Using NASA Satellite and Model Analysis for Renewable Energy and Energy Efficiency Applications

Paul Stackhouse (NASA LaRC)

With grateful acknowledgement to SSAI Team Members, NASA Partners at GISS, GMAO, and LaRC ASDC and Partners at DOE NREL and PNNL, NRCan RETScreen, USGS, USDA, State University of New York-Albany, Univ. of Ga, Univ. of Neb. And numerous small companies
Talk Organization

- NASA Science Objectives
- From Science to Climate and Energy Applications
- Developing Successful Applications in Energy - SSE History
- Current Energy Application Successes
- New Energy and Climate Projects
- Conclusions
Energy demand is rapidly increasing.
IPCC: 90% probability that climate change is due to anthropogenic GHG emissions.
Worldwide, industry efforts are underway and policies are being enacted for mitigating and adapting to climate change through reduction of GHG.
US and International scientific and applied research priorities are being planned to obtain these goals (CCSP/CCTP, NRC Decadal Survey, USGEO, GEO)
Energy efficiency/renewable energies growing 30-50% per year; represent one solution to face issues.

Challenge: Apply NASA scientific expertise, models, and satellite-derived and in-situ measurements in developing applied science data sets for industry, academia, and policy makers in the arena of climate change.
Researching Science Questions

• How is the global Earth system changing?

• What are the primary forcings of the Earth system?

• How does the Earth system respond to natural and human-induced changes?

• What are the consequences of changes in the Earth system for human civilization?

• How well can we predict future changes to the Earth system?
Relevant NASA Science Data Sets

Meteorological Information from GMAO

Daily Maximum Air Temperature For July 4, 2006

Daily Minimum Air Temperature For July 4, 2006
Relevant NASA Science Data Sets

GEWEX Surface Radiation Budget: 23 years of cloud (from ISCCP), SW and LW fluxes at TOA and Surface

GEWEX SRB SW v3.0 (ISCCP, GMAO)

23 Year Annual Average Solar Fluxes (W m$^{-2}$)

75 100 125 150 175 200 225 250 275
Relevant NASA Science Data Sets

FLASHFlux: Global TOA and Surface Fluxes within 1 week of observation from Terra and Aqua

FLASHFlux (CERES/MODIS, GMAO)

Daily Average Solar Irradiance (Wm$^{-2}$)
Relevant NASA Science Data Sets

FLASHFlux: Near-Real Time Energy
Summer 2007 minus Summer 2000-2004 Mean for Arctic

Cloud Fraction
Surface Total Net Energy
The POWER Project

POWER = Prediction of Worldwide Energy Resource

Objective: Improve the Nation’s public and private capability for integrating environmental data from NASA’s satellite-based analysis and modeling research into sound management of energy production and energy efficiency systems.

Goals:
1. Establish partnerships to facilitate the integration and adaptation of NASA satellite analysis and modeling data into electric power industry Decision Support System’s (DSS) and databases.
2. Target such datasets for Electric Power, Renewable Energy, Energy-Efficient Building Design and Biomass Crop Development Industries
3. Transition operational capabilities to government and/or private sector entities.
Relevant NASA Science Data Sets

Global Monthly Irradiance for 2000

Average Daily Solar Radiation for 2000 Jan
POWER: Hub for Applications

EARTH SYSTEM MODELS
- Earth System & Climate Change: GMAO Analysis (GEOS v4.0, v5.1)
- Atmospheric Analysis Projects: ISCCP, SRB, FLASHFlux (CERES, MODIS), GPCP

EARTH OBSERVATIONS
- Satellite: GOES, POES, TRMM, Terra, Aqua, TOMS, SORCE, Aura, CALIPSO, CloudSat, Glory, GPM, NPP
- Land: Aeronet, BSRN, ARM, SURFRAD

ENERGY FORECASTING
- MiniCAM (PNNL)
- Solar Forecasting (SUNY, NREL)

RENEWABLE ENERGY & ENERGY EFFICIENCY
- RETScreen (NRCan)
- HOMER (NREL)
- IEA Task (NREL)
- WMO Buildings
- ASHRAE

SELECTED PROPOSALS
- Crop-Yield Modeling (RPC) (USDA, U.Neb., U. Ga)
- SWERA 2 (Decisions) (USGS, NREL)
- Energy Load Forecasting (Battelle, MSFC)

POWER prototype data set generation

WEB PROTOTYPES
- SSE
- Sustainable Buildings
- Agroclimatology

*Future Mission
POWER Web Site

http://power.larc.nasa.gov
• 22 Years
• New parameters
• Updated Solar algorithm
• Improved validation
• Increased accessibility including regions/time series
• Direct connection to 3 renewable energy DSS tools
POWER Sustains Growth of SSE
Prototype and Web Interface

Surface meteorology and Solar Energy (SSE) Web Interface Usage

<table>
<thead>
<tr>
<th>Time (Year)</th>
<th>Monthly Averages</th>
<th>Release 1</th>
<th>Release 2</th>
<th>Release 3</th>
<th>Release 4</th>
<th>Release 5</th>
<th>Growth</th>
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<tr>
<td></td>
<td>Web Site Hits</td>
<td>1,278</td>
<td>12,533</td>
<td>35,000</td>
<td>74,500</td>
<td>121,180</td>
<td>95:1</td>
</tr>
<tr>
<td></td>
<td>Data Downloads</td>
<td>59</td>
<td>873</td>
<td>3,000</td>
<td>12,530</td>
<td>20,055</td>
<td>340:1</td>
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</table>

R1: DOE
R2: Small Business partners
R3: RET-Screen
R4: Higher resolution
R5: New parameters, HOMER

The thick line represents accruing web hits in time.

8.0 Million Total hits Since Rel 2
POWER Sustains Growth of SSE Prototype and Web Interface

- Web site hosted by ASDC (no charge)
- Site responsible for 88% of all data requests
- Now over 30,000 unique users
- 116 different countries
- Business (72%), University (12%), Government/Military (7%), Private Citizens (7%), Organization (2%)

Sustained growth due to improved data sets from science research and new partnerships

- Release 6: replaced solar data and Met data due to upgrades from SRB and GMAO science; now 22 years
RETScreen
www.retscreen.net

- Partners since 2000
- Variety of renewable energy projects
- Sponsored by Canada
Projects Facilitated by RETScreen

RETScreen® INTERNATIONAL
Solarwall® on High School in Northern Canada

Solar Water Heating at Vancouver International Airport

Photovoltaic Water Pumping System in Africa
### RETScreen International

#### Climate Data

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Temperature</th>
<th>Relative Humidity</th>
<th>Daily Solar Radiation</th>
<th>Atmospheric Pressure</th>
<th>Wind Speed</th>
<th>Earth Temperature</th>
<th>Heating Degree-Days</th>
<th>Cooling Degree-Days</th>
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<tbody>
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<td>49,2 °F</td>
<td>73.0%</td>
<td>2.61</td>
<td>1025</td>
<td>3.1</td>
<td>5.4</td>
<td>406</td>
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<tr>
<td>Feb</td>
<td>50.2 °F</td>
<td>70.4%</td>
<td>3.0</td>
<td>1024</td>
<td>3.0</td>
<td>6.4</td>
<td>330</td>
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<tr>
<td>Mar</td>
<td>49.1 °F</td>
<td>75.1%</td>
<td>3.5</td>
<td>1020</td>
<td>3.3</td>
<td>10.9</td>
<td>264</td>
<td>0</td>
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<tr>
<td>Apr</td>
<td>59.0 °F</td>
<td>73.9%</td>
<td>4.6</td>
<td>1015</td>
<td>3.2</td>
<td>14.3</td>
<td>90</td>
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<tr>
<td>May</td>
<td>68.9 °F</td>
<td>74.8%</td>
<td>5.0</td>
<td>1010</td>
<td>3.3</td>
<td>18.9</td>
<td>326</td>
<td>0</td>
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<tr>
<td>Jun</td>
<td>74.8 °F</td>
<td>81.6%</td>
<td>5.6</td>
<td>1010</td>
<td>3.3</td>
<td>18.9</td>
<td>326</td>
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<td>Jul</td>
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<td>80.0%</td>
<td>5.8</td>
<td>1006</td>
<td>3.3</td>
<td>22.8</td>
<td>414</td>
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<td>Aug</td>
<td>81.9 °F</td>
<td>81.3%</td>
<td>6.3</td>
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<td>3.3</td>
<td>26.6</td>
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<td>Sep</td>
<td>75.9 °F</td>
<td>76.6%</td>
<td>6.4</td>
<td>101.1</td>
<td>3.4</td>
<td>23.1</td>
<td>561</td>
<td>0</td>
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<tr>
<td>Oct</td>
<td>66.7 °F</td>
<td>73.8%</td>
<td>5.9</td>
<td>101.8</td>
<td>2.9</td>
<td>18.4</td>
<td>288</td>
<td>0</td>
</tr>
<tr>
<td>Nov</td>
<td>56.3 °F</td>
<td>73.0%</td>
<td>5.4</td>
<td>1023</td>
<td>3.0</td>
<td>13.2</td>
<td>135</td>
<td>105</td>
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<td>Dec</td>
<td>46.0 °F</td>
<td>71.7%</td>
<td>5.2</td>
<td>1026</td>
<td>2.8</td>
<td>7.7</td>
<td>316</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Source
- Ground

#### Measured at:
- m: 10

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**Five Step Start**

**Settings & Site Conditions**

Enter data in shaded cells from top to bottom of each worksheet.

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**Integrated Features**

**Climate Data**
RETScreen’s Reliance on POWER Data

- Clean energy project analysis software
- Funded by Canada (NRCan)
- Direct query of SSE data
- 155,100 users
- 222 countries
- 1000 new users every week
- Release 4: 26 languages

Points represent world’s cities (~10,000). Red have in situ observations. Blue defer to NASA LaRC data sets (~5,000). Data for locations between points are found through a direct link to SSE.
## RETScreen’s and NASA’s Impact

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>User Savings</td>
<td>$600 million</td>
<td>$7.9 billion</td>
<td>~$200 Billion</td>
</tr>
<tr>
<td>Installed Capacity</td>
<td>1,000 MW</td>
<td>24 GW</td>
<td>-</td>
</tr>
<tr>
<td>Installed Value</td>
<td>$1,800 million</td>
<td>41 billion</td>
<td>~$1 Trillion</td>
</tr>
<tr>
<td>GHG Reduction</td>
<td>630 kT CO&lt;sub&gt;2&lt;/sub&gt;/yr</td>
<td>20MT CO&lt;sub&gt;2&lt;/sub&gt;/yr</td>
<td>-</td>
</tr>
</tbody>
</table>

On the value of NASA’s contribution, Greg Leng, Directeur RETScreen Project: NASA would have an impact on every single project......

NASA is highly regarded by our users because of the contribution you have made to clean energy deployment via the partnership with RETScreen......

Source: <sup>1</sup>RETScreen International: Results and Impacts 1996-2012;  
<sup>2</sup>Personal Communication from RETScreen Directeur, Greg Leng

Currencies in Canadian dollars: $1 CAD ~ $.72 US, May 12, 2004
HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. HOMER’s optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. HOMER models both conventional and renewable energy technologies:

- **Power sources:**
  - solar photovoltaic (PV)
  - wind turbine
  - run-of-river hydro power
  - generator: diesel, gasoline, biogas, alternative and custom fuels, cofired
  - electric utility grid
  - microturbine
  - fuel cell

- **Storage:**
  - battery bank
  - hydrogen

- **Loads:**
  - daily profiles with seasonal variation
  - deferrable (water pumping, refrigeration)
  - thermal (space heating, crop drying)
  - efficiency measures

**You can now subscribe to the HOMER newsletter. Click here for details**

You can download and use HOMER for free. You must be a registered user to download the software. When you install HOMER, you automatically receive a free six-month license, which you can renew for free an unlimited number of times. To register, click **Log On / Register** on the left navigation and complete the registration form.
The Chiloé Islands are located off the Pacific Coast of Southern Chile. Of the more than 40 islands in the group, 32 are too far from the coast to be connected to the mainland electric grid and either have no access to electricity, or intermittent access provided by diesel generators. The islands range in size from 12 to 450 homes, with projected loads ranging from 17 to 1004 kWh/day. Economic activity on the islands includes farming, animal husbandry, and fishing. NREL, through a cooperative agreement between the governments of Chile and the United States, worked with a team of local and international experts to implement a pilot hybrid power system on Isla Tac, one of the Chiloé islands. The team conducted economic, loads, and renewable resource studies and used the results from those studies as inputs to HOMER.

The island of Tac, Region de los Lagos, Chile

An optimization analysis using HOMER showed that a wind-diesel system with battery storage would most cost-effectively supply the energy required by the island. HOMER’s sensitivity analysis capability helped the team assess the impact of fuel price on the least-cost system design.

The team also used two other NREL models: VIPOR to determine electric distribution mini-grid costs, and Hybrid2 to finalize the design of the hybrid power system. This work helped lead to a $40 million multilateral development bank loan to provide rural electrification projects, including replication of this pilot project, across the entire Chiloé island region.

Rural Electrification in the Chiloé Islands

The Isla Tac Power system provides power to the islands' 82 families.
• **NREL HOMER Micropower Optimization Model**
  - *HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications.*
  - Highlighted in CCSP SAP 5.1 as a case study in decision support using Earth observations
  - NASA and other Earth observation data sources critical to its success (e.g., solar from LaRC; AOD from GSFC GOCART model, MODIS, MISR, TOMS; Digital land cover from NASA & USGS)
  - Used extensively around the world for determining the optimal mix of power technologies for meeting specified load conditions at specified locations
  - “*Best hourly assessment tool for hybrid renewable electric generation systems in the world - bar none.*”
    Dr. Jan F. Kreider
    Building Systems Program, University of Colorado, January 2008

• **HOMER automatically accesses and inputs the POWER SSE data for the specific location that the model is analyzing.**
  - Collaboration with ROSES-funded SWERA II task at USGS EROS data center.
HOMER’s Relience on NASA

- Lead Dr. Peter Lilienthal, NREL, notes most users now use NASA’s solar irradiance data set.
- POWER/SSE is showing increasing HOMER related data requests

<table>
<thead>
<tr>
<th>Country</th>
<th>Users</th>
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<tbody>
<tr>
<td>USA</td>
<td>6074</td>
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<td>Canada</td>
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<tr>
<td>Australia</td>
<td>1034</td>
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<tr>
<td>Spain</td>
<td>993</td>
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<table>
<thead>
<tr>
<th>Organization Type</th>
<th>Users</th>
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<tbody>
<tr>
<td>Academic or research</td>
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<tr>
<td>For-profit corporation</td>
<td>3193</td>
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<tr>
<td>Government</td>
<td>1441</td>
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<td>Individual</td>
<td>6971</td>
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<tr>
<td>NGO</td>
<td>890</td>
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<tr>
<td>Other</td>
<td>551</td>
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</tbody>
</table>

Total Users: 20777
Countries: 189

Future: HOMER actively being modified by NREL for regional distributed power generation Assessment => perfectly suited for NASA coarse scale data sets
PNNL Integrated Assessment Model
Initialization with NASA/POWER Data

PNNL/Joint Global Change Research Center uses NASA POWER data sets for initiation of MiniCam 50-year energy market forecasts for policy planning

Direct Solar Irradiance for areas with 50 or less no-sun days per year

Forested and Agricultural Areas Excluded
PNNL’s Assessment Results

Figure 2-4. Reference Scenario and one stabilization case (550 ppm constraint). Stabilization of CO₂ concentration in the atmosphere implies fundamental change to the global energy system.
NASA POWER Contributes to International Energy Agency Task

- **International collaboration** representing >8 nations; >15 Organizations
- **5 Year Task**
- **NREL led**
- **NASA/POWER contributing expertise on solar resource estimation and validation, user and interface information, data sets and research (results from GEWEX SRB and GEWEX Radiative Flux Assessment)**
**NASA Energy Program Contributions to GEO**

- **Core member of GEO energy community of practice**
  - Applied Sciences-funded activities contribute directly to GEO work plan tasks EN06-04, EN07-01, EN07-03
  - IEA activity, leveraged with ESA partnership, provided first GEO energy early achievement project “Solar Information for Developing Countries”
  - One of principal authors of GEO Energy Strategic Plan, which closely mirrors Applied Sciences Program plan
  - Lead for **CEOS** Energy SBA activities (GEO-CEOS remapping activities)
  - Energy articles published in GEO summit publication (two with NASA involvement)

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**Informing decision making in the energy sector using NASA spaceborne observations and model predictions**

Richard S. Eckman and Paul W. Southworth, Jr., NASA Langley Research Center

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5/28/2008

NASA LaRC Research and Applied Science 29
GEOSS: 1st Energy Demonstration
(hosted by Ecole des Mines de Paris)

Results of your request

NASA SSE - Surface meteorology and Solar Energy
National Aeronautics and Space Administration (NASA, USA)

| Site latitude (positive means North) | 45.390 |
| Site longitude (positive means East) | -75.910 |
| Beginning date | 1983-07-01 |
| End date | 1993-01-01 |
| Irradiance | Daily mean of irradiance in W/m² (-999 if no data) |
| Irradiation | Daily irradiation in Wh/m² (-999 if no data) |

Daily means of Irradiances in W/m² from NASA SSE

<table>
<thead>
<tr>
<th>Month</th>
<th>Day</th>
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<th>Irradiation</th>
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<tr>
<td>1983</td>
<td>7</td>
<td>321</td>
<td>7720</td>
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SWERA 2: Renewable Resources for Developing Nations

- USGS-led ROSES Proposal
- Data archive, User Interface at UNEP GRiD/USGS
- NASA/POWER role: supply global data parameters

Welcome To SWERA

The SWERA website provides information about solar and wind energy resources in thirteen partner countries around the world. Products held in the SWERA archive include data on wind and solar energy potential, plus detailed country energy analyses. To learn more about renewable energy in each country or the partner agencies, click on the map or the menu. SWERA is a UNEP (United Nations Environment Programme) project with co-financing from GEF. The goal is to provide solar and wind energy assessments to potential investors and the public to promote more effective use of alternative energy resources.

Now with the completion of the successful pilot project, SWERA is being expanded into a full programme offering resource information and mapping tools across the spectrum of renewable energy sources. All information and tools can be found in one online location with a common user interface... click here for more details.
Potential Future Energy Applications

• **Advanced Long-term Solar Mapping (NREL)**
  – Earth System Science models (ESSM): GMAO MERRA, GOCART
  – Satellite-based: ISCCP B1U (w/ 8km pixels), TOVS-TOMS

• **Solar Energy Forecasting (NREL, SUNY)**
  – Earth System Science models (ESSM): GMAO forecasts
  – Satellite-based: FLASHFlux (for validation)

• **Building Targeting and Monitoring (NRCan)**
  – ESSM: GMAO operational assimilation
  – Satellite-based: FLASHFlux

• **Building data sets for design (DOE, ASHRAE)**
  – ESSM: GMAO GEOS-4, MERRA, GOCART
  – Satellite-based: GEWEX SRB

• **Load Forecasting (Battelle, Ventyx)**
  – ESSM: GMAO operational assimilation, forecasts; SPORT
Advanced Long-term Solar Mapping

Using newly archived ISCCP B1U and latest long-term H2O, O3, aerosol information develop long-term solar maps at high resolution
Benchmaking Solar Forecasts

Vital for assessing potential large scale PV and/or CSP production when integrating into traditional power grid.

Multi-Model Solar Irradiance Comparison

GMAO Solar Irradiance Forecast

Draft courtesy Perez, SUNY
Building Monitoring and Targeting

• **Monitoring and Targeting**: gaining and maintaining control over energy consumption through measurement and analysis followed by well-directed actions.
  – *Comparison between energy consumption and influencing factors such as weather; establish and evaluate consumption targets*
  – *Purpose: energy cost savings for budgeting, evaluation of energy efficiency upgrades, product/service costing*

• **NRCAN CETR RETScreen leading effort for newly formed building monitoring and targeting program**
  – Need global near-real time (within 1 month) solar and meteorological (i.e. heating degree day) data sets
  – FLASHFlux with operational GMAO assimilation perfectly suited by providing daily and monthly estimates of parameters
Long-term Climate Information
For Building Design

Global Building Design Climate Zones
(with ASHRAE and DOE)

Location Specific Traditional
Architectural Comfort Zone
Design Charts (with AIA)

30 Years Needed!
Energy Load Forecasting

ROSES proposal w/ Evaluation NASA long and high resolution Spokane, Washington

Recently highlighted in Press!

Courtesy E. Zell
Conclusions

• Energy Management Program has and continues to yield significant results for nation and international programs through Science => Applications transfer

• Successes involve supporting renewable energy and energy efficient technology optimization; thus are relevant to identified priorities in climate change mitigation and adaptation.

• The model of success in this field has been long-term partnerships featuring the development and dissemination of specifically tailored data sets.

• Data sets made available through web based interfaces provide opportunities for new projects and new partnerships