Using NASA Satellite and Reanalysis to Provide Climate Data Products for Energy Industry Applications

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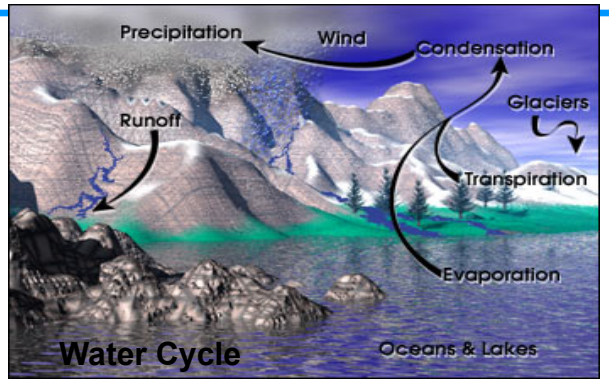
Why NASA?

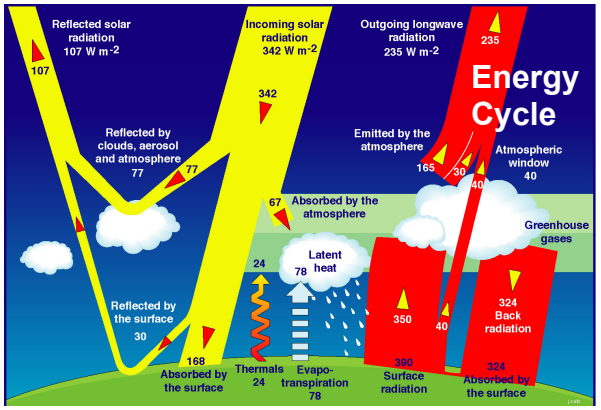
Researching Science Questions

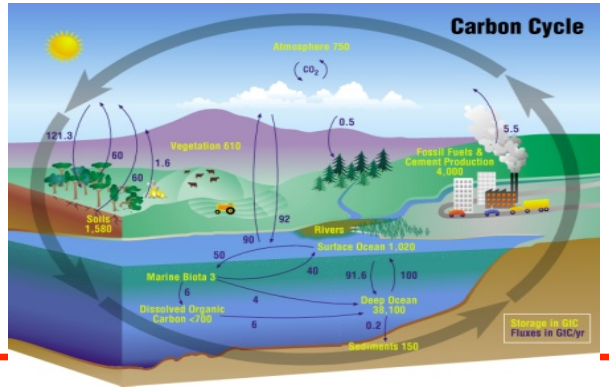
- ***How is the global Earth system changing?***
- ***What are the primary forcings of the Earth system?***
- ***How does the Earth system respond to natural and human-induced changes?***
- ***What are the consequences of changes in the Earth system for human civilization?***
- ***How well can we predict future changes to the Earth system?***

Capabilities for Science Answers

- ***New instrumentation on various observing platforms***
- ***New/improved analysis techniques***
- ***Enhanced modeling and assimilation***





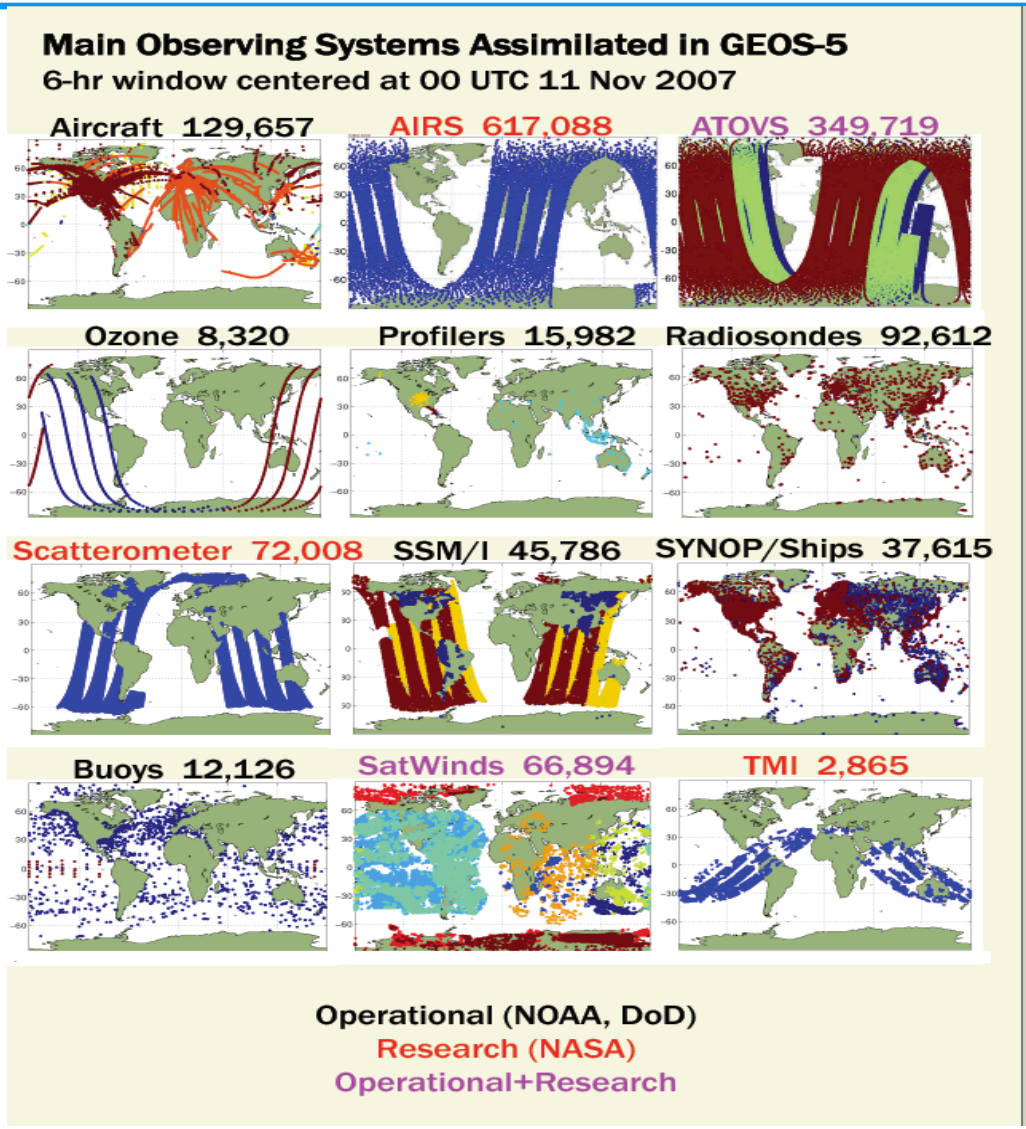


Meteorological Data Sources

NASA's Global Modeling & Assimilation Office (GMAO)

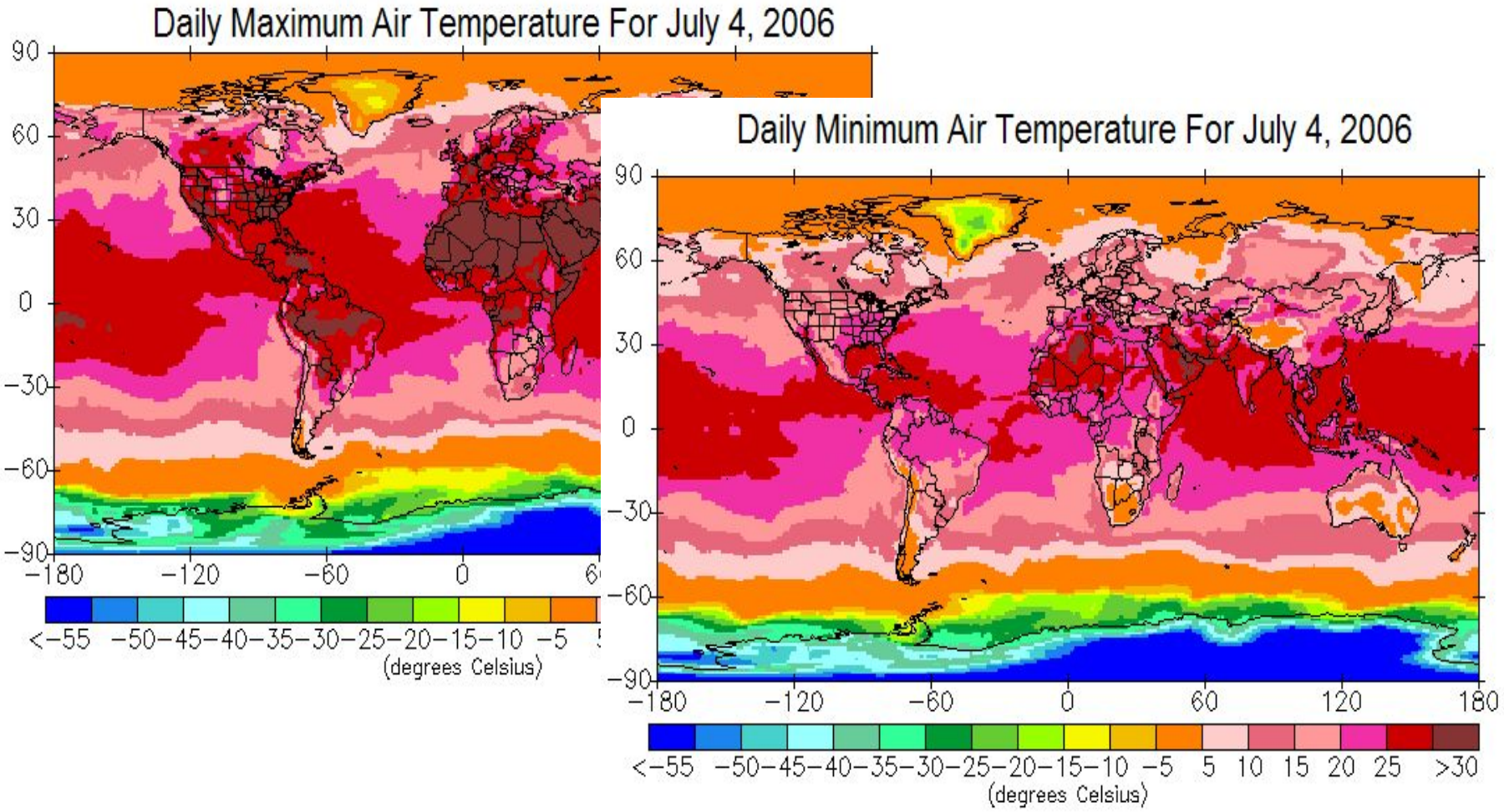
The GMAO (based at GSFC) develops and uses comprehensive models and assimilation systems that support NASA's Earth science research enterprise and contribute to the nation's capabilities in climate, weather and composition prediction.

Global Weather and Climate Models + Observations = Assimilation Model



Example Global Parameters

Temperature Information from GMAO GEOS-4



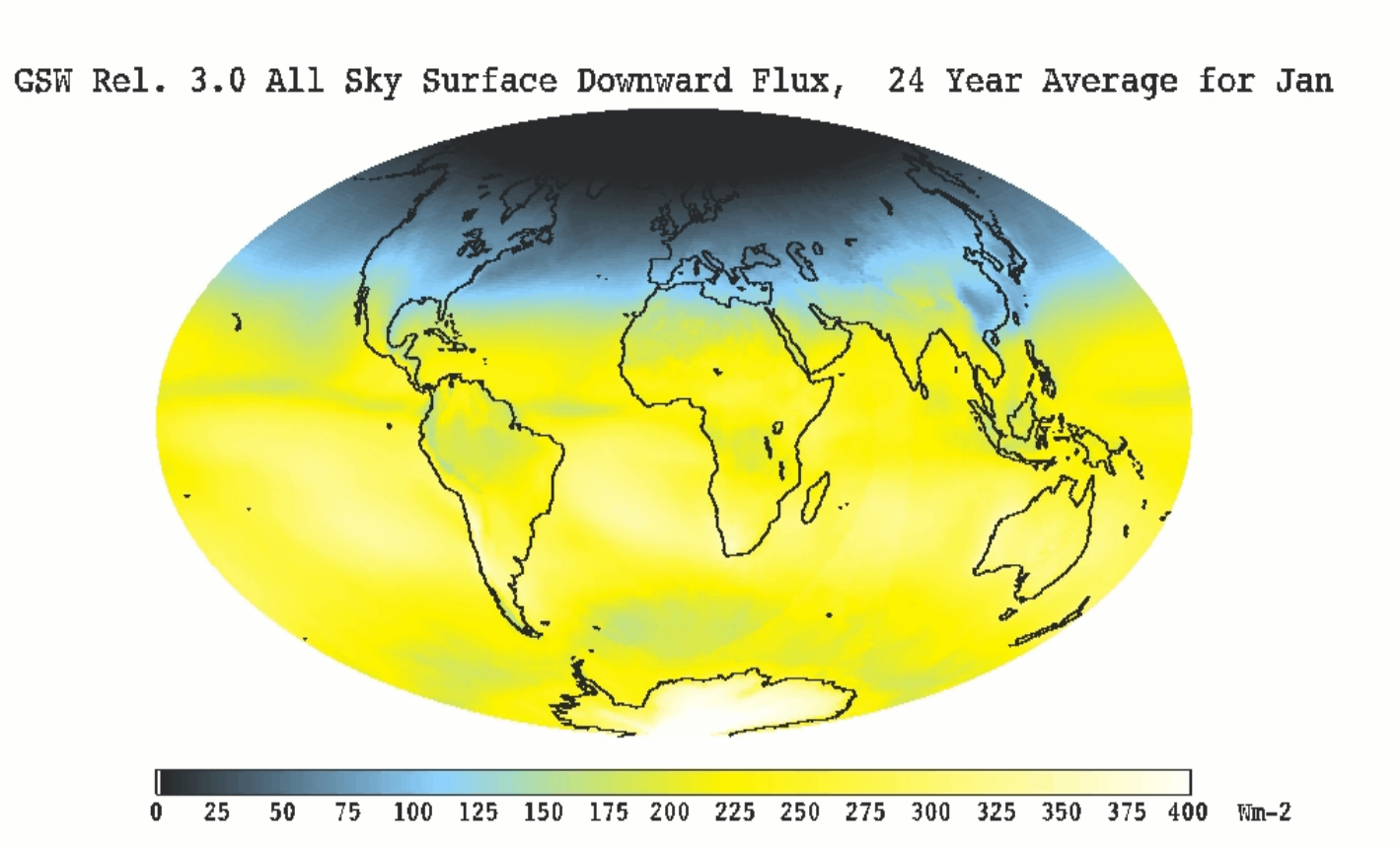
Relevant NASA Science Data Sets

GEWEX Surface Radiation Budget: 24+ years of cloud (from ISCCP), SW and LW fluxes at TOA and Surface

GEWEX SRB SW v3.0 (ISCCP, GMAO)

24 Year Annual Cycle Surface Solar Fluxes ($W\ m^{-2}$)

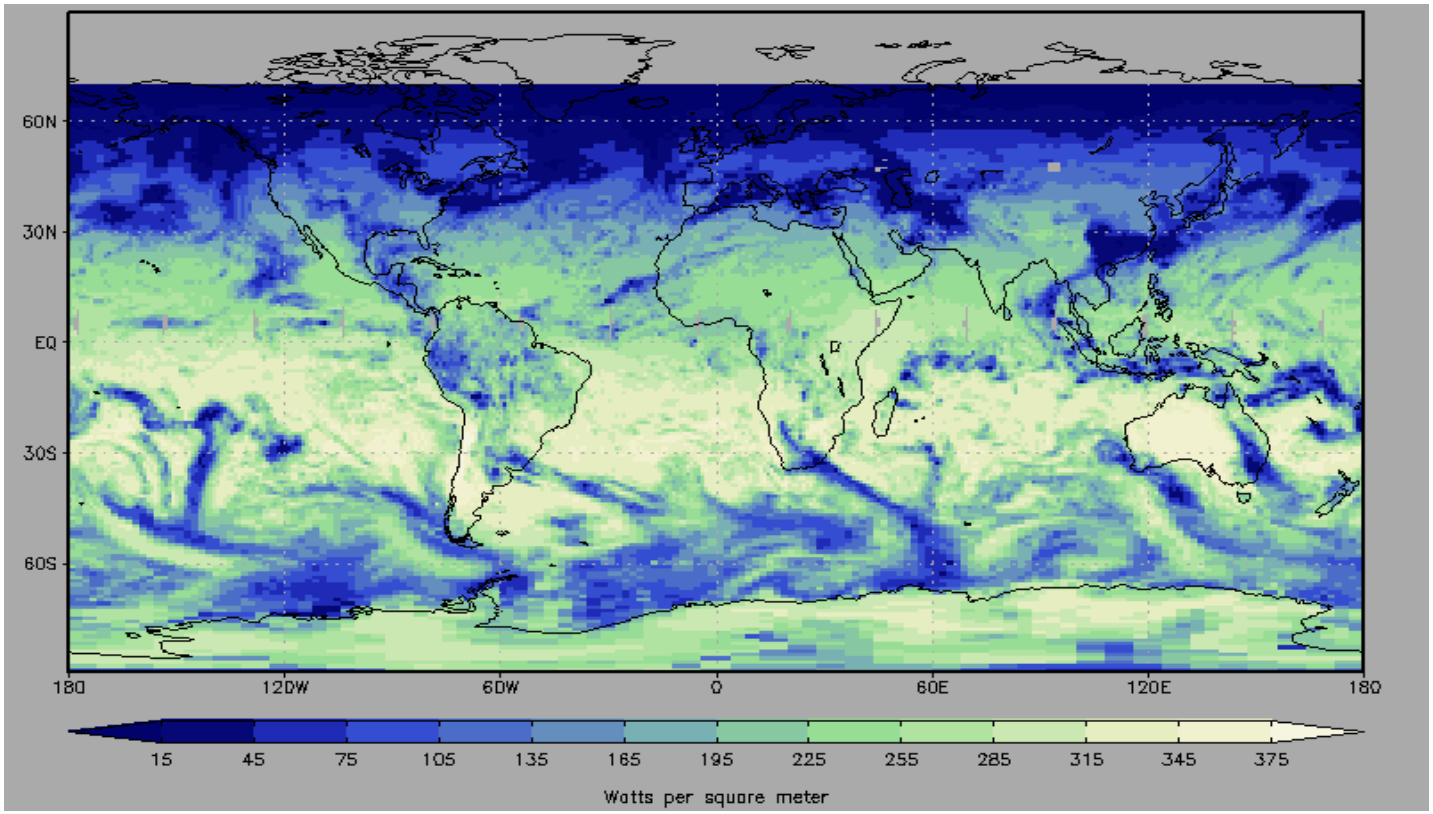
(Jan 1984 – Dec 2007)



Relevant NASA Science Data Sets

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

CERES FLASHFlux (CERES/MODIS, GMAO)



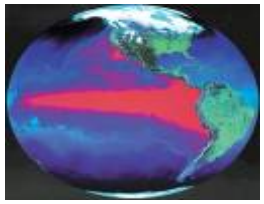
Daily Average Solar Irradiance for Feb 2, 2012 (Wm^{-2})

NASA Applied Earth Science: POWER Project

Applied Sciences Goal: The Applied Sciences program *extends* NASA Earth Science research and observations *for practical use* in environmentally-related decision and policy making.

- Emphasizes partnerships in variety of application theme areas

Key Theme



Climate & Energy

POWER = Prediction of Worldwide (renewable) Energy Resource

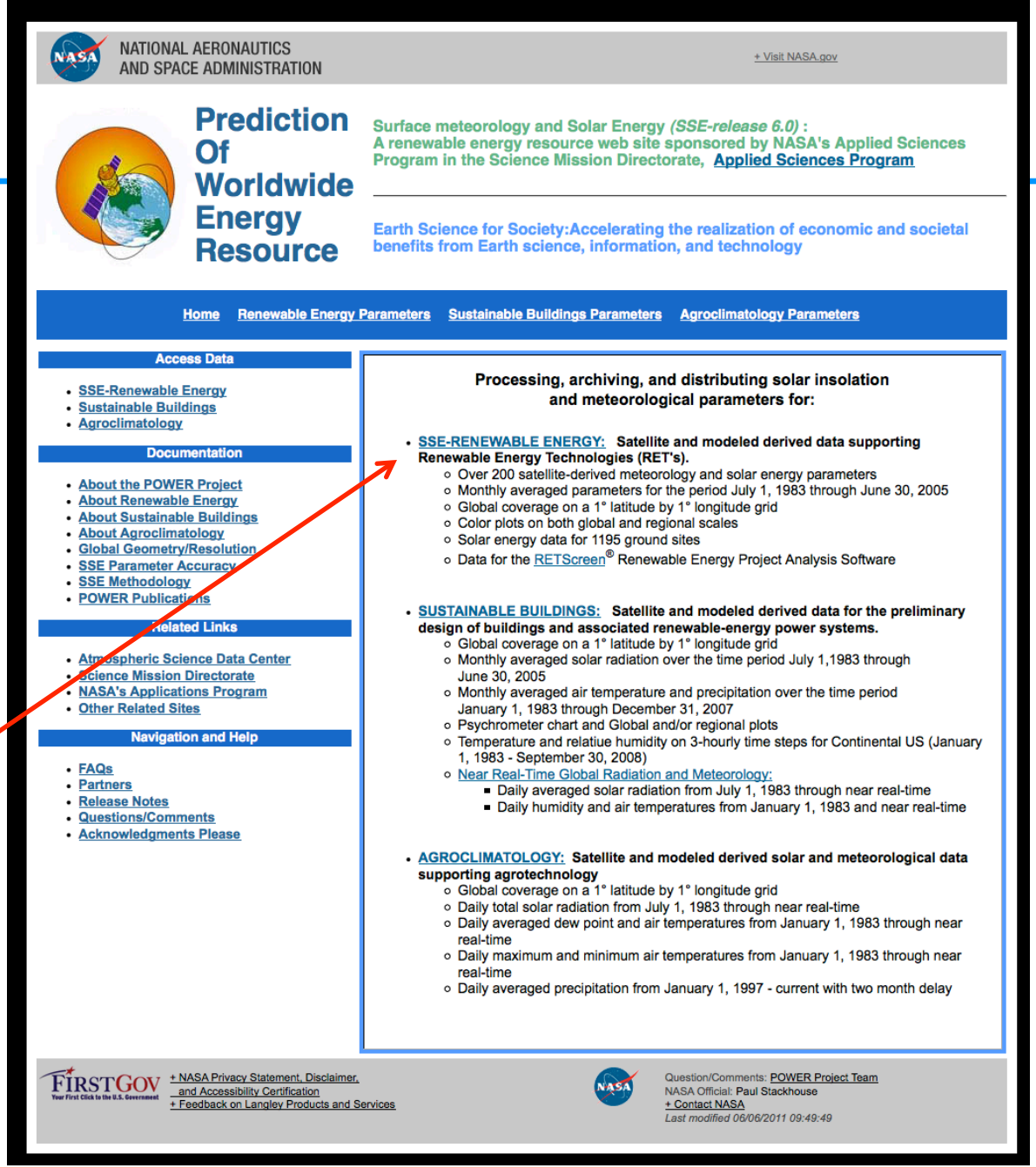
Objective: *Improve* the Nation's public and private capability for *integrating environmental data* from NASA research to support energy production and increased energy efficiency.

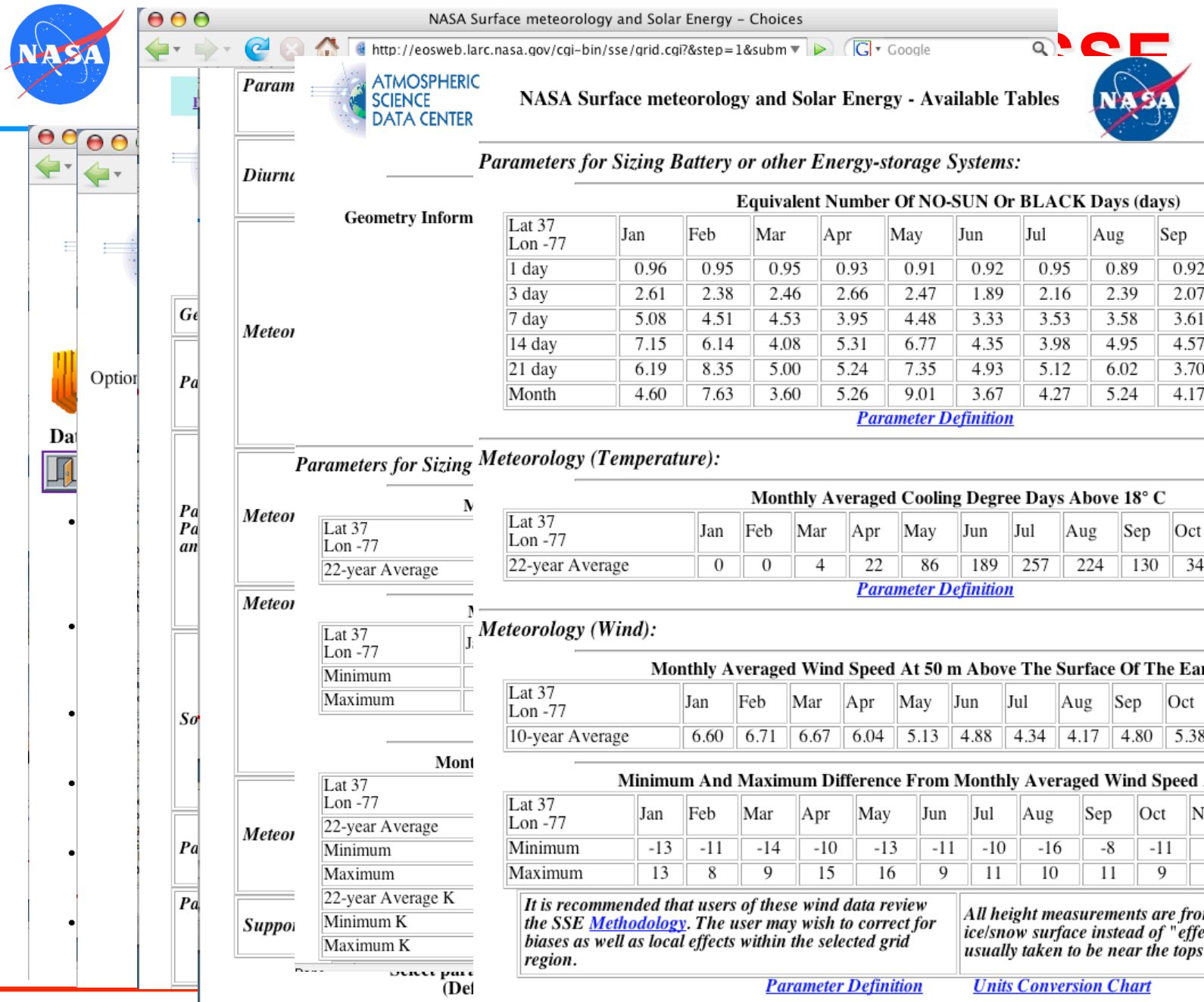
Goals: Through partnerships *derive/validate/provide* parameters relevant to industry needs; link to decision support, transition when possible.

POWER Web Site

http://power.larc.nasa.gov

Provides access to both Long-term and Near-Term Time Data Sets




NASA Surface meteorology and Solar Energy - Choices
http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&step=1&subm
Google
ATMOSPHERIC SCIENCE DATA CENTER
NASA Surface meteorology and Solar Energy - Available Tables
Parameters for Sizing Battery or other Energy-storage Systems:
Equivalent Number Of NO-SUN Or BLACK Days (days)
Lat 37 Lon -77 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec
1 day | 0.96 | 0.95 | 0.95 | 0.93 | 0.91 | 0.92 | 0.95 | 0.89 | 0.92 | 0.96 | 0.94 | 0.96
3 day | 2.61 | 2.38 | 2.46 | 2.66 | 2.47 | 1.89 | 2.16 | 2.39 | 2.07 | 2.37 | 2.46 | 2.44
7 day | 5.08 | 4.51 | 4.53 | 3.95 | 4.48 | 3.33 | 3.53 | 3.58 | 3.61 | 4.43 | 3.58 | 4.11
14 day | 7.15 | 6.14 | 4.08 | 5.31 | 6.77 | 4.35 | 3.98 | 4.95 | 4.57 | 5.39 | 4.74 | 7.12
21 day | 6.19 | 8.35 | 5.00 | 5.24 | 7.35 | 4.93 | 5.12 | 6.02 | 3.70 | 7.40 | 5.82 | 8.44
Month | 4.60 | 7.63 | 3.60 | 5.26 | 9.01 | 3.67 | 4.27 | 5.24 | 4.17 | 6.81 | 6.49 | 6.65
Parameter Definition
Meteorology (Temperature):
Monthly Averaged Cooling Degree Days Above 18° C
Lat 37 Lon -77 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Sum
22-year Average | 0 | 0 | 4 | 22 | 86 | 189 | 257 | 224 | 130 | 34 | 5 | 1 | 952
Parameter Definition
Meteorology (Wind):
Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)
Lat 37 Lon -77 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average
10-year Average | 6.60 | 6.71 | 6.67 | 6.04 | 5.13 | 4.88 | 4.34 | 4.17 | 4.80 | 5.38 | 6.27 | 6.65 | 5.63
Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)
Lat 37 Lon -77 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average
Minimum | -13 | -11 | -14 | -10 | -13 | -11 | -10 | -16 | -8 | -11 | -8 | -11 | -11
Maximum | 13 | 8 | 9 | 15 | 16 | 9 | 11 | 10 | 11 | 9 | 10 | 7 | 11
It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.
All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.
Parameter Definition
Units Conversion Chart

Parameter Validation: Key to Usage

Power validation significant, included in extensive methodology document

Table I-1: Regression analysis of SSE versus BSRN monthly averaged values for the time per

Table I-2: Linear least squares regression analysis of SSE versus NCDC monthly averaged values for the time period 1983 through 2006

Parameter	Slope	Intercept	R^2	RMSE	Bias
Tmax (°C)	0.99	-1.58	0.95	3.12	-1.83
Tmin (°C)	1.02	0.10	0.95	2.46	0.24
Tavg (°C)	1.02	-0.78	0.96	2.13	-0.58
Tdew (°C)	0.96	-0.80	0.95	2.46	-1.07
RH (%)	0.79	12.72	0.56	9.40	-1.92
Heating Degree Days (degree days)	1.02	12.47	0.93	77.20	17.28
Cooling Degree Days (degree days)	0.86	2.36	0.92	28.90	-5.65
Atmospheric Pressure (hPa)	0.89	102.16	0.74	27.33	-10.20

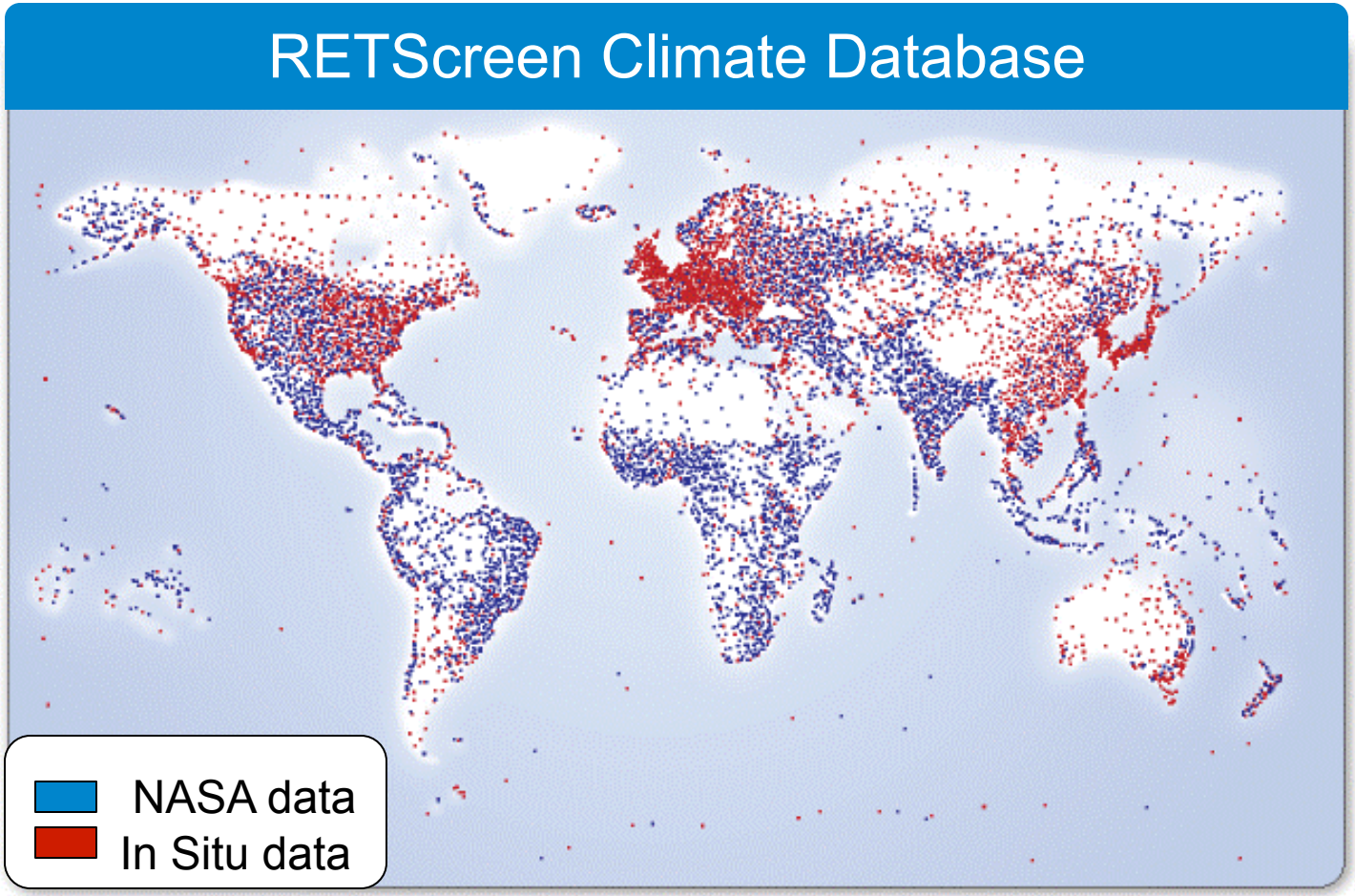
Decision Support: RETScreen

www.retscreen.net

- Clean Energy Project Analysis Tool
- Aimed for both feasibility and detailed scenario analysis
- RETScreen 4 built on Excel; New RETScreen Plus stand-alone
- Partners since 2000
- Over 330,000 users in 36 different languages

RETScreen's Reliance on POWER Data

- Built-in cities of world
- *In situ* used if present (red)
- If missing uses NASA (blue)
- If partial missing supplement with NASA (most)
- Direct query of SSE data through web



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.

Example Usage: RETScreen Clean Energy Projects

RETSCREEN® INTERNATIONAL www.retscreen.net

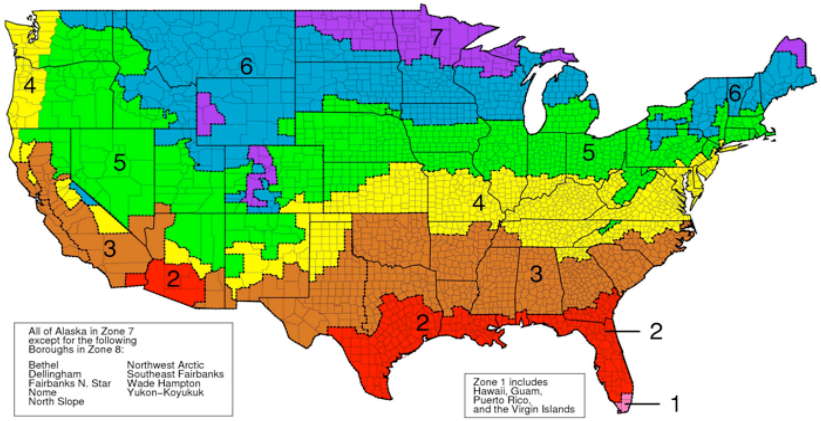
Solarwall® on High School in Northern Canada

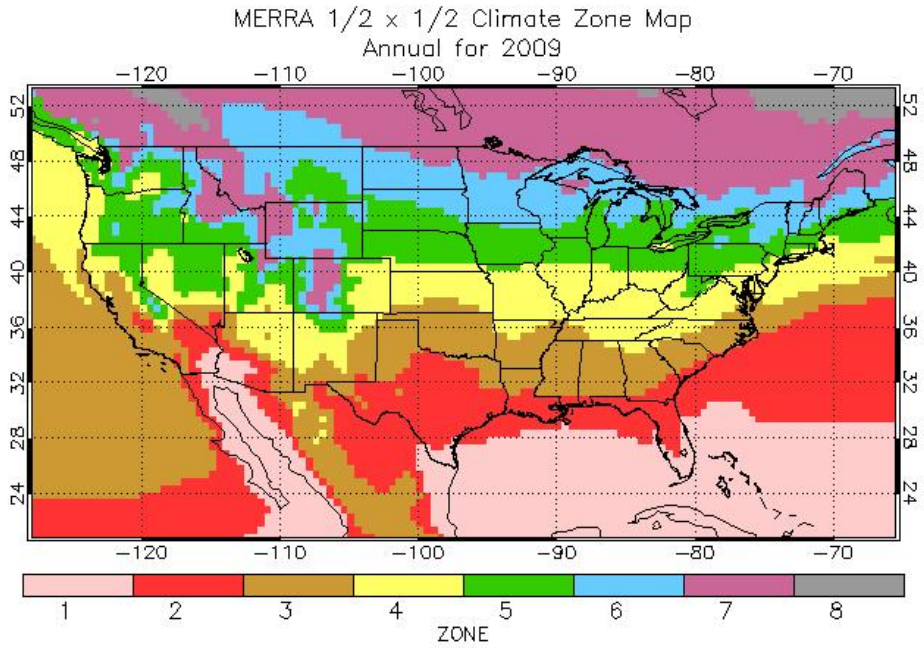
Solar Water Heating at Vancouver International Airport

Photovoltaic Water Pumping System in Africa

Sector Impact: Building Climate Zone Maps

- *Derive long-term climate zone maps for building guidelines – determines building codes*
- *Assess variability of zones*
- *Working w/ GMAO (MERRA) and ASHRAE*





POWER Web Site

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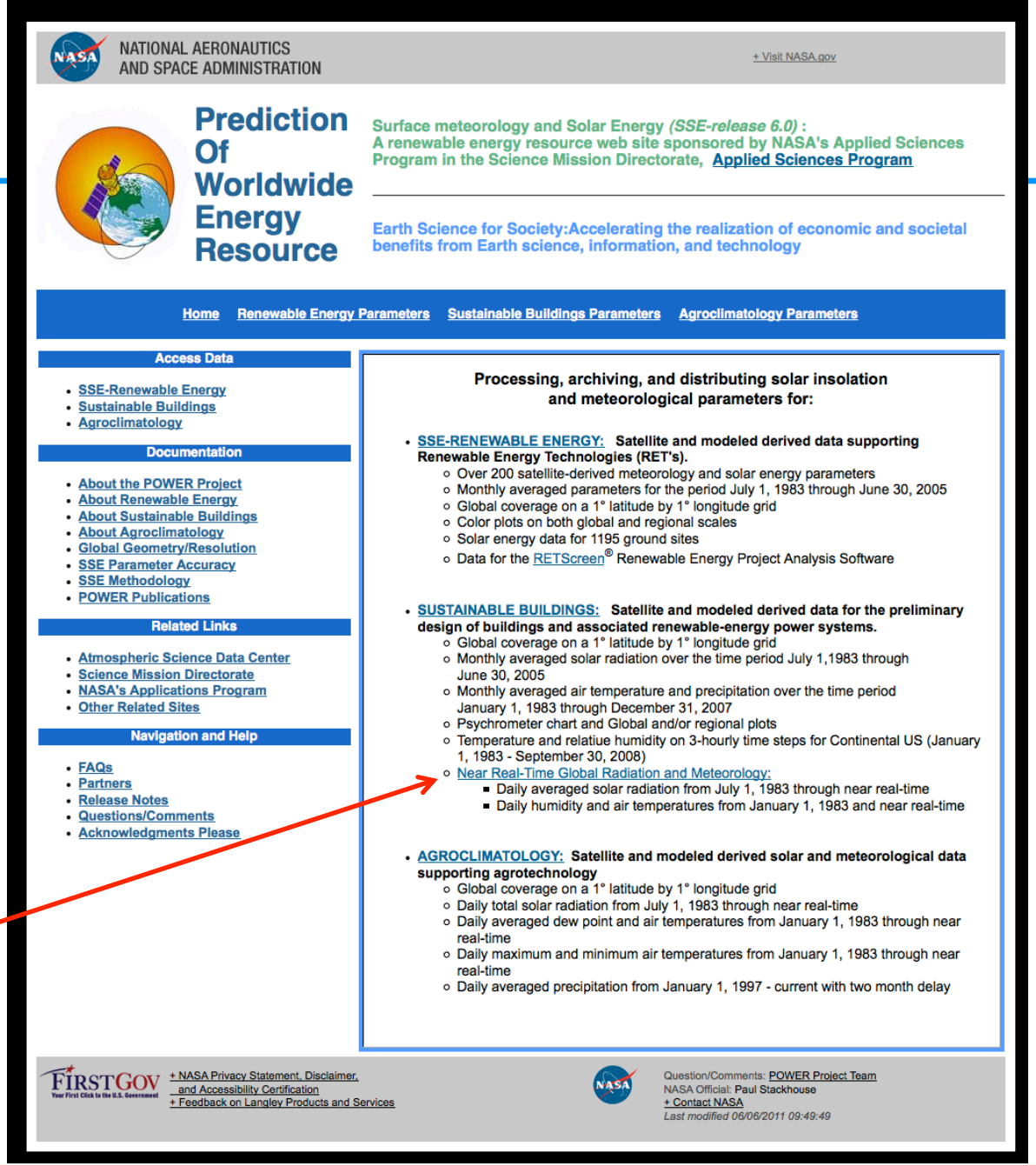


NASA's Near Real-time Daily Averaged Data Time Series

Variable	Parameter	Units
swv_dwn	Average Insolation Incident On A Horizontal Surface	kWh/m^2/day
lwv_dwn	Average Downward Longwave Radiative Flux	kWh/m^2/day
toa_dwn	Average Top-of-atmosphere Insolation	kWh/m^2/day
avg_kt	Average Insolation Clearness Index	0 to 1.0
clr_sky	Average Clear Sky Insolation On A Horizontal Surface	kWh/m^2/day
clr_kt	Average Clear Sky Insolation Clearness Index	0 to 1.0
PS	Average Atmospheric Pressure	kPa
T2M	Average Air Temperature At 2 m	degrees C
T2MN	Minimum Air Temperature At 2 m	degrees C
T2MX	Maximum Air Temperature At 2 m	degrees C
Q2M	Average Humidity Ratio At 2 m	
RH2M	Relative Humidity At 2 m	%
DFP2M	Dew/Frost Point Temperature At 2 m	degrees C
TSKIN	Average Earth Skin Temperature	degrees C
WS10M	Wind Speed At 10 m	m/s

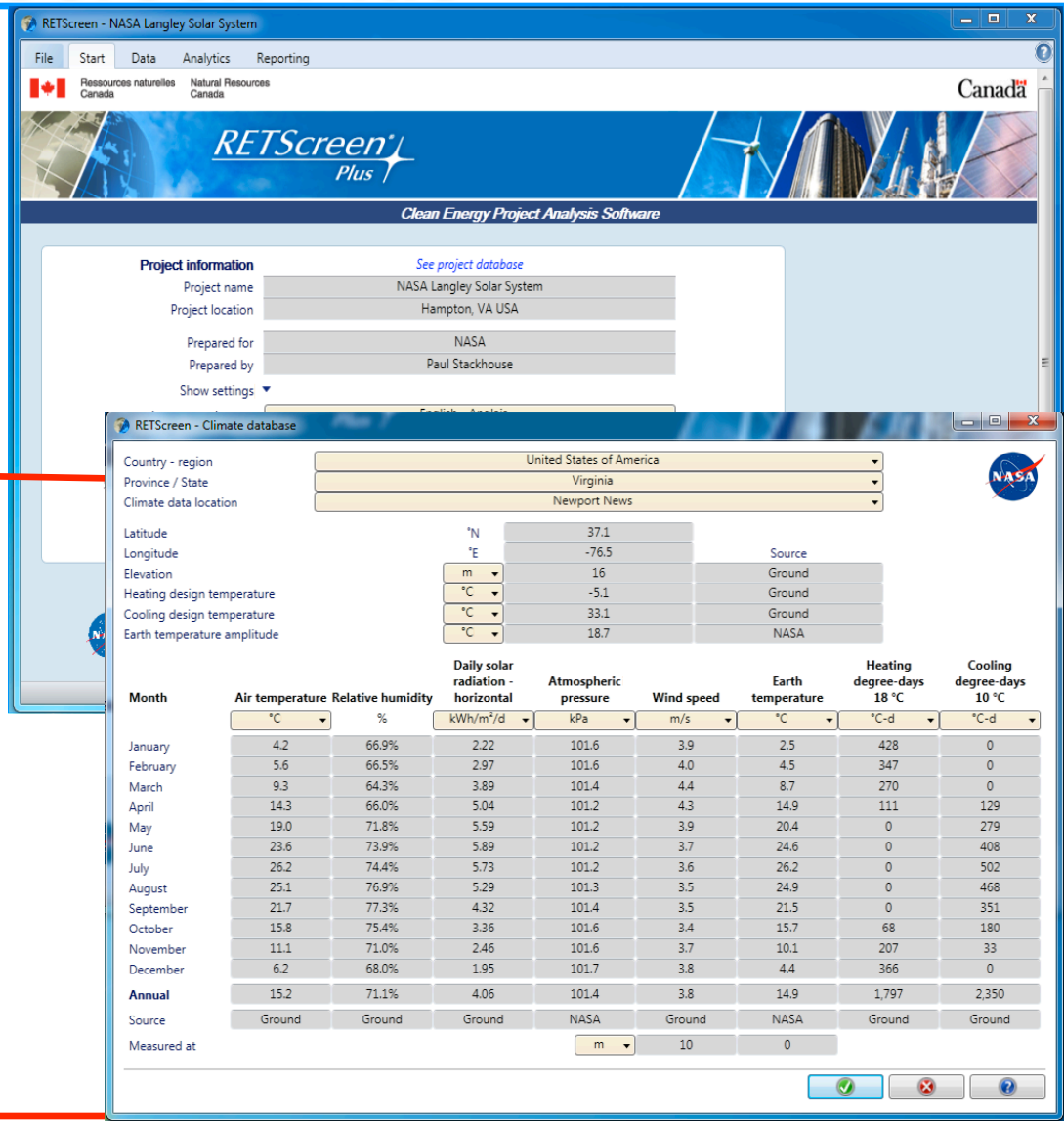
Note: Precipitation will be included in future data products

Energy Monitoring with RETScreen Plus

Objective: Enable "users to monitor, analyze and report key energy performance data to facility operators, managers and senior decision-makers."

Usage:

1. Determine & obtain building energy and meteorological information for any location in world
2. Use multivariate analysis to determine system performance as a function of meteorological variability
3. Monitoring building energy performance for system changes, target higher efficiency and reporting verification



Month	Air temperature °C	Relative humidity %	Daily solar radiation - horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days 18 °C °C-d	Cooling degree-days 10 °C °C-d
January	4.2	66.9%	2.22	101.6	3.9	2.5	428	0
February	5.6	66.5%	2.97	101.6	4.0	4.5	347	0
March	9.3	64.3%	3.89	101.4	4.4	8.7	270	0
April	14.3	66.0%	5.04	101.2	4.3	14.9	111	129
May	19.0	71.8%	5.59	101.2	3.9	20.4	0	279
June	23.6	73.9%	5.89	101.2	3.7	24.6	0	408
July	26.2	74.4%	5.73	101.2	3.6	26.2	0	502
August	25.1	76.9%	5.29	101.3	3.5	24.9	0	468
September	21.7	77.3%	4.32	101.4	3.5	21.5	0	351
October	15.8	75.4%	3.36	101.6	3.4	15.7	68	180
November	11.1	71.0%	2.46	101.6	3.7	10.1	207	33
December	6.2	68.0%	1.95	101.7	3.8	4.4	366	0
Annual	15.2	71.1%	4.06	101.4	3.8	14.9	1,797	2,350
Source	Ground	Ground	Ground	NASA	Ground	NASA	Ground	Ground
Measured at				m	10	0		

Monitoring and Targeting Case: NASA LaRC Badge and Pass Office

SOUTHERN ENERGY MANAGEMENT
ENERGY EFFICIENCY & SOLAR POWER

Badge and Pass Office Solar Energy Project

ESG ENERGY SYSTEMS GROUP

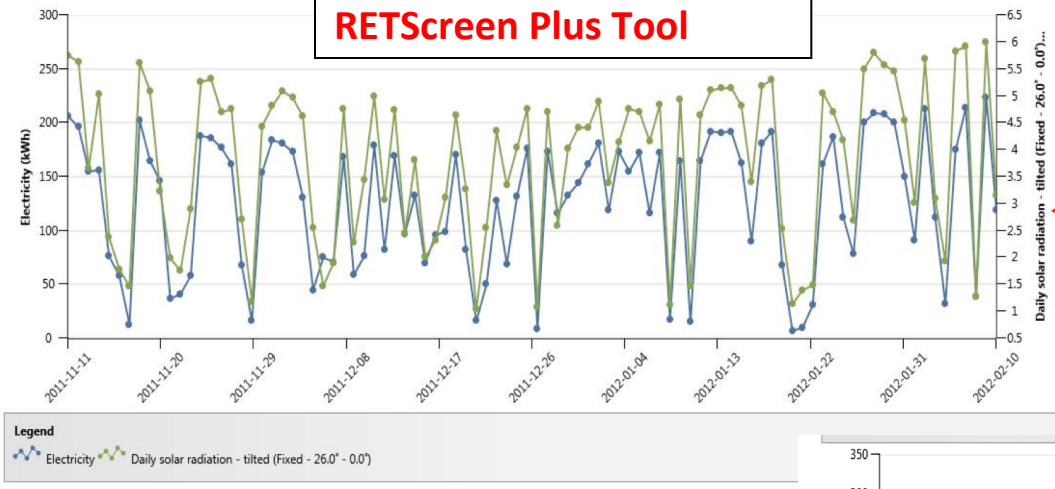
- Overview
- Current Status
- Weather Conditions

Installed in September 2010, this 39.5 KW ground-mounted solar energy system and will produce around 50,000 kilowatt-hours of electricity each year. The system consists of 168 photovoltaic modules mounted in two arrays located behind the Badge and Pass Office. This project demonstrates the performance of solar energy and the benefit of renewable energy being in our overall energy strategy.

Energy Today	Energy Yesterday	Lifetime Energy
193 kWh	206 kWh	38,035 kWh
Total energy generated by the system today	Total energy generated by the system yesterday	Total energy generated by the system since installation

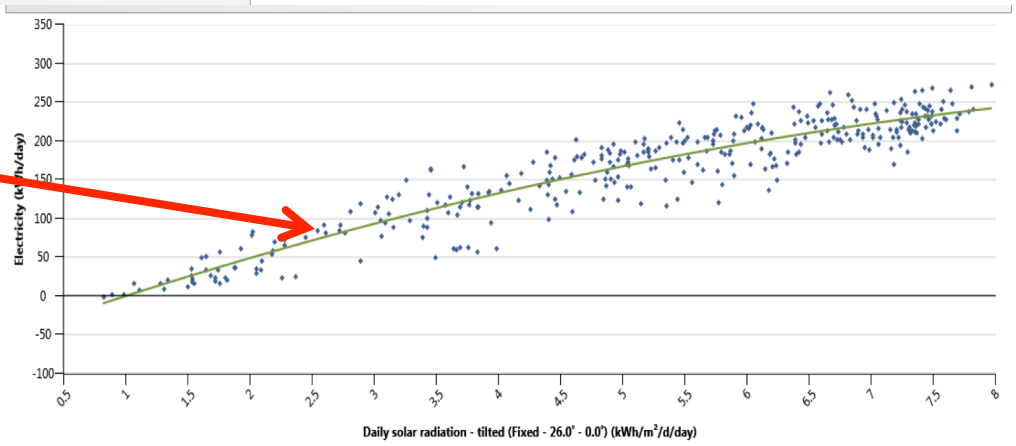
Monitoring and Targeting Case 1: NASA LaRC Badge and Pass Office

RETScreen Plus Tool

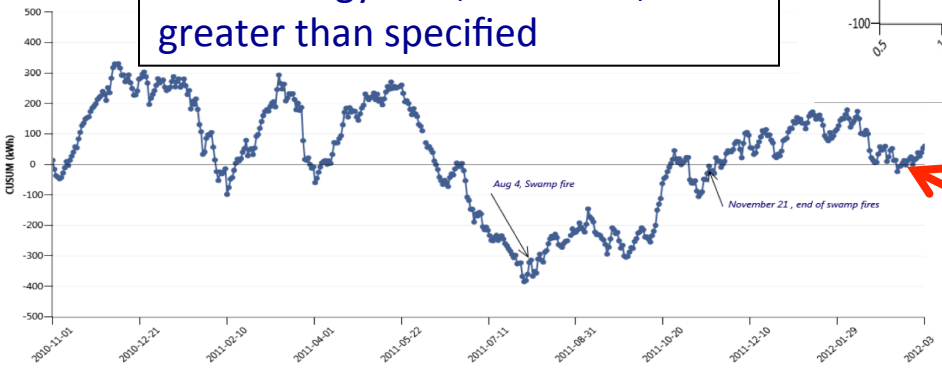


Step 1: LaRC based CERES FLASHFlux project surface solar flux (blue) vs. Solar Panel Electrical Output (green) gives excellent correlation.

Step 2: Regression relationship defines the system as a function of available solar energy



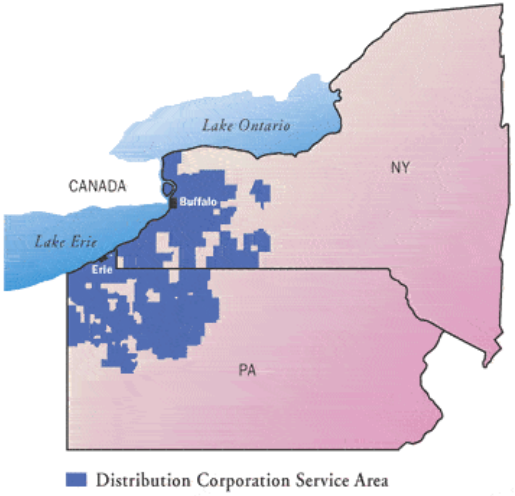
Total Energy = 59,000 kWhr, 18% greater than specified



Step 3: Cumulative differences in output relative to system function shows noise but performance steady.

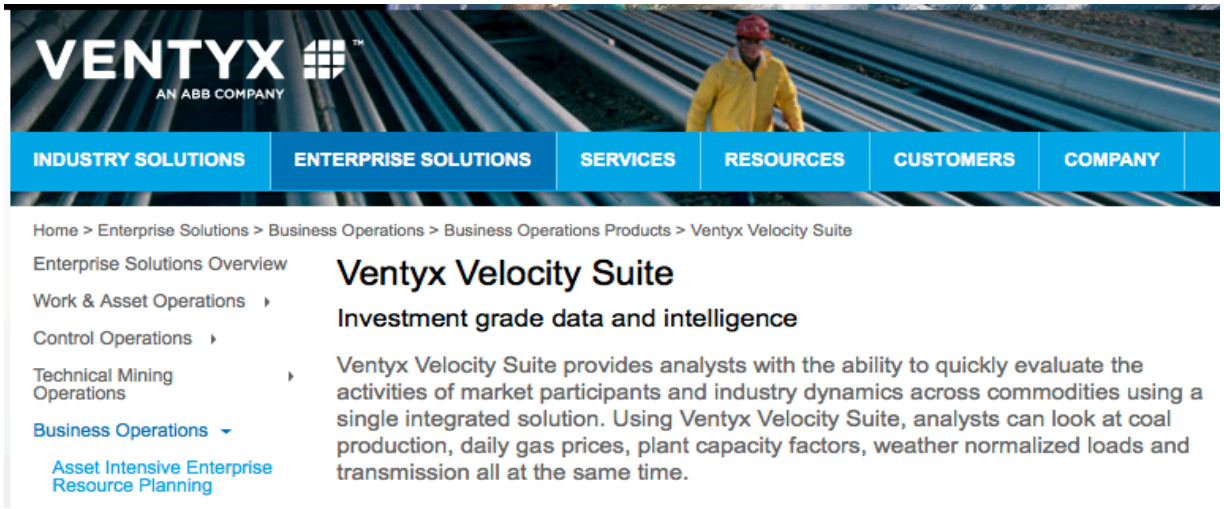
POWER for Energy Forecasting

Collaborated with Battelle and Ventyx to evaluation NASA long-term data sets (GMAO) and high resolution forecasts (SPORT)



- Gas utilities use daily averaged data
- Most recent daily averaged 4 years of POWER/FLASHFlux delivered for 4 regions => deliveries continued

Ventyx corporation now including daily data in “Velocity Suite” tool for Energy Utility Industry



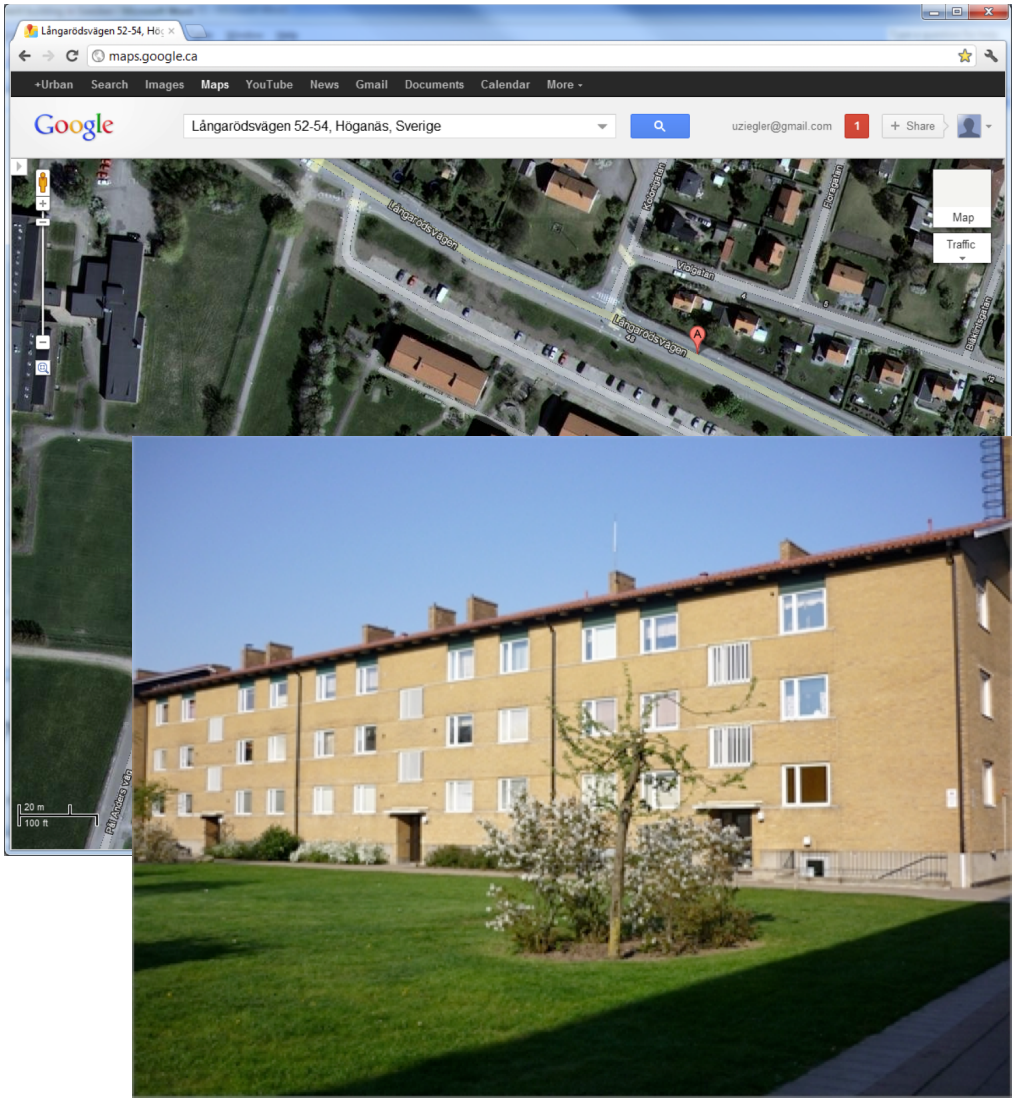
Conclusions

- *NASA long-term and near-term time data sets are tailored to energy industry data needs with partnerships such as with RETScreen and ASHRAE*
- *Current accuracies sufficient to determine statistics of meteorological and solar variability for project feasibility and climatological information (i.e., building climate zones)*
- *Time series data together with RETScreen Plus tool together provide a new capability to assess building energy system performance at any location in the world.*
- *The potential usefulness grows as these global data sets are improved in quality and in resolution, a byproduct of continuing research*

Extras

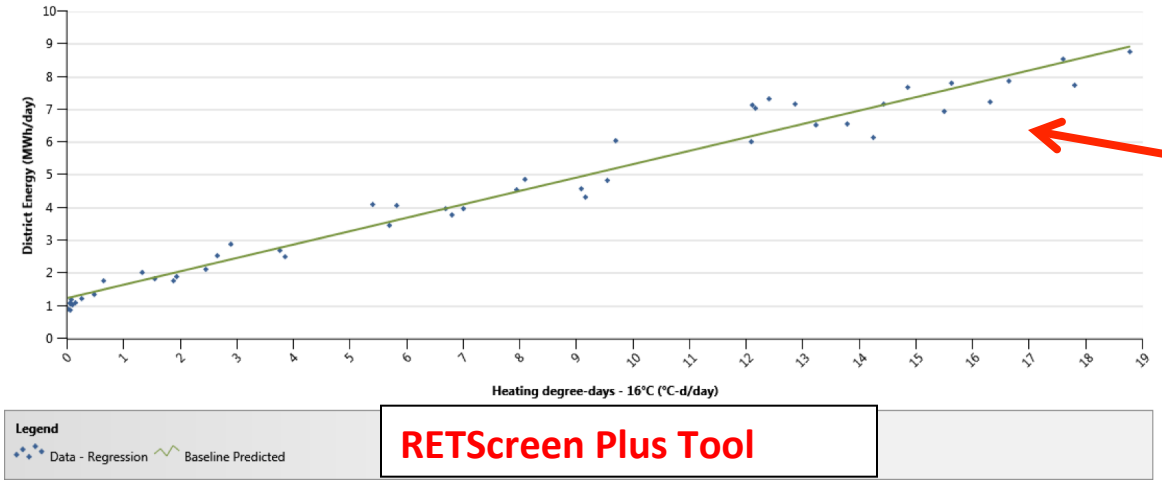
Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

- *Apartment building complex in Sweden*
- *Use RETScreen Plus & NASA temperature data to assess energy usage before and after energy efficiency upgrade*



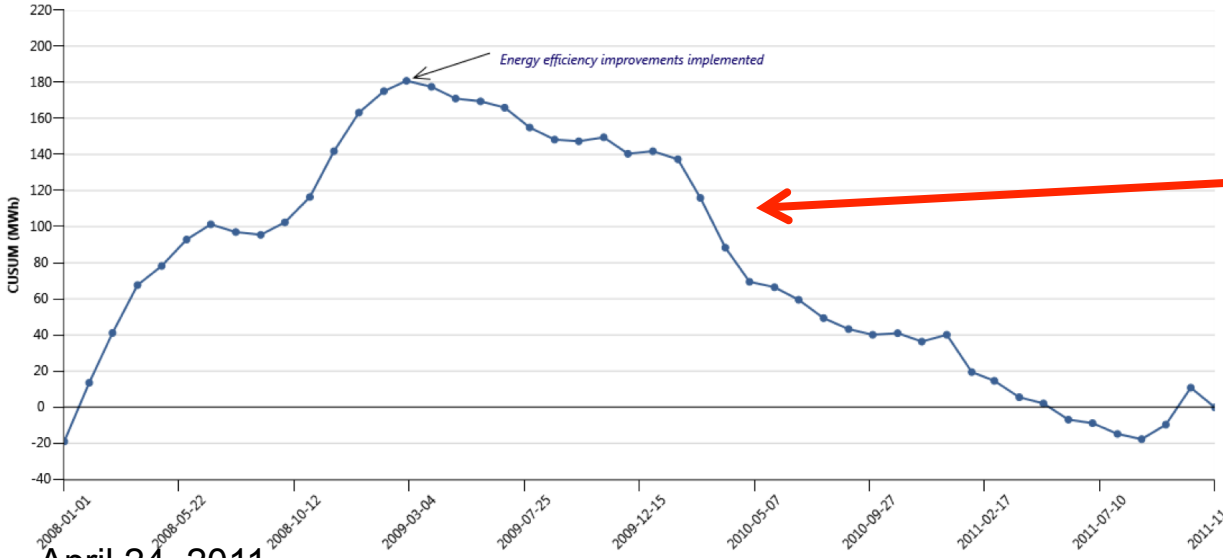
Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

Pass 1: Identified system upgrade point



RETScreen Plus Tool

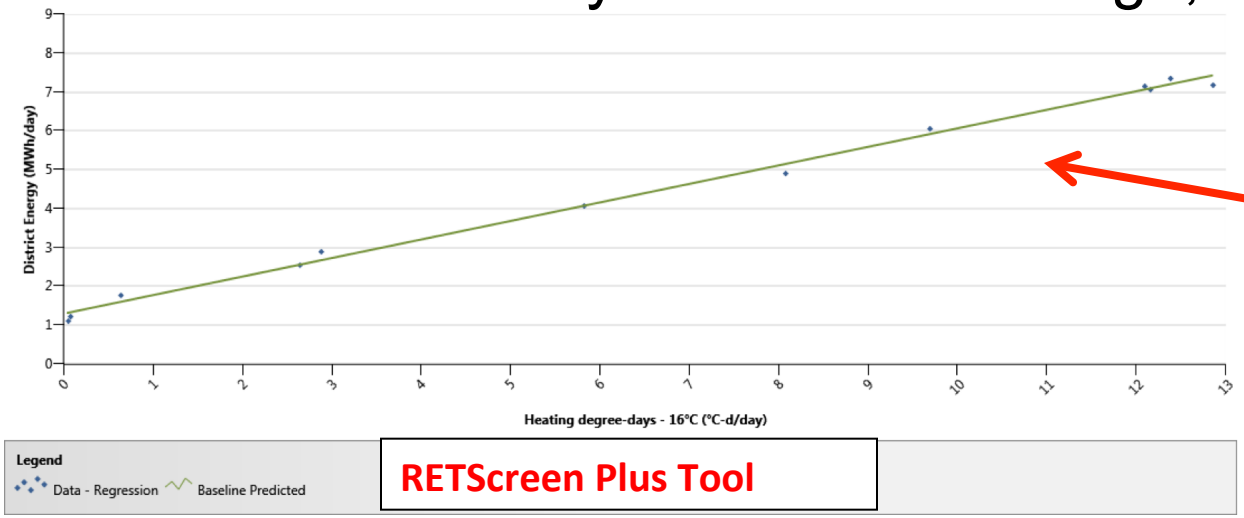
Step 1: Regress Heating Degree Day (16 C) from NASA GEOS 5.2 Reanalysis to Apartment Complex Energy usage for entire period



Step 2: Evaluate cumulative difference over entire period – system change clearly shown since fit includes points before and after change

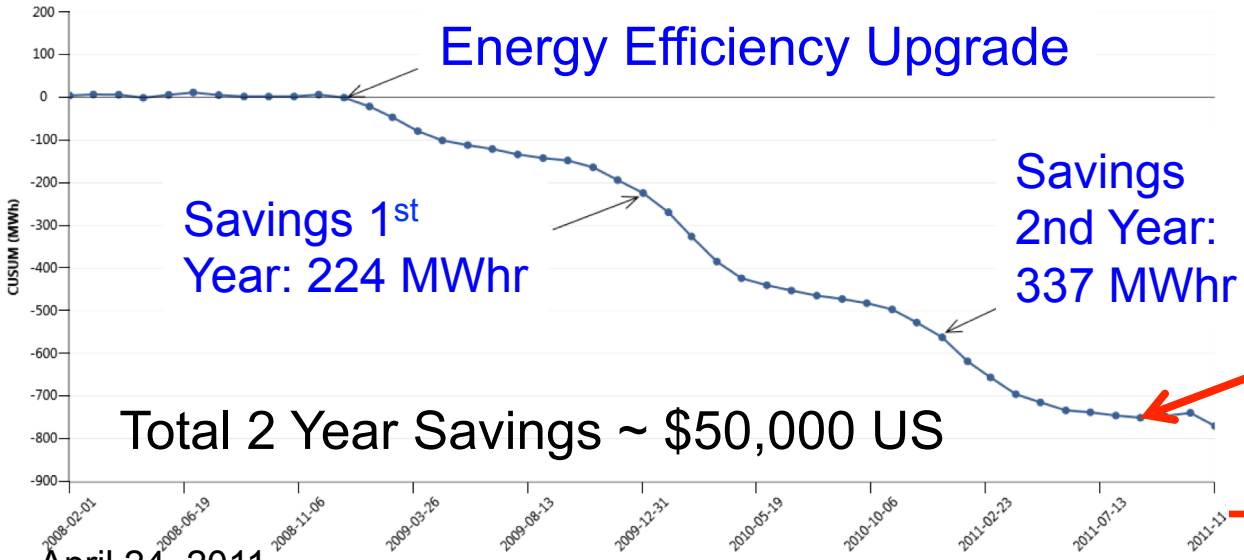
Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

Pass 2: Define system before change, assess impact



RETScreen Plus Tool

Step 1: Regress Heating Degree Day (16 C) from NASA GEOS 5.2 Reanalysis to Apartment Complex Energy usage for period preceding change



Step 2: Evaluate cumulative difference over entire period – system change clearly shown since fit includes points before and after change

Near Rea

Northern boundary
44

Western boundary
-79

Center
Latitude **43.5**
Longitude **-78.5**

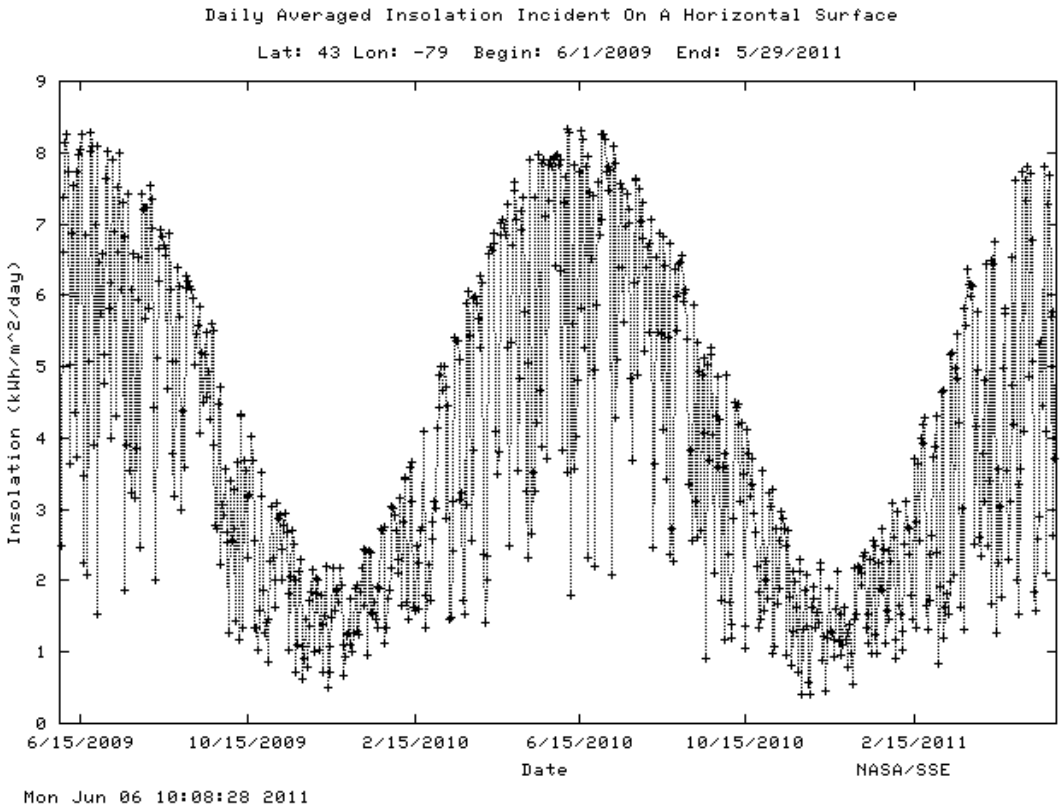
Eastern boundary
-78

Southern boundary
43

Show A Location Map

Download a text file

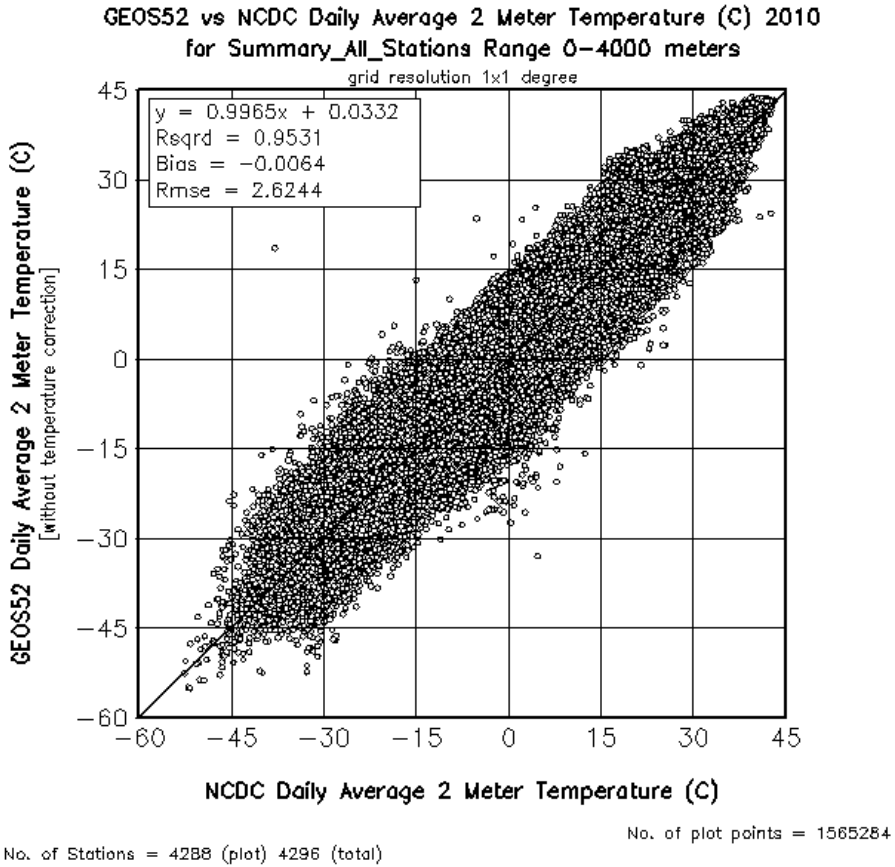
Units conversion charts:
Temperature ***Wind Speed***



Monitoring and Targeting Case 1: NASA LaRC Badge and Pass Office

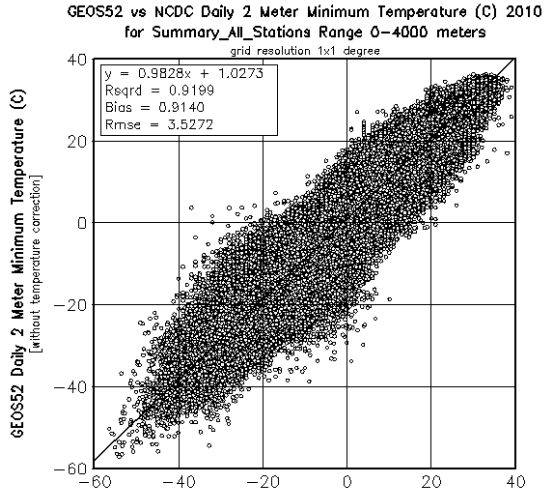
- ***RETScreen Plus and NASA resolve system specification misunderstanding***
  - Contractor provided climatological specifications for system with constant 20 degree tilt, but system plans showed a 25 degree tilt.
  - Original RETScreen Plus analysis using NASA surface irradiance produced a poor fit with unexplained behavior.
  - Behavior was only explained by changing the tile angle of the panels in RETScreen Plus. Subsequent measurements verified that the system has a 26 degree tilt.

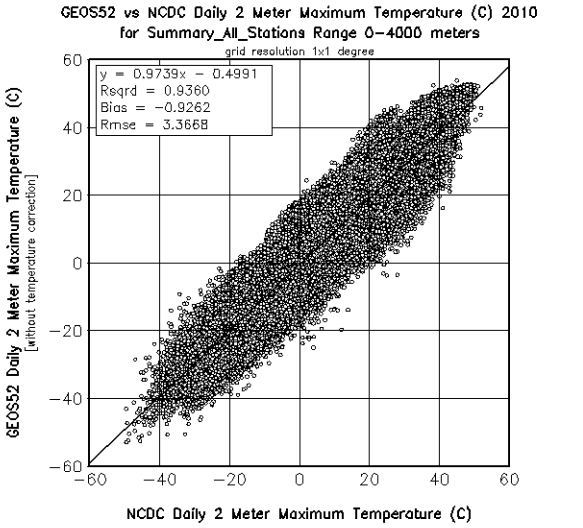
NASA GEOS 5.2 (1 x 1) vs NCDC Surface Obs



No. of Stations = 4288 (plot) 4296 (total)

No. of plot points = 1565284

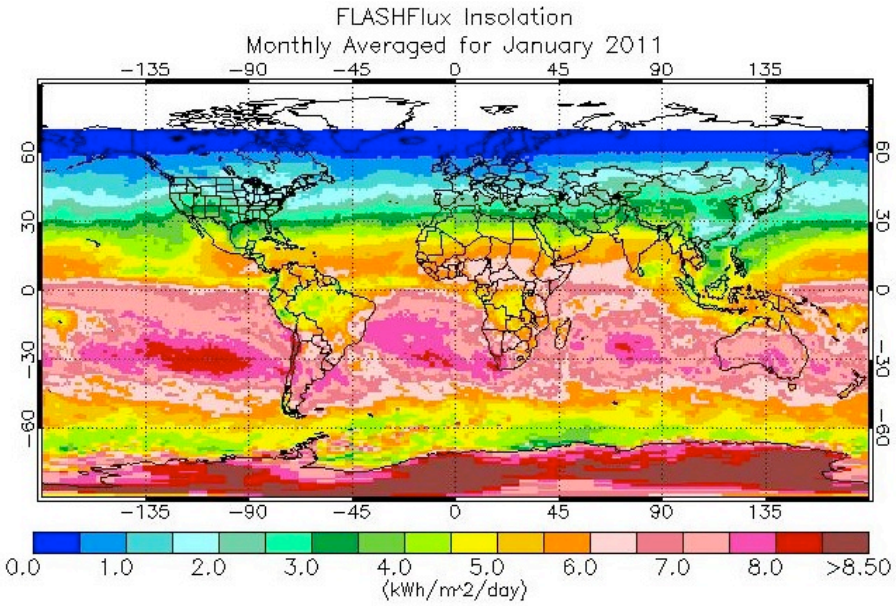


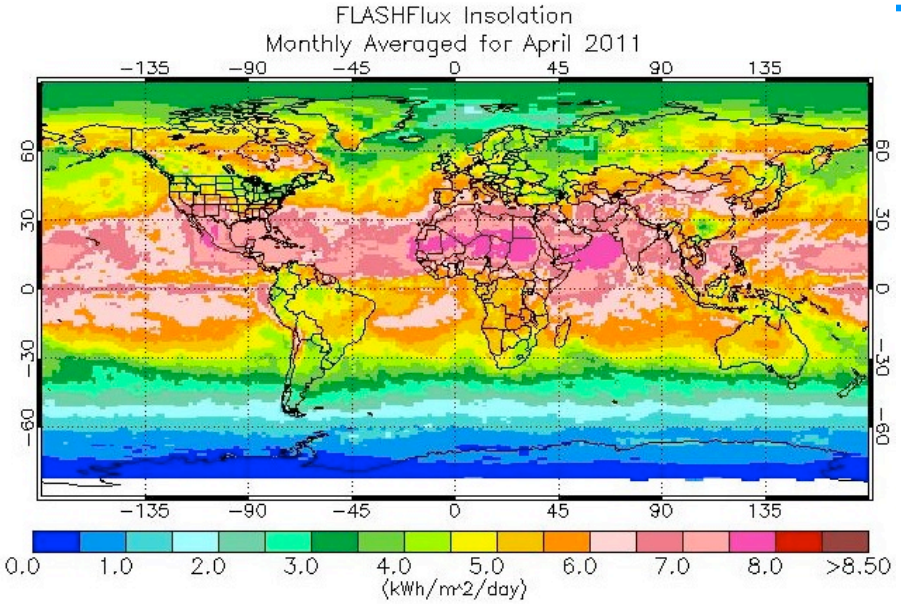


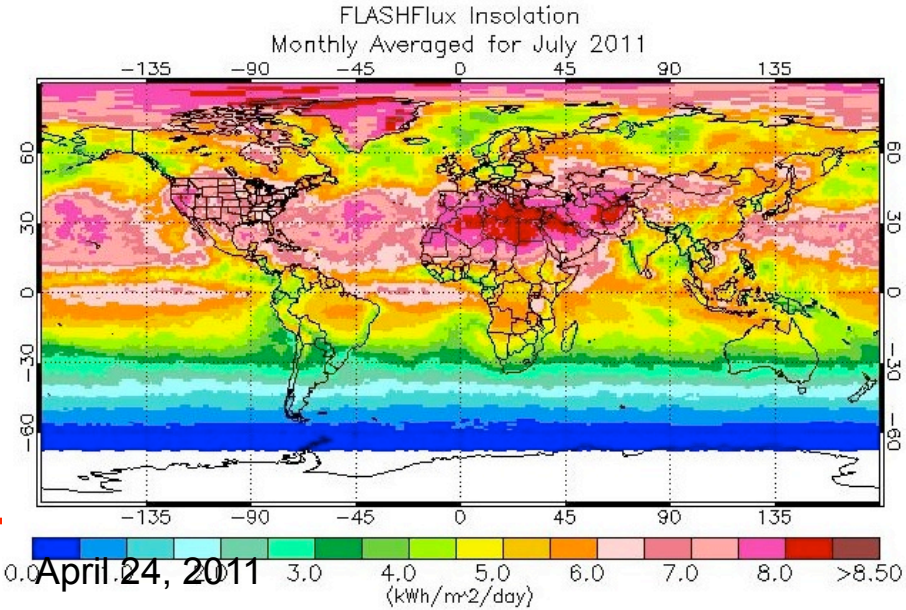
No. of Stations = 4287 (plot) 4296 (total)

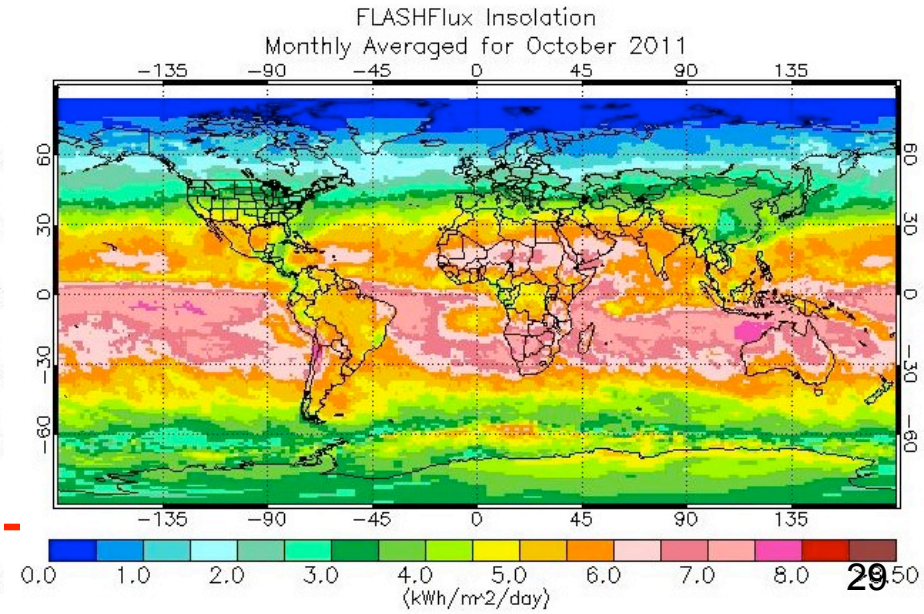
No. of plot points = 1564585

CERES FLASHFlux Seasonal Insolation

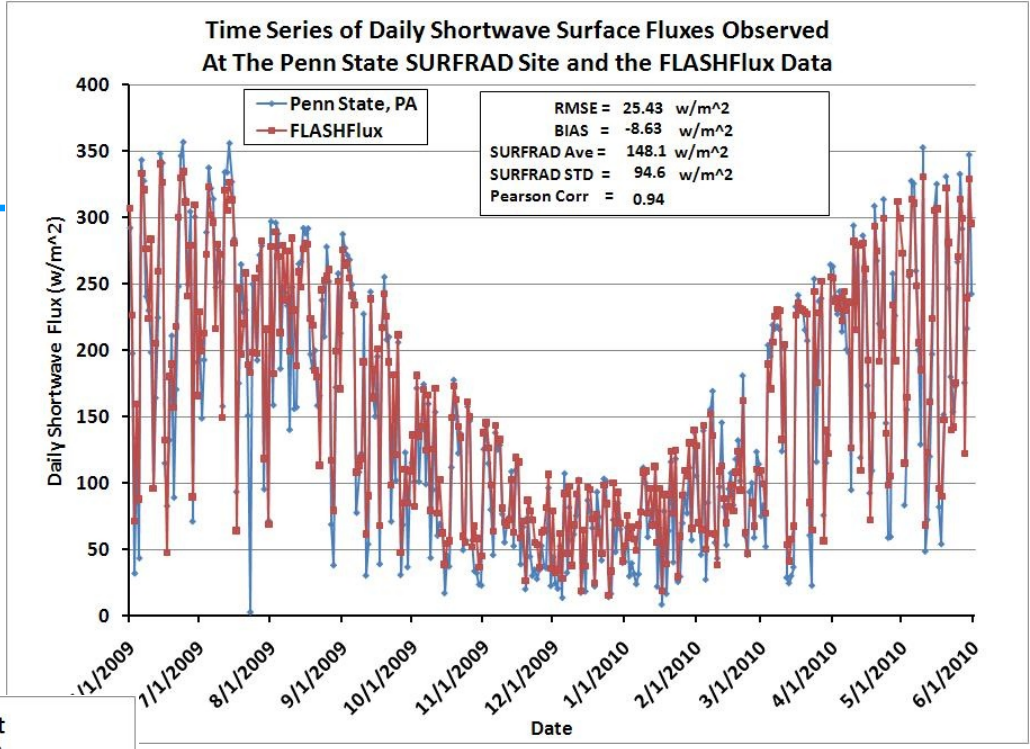


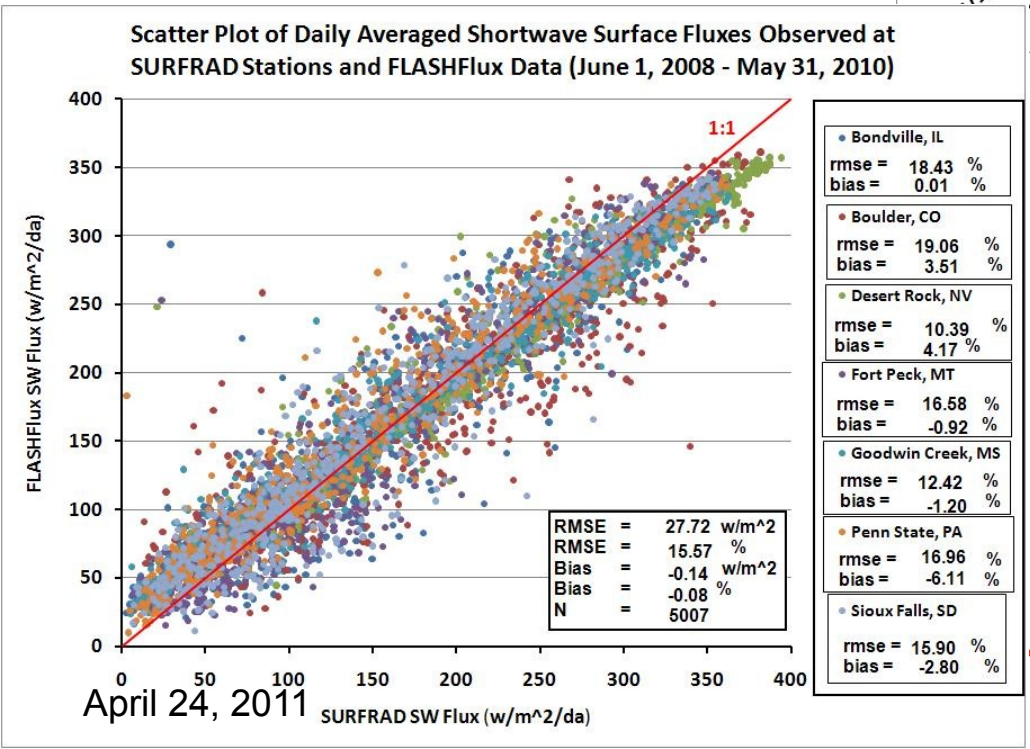






CERES FLASHFlux Solar Flux Validation vs SURFRAD





Daily Averaged Ensemble Differences:

Bias << 1%

RMS < 16%

well within industry needs