



SOLAR ENERGY APPLICATIONS

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THE “GOES SOLAR RADIATION PRODUCTS IN SUPPORT OF RENEWABLE ENERGY” PROJECT

- **Team:**

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- NOAA/OAR/ESRL: E. Dutton;
- US Department of Energy (DOE)/National Renewable Energy Laboratory (NREL): B. Walter, T. Stoffel, M. Sengupta

SOLAR RESOURCE DATA NEED

- Solar power has been growing at an annual rate of 40% in recent years. By 2025 it could grow to 10% of U.S. power needs.
- Sunlight is the fuel for solar power generation technologies. Need to know quality and future availability of the fuel for accurate analysis of system performance.
- Variability of sunlight is probably the single greatest uncertainty in a plant's predicted performance [1].
- Solar resource data is used for
 - Site selection
 - Predicting annual plant output
 - Analysis of temporal performance and operating strategy.
- Solar resource data needed:
 - direct normal irradiance (DNI)
 - diffuse horizontal irradiance (DHI)
 - global horizontal irradiance ($GHI = DNI \cdot \cos(SZA) + DHI$)
- Neither current operational nor future GOES-R solar product contain all components as output.

[1] Stoffel et al., Concentrating solar power – Best practices handbook for the collection and use of solar resource data, NREL/TP-550-47465, Sep 2010

THE “GOES SOLAR RADIATION PRODUCTS IN SUPPORT OF RENEWABLE ENERGY” PROJECT

- **Objective:**

Modify/improve and test the geostationary solar radiation budget algorithms such that they meet the requirements of solar energy (SE) applications.

- **Tasks:**

1. increase spatial resolution of GSIP & GOES-R products (GPSDI,R3);
2. add direct normal and diffuse radiation as products (R3);
3. add tailored products (R3);
4. create and evaluate climatology of GOES-based solar radiation data for renewable energy (R3)
5. Explore “pseudo” forecast of SE

ACCOMPLISHMENTS

Task	Status
Create climatology of SE parameters from 50-km GSIP-CONUS	<ul style="list-style-type: none">• Initial assessment of SE climatology• Corrected data (1998-2010) for known problems (gaps , clear/cloudy biases)• Re-evaluated insolation• Started re-calculating and evaluating SE parameters
Revise current GSIP-v2 algorithm for SE	<ul style="list-style-type: none">• Increased spatial resolution from 14 km to 4 km• Added capability for calculating direct and diffuse fluxes• Deriving SE parameters
Revise GOES-R/ABI SW radiation budget algorithm for SE	<ul style="list-style-type: none">• Added capability for calculating direct and diffuse fluxes• Initial assessment of direct and diffuse fluxes• Expanded data base and performed detailed evaluation
Explore a pseudo forecast capability of insolation for GOES-R	<ul style="list-style-type: none">• Not (yet) performed

Note: Due to contracting/hiring issues the project start was delayed by almost a year

GSIP-CONUS CLIMATOLOGY FOR SE

GAP FILLING (1)

GSIP-CONUS

For climatology data without gaps are needed

- Time interpolation, TI
 - uses cell values one hour before and/or one hour after
- Space interpolation, SI
 - uses “good” neighboring cells
 - “+” cells have higher correlation with and smaller bias from the true value than “x” cells. Both are used with “+” cells having higher rank (priority).

x	+	x
+	c	+
x	+	x

GAP FILLING (2)

GSIP-CONUS

- Decision tree selects the possible interpolation scheme with highest rank.
- Interpolations are iterated on a day worth of data until the last gap is filled or until the limit of iterations is reached (5).

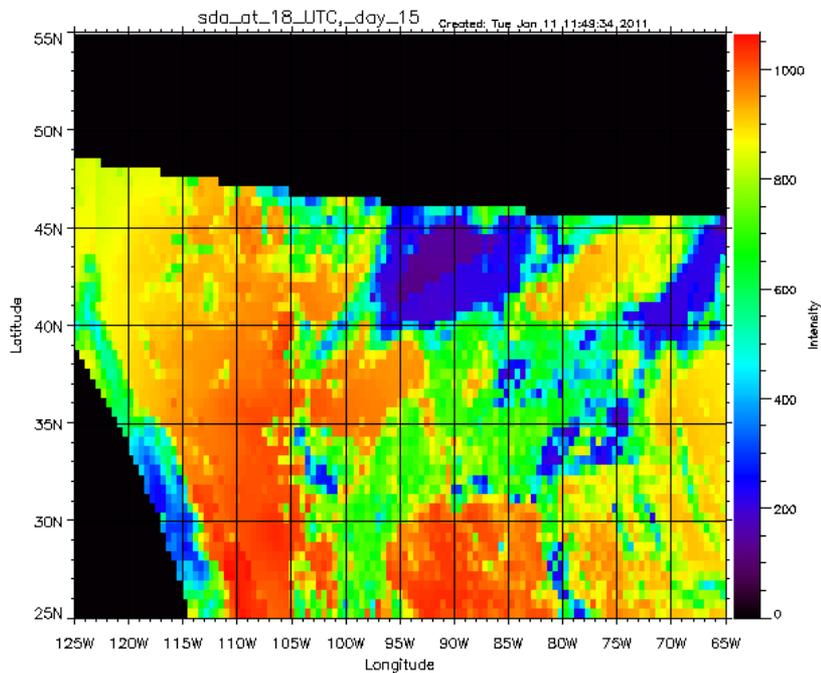
Rank	Method	R	residual	Comment
5	TI (2 neighbors)	0.96	8.3%	SZA-adjusted average
4	SI (+)	0.96	7.2%	Average
3	SI (x)	0.92	10.6%	Average
2	TI (neighbor at h-1)	0.90	12%	SZA-adjusted
1	TI (neighbor at h+1)	0.90	12%	SZA-adjusted
0	Bad cell	-	-	Discarded

GSIP-CONUS DATA ENHANCEMENTS

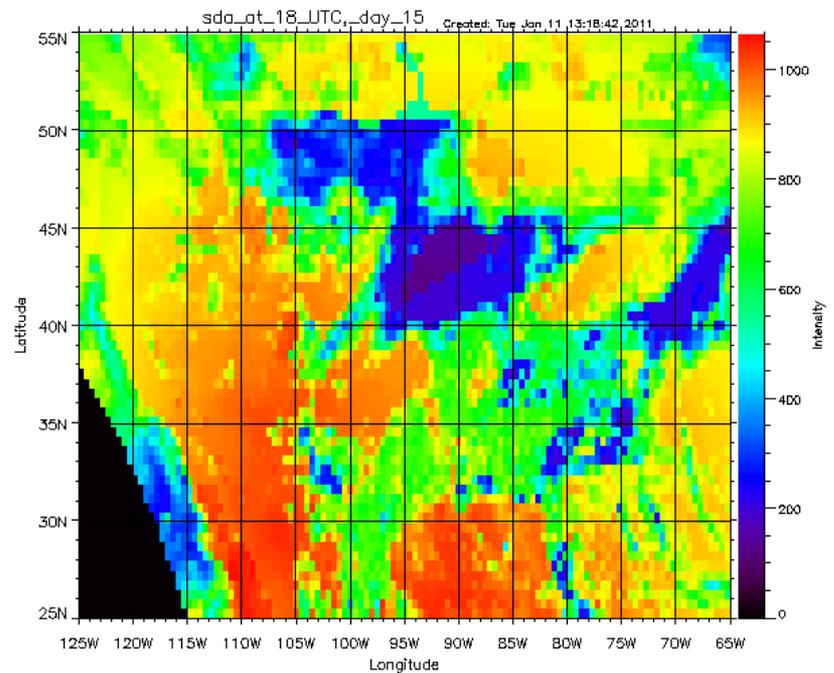
Gap filling - example (1)

Temporal Interpolation (TI)

Original image



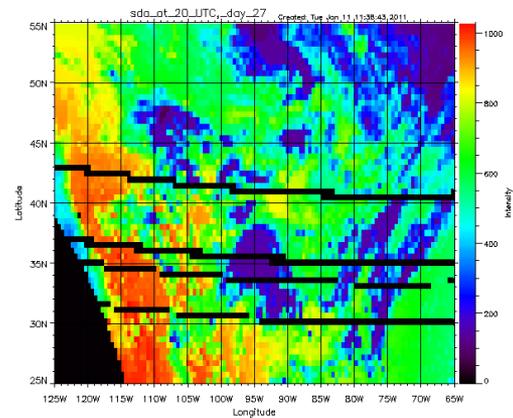
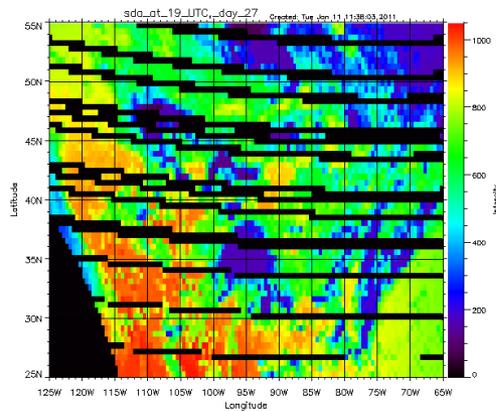
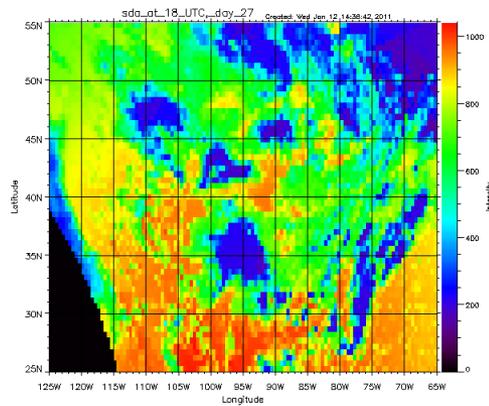
Gap-filled image



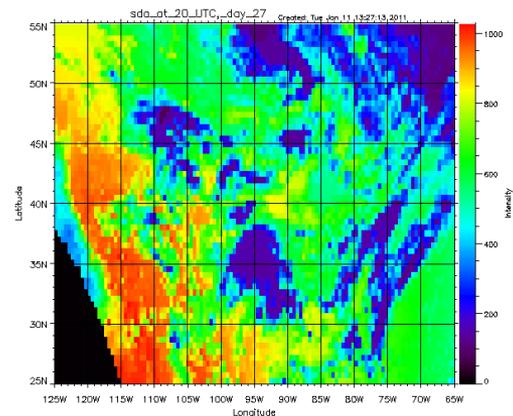
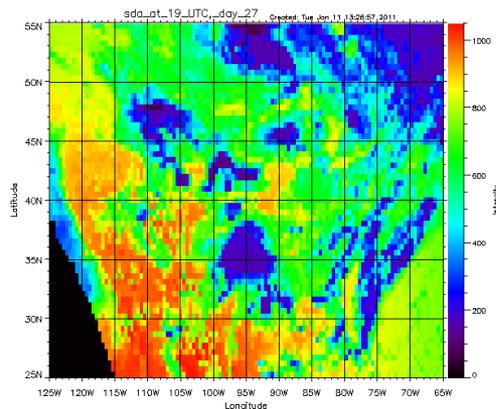
GSIP-CONUS DATA ENHANCEMENTS

Gap filling - example (2)

More complicated case: later image is also “damaged” – TI and SI are combined.



Time →



Gap-filled central image

Gap-filled right image

GSIP-CONUS DATA EVALUATION

- Gap-filled data are adjusted
 - Applied seasonally-dependent empirical adjustments to clear and overcast GSIP fluxes
 - Adjustments were derived from one year of data per satellite
 - Adjustment also considered uncertainty in SURFRAD ($\sim 11 \text{ Wm}^{-2}$)
- Adjusted fluxes are compared with data from SURFRAD (7 sites)
 - Spatial/temporal representation of ground measurements and that of satellite retrievals differ
 - Applied a similarity filter ($SF \leq 0.5$)
$$SF = \{ \{ [(1 - CF)^2 + (CF - R)^2] / 2 \} \}^{-1/2}$$
 - CF: GSIP clear fraction
 - R: ratio of direct to total downwelling flux from ground

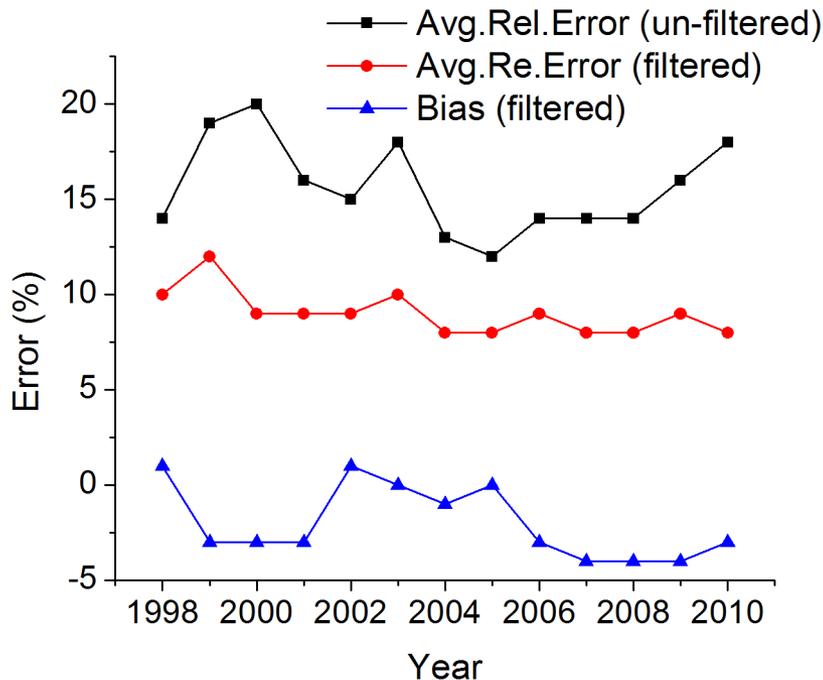
GSIP-CONUS DATA EVALUATION

$$\text{Avg. Rel. Error} = \left(\sum |F_{gi} - F_{si}| \right) / \sum F_{si}$$

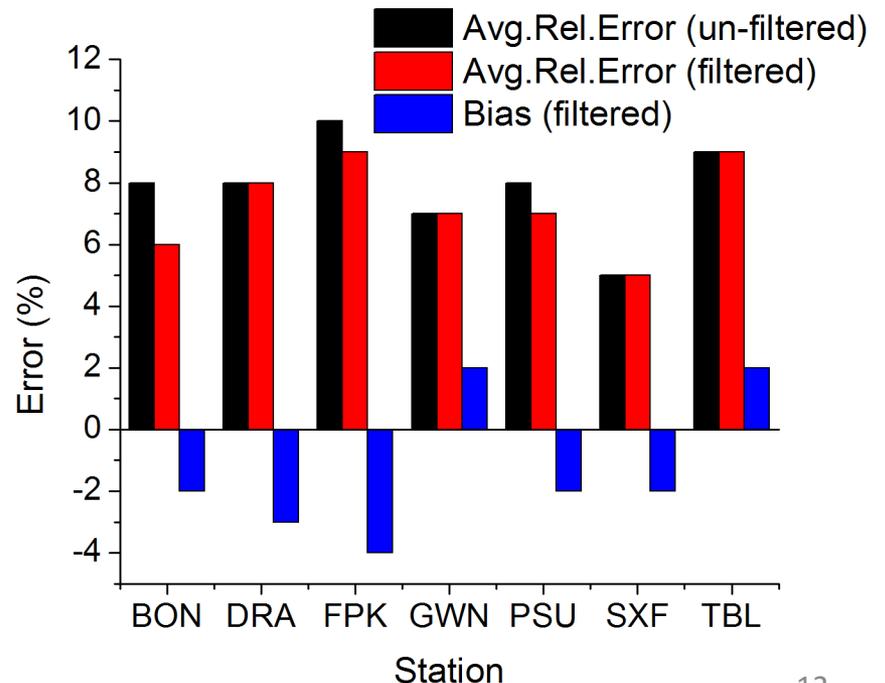
$$\text{Bias} = \left(\sum (F_{gi} - F_{si}) \right) / \sum F_{si}$$

F: GHI; g: GSIP; s: SURFRAD

Hourly averages of GHI



Monthly averages of GHI



SE PARAMETERS

GSIP-CONUS Data

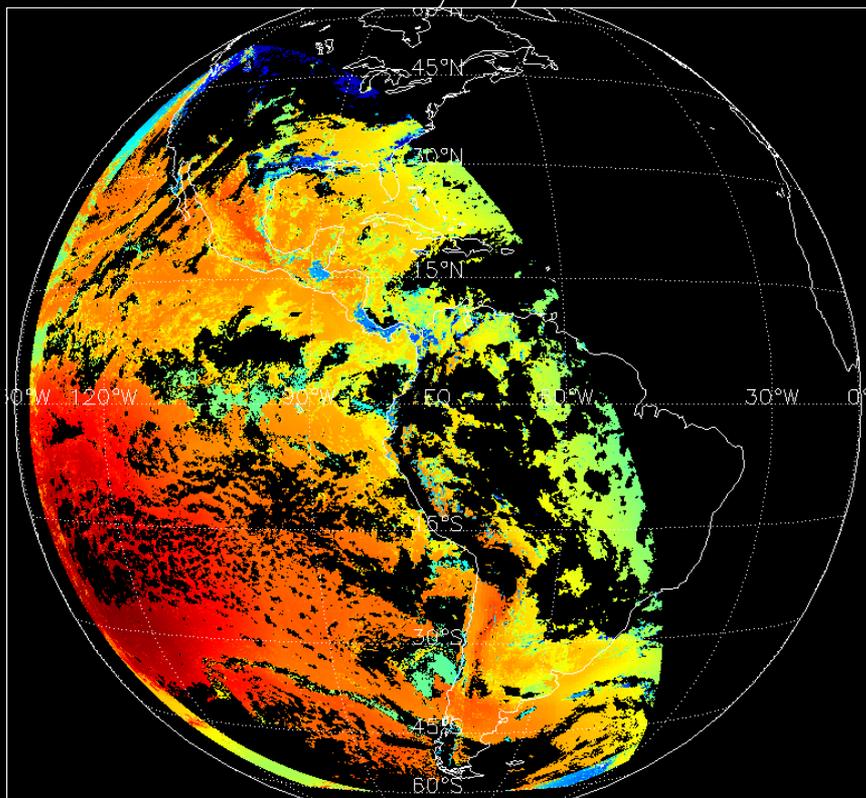
Parameter	Validation
<p>Average insolation (Amount of solar radiation incident on the surface of the earth)</p>	Validated
<p>Midday insolation (Average insolation available within 1.5 hours of Local Solar Noon)</p>	Ongoing
<p>Clear sky insolation (Average insolation during clear sky days (cloud amount < 10%))</p>	Ongoing
<p>Clear sky days (Number of clear sky days (cloud amount < 10%))</p>	Ongoing
<p>Diffuse radiation on horizontal surface (Amount of solar radiation incident on the surface of the earth under all-sky conditions with direct radiation from the Sun's beam blocked)</p>	Planned
<p>Direct normal radiation (Amount of solar radiation at the Earth's surface on a flat surface perpendicular to the Sun's beam with surrounding sky radiation blocked)</p>	Planned

GSIP-V2 SE EXAMPLES

SE PARAMETERS

GSIP-v2 Examples

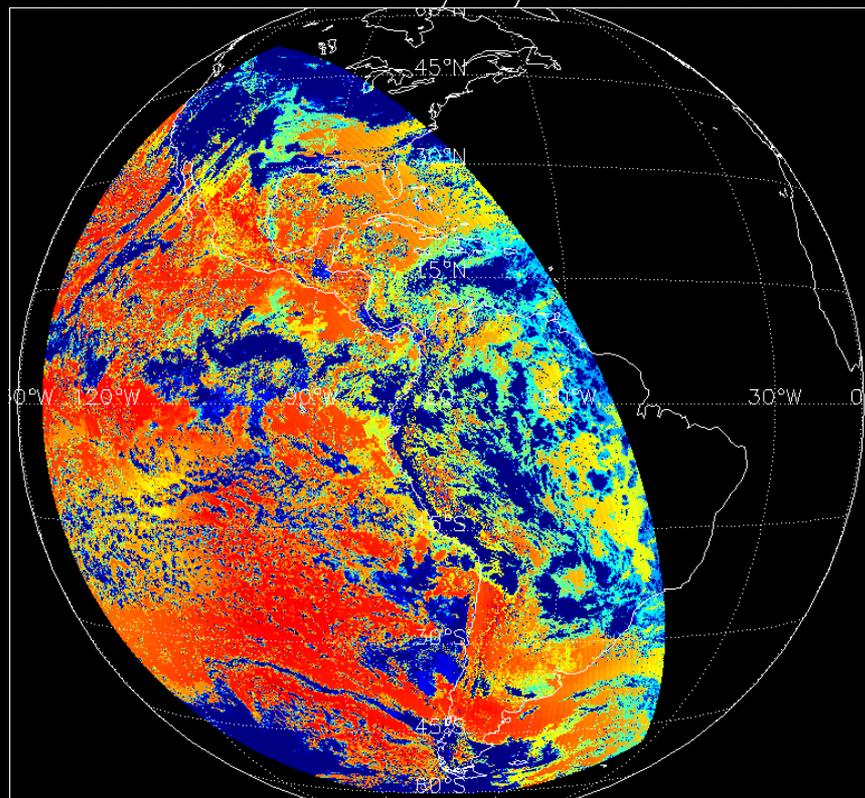
GOES-13 GENHEM 12/22/2010 20:45 UTC



Clearness index



GOES-13 GENHEM 12/22/2010 20:45 UTC



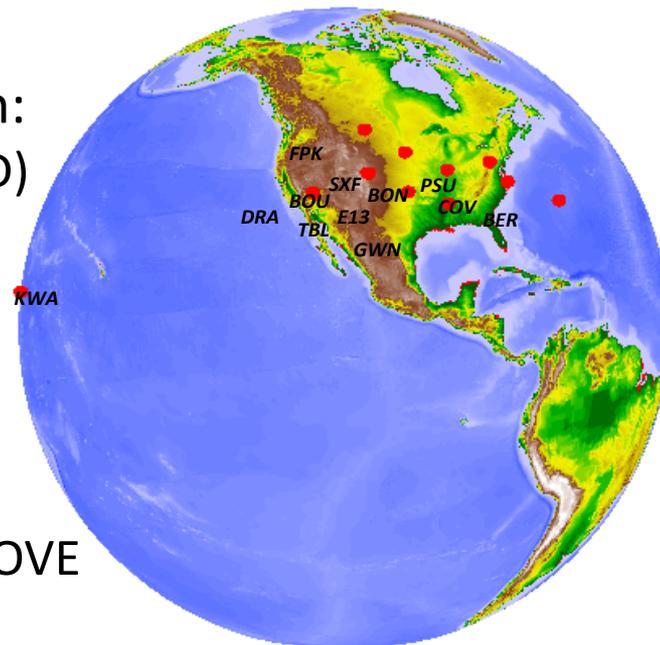
Direct normal SW downward surface flux (W/m^2)



GOES-R ABI FLUX EVALUATION

VALIDATION SITES AND TIMES

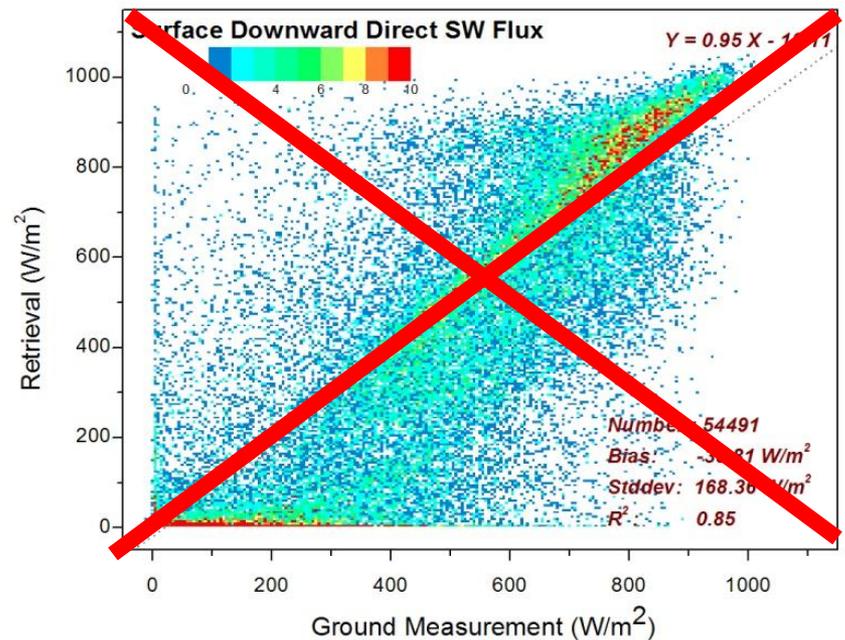
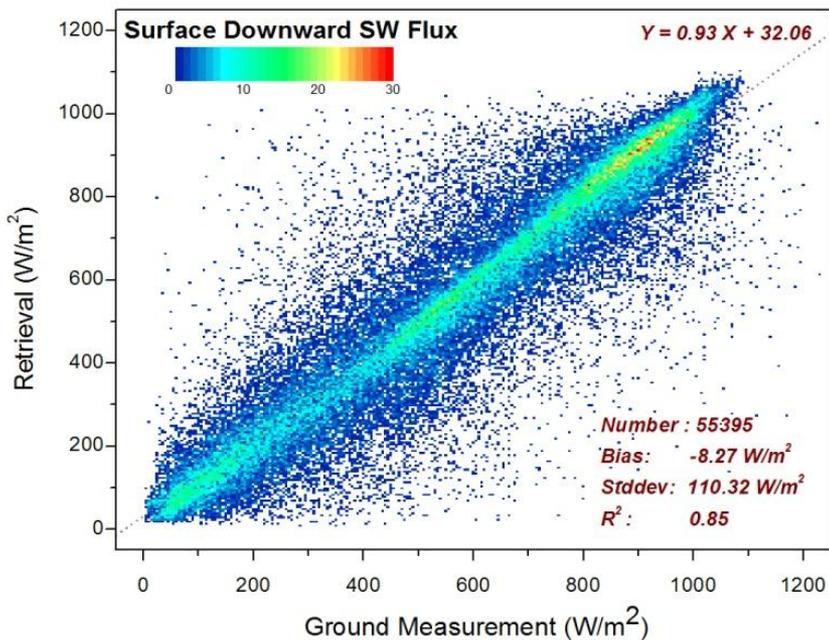
- Sites: 12 stations within current GOES domain:
 - BON, DRA, FPK, GWN, PSU, SXF, TBL (SURFRAD)
 - COV (COVE)
 - E13 (ARM)
 - BER, BOU, KWA (CMDL)
- Time Period:
 - 2000.03 – 2009.12 (Terra);
2002.07 – 2009.12 (Aqua) for SURFRAD and COVE stations;
 - 2000.03 – 2006.06 (Terra);
2002.07 – 2005.02 (Aqua) for ARM and CMDL stations.
- Retrieval spatial scale: 5 km (from MODIS data/products)
- Ground data temporal scale: 15-min average



VALIDATION – ALL SKY

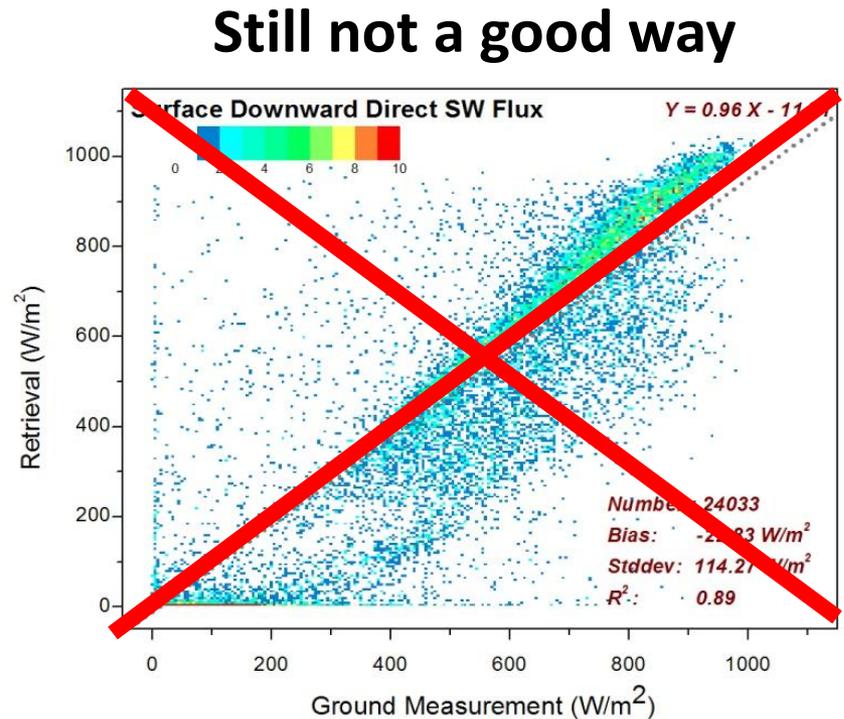
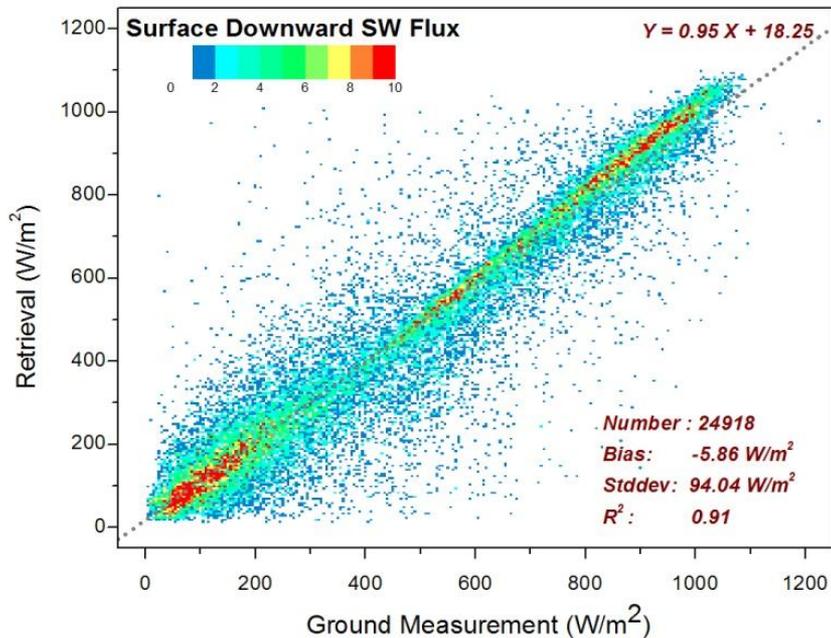
- Validation of retrieved DSR and DIR against ground measurements.

Not a good way



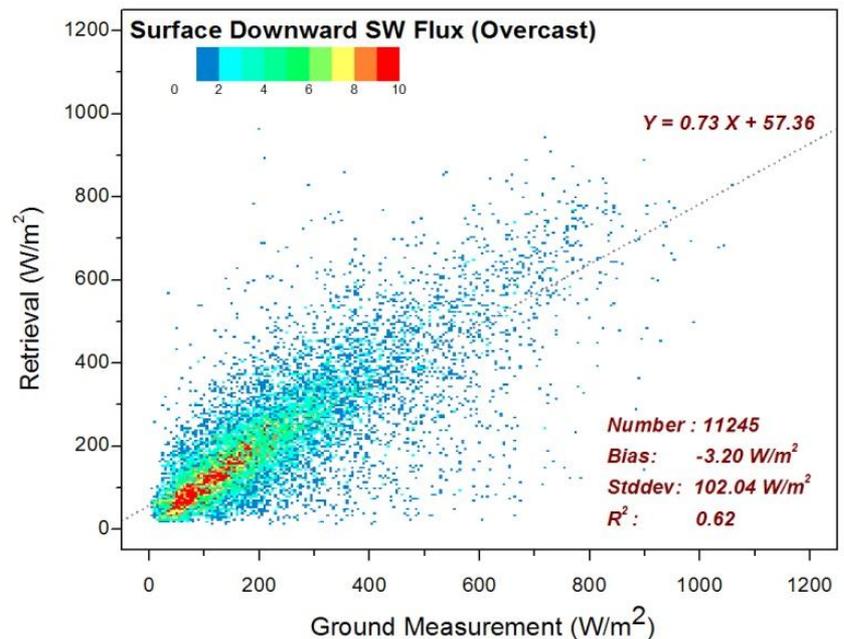
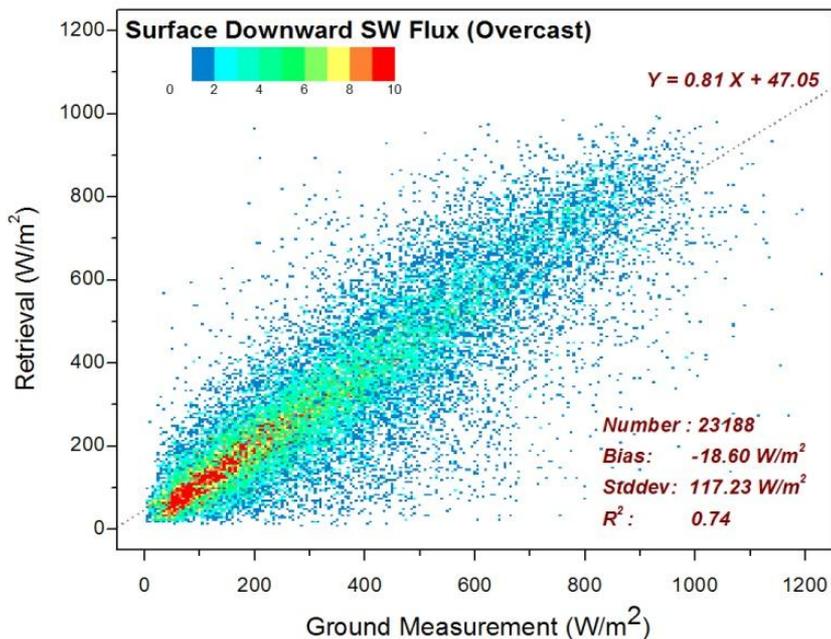
VALIDATION – ALL SKY

- Same cloud fraction from both satellite and ground.



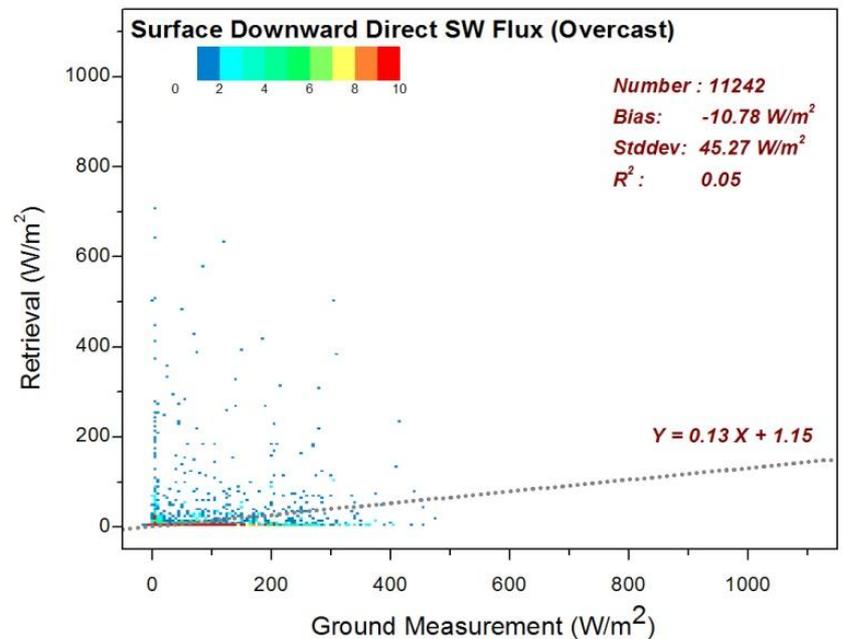
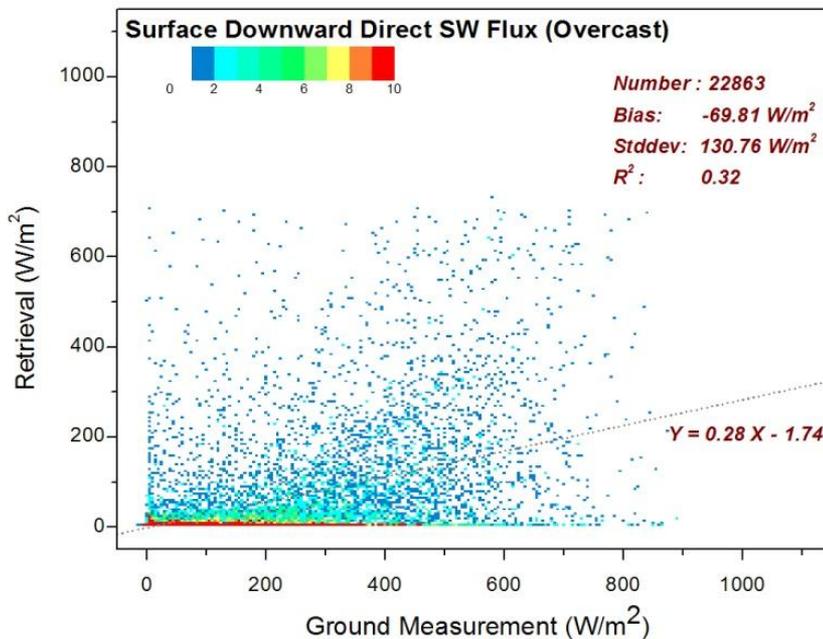
VALIDATION - OVERCAST

- Validation of **DSR** against ground measurement:
 - Left: 100% cloudy sky is identified by satellite
 - Right: both satellite and ground report 100% cloudy sky



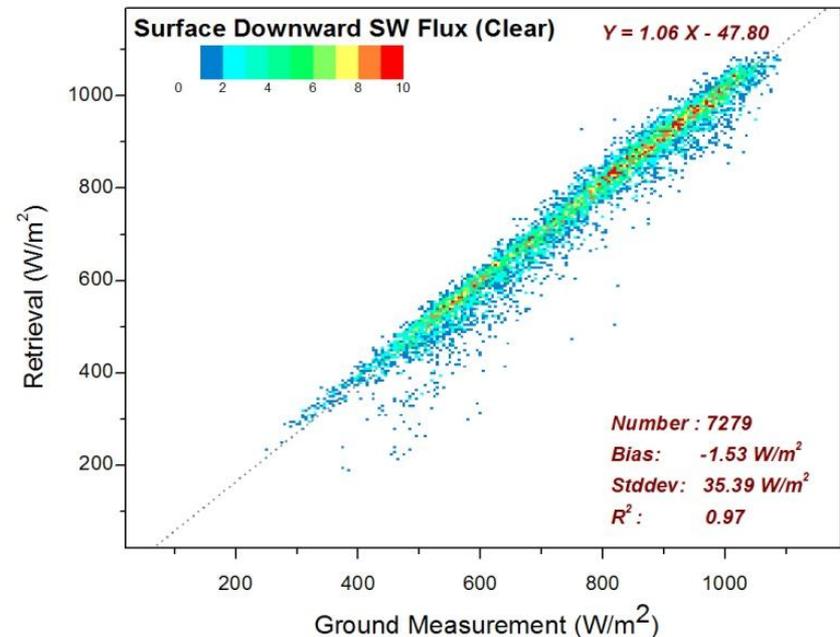
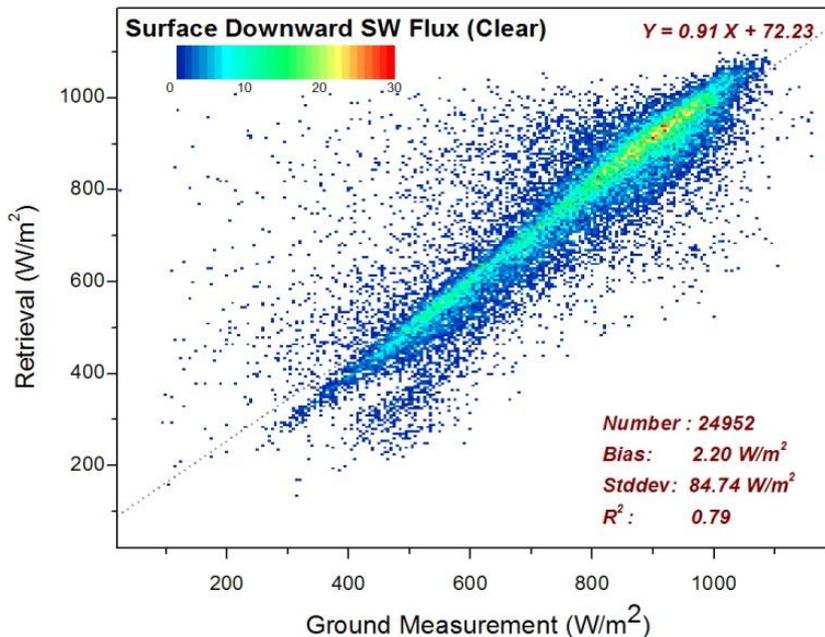
VALIDATION – OVERCAST

- Validation of **DIR** against ground measurement:
 - Left: 100% cloudy sky is identified by satellite
 - Right: both satellite and ground report 100% cloudy sky



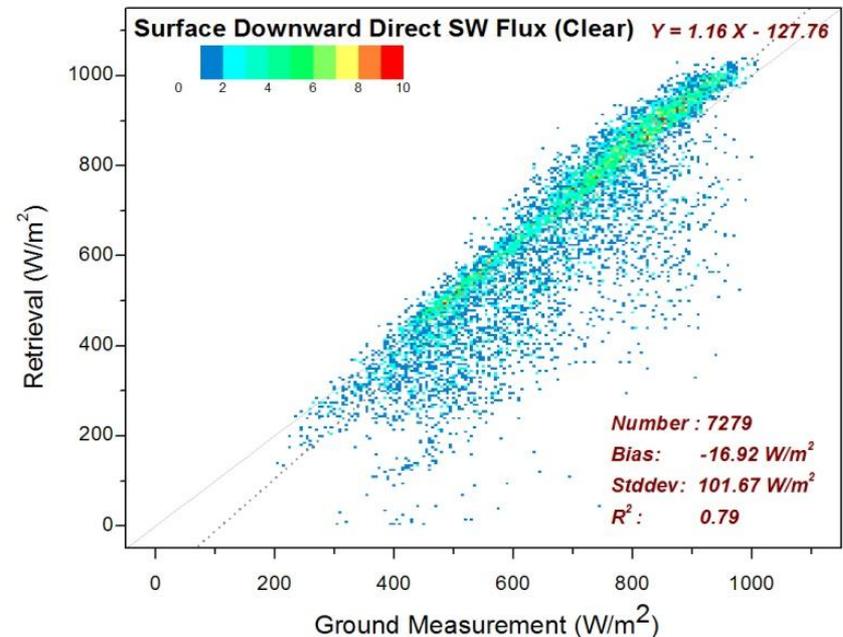
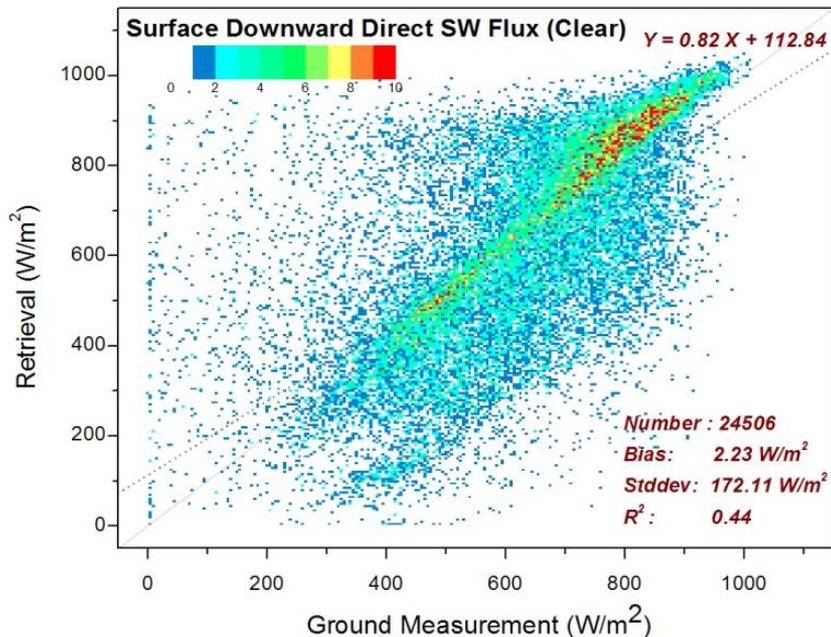
VALIDATION – CLEAR SKY

- Validation of **DSR** against ground measurement:
 - Left: 100% clear sky is identified by satellite
 - Right: both satellite and ground report 100% clear sky



VALIDATION – CLEAR SKY

- Validation of **DIR** against ground measurement:
 - Left: 100% clear sky is identified by satellite
 - Right: both satellite and ground report 100% clear sky



SUMMARY AND PLANS

- Enhanced and started characterization of 13-year GSIP-CONUS data; will finish evaluation and will make data available over the Internet
- Ready to start routine experimental runs of 4-km SE parameters (GHI and DNI) from GSIP-v2; will evaluate, and pursue transition to operations
- Characterized performance of GOES-R ABI algorithm for SE applications:
 - good DSR (=GHI) retrievals – PV systems can use data
 - large errors of DIR (=DNI*cos(SZA)) – need to improve for CSP systems
 - Note: satellite data may not be actually this bad – need to design a better way to compare with ground data