The Development of a Long-term, Continually Updated Global Solar Resource at 10 km Resolution: Preliminary Results From Test Processing and Continuing Plans

P. Stackhouse¹, R Perez³, M. Sengupta⁴ and K Knapp⁵

Stephen Cox, J. Colleen Mikovitz¹, T. Zhang¹, K. Hemker³, J. Schlemmer³, S. Kivalov³

¹NASA LaRC, ²SSAI/NASA LaRC, ³SUNY Albany, ⁴NREL, ⁵NCDC
Improving Long-term Solar Resource Maps: Goals

- **Solar irradiance maps**
  - At least 30 year record of surface solar energy & components (direct normal and diffuse); TSI
  - Global coverage at 10 km horizontal resolution
  - At least 3-hourly temporal resolution (interpolated to 1 hour)
  - Other ancillary parameters for DSS including: 2m T, Td, ps; 10 m Ws & Wd (from latest NASA data assimilation, i.e., MERRA)
  - Time series by lat/lon coordinate; statistics

- **Sustained Capabilities**
  - Production system runnable from NREL integrating chief inputs including ISCCP (satellite radiance & cloud properties), MERRA, Ozone, Snow/Ice
  - Resource maps updated on annual basis
  - Web services for data distribution
NREL Decision Support Tools

In My Backyard
(residential system design)

PV Watts
(photovoltaic system design)

Solar Advisor Model
(renewable energy financial)

Solar Prospector
(concentrated solar power)

NSRDB – US Solar Resource
US Surface (‘76-’05) and Satellite (’98-’05) Derived Climatology
Addition Int’l Surface Measurements

(photovoltaic system design)
Additional Plan: Provide Global Long-term Solar Resource Maps for IRENA

<table>
<thead>
<tr>
<th>Source</th>
<th>Shared by</th>
<th>Scope</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWERA Archive</td>
<td>NREL</td>
<td>Solar / Wind</td>
<td></td>
</tr>
<tr>
<td>HelloClim 1</td>
<td>Mines ParisTech</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>HelloClim 3 (part.)</td>
<td>Mines ParisTech</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>PACA</td>
<td>Mines ParisTech</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>Solar-Med atlas</td>
<td>DLR</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>NASA solar dataset</td>
<td>NREL</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>Solar GIS</td>
<td>Geomodel</td>
<td>Solar</td>
<td>Geomodel</td>
</tr>
<tr>
<td>CENER dataset</td>
<td>CENER</td>
<td>Solar / Wind</td>
<td></td>
</tr>
<tr>
<td>Reanalysis data</td>
<td>DTU Wind</td>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>Global wind data</td>
<td>DTU Wind</td>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>MNRE</td>
<td>Solar/Wind</td>
<td></td>
</tr>
<tr>
<td>WASA</td>
<td>SANERI</td>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>GCC solar</td>
<td>MASDAR</td>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>Complementary datasets</td>
<td>Geomodel</td>
<td>Terrain, population, landcover</td>
<td>Geomodel</td>
</tr>
<tr>
<td>Complementary datasets</td>
<td>TBD</td>
<td>Policy, Grid infrastructure, roads</td>
<td></td>
</tr>
</tbody>
</table>

Future partnerships: UNDP GEF, ADB, ESMAP, WMO, AFRETEP/EU JRC, Chile, Lebanon, GL/GH...

Hosting and dissemination

All partners
Multi-agency Configuration

NASA LaRC
- Latest data set inputs (i.e., ozone, snow/ice, water vapor, etc.)
  - Solar algorithms
  - Surface measurements
  - Production System Development

NOAA NCDC
- Operational provision of ISCCP satellite radiance and cloud properties
  - Responsible for maintenance of inter-calibration

SUNY/Albany
- Solar algorithms
  - Analysis, Assessment & Applications

DOE/NREL
- Produce global solar maps
  - Annual update
  - Provide web services and data distribution
Key Input: Satellite Radiance from ISCCP

- ISCCP = International Satellite Cloud Climatology Project
- Provides cross-calibrated radiance and cloud properties since 1983
- All world’s geosynchronous
- NOAA AVHRR
- New ISCCP “H” products (in Beta)
Improved Spatial Resolution for ISCCP HX

ISCCP HX GOEA Visible Radiance Jun 01, 2001, 18Z

0.00 0.02 0.03 0.05 0.07 0.09 0.12 0.14 0.16 0.17 0.19 0.22 0.23 0.25 0.28 0.29 0.31 0.34 1.00
ISCCP “H” Data sets
- ISCCP H => original plan to use new version, planned for release in late 2009, 2010
- Still not released (but now in beta) => needed alternative for initial development and testing

Multi-Satellite Option: NCDC GridSat (global stitch)
- Long-term, all pixels blended satellite, but no polar data
- Improved navigation over ISCCP B1U
- Improved IR calibration, similar vis calibration to B1U
- Gridded to 8 km
- Used to develop and test concepts and production system
 Improved Inputs and Solar Algorithms:

- SUNY/Albany (Perez): requires vis radiances, aerosol, ozone, snow/ice, other meteorological and surface information.
  - Most versatile and self-calibrating, but physical parameterization
  - Uses IR for improved snow coverage treatment
  - *Will be used exclusively for today’s talk*

- NASA GEWEX (Pinker/Laszlo based): requires radiances plus cloud fraction information, aerosol, snow/ice, column H2O, ozone, spectral albedo, etc.
  - Radiative transfer based using Fu/Liou bands for spectral treatment from UV to near–IR (0.2 – 4.0 μm).
  - Developed version to produce pixel fluxes rather than gridded fluxes.
Data set delivered to NREL to test formats and place into GIS tools; GridSat v2 is a precursor to the ISCCP HX
Global Processing: NCDC GridSat v1
(Sample Images)

Enhanced IR Image
(1/1/05, 12UT)

Visible Image
(1/1/05, 12UT)
3 Hourly Loop for US Region

Satellite Solar Irradiance (W m⁻²)
09 UT July 6 2006
Daily Averages for January 2005

Satellite Solar Irradiance at 10x10 km (Wm^-2)
January 1 2005
Annual Averaged Solar Map (60N – 60S)

Satellite Solar Irradiance at 10x10 km (Wm⁻²)
Annual Average 2005

Renewable Energy II (GC42B-03), Fall AGU 2014
First Results Using ISCCP HXG (10 km pixel data set)

Results from Beta Version
IR Radiance
January 15, 2007, 9Z

VIS Radiance
January 15, 2007, 9Z
- clear, cloudy and clear-sky composite radiances
- cloud optical property estimates
First Look Validation

GridSat v2 2007

GridSat v2 2007 vs BSRN 3-Hourly GHI Comparison from 2007-01 to 2007-12

- Max Abs Count = 145
- Max Rel Count = 0.37%
- Total Count = 39163
- Linear Fitting: $Y = a + bX$
  - $a = 1.6235$
  - $b = 1.0094$
  - $R^2 = 0.8629$

- Bias = 5.3254 (W m$^{-2}$)
- RMS = 109.1540 (W m$^{-2}$)
- $\sigma = 109.0254$ (W m$^{-2}$)
- $H_{BSRN} = 392.6746$ (W m$^{-2}$)
- $H_{1HHR} = 398.0025$ (W m$^{-2}$)
- $N = 39163$

HXG beta 2007

HXG beta 2007 vs BSRN 3-Hourly SWD comparison from 2007-01 to 2007-12

- Max Abs Count = 56
- Max Rel Count = 0.17%
- Total Count = 33585
- Linear Fitting: $Y = a + bX$
  - $a = 0.3201$
  - $b = 0.9972$
  - $R^2 = 0.6466$

- Bias = -0.9329 (W m$^{-2}$)
- RMS = 109.3827 (W m$^{-2}$)
- $\sigma = 109.3804$ (W m$^{-2}$)
- $H_{BSRN} = 445.5836$ (W m$^{-2}$)
- $H_{1HHR} = 445.0512$ (W m$^{-2}$)
- $N = 33585$
Histogram of Modeled-BSRN 3-Hourly GHI Differences from 2007-01 to 2007-12

3-Hourly
33 BSRN Sites 60° Equatorward
The red curve is a normal distribution with 0 mean and the same standard deviation as the dataset.

Leptokurtic: Kurtosis = 5.4868
Modeled-BSRN 3-Hourly GHI Comparison from 2007-01 to 2007-12

Bias (W m⁻²)
RMS (W m⁻²)
Sub N

2014-12-06

Cosine of Solar Zenith Angle

2014-12-06

Renewable Energy II (GC42B-03),
Fall AGU 2014
Statistics of Modeled GHI-BSRN 3-Hourly Comparisons from 2007-01 to 2007-12 on A Site-by-Site Basis
HXG pre-Beta: 2008

January 2008 Monthly Average
GHI

June 2008 Monthly Average
GHI
HXG Reprocessed BSRN Validation: 2008

Modeled-BSRN 3-Hourly GHI Comparison from 2008-01 to 2008-12

- Bias = 4.6203 (W m²)
- RMS = 109.7672 (W m²)
- ρ = 0.9223
- σ = 109.6710 (W m²)
- μₘₙₐₓ = 454.9877 (W m²)
- μₘₙₐᵢₙ = 459.5878 (W m²)
- N = 29368
- Rₘₚ = 10.2 (%)
- Rₙₚ = 24.13 (%)

3-Hourly Mean

33 BSRN Sites 60° Equatorward

Stacked Histogram of Modeled-BSRN 3-Hourly GHI Differences from 2008-01 to 2008-12 in 5 Latitudinal Zones

- 60°N-90°N
- 20°N-60°N
- 20°S-20°N
- 60°S-20°S
- 90°S-60°S

3-Hourly

The red curve is a normal distribution with 0 mean and the same standard deviation as the whole dataset.

Leptokurtic
Kurtosis = 5.3699

2015-04-30
Summary and Conclusions

Future Work
Conclusions and Future Work

- Work is progressing towards a long-term, sustainable global solar resource data set.
- The collaboration between NASA LaRC, SUNY, NCDC and NREL has lead to:
  - Development of a 3 year, 10 km solar resource mapping prototype; validation is promising.
  - Delivered to NREL for testing in GIS system tools.
- NCDC has processed ISCCP H Series products for the year 2007 & reprocessed 2008:
  - Pre-Beta version is being assessed and tested (does required reprocessing).
  - Validation of 2007/2008 relatively consistent compared between GridSat v2 and ISCCP HXG data sets.
Solar Mapping Project Plans

- Continue testing/evaluating solar resource estimates from ISCCP HXG
  - Improve inputs (e.g., aerosols) and algorithms using surface measurement.
  - Get feedback from NREL regarding test data
  - Incorporate parameter, format changes
  - Production system for long-term production

- Transition production system to NREL for sustained production and annual update
  - Test NREL production by comparing to NASA produced sample data sets
  - NREL is developing web service interface for user interface
  - Evaluate and adapt tools for release
NASA investigates atmospheric and climate sciences on global scales
- Resulting data sets represent NASA’s latest instruments, calibration techniques, analysis and models
- The data sets are steadily improved over time
- Aims to pioneer efforts in “research to operations”

NASA makes provision of these data sets for societal benefit
- Applied Science program partners with data users spanning a wide variety of fields such as solar energy
- Also provide data sets specifically adapted for various decision making tools
- Now NASA is developing capabilities to provide data sets in new geospatial formats
Validation Against BSRN: Years 2005–2007

Scatter Density of NSNN-BSRN Daily Mean GHI Comparison from 2005-01 to 2007-12

- Max Abs Count = 234
- Max Rel Count = 0.7689%
- Total Count = 30435
- Linear Fitting: $Y = a + bX$
  - $a = 9.9942$
  - $b = 0.9495$
  - $R^2 = 0.8786$

- Bias = 0.3362 (W m$^{-2}$)
- RMS = 33.6447 (W m$^{-2}$)
- $\rho = 0.9374$
- $\sigma = 33.6436$ (W m$^{-2}$)
- $\mu_{BSRN} = 191.2402$ (W m$^{-2}$)
- $\mu_{NSNN} = 191.5763$ (W m$^{-2}$)
- $N = 30435$

Histogram of NSNN-BSRN Daily Mean GHI Differences from 2005-01 to 2007-12

- Daily Mean
- BSRN DIR+DIF

- Leptokurtic: Kurtosis = 6.6098

The red curve is a normal distribution with 0 mean and the same standard deviation as the dataset.
Inputs

**Satellite Radiances and Retrievals:**
NASA/NCDC GridSat v1
And/Or
NCDC ISCCP HXG+ (10 km x 10 km)

**Surface and Ancillary:**
National Snow Ice Data Center
Snow cover (25 km); GTOPO30;
MODIS/MISR (BDRF/albedo);

**NASA GMAO:**
MERRA (0.5°x0.667°, 3-hr upper-air, hourly surface):
Temp, Humidity, Winds

**Column Ozone:**
NOAA TOVS/ NASA OMI TOMS/
NOAA SMOBA (1°x1°, daily)

**Aerosols:**
AEROCOM (MAC v1), NREL Regional

Module 1

Monthly pre-processing:
Calibration, navigation, background surface reflection

Module 2

Satellite pixel/3-hour mask

Module 3

Global, Pixel Radiances; Background radiances and statistics

Global 3-Hour Pixel Meteorology: Matched by Satellite

Module 4

Process Global Land, Hourly Time Interpolation:
Gap Filling

Global Pixel Level Solar Irradiance, Meteorological, Surface Data (3-hourly)

Module 3 Outputs

Global, Hourly Solar Timeseries

Global Land Daily/Monthly Solar Maps

Module 1 Outputs

Produce Meteorological/Aerosol/Surface data hourly at satellite pixel resolution

Module 2 Outputs

Grid box Land Hourly Solar Timeseries

NREL primary deliverable

December 18, 2014

Renewable Energy II (GC42B-03), Fall AGU 2014