NOAA SURFRAD Current Activities

NOAA GRAD: Kathleen Lantz, John Augustine, Gary Hodges, Jim Wendell, Emiel Hall, David Longenecker, Joseph Michalsky, Chuck Long, Allison McComiskey

NOAA SFIP: Melinda Marquis, Stan Benjamin, Joseph Olson, Eric James, Kathleen Lantz, Andy Heidinger, Christine Molling

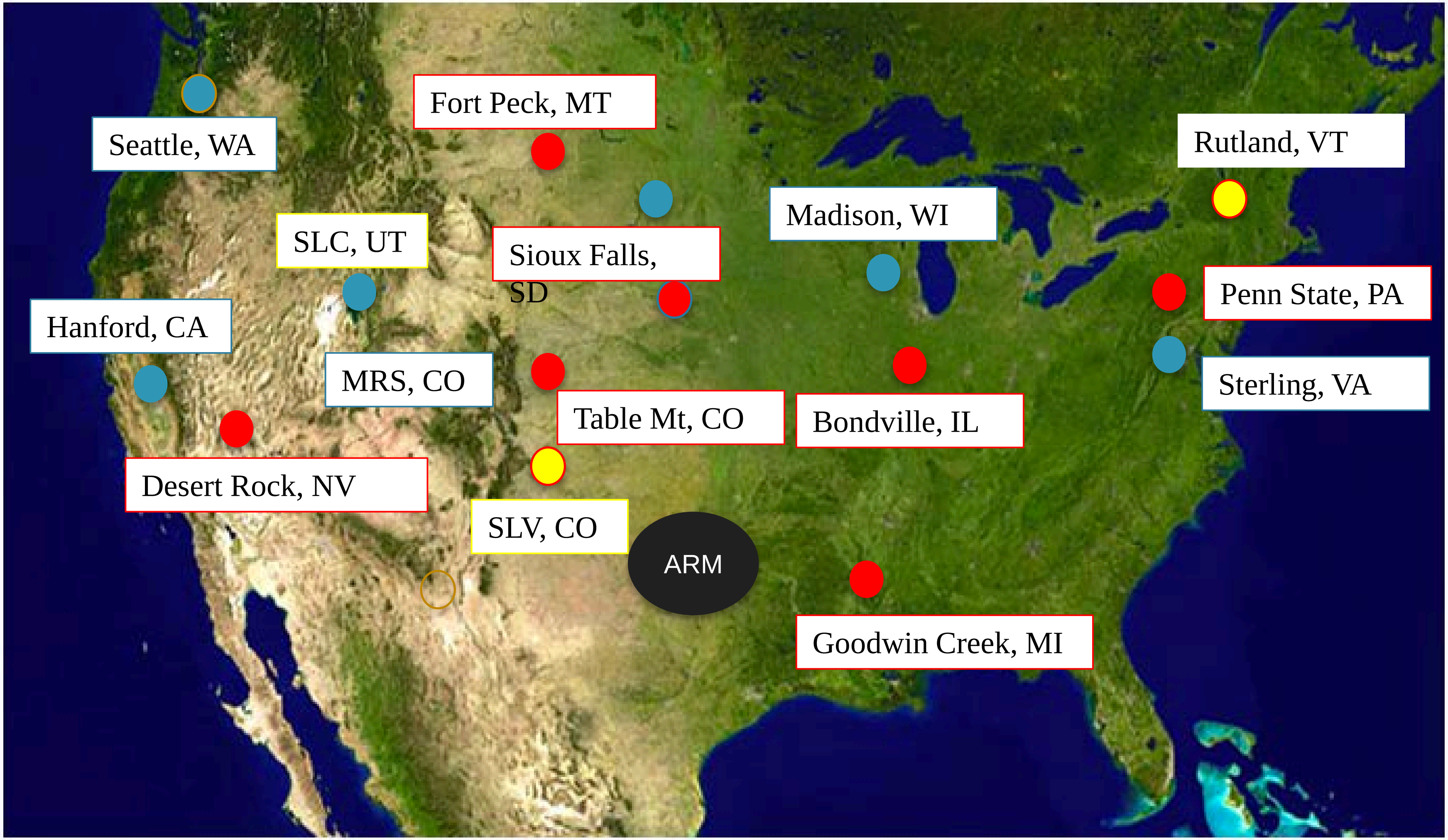
NOAA GOES-R: Istvan Laszlo, Shobha Kondragunta

Recent G-RAD Funded Programs

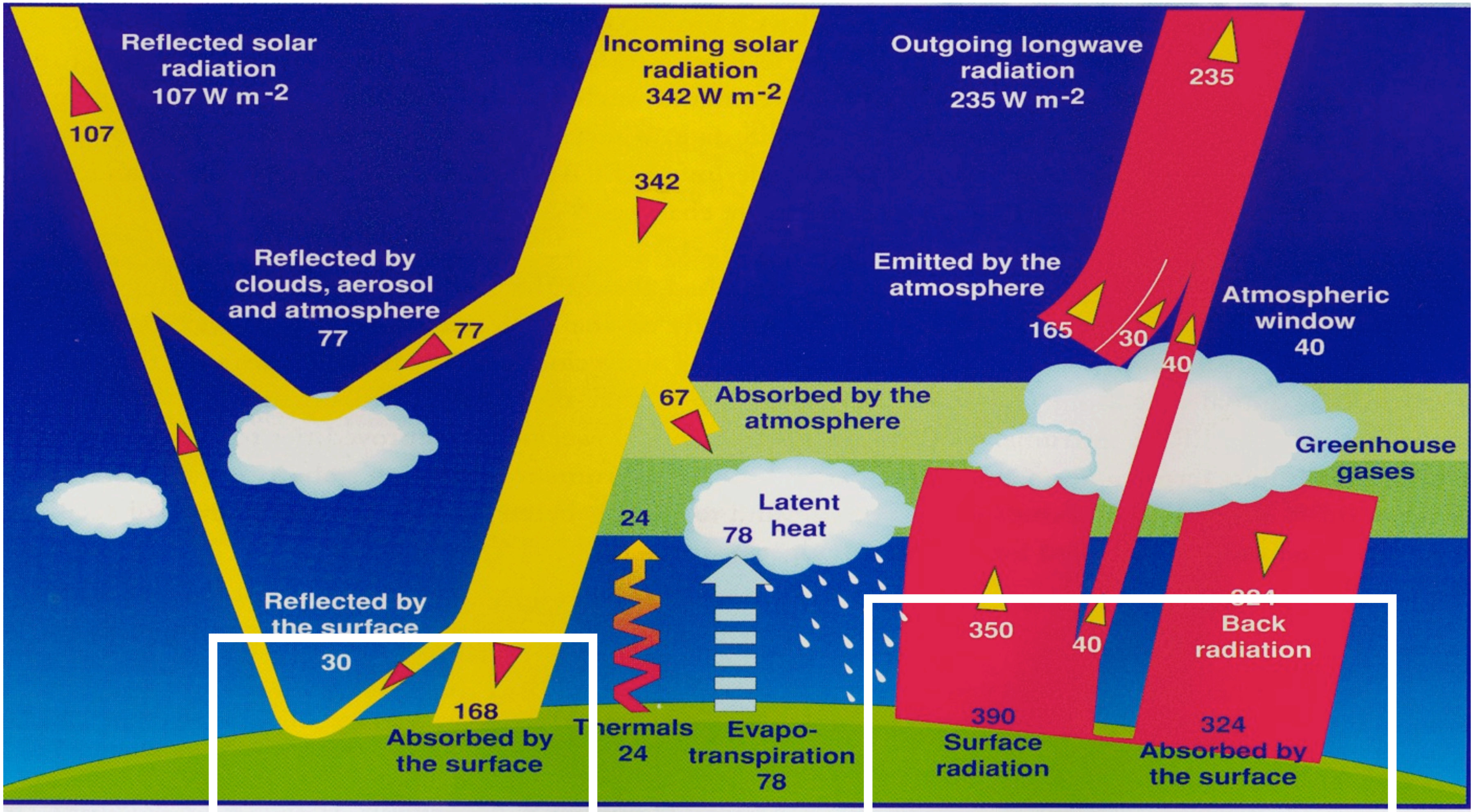
- NOAA GOES-R Satellite Cal/Val Activities for Product Validation
- NOAA-DOE Solar Forecasting Improvement Project (SFIP)

SURFRAD and ISIS Site Locations

- Surface Radiation Budget Network (SURFRAD)
- Integrated Solar Irradiance Study (ISIS)
- Mobile SURFRAD

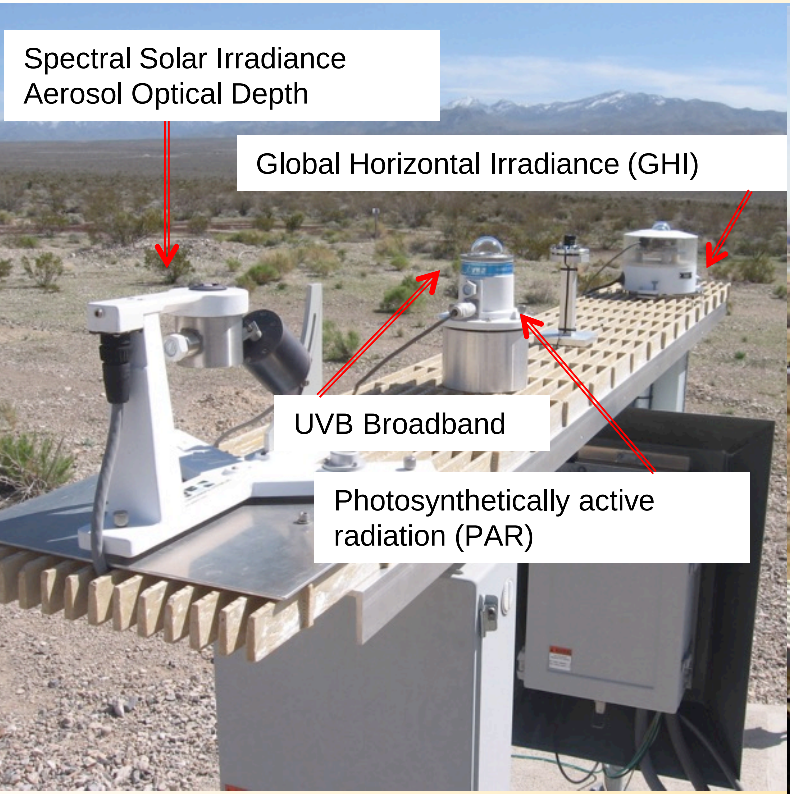


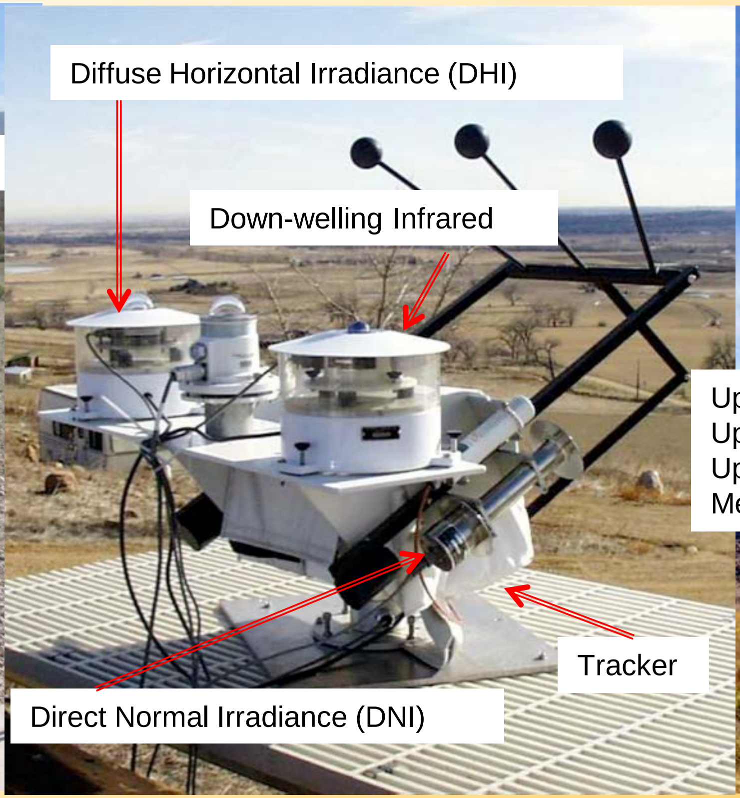
What do SURFRAD stations measure?

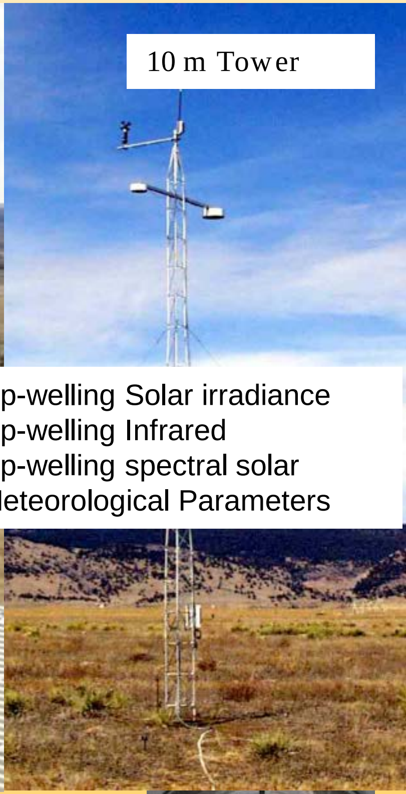


Radiation Balance of the Earth (Jeffrey T. Kiehl)

SURFRAD Quantities Products







Radiative Flux Analysis – Clear-sky direct, diffuse and total irradiance, Cloud fraction, Cloud Optical Depth (Long et al.,2000; 2006; 2008)
Spectral Surface Albedo
Normalized Difference Vegetation Index (NDVI); Green Fraction
Land Surface Temperature

Total Sky Imager –
Sky Images
_ Cloud Fraction

GOES-R – Product Validation

Baseline Products

Advanced Baseline Imager (ABI)

- Aerosol Detection (Including Smoke and Dust)
- Aerosol Optical Depth (AOD)
- Clear Sky Masks
- Cloud and Moisture Imagery
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Top Height
- Cloud Top Phase
- Cloud Top Pressure
- Cloud Top Temperature
- Derived Motion Winds
- Derived Stability Indices
- Downward Shortwave Radiation: Surface
- Fire/Hot Spot Characterization
- Hurricane Intensity Estimation
- Land Surface Temperature (Skin)
- Legacy Vertical Moisture Profile
- Legacy Vertical Temperature Profile
- Radiances
- Rainfall Rate/QPE
- Reflected Shortwave Radiation: TOA
- Sea Surface Temperature (Skin)
- Snow Cover
- Total Precipitable Water
- Volcanic Ash: Detection and Height

Geostationary Lightning Mapper (GLM)

- Lightning Detection: Events, Groups & Flashes

Space Environment In-Situ Suite (SEISS)

- Energetic Heavy Ions
- Magnetospheric Electrons & Protons: Low Energy
- Magnetospheric Electrons: Med & High Energy
- Magnetospheric Protons: Med & High Energy
- Solar and Galactic Protons

Magnetometer (MAG)

- Geomagnetic Field

Extreme Ultraviolet and X-ray Irradiance Suite (EXIS)

- Solar Flux: EUV
- Solar Flux: X-ray Irradiance

Solar Ultraviolet Imager (SUVI)

- Solar EUV Imagery

Future Capabilities

Advanced Baseline Imager (ABI)

- Absorbed Shortwave Radiation: Surface
- Aerosol Particle Size
- Aircraft Icing Threat
- Cloud Ice Water Path
- Cloud Layers/Heights
- Cloud Liquid Water
- Cloud Type
- Convective Initiation
- Currents
- Currents: Offshore
- Downward Longwave Radiation: Surface
- Enhanced "V"/Overshooting Top Detection
- Flood/Standing Water
- Ice Cover
- Low Cloud and Fog
- Ozone Total
- Probability of Rainfall
- Rainfall Potential
- Sea and Lake Ice: Age
- Sea and Lake Ice: Concentration
- Sea and Lake Ice: Motion
- Snow Depth (Over Plains)
- SO_2 Detection
- Surface Albedo
- Surface Emissivity
- Tropopause Folding Turbulence Prediction
- Upward Longwave Radiation: Surface
- Upward Longwave Radiation: TOA
- Vegetation Fraction: Green
- Vegetation Index
- Visibility

Mobile SURFRAD Deployments

GOES-R Plans

- Deploy new MFR and MFRSR at 7 SURFRAD sites for **new products**:
  - Spectral surface albedo
  - Improved aerosol optical depth
- **Logistics**
  - Characterizing and calibrate 12 MFRSRs for deployment at SURFRAD sites this spring – fall, 2015 (on-going).
  - Prior to adding MFR to towers for spectral albedo measurements, power will need to be extended to the towers at the sites. For several sites this requires negotiations with site owners for trenching etc, e.g. Desert Rock, NV.
- **Science Goals**
  - Develop continuous spectral surface albedo product
  - Calculate and provide operational NDVI and Green Fraction
  - Analyze data from mobile deployments from DISCOVER-AQ campaigns (ancillary ground-based data and vertical profile information)
  - Deploy mobile SURFRAD site at two locations in 2016 and 2017 for GOES-R post-launch validation field campaign (with detailed ground and aircraft vertical profile information).

DOE SunShot Initiative

In 2011, DOE announced the SunShot Initiative—a collaborative national effort that aggressively drives innovation to make solar energy fully cost competitive (subsidy-free) with traditional energy sources before 2020.

Alamosa High concentrating Solar Power Plant, ~ 30 MW

SunShot FAQS:

- SunShot has invested nearly $900 million in game changing innovation in a broad spectrum of areas, e.g. CSP/PV Technology, System Integration, Soft Costs
- In 2013, solar energy reached more than 1% (13 GW) of the nation's electricity, an increase from 0.1% in 2008.
- In 3 years of DOE's decade long initiative, PV is already achieved 60% of its cost targets and CSP just over 50% of its cost target.

NOAA RE and SFIP Mission Statement

NOAA will provide expertise in **weather-driven renewable energy** in areas of wind, solar and ocean.

NOAA SFIP -The utility industry needs reliable solar power forecasts including forecasts of clouds and aerosols to facilitate integration of photovoltaic (PV) and concentrating solar power (CSP) into the nation's grid.

Why? Accurate solar irradiance forecasts will enable power grid operators, who must constantly balance power supply and demand, to make better scheduling decisions about the optimal mix of power generation sources, and to avoid excessive back-up reserves.

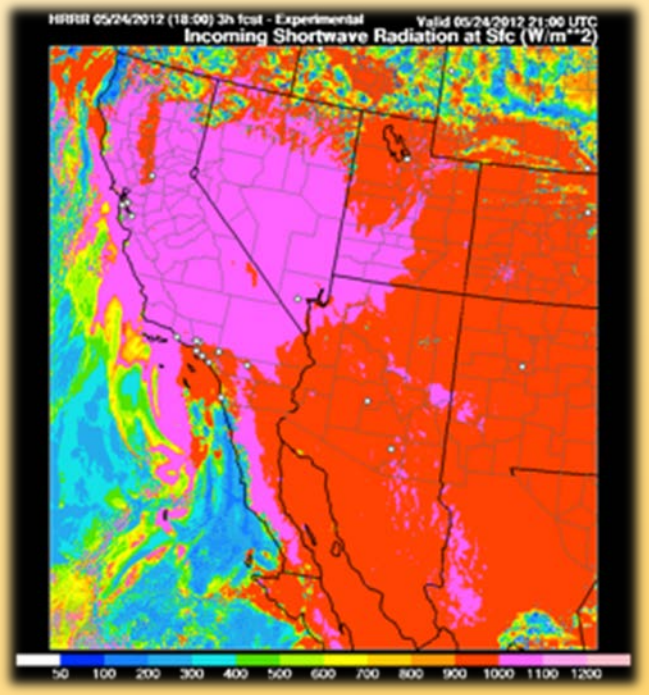
DOE Solar Forecasting Mission Statement

Improve accuracy of solar forecasting in the short-term (15 min - 6 hrs) to day-ahead and for ramp events.

- Transformational improvements in methods/algorithms/processes for **solar irradiance forecasting**
- Establish a standard set of **metrics** for quantifying solar forecast accuracy (ramp, hourly, day ahead)
- How do improved accuracy in solar forecasting affect power system operations: A rigorous estimation of the various value streams (including economic and reliability aspects)

NOAA's SFIP Role

- NOAA/ESRL will provide solar irradiance forecasts from their Rapid Refresh (RAP) and High Resolution Rapid Refresh models (HRRR)
- NOAA/ESRL will provide high quality solar irradiance measurements from the SURFRAD and ISIS Networks for model verification and data assimilation
- NOAA/NESDIS will provide advanced Satellite Cloud Products



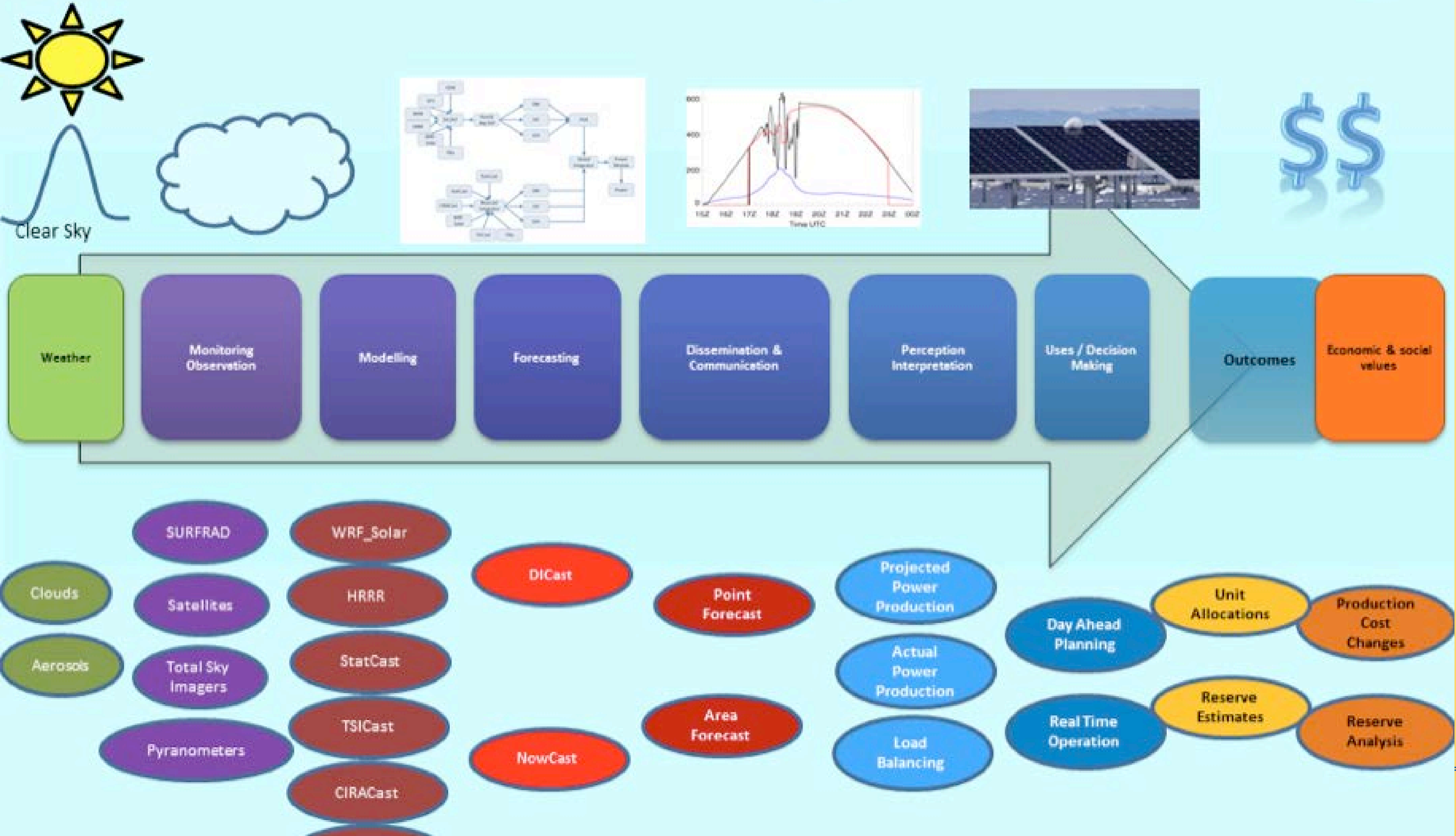
NOAA SFIP Partner Teams

NCAR: *A Public Private-Academic Partnership to Advance Solar Power Forecasting*

IBM: *Watt-Sun: A Multi-scale, Mult-Model, Machine-Learning Solar Forecasting Technology*

NCAR Team

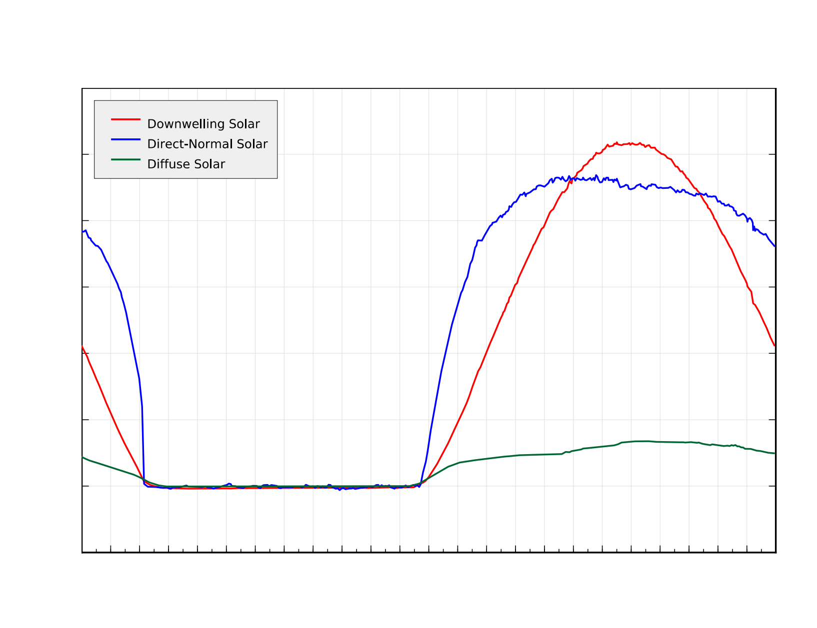
What is the value of solar power forecasting?

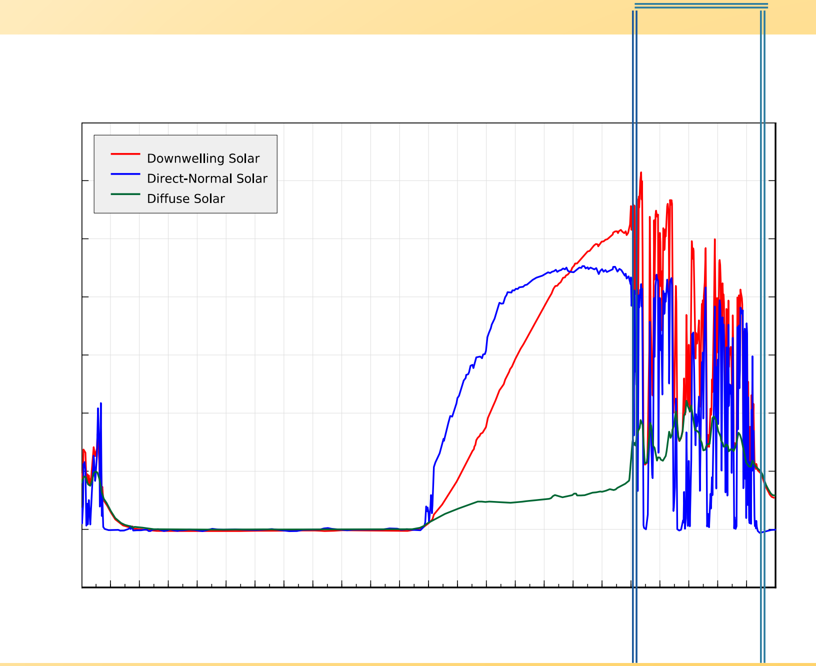


NCAR: Lead, Sue Ellen Haupt

Challenges to Solar Forecasting

Solar Variability – Inherent variability of solar irradiance can increase uncertainties in power systems.

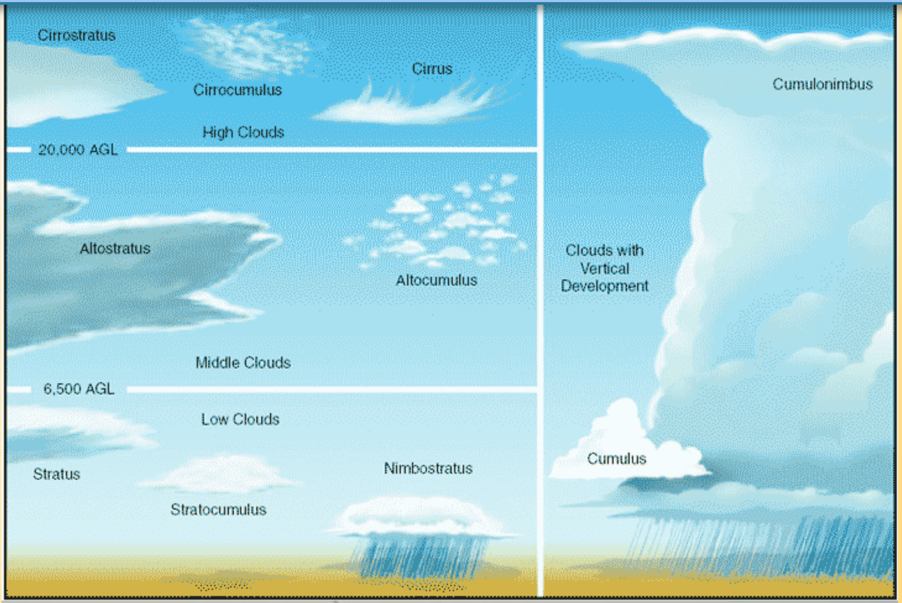




CIRES

Challenges to Solar Forecasting

- **Clouds**
  - Predicting clouds temporally and spatially both in the horizontal and vertical direction.
- **Aerosols/Particulates**
  - Attenuate solar radiation reaching the Earth’s surface
  - Atmospheric aerosols such as sea salt, ammonium sulfate, organics, pollen, mineral dust, etc. are the fundamental starting point of all water droplets and ice crystals (Enhance cloud physics).



Mobile SURFRAD sites

NOAA deployed two SURFRAD platforms for IBM and NCAR for a one year study.

- **IBM**:
  - IBM is partnering with Green Mountain Power (GMP), Rutland, Vermont.
  - 150 KW array located near the GMP headquarters. (solar array = fixed axis facility)
- **NCAR:**
  - NCAR is partnering with Xcel Energy purchased from Iberdrola's San Luis Valley Solar Ranch.
  - 110,000 photovoltaic (PV) modules with 30 megawatts (MW) of clean energy. Horizontal single-axis tracking.

Calculation of solar irradiance on tilted surfaces

Plane-of-Array solar irradiance (POA):

The calculation of solar irradiance on a tilted surface is called transposition

Finding the components of the total solar irradiance (GHI), i.e. diffuse (DNI) and direct horizontal irradiance (DNI), is called either decomposition or separation.

$E_s = E_{bn}*\cos\theta + Ed*Rd + \rho*E*R_r$

E_s = irradiance on a tilted plane
θ = angle of incidence on plane
E_{bn} = DNI
E_d = DHI
Rd = DHI transposition factor
ρ = surface albedo
R_f = transposition factor for surface albedo

References:
Perez et al, 1987
Gueymard, 1988; 2008
Hay et al, 1986

CIRES NOAA GOES-R

SFIP GRAD Accomplishments and Plans

- ***SURFRAD and ISIS site measurements***
  - ✓ Provide high quality solar radiation measurements for 14 ISIS and SURFRAD sites
  - ✓ Install communications and hardware upgrades to provide near-real time SURFRAD radiation measurements
  - ✓ Update ISIS measurements from 1 min to 3 minutes
  - Purchase and install new pyrheliometers (DNI) at SURFRAD sites

- ***NOAA test-bed radiation platforms***
  - ✓ Deploy one mobile SURFRAD unit for up to 1 year
  - ✓ Build, test, deploy 2nd SURFRAD unit for up to 1 year
  - ✓ Provide near-real time mobile SURFRAD radiation, aerosol, cloud fraction products
  - ✓ Provide high quality diffuse and direct solar irradiance with GHI and tilted irradiance for calculations of plane-of-array solar irradiance (POA).

- ***Ground-based Verification*** - Using SURFRAD and ISIS sites spatially and temporally average radiation for comparison to CIMSS satellite products and HRRR/RAP model products using defined Metrics.

- ***SURFRAD data products***
  - Cloud fraction, cloud optical depth (Radiative Flux Analysis)
  - Spectral solar irradiance, continuous spectral albedo
  - Verification study of modeled plane-of-array solar irradiance


THANK YOU

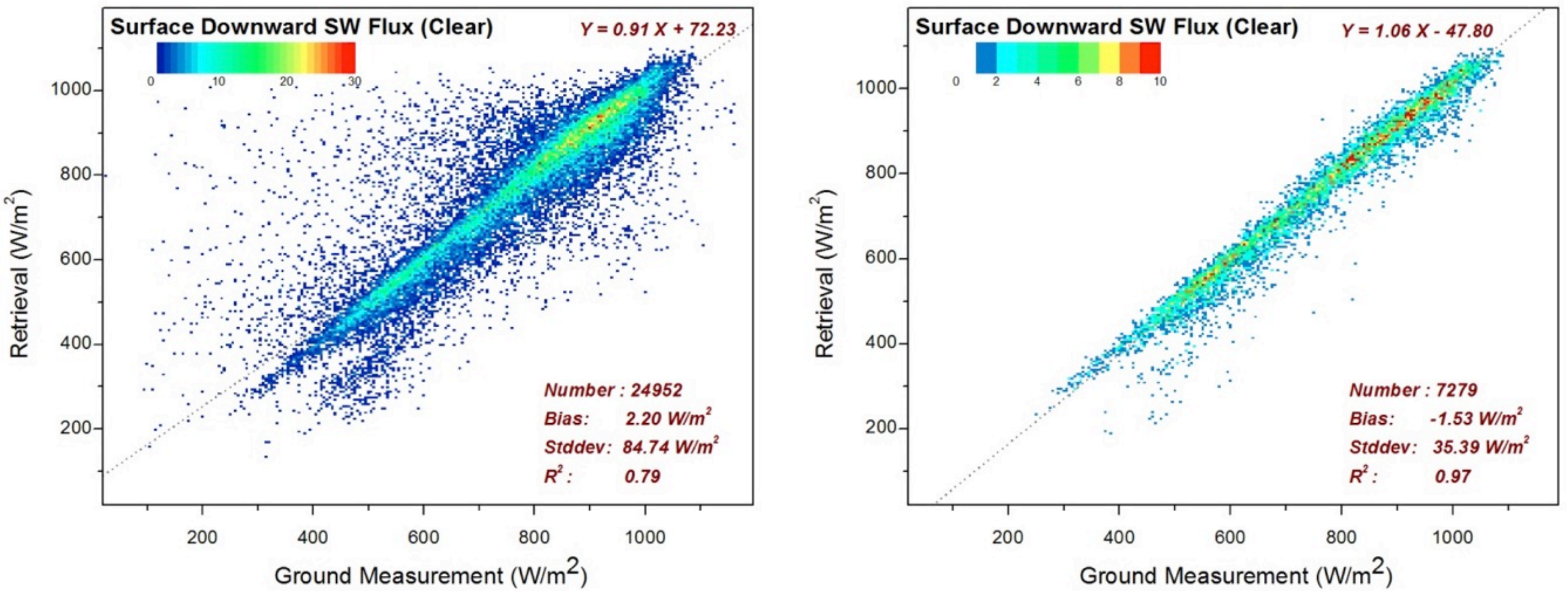
RAP and HRRR Target Development Areas

- Development within the **13-km Rapid Refresh (RAP)**:
  - Incorporating aerosol information into radiation physics and microphysics
    - RRTMG longwave and shortwave radiation schemes
    - Aerosol-aware Thompson microphysics scheme
  - Improving the coupling of turbulence and microphysics schemes
  - Developing subgrid-scale cloud parameterizations, and coupling them to radiation schemes:
    - Deep cumulus from Grell-Frietas deep cumulus scheme
    - Shallow cumulus from Grell-Frietas-Olson shallow cumulus scheme
    - Boundary layer clouds
  - Improvements to the RUC land surface model (LSM), including wilting point change

- Development within the **3-km High-Resolution Rapid Refresh (HRRR)**:
  - Testing the hourly cycling of 3-km land surface fields
  - Building hydrometeors in regions of lightly precipitating clouds

GOES Satellite – Clear Sky

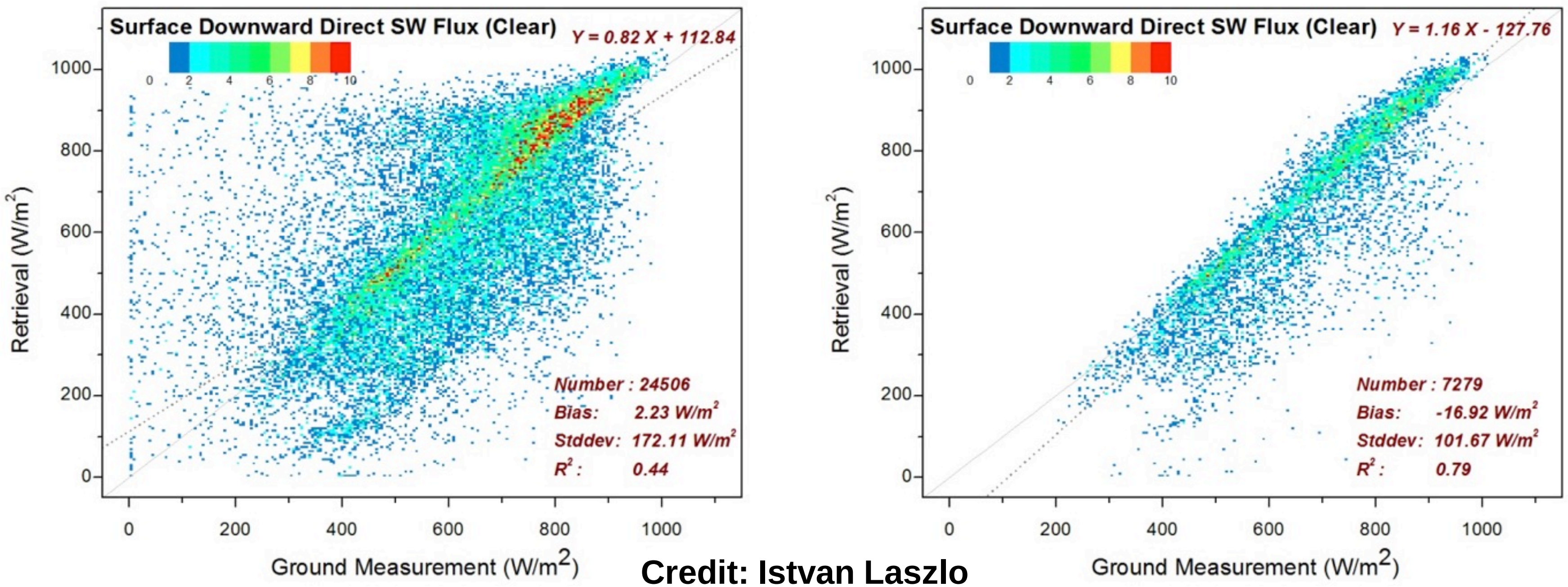
- Validation of **GHI** against ground measurement:
  - Left: 100% clear sky is identified by satellite
  - Right: both satellite and ground report 100% clear sky



Credit: Istvan Laszlo

GOES Satellite – Clear Sky

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



Credit: Istvan Laszlo

GOES-R Mobile SURFRAD deployments

Field Campaign	Location	Dates	Instrumentation
DOE TCAP (Two Column Aerosol Project)	Cape Cod, MA	July – September, 2012	AOD (415, 500, 675, 870, 1626 nm) Spectral Albedo (415, 500, 675, 870, 940, 1626 nm) Meteorology (wind speed/direction, T, P)
NASA DISCOVER-AQ Central Valley CA	Porterville, CO	January – February, 2013	Upwelling and downwelling surface shortwave radiation Upwelling and downwelling IR Direct, diffuse, and total shortwave radiation AOD (415, 500, 675, 870, 1626 nm) Spectral Albedo (415, 500, 675, 870, 940, 1626 nm) Meteorology (wind speed/direction, T, P)
NASA DISCOVER-AQ Houston Area TX	Smith Point, TX	August – September, 2013	Upwelling and downwelling surface shortwave radiation Upwelling and downwelling IR Direct, diffuse, and total shortwave radiation AOD (415, 500, 675, 870, 1626 nm) AOD UV and Total Ozone Spectral Albedo (415, 500, 675, 870, 940, 1626 nm) Meteorological parameters (wind speed/direction, T, P)
NASA DISCOVER-AQ Front Range CO	Erie, CO Table Mountain, CO Platteville, CO	July – August, 2014	Upwelling and downwelling surface shortwave radiation Upwelling and downwelling IR Direct, diffuse, and total shortwave radiation AOD (415, 500, 675, 870, 1626 nm) Spectral Albedo (415, 500, 675, 870, 940, 1626 nm) Meteorological parameters (wind speed/direction, T, P)

G-RAD and SURFRAD Mission Statement

The Global Monitoring Division's radiation group (**G-RAD**) is involved in observational and theoretical research of the Earth's surface and atmospheric radiation and radiation budgets. Our group specializes in the investigation of climatically significant variations in long-term radiation and meteorological measurements made at diverse globally-remote sites and continental US sites (**SURFRAD** and **ISIS and NEUBrew**).

The Surface Radiation Budget Network (**SURFRAD**) was established in 1993 through the support of NOAA's Office of Global Programs. The primary objective of SURFRAD is to support climate research with accurate, continuous, long-term measurements of the surface radiation budget over the United States.

Metrics for Solar Forecast Verification

Solar Forecasting Metrics verification can be broken into two 5 general categories:

(i) **Statistical metrics** - Pearson's correlation coefficient, (normalized) root mean squared error, mean absolute error, mean absolute percentage error, mean, and Kolmogorov–Smirnov test Integral (KSI))

(ii) **Variability estimation metrics -** including different time and geographic scales, and distributions of forecast errors

(iii) **Uncertainty quantification and propagation metrics -** including standard deviation and information entropy of forecast errors

(iv) **Ramping characterization metrics -** including ramp hit rate, swinging door algorithm signal compassion, and heat maps

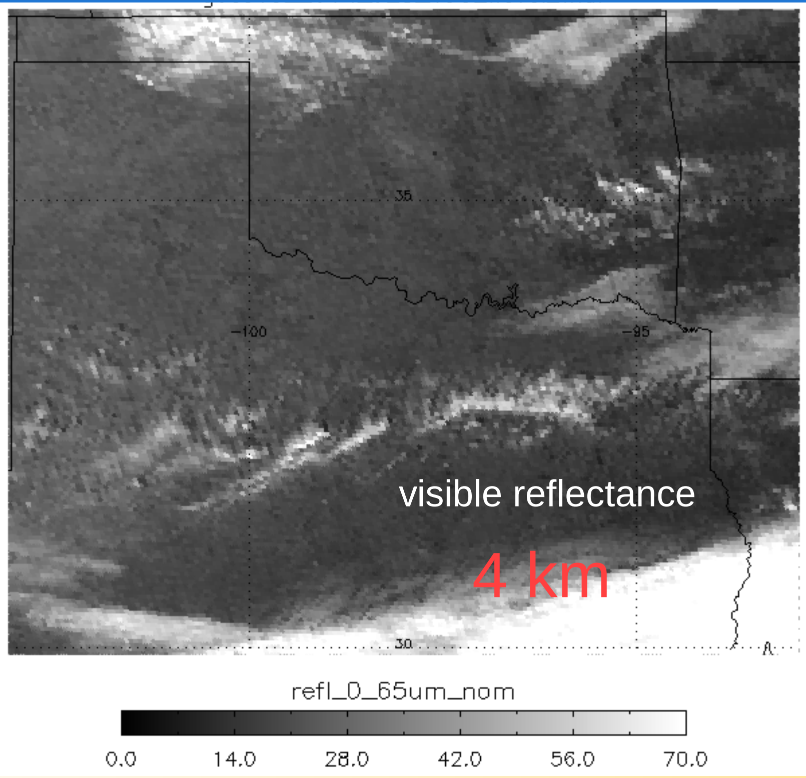
(v) **Economic and reliability metrics -** including regulating reserve requirement and flexibility reserve requirement represented by 95th and 70th percentiles of forecast errors, respectively.

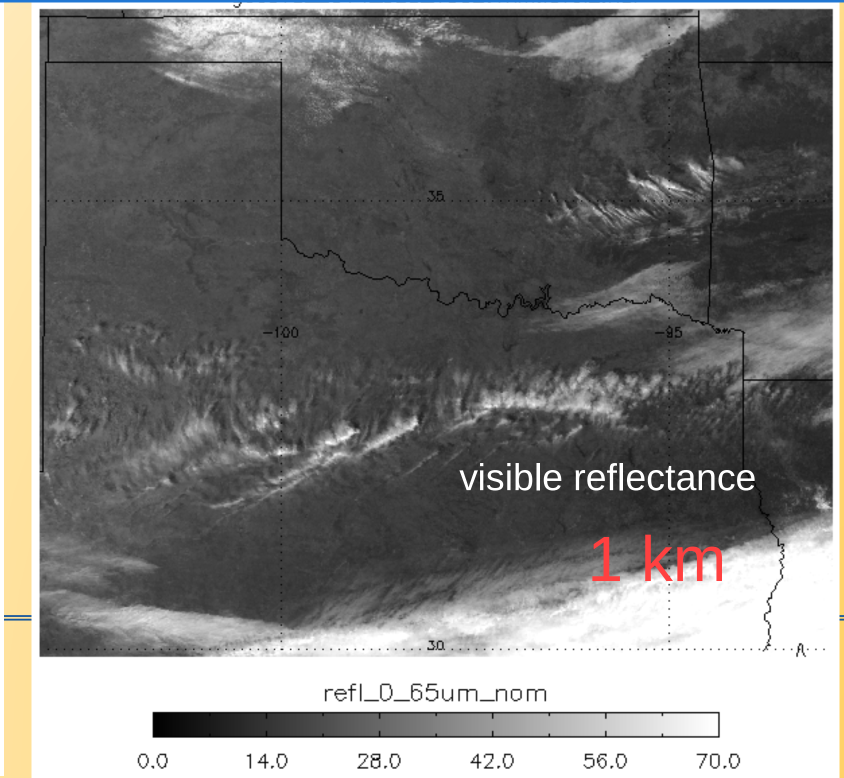
Metrics Team
J. Zhang, Bri-Mathias Hodge, A. Florita,, Metrics for Solar Forecating, NREL Report, 2014

NOAA Advanced Satellite Products

NOAA will provide a stream of real-time cloud products from the NOAA GOES Imagers, which will differ from the operational products in that they will be at the full spatial and temporal resolution of the sensor (15 mins and 1 km). The spatial coverage of these data is limited to the contiguous USA.

Improved Resolution





Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

Replaces RUC

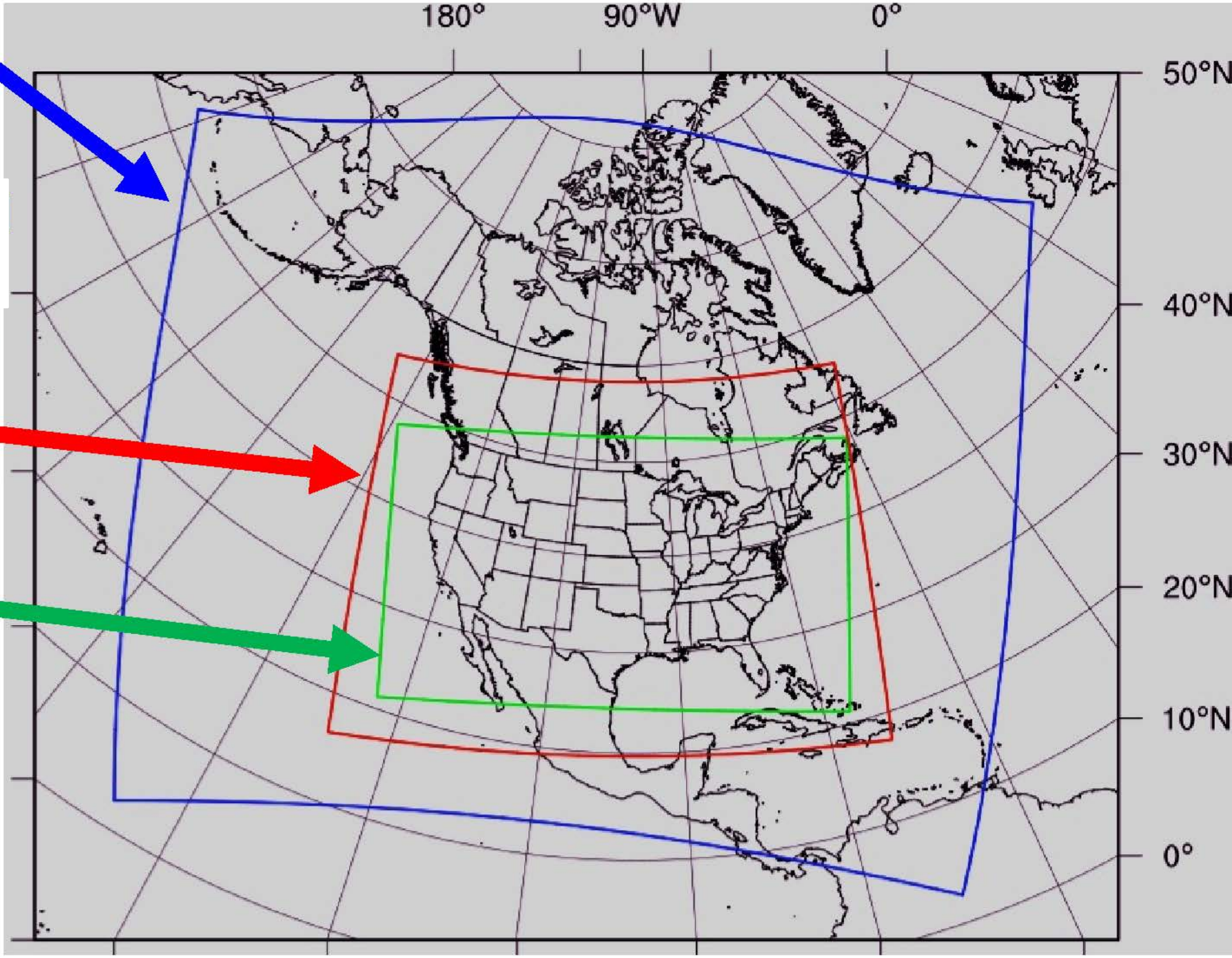
WRF, GSI, RUC features

13km RUC (mesoscale)

3km HRRR (storm-scale)

High-Resolution Rapid Refresh

Experimental 3km nest inside RAP, hourly 15-h fcst



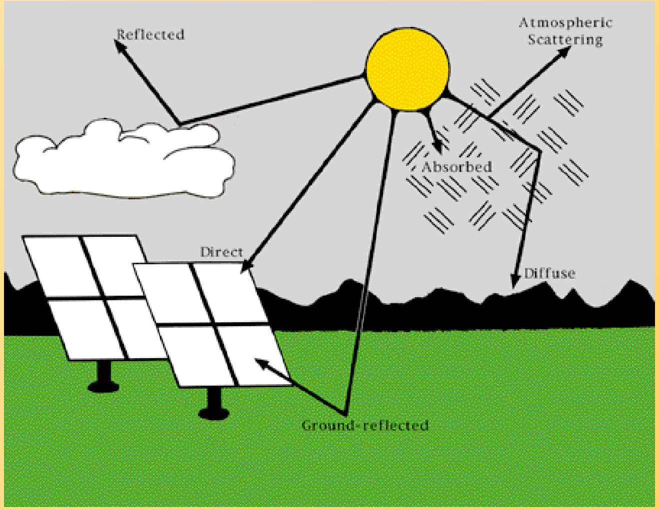
Solar Irradiance Primer

Direct Normal Irradiance (DNI) – The amount of solar radiation from the direction of the sun per unit area striking a surface held perpendicular to the direction of the beam.

Diffuse Horizontal Irradiance (DHI) – Solar radiation per unit area from the sky due to scattering from molecules, aerosols and clouds.

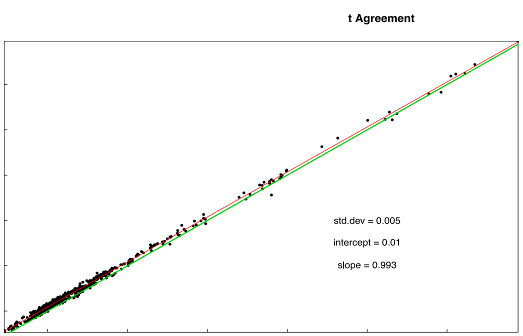
Global Horizontal Irradiance (GHI) – Sum of the Direct and Diffuse solar irradiance striking a horizontal flat plate detector.

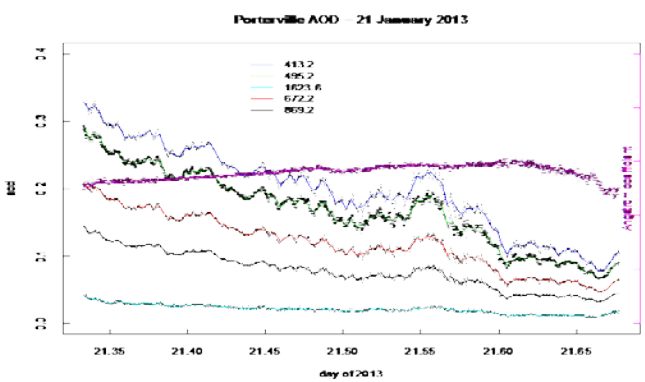
GHI = DHI + DNI * cos (Z)

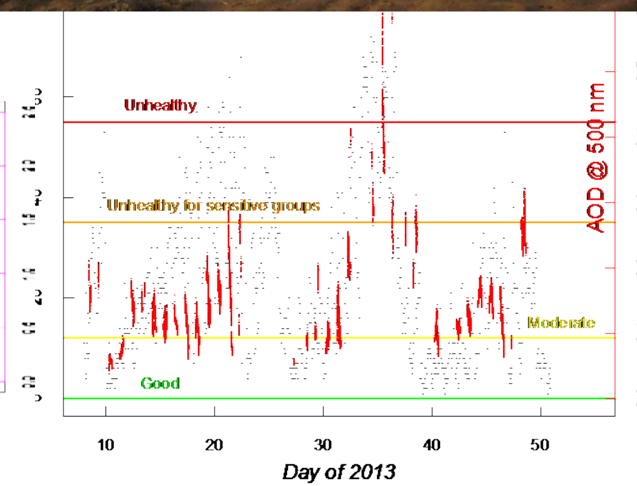


GOES-R Mobile SURFRAD deployments

- **DOE TCAP Campaign** (Two column aerosol Project – <u>Cape Cod, MA</u>), **July – August, 2012**
  - Project: Diurnal aerosol radiative forcing – Kassianov et al.
- **NASA DISCOVER-AQ Central Valley, CA (<u>Porterville, CA</u>):**
  - **January – February, 2013**
  - **Project: PM2.5 versus AOD**

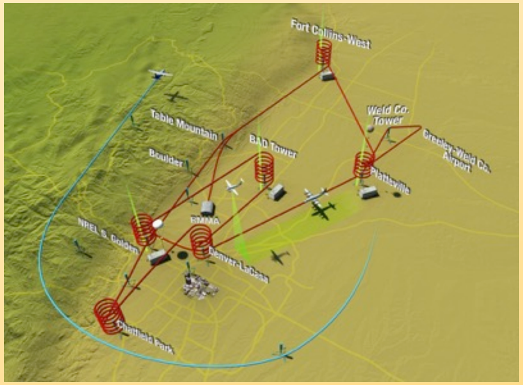


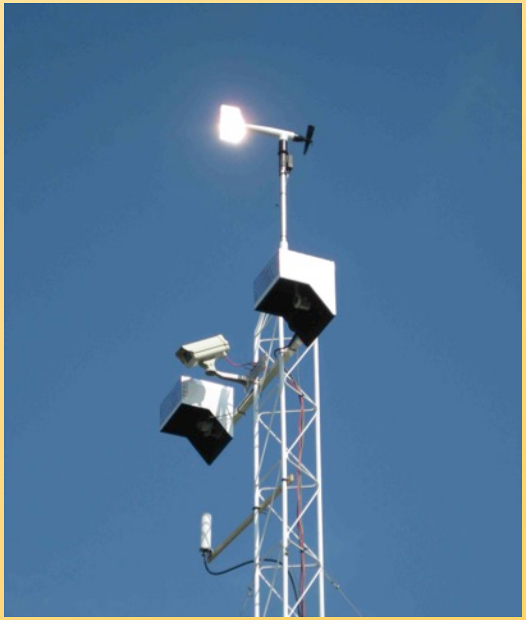




GOES-R Mobile SURFRAD deployments

- **NASA DISCOVER-AQ Houston Area (<u>Smith Point, TX</u>):**
  - **August – September, 2013**
  - **Projects: SW, IR, and Surface albedo over water**
- **NASA DISCOVER-AQ Front Range:**
  - **July - August, 2014**
  - **3 sites (Erie, CO, Table Mountain, CO, Platteville, CO)**
  - **Projects:**
  - Spatial variability from 3-4 sites across the region measuring radiation products
  - BAO Tower (300-m) and 10-m Tower measurements





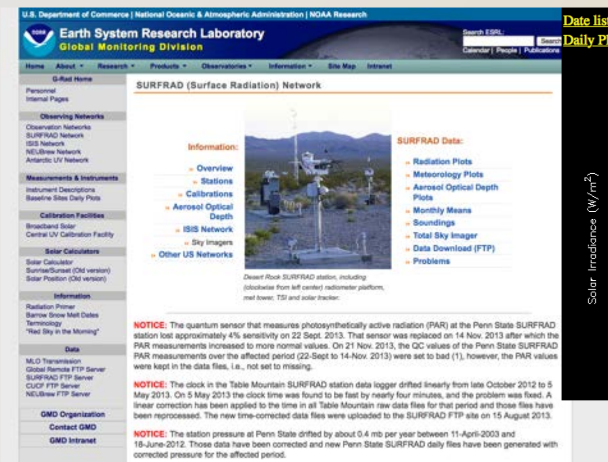
Web-site Data Delivery

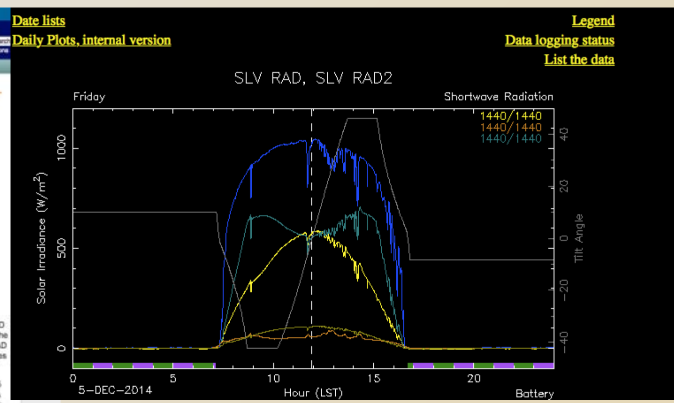
Daily data monitoring

- http://www.esrl.noaa.gov/gmd/grad
- http://cmdl1.cmdl.noaa.gov:8000/~star/daily/active_sta.html

Radiation Data access

- QA/QC data next day: ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/Bondville_IL
- Real-time every 15 min: ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/realtime





Almanac for 7-DEC-2014, DOY: 341

	Sunrise	Noon	Sunset
1. ALT		7-DEC-2014 11:01	
2. SUM	7-DEC-2014 11:42	7-DEC-2014 12:25	7-DEC-2014 11:42
3. TIK	7-DEC-2014 23:42	7-DEC-2014 13:15	7-DEC-2014 23:42
4. BRW	7-DEC-2014 04:42	7-DEC-2014 13:18	7-DEC-2014 04:42
5. RUT	7-DEC-2014 07:12	7-DEC-2014 11:43	7-DEC-2014 16:13
6. THD	7-DEC-2014 07:29	7-DEC-2014 12:08	7-DEC-2014 16:47
7. SPL	7-DEC-2014 07:17	7-DEC-2014 11:58	7-DEC-2014 16:39
8. TBL	7-DEC-2014 07:10	7-DEC-2014 11:52	7-DEC-2014 16:34
9. BAO	7-DEC-2014 07:09	7-DEC-2014 11:51	7-DEC-2014 16:33
10. SKAG	7-DEC-2014 07:10	7-DEC-2014 11:52	7-DEC-2014 16:34
11. SLV	7-DEC-2014 07:06	7-DEC-2014 11:55	7-DEC-2014 16:44
12. MLO	7-DEC-2014 06:44	7-DEC-2014 12:13	7-DEC-2014 17:42
13. KWAJ	7-DEC-2014 06:51	7-DEC-2014 12:40	7-DEC-2014 18:28
14. SMO	7-DEC-2014 05:45	7-DEC-2014 12:13	7-DEC-2014 18:41
15. SPO			

Cloud Image Data:

- ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/TSI/Daily/RUT-Images
- ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/TSI/Daily/SLV-Images

Total Sky Imager

Products and Applications:

1) Cloud Fraction: TSI gives cloud fraction for the local area for several cloud types, e.g. opaque and thin clouds. Compare with satellite estimates and model forecasts.
2) Cloud Heights: Using several Sky Imagers.
3) Cloud motion vectors: Cross-correlating two Sky imagers in proximity can give cloud motion vectors.

Chow et al., 2013

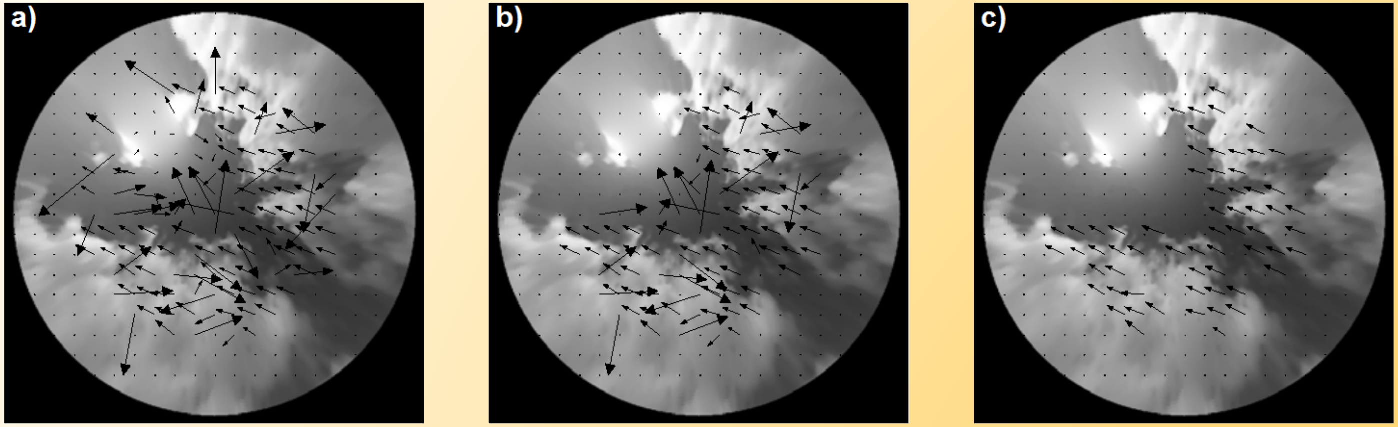


Figure 8: Illustration of procedures for obtaining a motion vector field on a sky image in sky coordinates on March 4, 10:21:30 PST. (a) Original vector field resulting from the cross-correlation method, (b) after removing vectors near the sun and vectors with a correlation of less than 0.8, and (c) after removing outliers. The average cloud velocity was 4.0 m s^{-1}.

1) TSI Movie: Cloud formation over site http://sky.ccny.cuny.edu/wc/skyimager2.php?video=20060121.flv

VG Forecast Value for Xcel Energy

	Forecasted MAE 2009	Forecasted MAE 2013*	Total Improvement	Percentage Improvement	Total Savings ($000,000)
PSCo	18.01%	11.04%	6.97%	38.7%	$20.4
NSP	15.65%	9.05%	6.60%	42.2%	$15.0
SPS	16.35%	12.32%	4.02%	24.6%	$1.4
Xcel	**16.80%**	**10.57%**	**6.23%**	**37.1%**	**$36.8**

*Data through November, 2013

Drake Bartlett, Xcel Energy

SURFRAD and ISIS Networks

NOAA will provide observations for model verification and data assimilation

- SURFRAD and ISIS radiation products are currently provided next workday; NOAA will upgrade communications pathways for this project in order to provide data in near real-time.
- Movable SURFRAD units will be built, tested, and deployed to one solar power installation chosen by NCAR and one chosen by IBM for up to one year each.
- NOAA will provide/develop several products including:
  - Aerosol Optical Depth
  - Spectral Solar irradiance
  - Spectral Surface Albedo
  - Cloud Fraction
  - Cloud Optical Depth
  - Plane-of-Array Solar Irradiance

Figure 1.1 Annual U.S. Solar PV Installations, 2000-2014

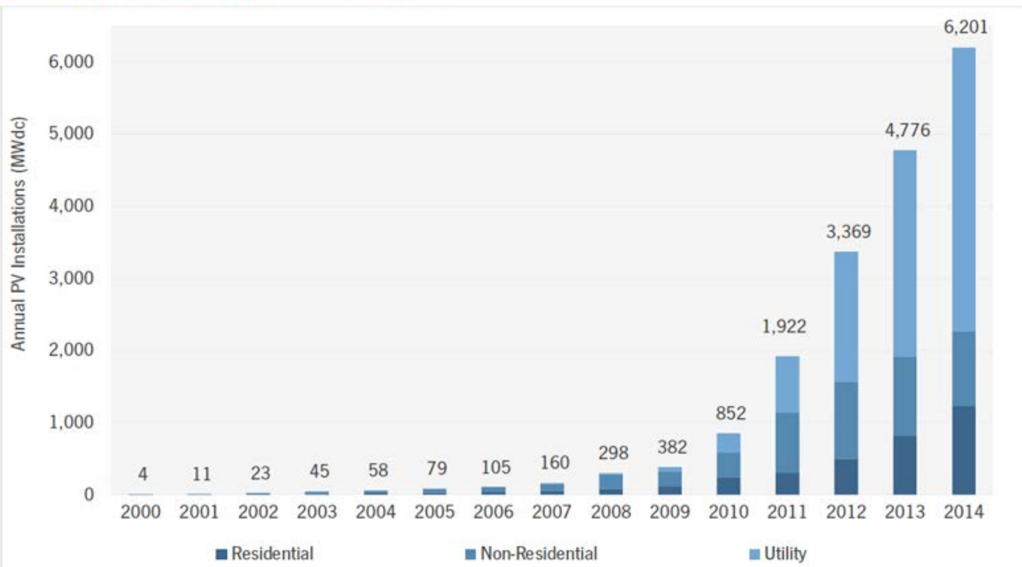
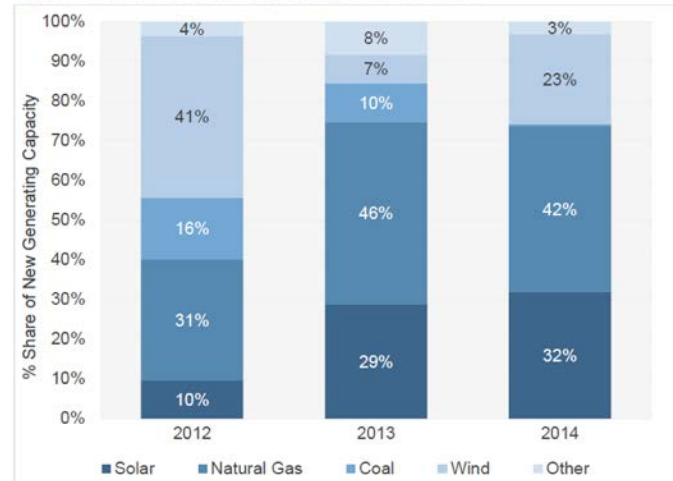


Figure 1.2 New U.S. Electric Generating Capacity Additions, 2012-2014



Source: GTM Research, FERC

Note: SMI data used for solar and PV installation figures converted from DC to AC for apples-to-apples comparison. FERC data used for all other technologies.