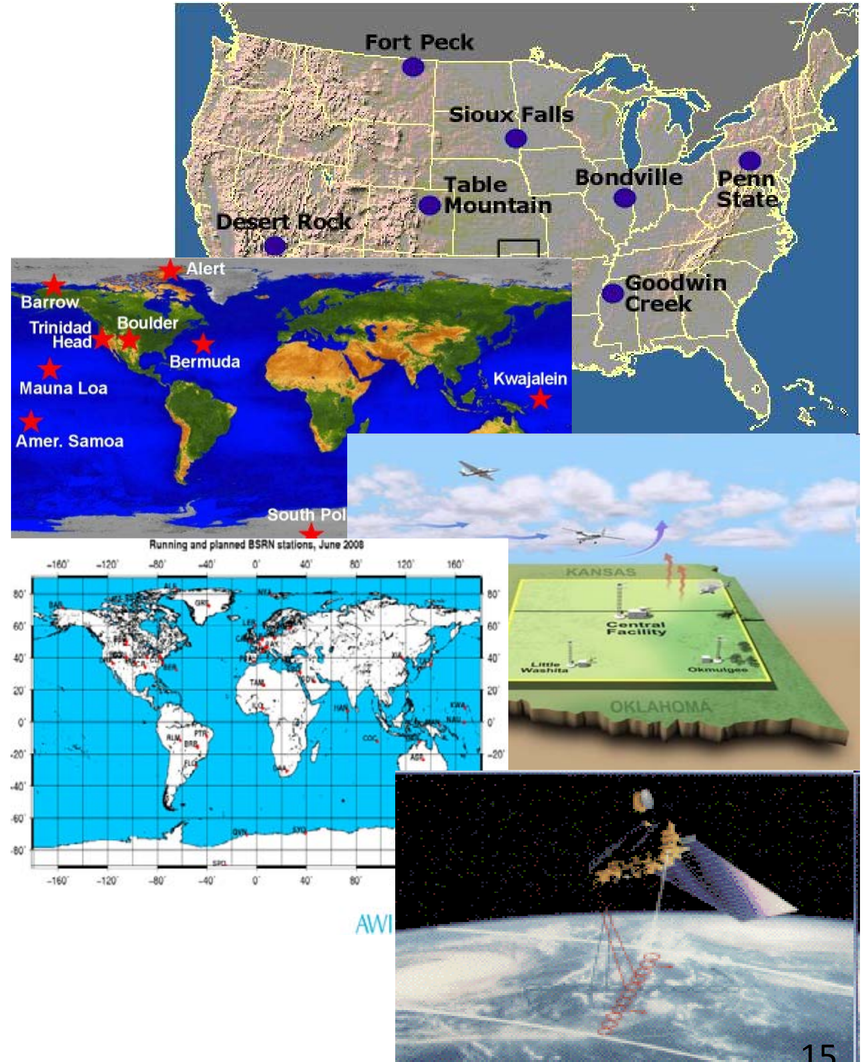
Station Code	Longitude	Latitude	Elevation (m)	Network
BON	-88.37	40.05	213	SURFRAD
DRA	-116.02	36.63	1007	SURFRAD
FPK	-105.10	48.31	634	SURFRAD
GWN	-89.87	34.25	98	SURFRAD
PSU	-77.93	40.72	376	SURFRAD
SXF	-96.62	43.73	473	SURFRAD
TBL	-105.24	40.13	1689	SURFRAD
COV	-75.71	36.90	30	COVE
E13	-97.48	36.61	318	ARM
BER	-64.77	32.30	60	GMD
BOU	-105.01	40.05	1584	GMD
KWA	167.72	8.76	10	GMD
MLO	-155.58	19.54	3397	GMD

- Proxy MODIS data over 13 ground stations:
- seven SURFRAD sites (BON, DRA, FPK, GWN, PSU, SXF, TBL);
- CERES Ocean Validation Experiment (COVE) site,
- Atmospheric Radiation Measurement Project (ARM) site (E13)
- four Global Monitoring Division (GMD) sites (BER, BOU, KWA, MLO).



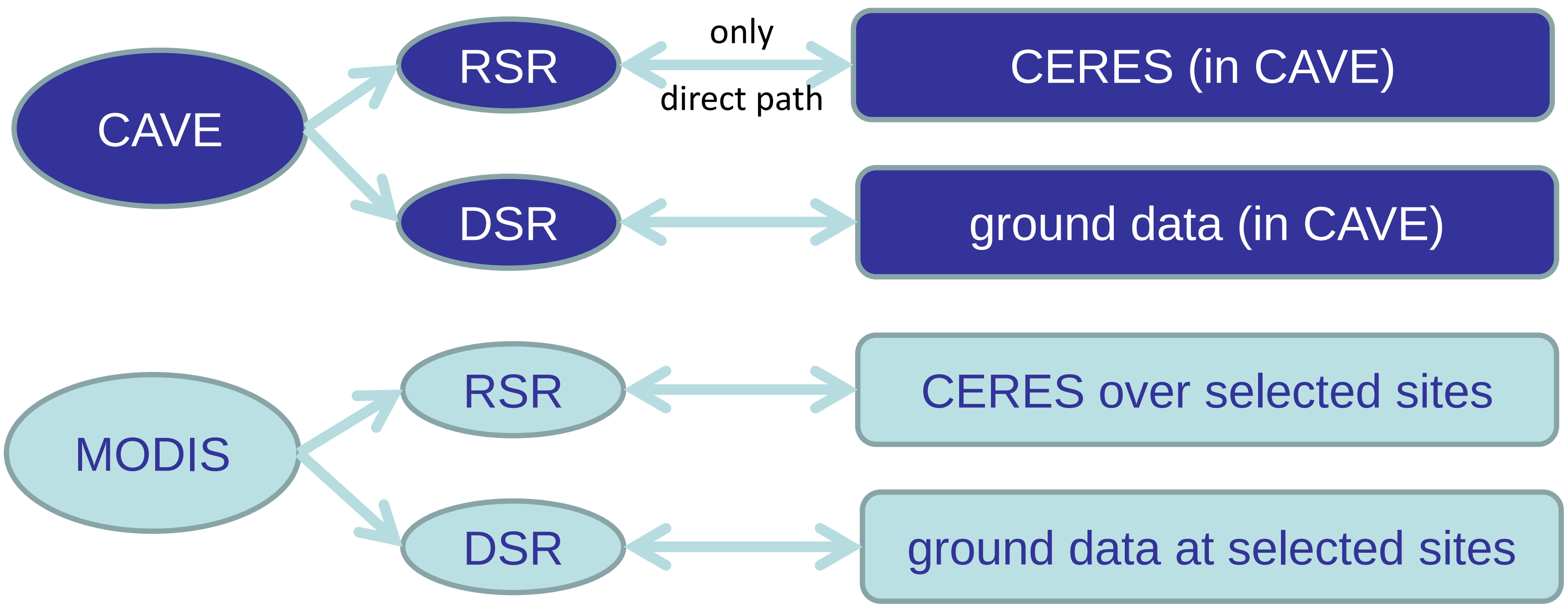
Algorithm Validation: Truth Data

- Surface Radiation Network (SURFRAD)
- Global Network-STAR
- Atmospheric Radiation Measurement (ARM) Program
- Baseline Surface Radiation Network (BSRN)
- **Cloud and the Earth's Radiation Energy System (CERES)** – both TOA and surface (derived fluxes)



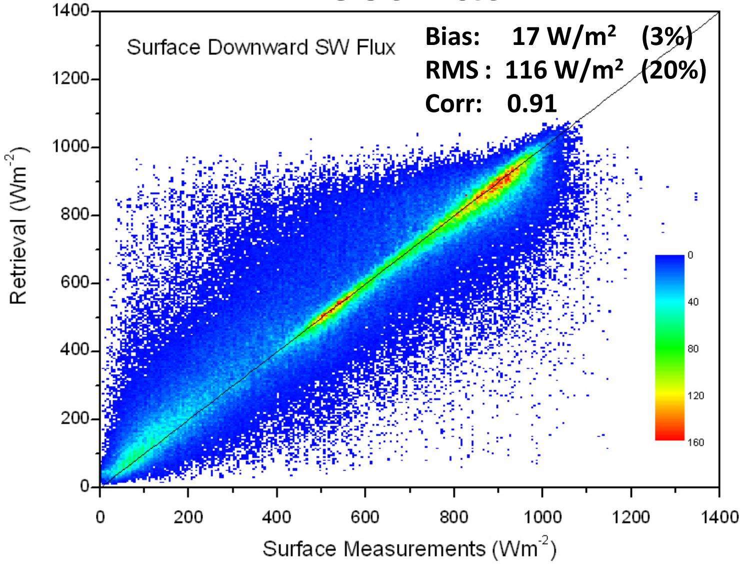
Algorithm Validation: Test Methods

- Retrieve DSR & RSR using test datasets
- Collocate in space and time with satellite and ground “truth”
  - CAVE input: already done in CAVE (Thank you SARB Team!)
  - MODIS input: matchup in time guided by CAVE; centered on site
- Generate comparative statistics
  - Bias, RMS, correlation, accuracy and precision, histogram

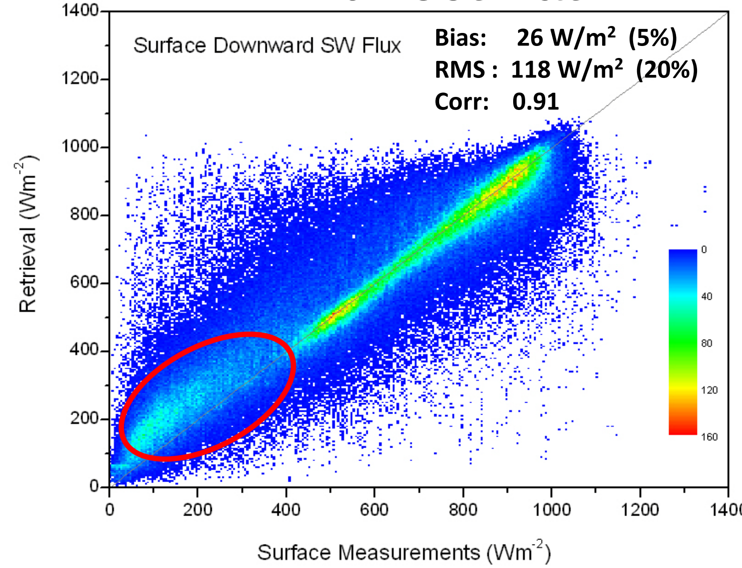


Validation Results
CERES/CAVE Dataset - DSR

Direct Path



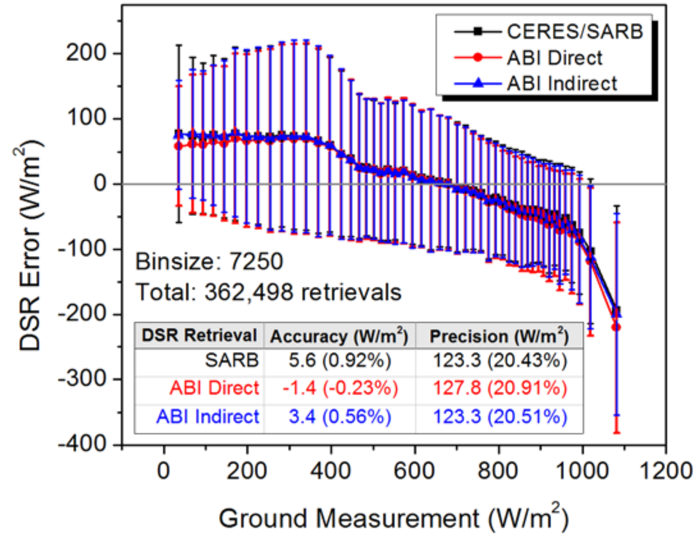
Indirect Path



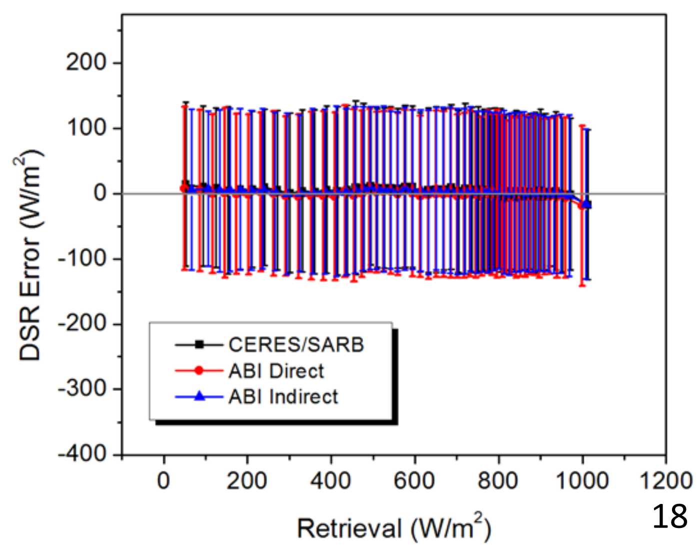
- ABI retrievals from CAVE data (from 52 sites and from ~7 years)
  - Direct Path Algorithm: atmosphere and surface inputs
  - Indirect Path Algorithm: broadband TOA albedo input
- Scatter in both paths are similar

Validation Results
CERES/CAVE Dataset – DSR (2)

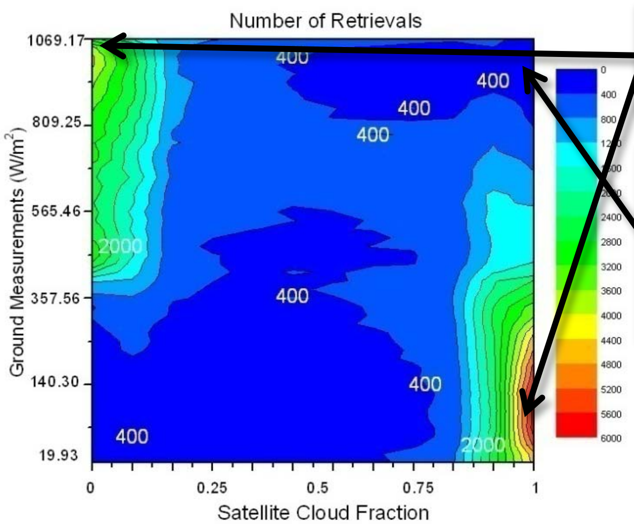
- Top: accuracy/precision vs. ground observations
  - symbols: bias
  - whiskers: 1-σ standard deviation
  - Accuracy is a function of “true” flux
    - over (under) estimation at low (high) value
  - ABI algorithm does not perform equally well for all ranges of “true” fluxes
- Bottom: accuracy/precision vs. retrieval
  - error of a given estimate
  - maybe more relevant for users
  - no obvious dependence (except in last bin)
- CERES/SARB retrievals show similar pattern



DSR Retrieval	Accuracy (W/m²)	Precision (W/m²)
SARB	5.6 (0.92%)	123.3 (20.43%)
ABI Direct	-1.4 (-0.23%)	127.8 (20.91%)
ABI Indirect	3.4 (0.56%)	123.3 (20.51%)



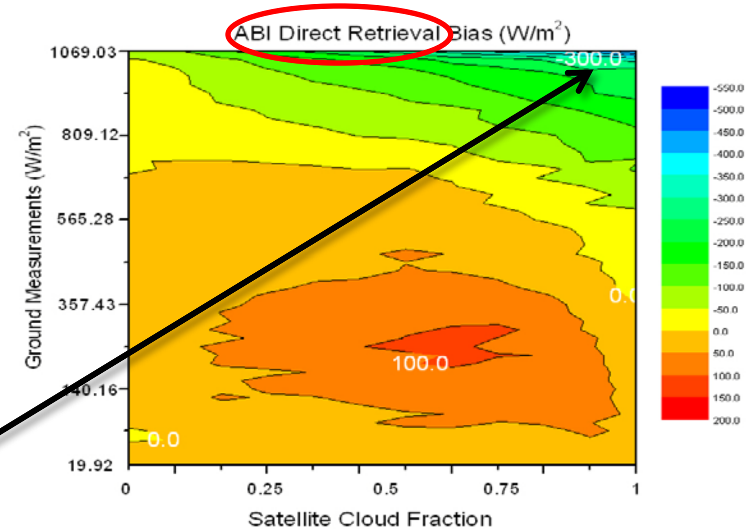
Validation Results
CERES/CAVE Dataset – DSR (3)

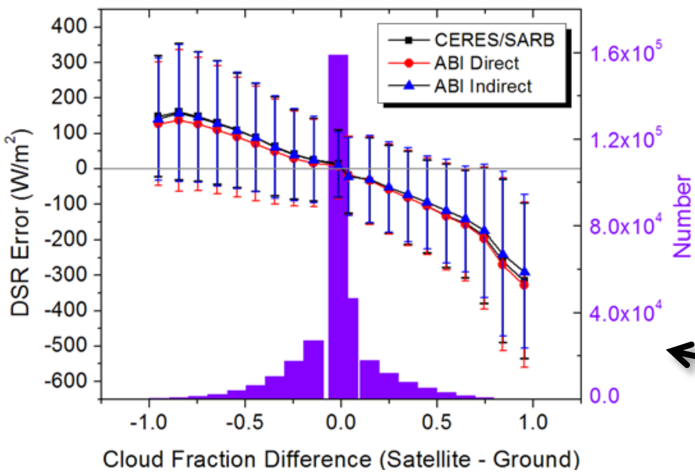


many clear & overcast …

… but there are some overcast cases with large insolation …

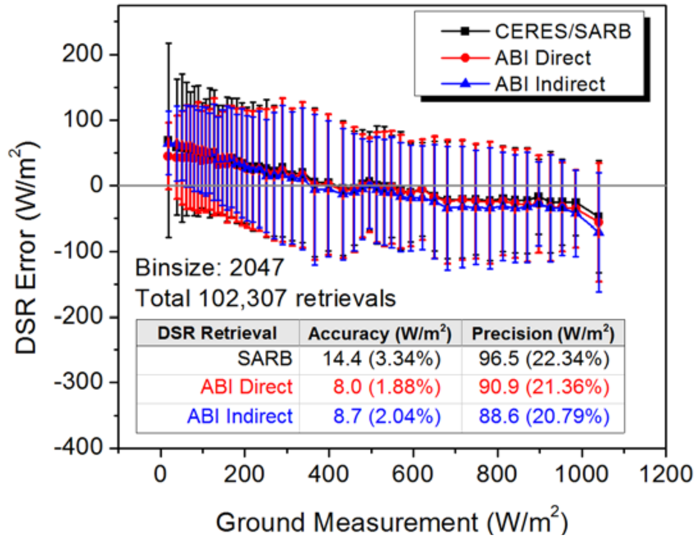
… large negative bias





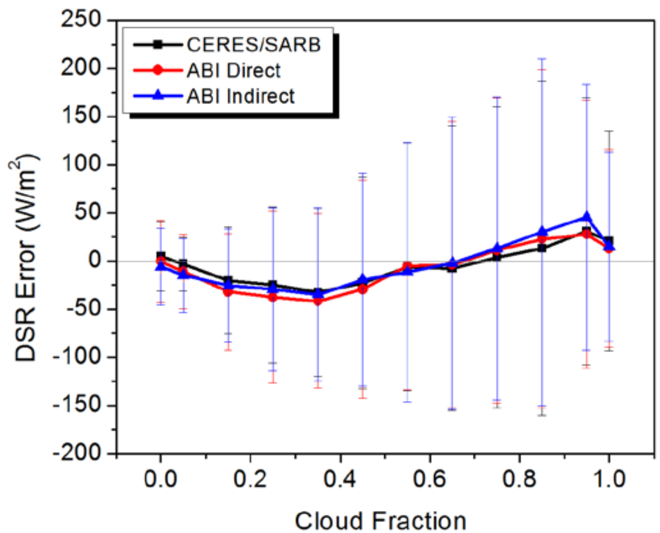
- pattern for CERES/SARB is similar
- large fraction of observed dependence "error vs. ground" plot is explained by inconsistent satellite and ground cloud fractions
- negative (positive) cloud fraction difference leads to over (under) estimation of DSR

Validation Results
CERES/CAVE Dataset – DSR (3)



DSR Retrieval	Accuracy (W/m^2)	Precision (W/m^2)
SARB	14.4 (3.34%)	96.5 (22.34%)
ABI Direct	8.0 (1.88%)	90.9 (21.36%)
ABI Indirect	8.7 (2.04%)	88.6 (20.79%)

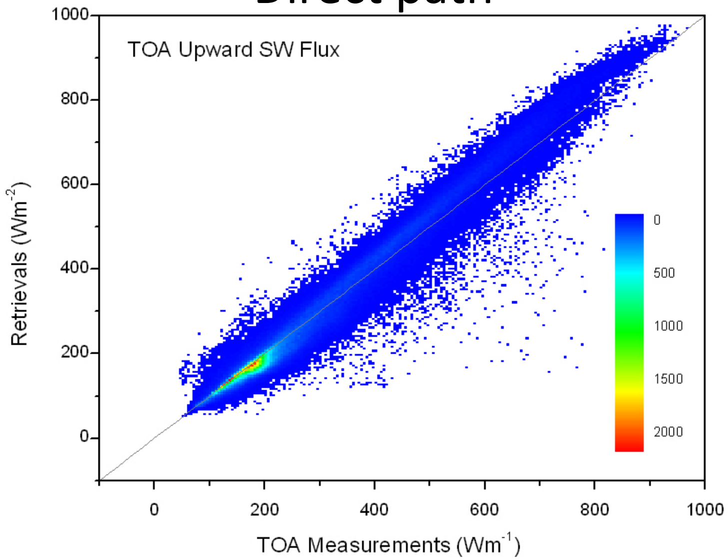
- subsetting: satellite-ground cloud fraction difference < |0.01|
- dependence of error on ground value is reduced (especially at high value)
- overall bias increased – indicates cancellation of errors in the total sample



- dependence of DSR error on cloud fraction (CF) when satellite and ground CF agree
- error is smallest for clear and overcast skies, and for CF 0.65
- negative error for 0.0 < CF < 0.65
- positive error for 0.65 < CF < 1.0
- std generally increases with CF up to ~0.85 CF, decreases afterward

Validation Results
CERES/CAVE Dataset – RSR

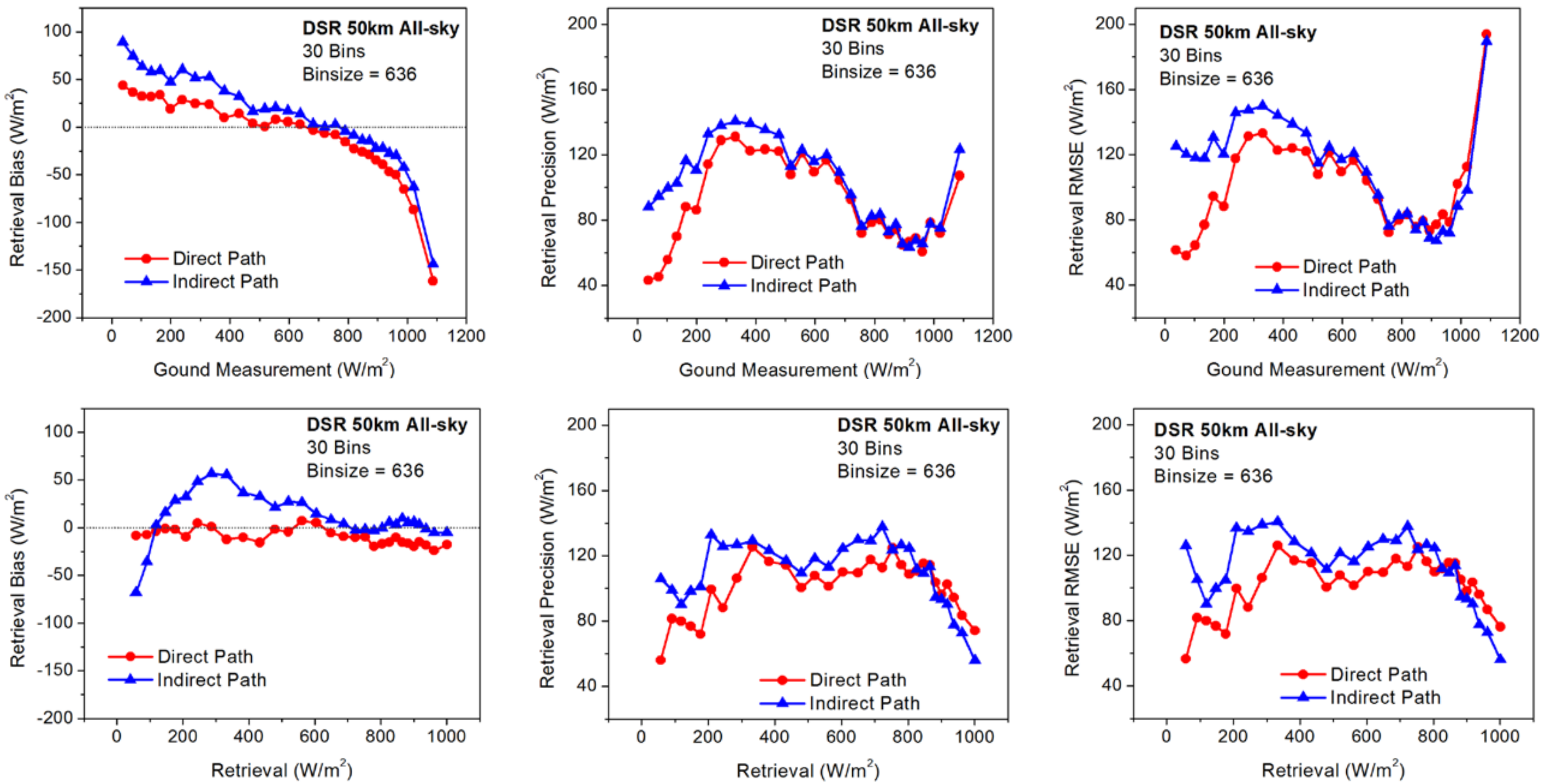
Direct path



Bias: -0.9 W/m^2 (-0.3%)
RMS : 30 W/m^2 (11%)
Corr: 0.986

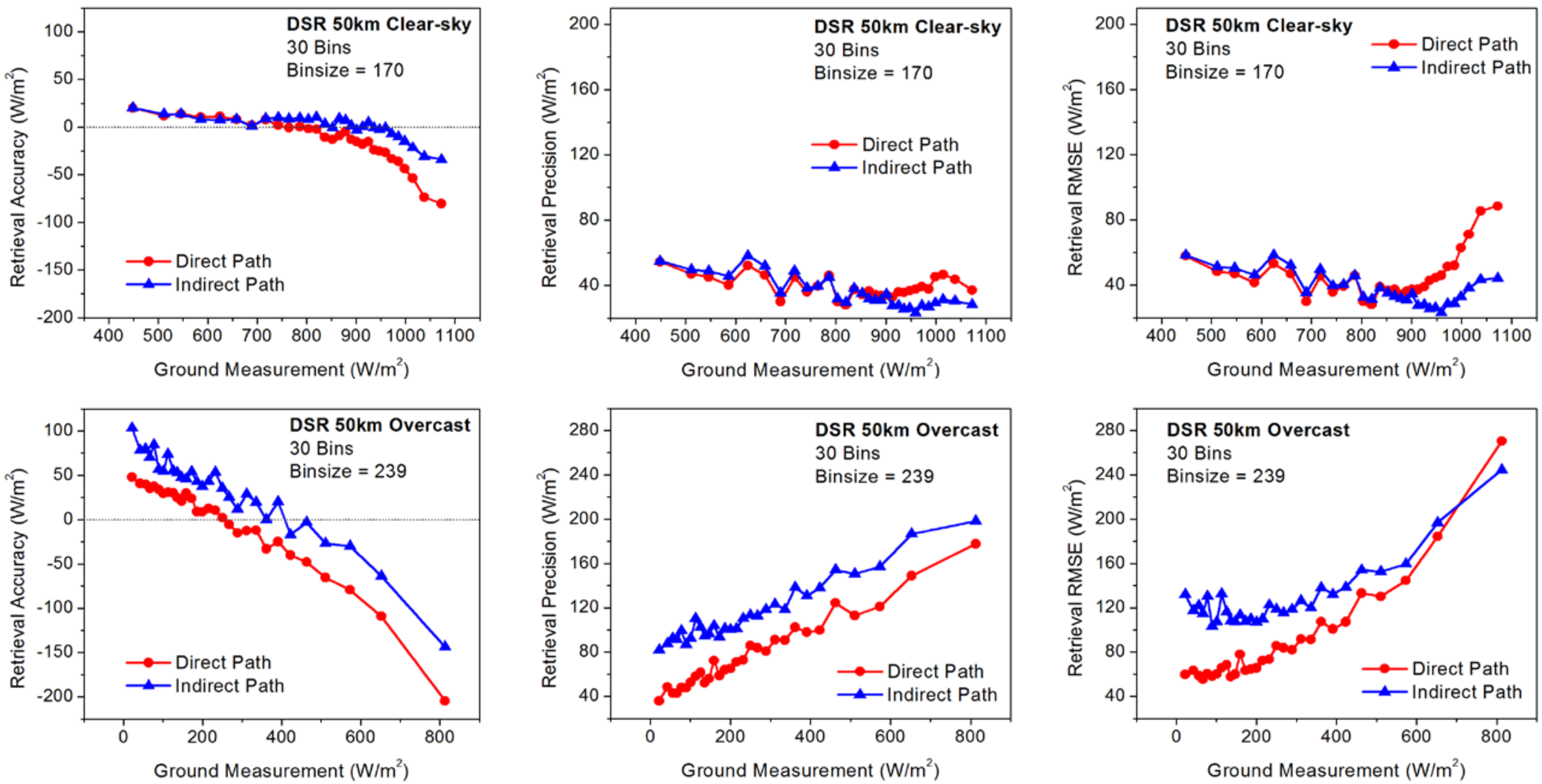
- small bias and rms error
- Only DPA results shown since IPA used CERES TOA value as input
  - IPA assumed "perfect" narrow-to-broadband conversion and ADM!

Validation Results
MODIS data – DSR (1)



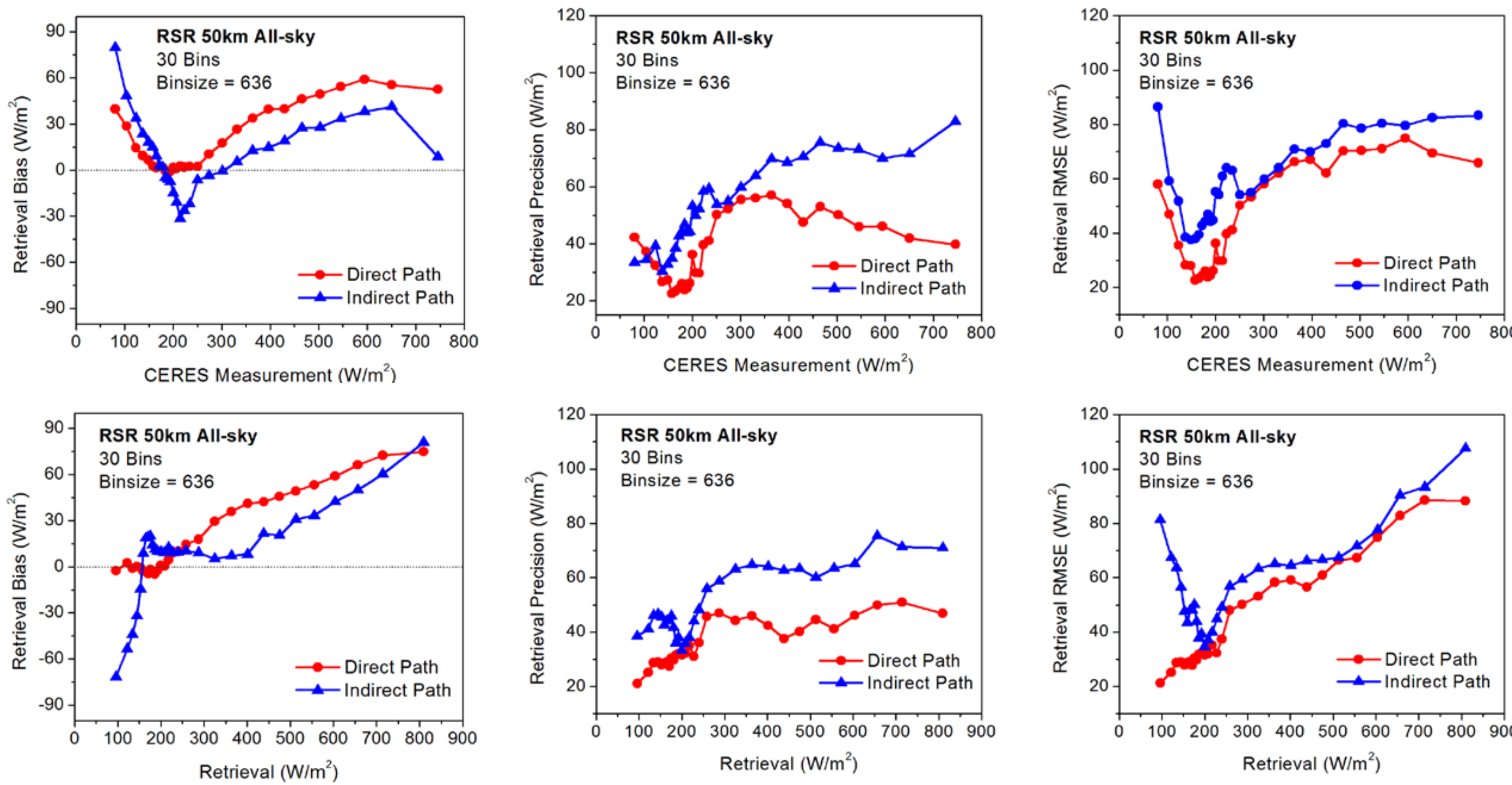
- bias vs. ground/retrieval pattern from DPA is similar to that with CAVE input
- IPA has larger bias and std than DPA at low DSR – larger error in overcast sky (next slide)

Validation Results
MODIS data – DSR (2)



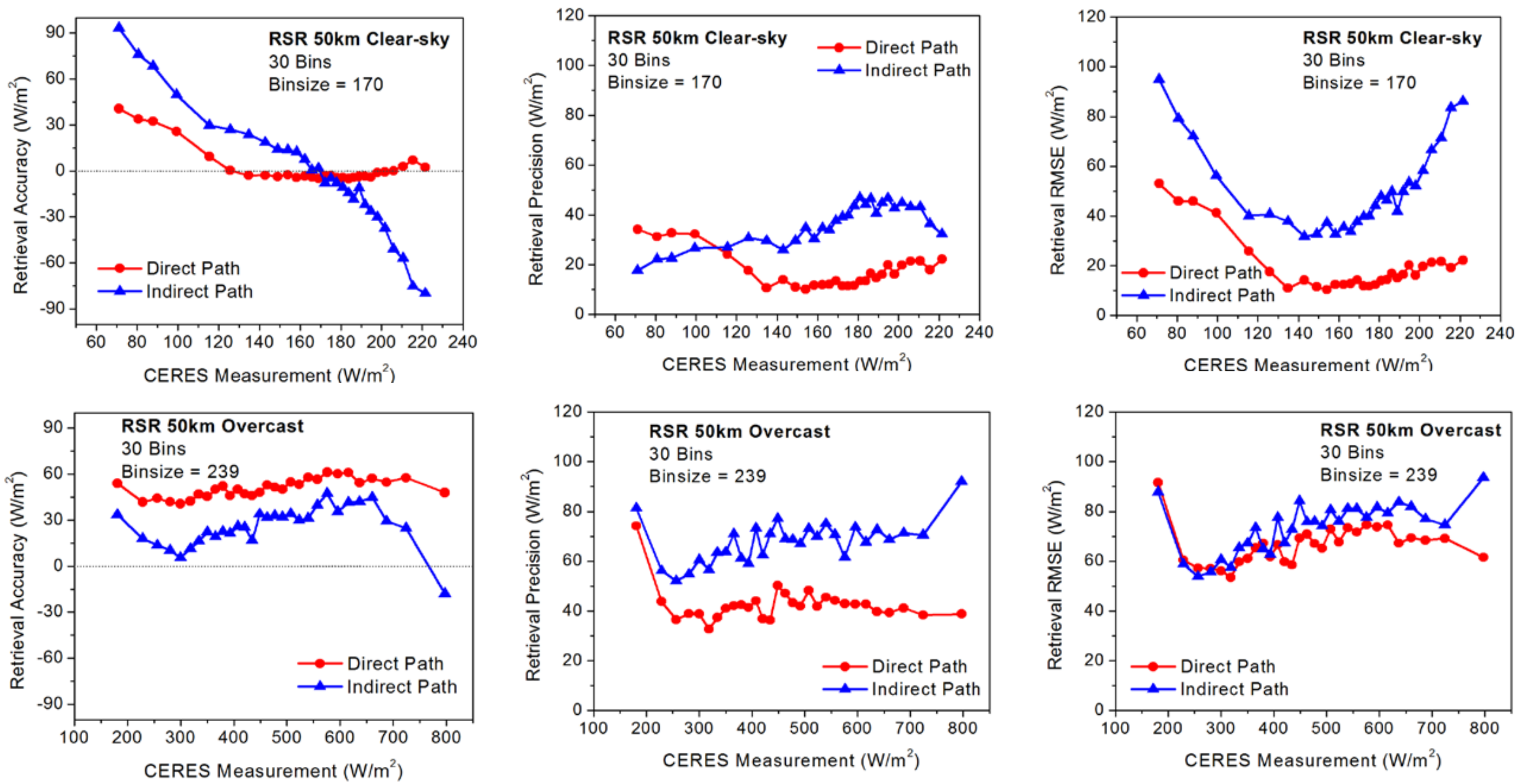
- clears sky: accuracy, precision and RMSE in DPA and IPA are similar at low DSR
- clear sky: IPA has smaller error than DPA at high DSR
- overcast sky: std in IPA is larger than in DPA; IPA bias is larger(smaller) than DPA bias below (above) ~400 W/m^2 DSR

Validation Results
MODIS data – RSR (1)



- bias/std/rmse are functions of RSR for both types of plots – even IPA bias strongly depends on retrieval
- DPA bias is larger than that from IPA at mid-large RSR

Validation Results
MODIS data – RSR (2)



- clear IPA bias > overcast IPA bias at low & high RSR
- overcast std > clear std; IPA std > DPA std
- clear IPA RMSE > clear DPA RMSE; overcast DPA and IPA RMSEs are similar at low RSR

Validation Results
MODIS Dataset – Summary Table

	DSR			RSR		
	All Sky	Clear	Overcast	All Sky	Clear	Overcast
Number of Retrievals	19103	5111	7195	19103	5111	7195
Direct Path Algorithm						
Accuracy (bias) (W/m^2)	-9.34 (-1.6%)	-13.88 (-1.7%)	-6.70 (-2.6%)	20.08 (6.9%)	2.97 (1.8%)	50.90 (10.9%)
Precision (σ) (W/m^2)	102.23 (17.6%)	46.67 (5.7%)	101.49 (38.9%)	45.46 (15.6%)	23.05 (14.0%)	43.38 (9.3%)
RMSE (W/m^2)	102.66 (17.6%)	48.69 (5.9%)	101.71 (38.9%)	49.70 (17.0%)	23.24 (14.1%)	66.88 (14.4%)
Indirect Path Algorithm						
Accuracy (bias) (W/m^2)	10.71 (1.8%)	0.78 (0.1%)	29.16 (11.2%)	10.57 (3.6%)	-3.73 (-2.3%)	25.79 (5.5%)
Precision (σ) (W/m^2)	114.37 (19.6%)	39.30 (4.8%)	129.84 (49.7%)	61.11 (20.9%)	56.28 (34.1%)	69.59 (14.9%)
RMSE (W/m^2)	114.86 (19.7%)	39.31 (4.8%)	133.06 (51.0%)	62.02 (21.2%)	56.40 (34.1%)	74.21 (15.9%)