SMUD HIGH PENETRATION PV
TASK 5:
PV PRODUCTION FORECASTING
18 MONTH
PROGRESS REPORT

NEO Virtus Engineering, Inc.
April 20, 2012

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Project Sponsors and Partners

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SMUD
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NEO Virtus Engineering, Inc.

- Established 2001
- Electrical & Solar Engineering Photovoltaic System Consulting Firm
  - PV Electrical & Solar System Design
  - PV System Performance Verification
  - PV Production Data Acquisition & Monitoring
  - Solar Forecasting, EU & US patents 2008, 2009
- Sister Company: Day Ahead Instrumentation
  - Instrumentation hardware

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NEO's Tasks and Subtasks

- Task 5: PV Production Forecasting
  - Subtask 5.1: Solar Irradiance Monitoring & Data Retrieval
  - Subtask 5.2: Develop 20-36 Hour (Day Ahead) PV Forecasting Model
  - Subtask 5.3: Develop 0-3 Hour Feed-Forward PV Forecasting Program
  - Subtask 5.4: Validate Irradiance/PV Production/Load Forecast Model

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Project Deliverables

- 71 sensor monitoring network deployed at SMUD
- Demonstration of Two PV Production Forecast Methodologies
  - 20-36 hour ahead forecast
    - NDFD>REST2>Sandia PV Array Performance Model
  - 0-3 hour ahead forecasts
    - Measured data>vector model>measured feedback
- Validation of forecast results
  - Measured irradiance data
  - Measured PV system production data
- Large Scale High Resolution Irradiance Database

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NEO's Scope of Work

- Design, procure, build, program primary & secondary stations
- Develop MySQL database
  - NDFD forecast data retrieval
  - Primary & secondary station automated data retrieval
  - Integration of REST2 algorithm
  - Integration of PV system geometry & shading obstruction algorithm
  - Integration of PV system parameters in Sacramento test area
- Design measured vs. forecast validation program
- Consider appropriate metrics for PV forecast accuracy and utility grid forecast requirements

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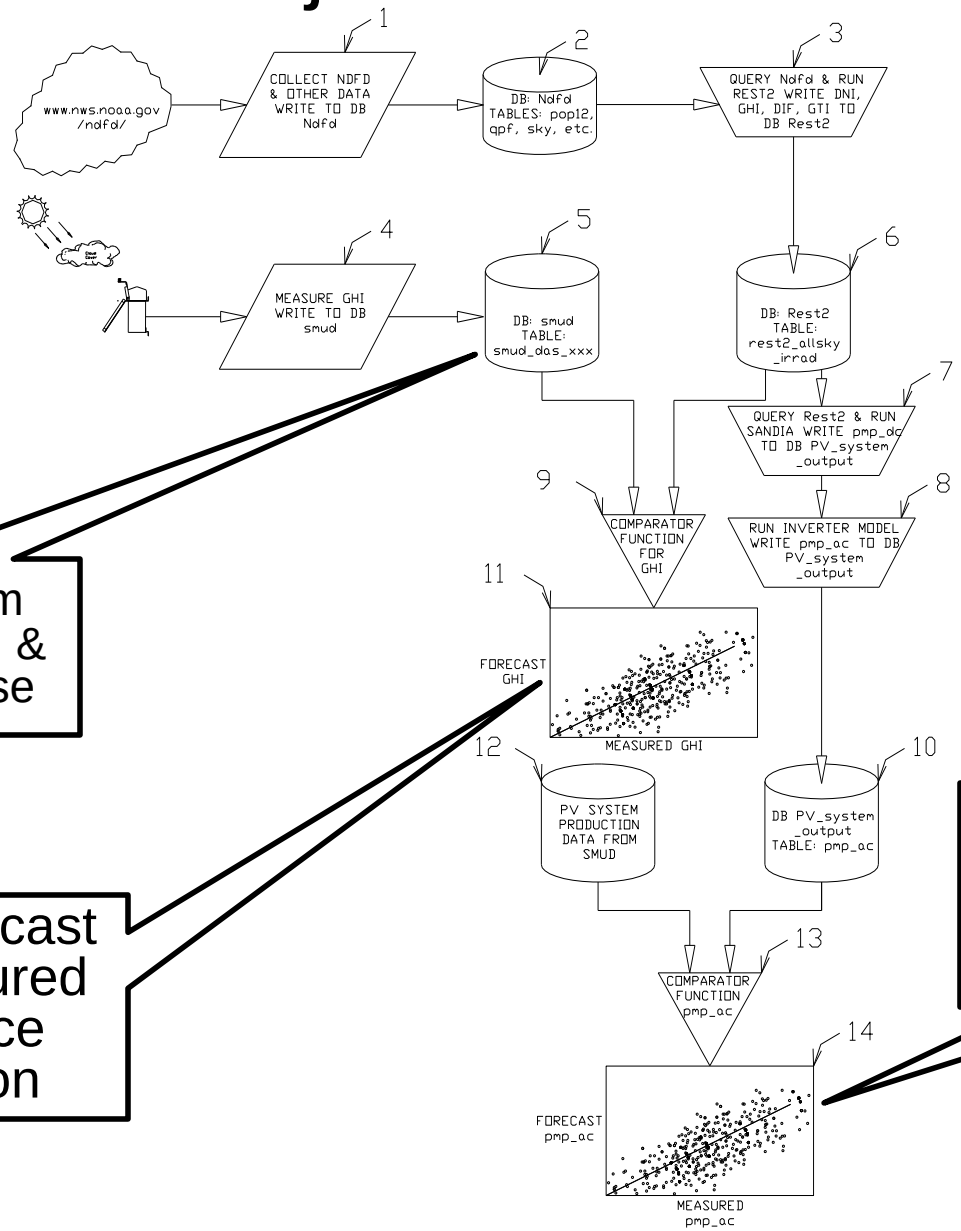
Project Deliverables



1-minute, 5km resolution GHI & Temp database

NEO Forecast vs. Measured irradiance validation

NEO Forecast vs. Measured PV power production validation

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Subtask 5.1: Irradiance & PV Production Monitoring Data Retrieval & Data Hosting

- Irradiance Monitoring Network:
  - Design
  - Manufacture
  - Deploy
- Automated GHI, DNI, DHI data retrieval
- Automated PV system production data retrieval (w/SMUD): on going for FIT systems

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Primary & Secondary Monitoring Station Specifications

- 5 Primary Stations: RSRs
  - GHI, DNI, DHI & Ambient Temperature
  - Cellular & spread spectrum communication
- 66 Secondary Stations: NEO SMUD DAS
  - GHI & Ambient Temperature
  - Cellular communication
- 4 Eppley Precision Spectral Pyranometers
  - Installed on RSRs for reference GHI

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Secondary Station Design & Fabrication

- Irradiance Monitoring Network
  - 5km grid Sacramento
    - NDFD Lambert conformal projection
    - Primary stations installed in SMUD substations
    - Secondary stations installed on SMUD utility poles
    - Automated data retrieval via cellular modem

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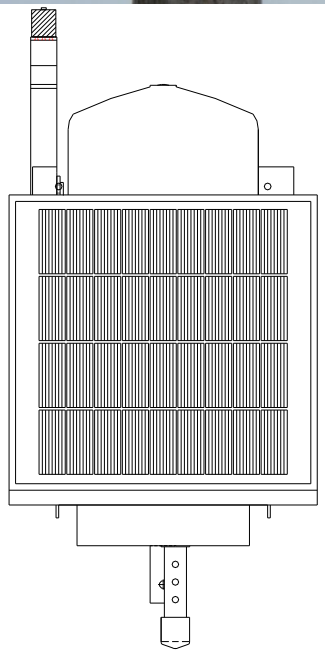
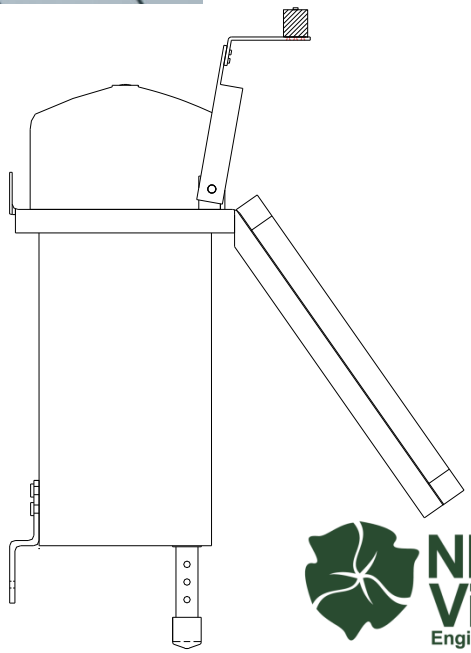
Primary & Secondary Monitoring Stations





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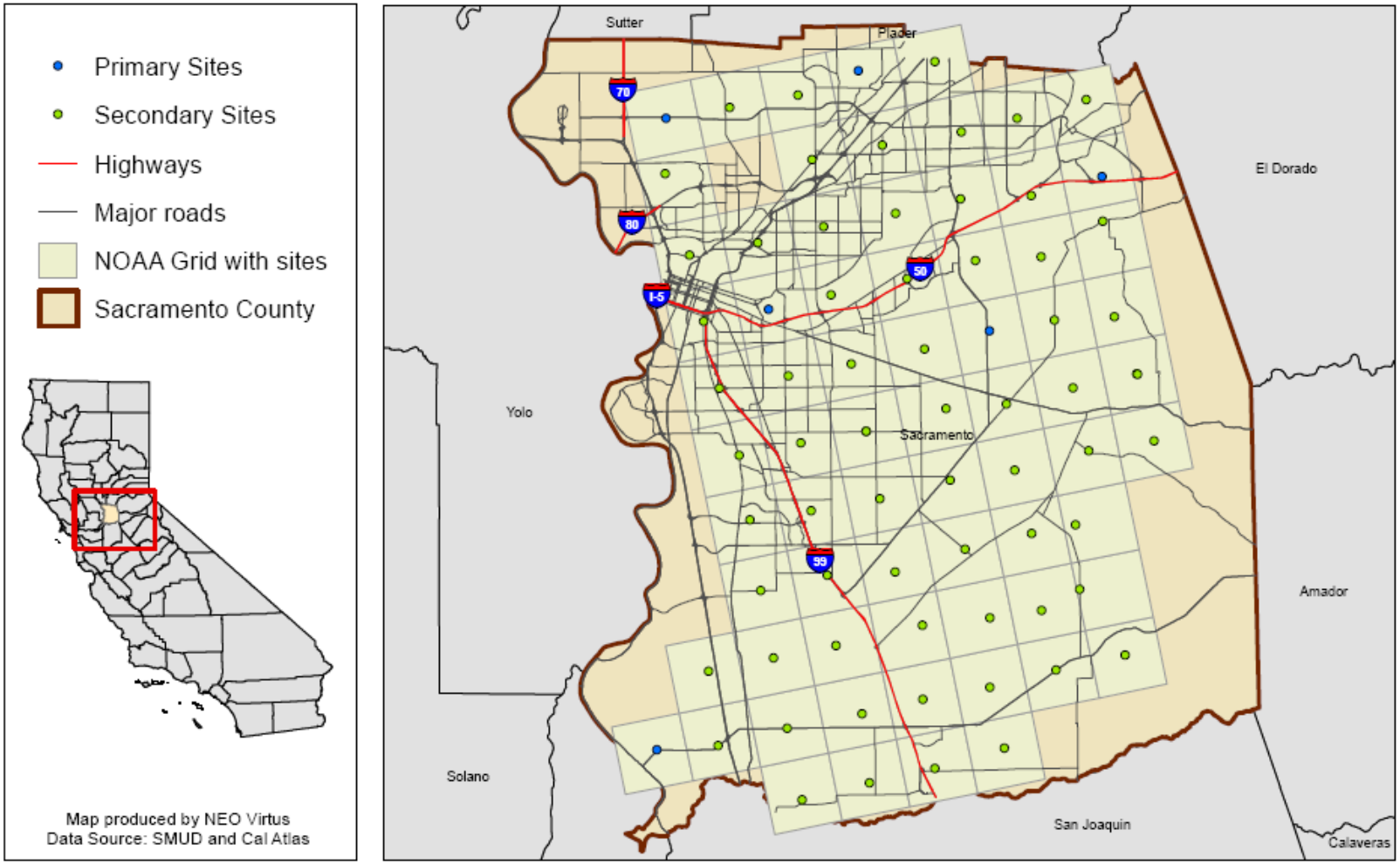
NDFD Grid, Primary & Secondary Sites in Sacramento County



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Status of Subtask 5.1

- Secondary monitoring fully deployed June 2011
- Primary monitoring fully deployed August 2011
- All primary and secondary station reporting
- Approximately 97% complete data set
- 10 of 12 months of irradiance data
- SMUD FIT system specs (no production data)
- NEO developing a compact transmitting pyranometer (CTP), a low cost, “real time” version of the SMUD secondary network*

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Subtask 5.2: 20-36 Hour Feed-Forward PV Forecasting Model

- Adapt Gueymard REST2 Model (not CRM)
- PV Surface Irradiance Model REST2 Global Tilt Irradiance (GTI)
- Photovoltaic Generation Model (Sandia PV Array Performance Model) Integration
- 20-36 Hour Feed-Forward PV Forecasting Model Integration
- Load Data Collection (w/SMUD)

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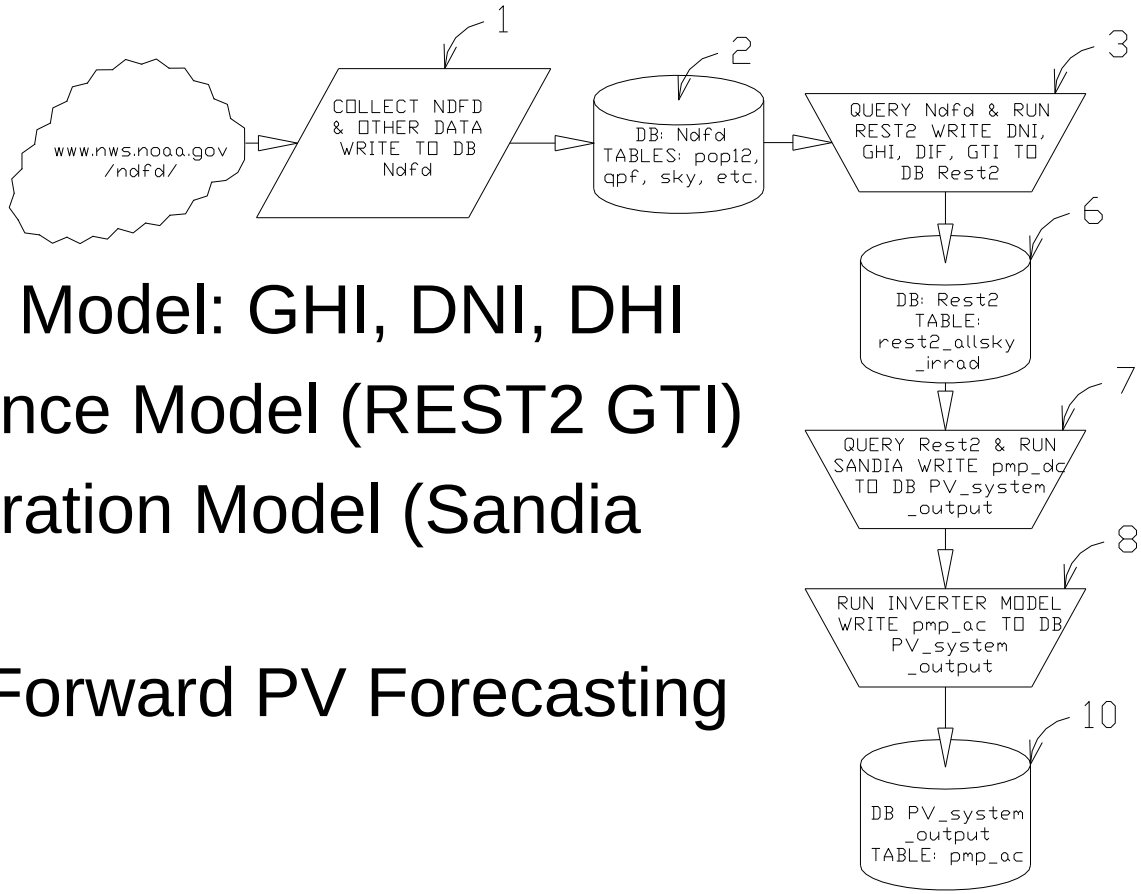
Develop 20-36 Hour Day Ahead PV Forecasting Model



- Gueymard REST2 Model: GHI, DNI, DHI
- PV Surface Irradiance Model (REST2 GTI)
- Photovoltaic Generation Model (Sandia Model) Integration
- 20-36 Hour Feed-Forward PV Forecasting Model Integration

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NEO's Day Ahead Data Collection Schedule

DAY AHEAD IRRADIANCE FORECASTING SCHEDULE

NDFD FORECAST REFERENCE TIME

PERIOD TO BE FORECAST

NDFD VALID				Ref	V	V+1	V+2	V+3	V+4	V+5	V+6	V+7	V+8	V+9	V+10	V+11	V+12	V+13	V+14	V+15	V+16	V+17	V+18	V+19	V+20	V+21	V+22	V+23	V+24	V+25	V+26	V+27	V+28	V+29	V+30	V+31	V+32	V+33	V+34	V+35	V+36	NDFD VALID
NEO'S SMUD CONTRACT REQUIRES A 20 TO 36 INTO THE FUTURE FORECAST DELIVERED AT 8:00am PST.						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	SMUD FRCST HOUR
UTC	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	UTC
PST 24hr	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	PST 24hr
PST 12hr	4:00am	5:00am	6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:00pm	12:00am	1:00am	2:00am	3:00am	4:00am	5:00am	6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	PST 12hr
EST 24hr	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	EST 24hr
EST 12hr	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:00pm	12:00am	1:00am	2:00am	3:00am	4:00am	5:00am	6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:00pm	PST 12hr

NEO 20 TO 36 AHEAD FORECAST DELIVERED TO SMUD

IRRADIANCE AND PV PRODUCTION FORECASTING METHODOLOGY

1) AT 15:00 UTC (10:00 EST; 7:00 PST) A 39 HOUR FORECAST OF 1-HOUR INTERVALS OF SKYCOVER AND TEMPERATURE WILL BE DOWNLOADED FROM THE NDFD. NEO USES THE FIRST 37 HOURS OF THIS SERIES OF FORECAST HOURS. THESE DATA WILL BE VALID AS OF 15:00 UTC. THE NDFD FORECAST HOURS SPAN A PERIOD FROM 7:00AM PST TO 8:00PM PST THE FOLLOWING DAY (FROM 15:00 UTC TO 4:00 UTC THE FOLLOWING DAY).

2) IRRADIANCE AND PV PRODUCTION FORECASTS WILL BE COMPUTED FOR A WINDOW SPANNING FROM 21 TO 37 HOURS INTO THE FUTURE FROM THE TIME AT WHICH DATA IS DOWNLOADED FROM NDFD AND WAS VALID. THIS CORRESPONDS TO A TIME WINDOW OF 20 TO 36 HOURS IN THE FUTURE FROM THE TIME WHICH THE FORECAST IS SUBMITTED TO SMUD. THIS IS THE TIME WINDOW DEFINED IN OUR CURRENT RESEARCH CONTRACT AS "DAY AHEAD." THIS TIME WINDOW SPANS THE HOURS BEFORE SUNRISE TO AFTER SUNSET IN CALIFORNIA THE DAY AFTER THE FORECAST IS DELIVERED.

3) THE FORECAST IS DELIVERED TO THE SMUD (CALIFORNIA CLIENT) AT 8:00AM PST (11:00AM EST; 16:00 UTC)

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NEO's Day Ahead Data Collection Schedule

NDFD FORECAST REFERENCE TIME

NDFD VALID				Ref	V	V+1	V+2	V+3	V+4	V+5	V+6	V+7	V+8
NEO'S SMUD CONTRACT REQUIRES A 20 TO 36 INTO THE FUTURE FORECAST DELIVERED AT 8:00am PST.						1	2	3	4	5	6	7	8
UTC	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
PST 24hr	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
PST 12hr	4:00am	5:00am	6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pn
EST 24hr	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
EST 12hr	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pn

NEO 20 TO 36 AHEAD FORECAST DELIVERED TO SMUD

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NEO's Day Ahead Data Collection Schedule

PERIOD TO BE FORECAST

19	V+20	V+21	V+22	V+23	V+24	V+25	V+26	V+27	V+28	V+29	V+30	V+31	V+32	V+33	V+34	V+35	V+36	NDFD VALID
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	SMUD FRCST HOUR
00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	UTC
00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	PST 24hr
am	4:00am	5:00am	6:00am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	PST 12hr
00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	EST 24hr
am	7:00am	8:00am	9:00am	10:00am	11:00am	12:00pm	1:00pm	2:00pm	3:00pm	4:00pm	5:00pm	6:00pm	7:00pm	8:00pm	9:00pm	10:00pm	11:00pm	PST 12hr

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Status of Subtask 5.2

- 20-36 Hour Feed-Forward Irradiance & PV Forecasting Model integrated and working
  - Gueymard REST2 Model “trained” for Sacramento
  - REST2 Global Tilt Irradiance complete (requires near field shading model)
  - Sandia PV Array Performance Model integrated and working (requires additional modules simulated for Sandia module DB)
- Load Data Collection (w/SMUD) not started
- Started day ahead FIT system forecasts for SMUD*

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Subtask 5.3
1-3 Hour Feed-Forward PV Forecasting Program

- Develop 1-3 Hour Forecasting Algorithm
- 1-3 Hour Feed-Forward PV Forecasting Model Integration

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Status of Subtask 5.3

- Subcontractor (E. Kern) started on 1-3 Hour Forecasting Algorithm
- 1-3 Hour Feed-Forward PV Forecasting Model Integration not started

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Subtask 5.4
Validate Irradiance/PV Production/Load Forecast Models

- Validate Irradiance 20-36 Hour Forecast Model
- Validate Irradiance 1-3 Hour Forecast Model
- Validate Modified Load Forecast Model

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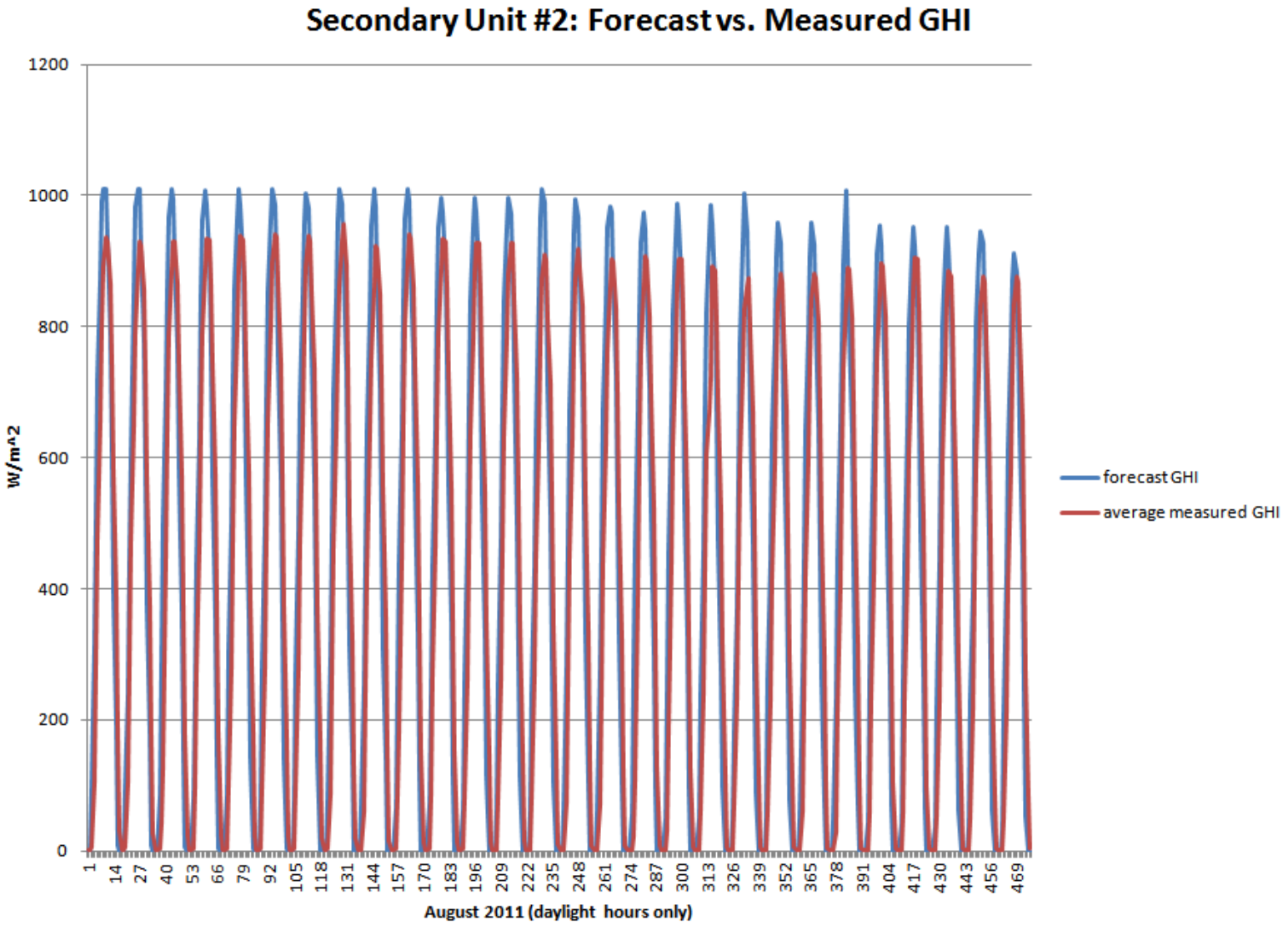
NEO's Day Ahead Forecast vs. Measured GHI



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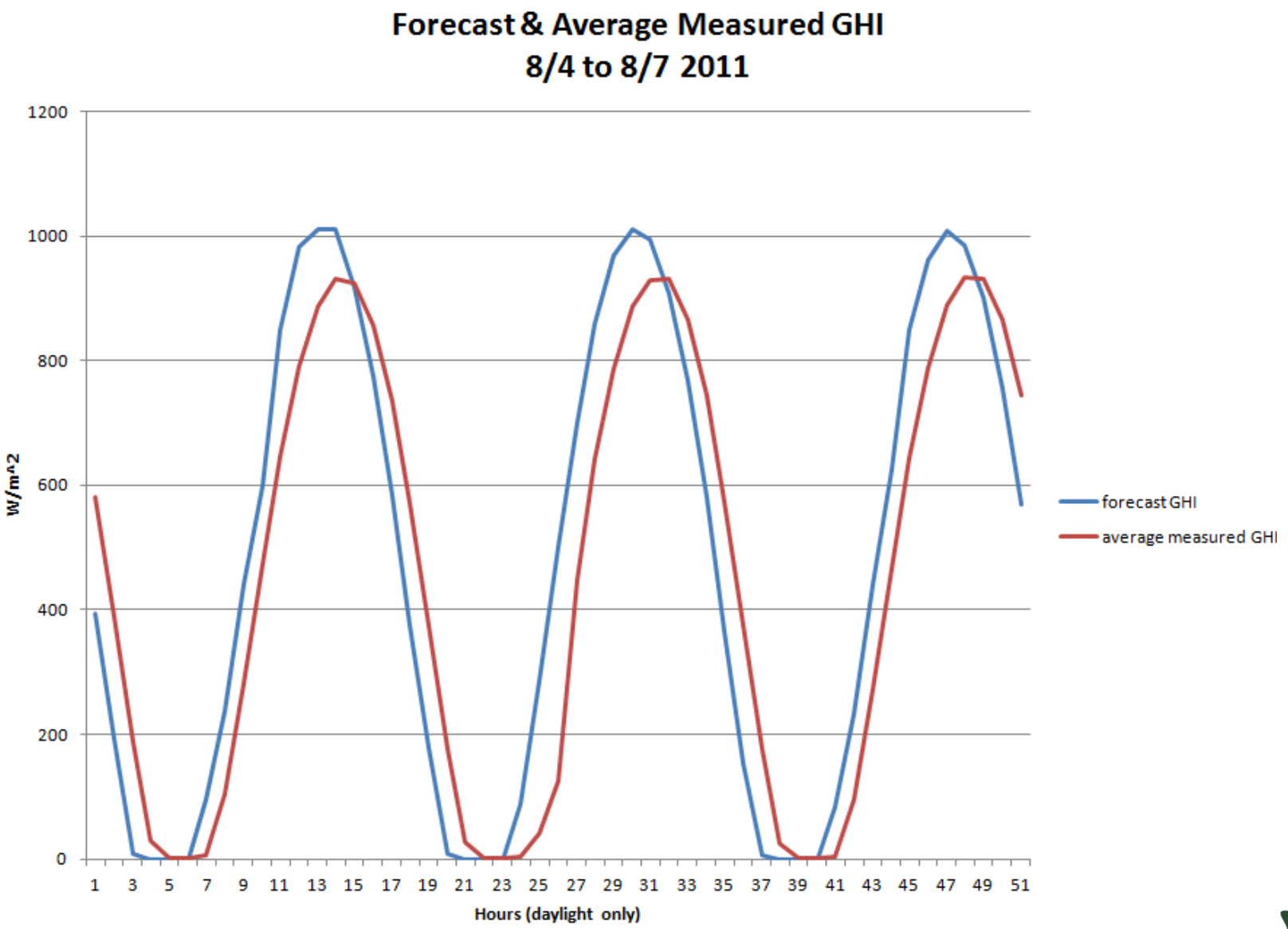

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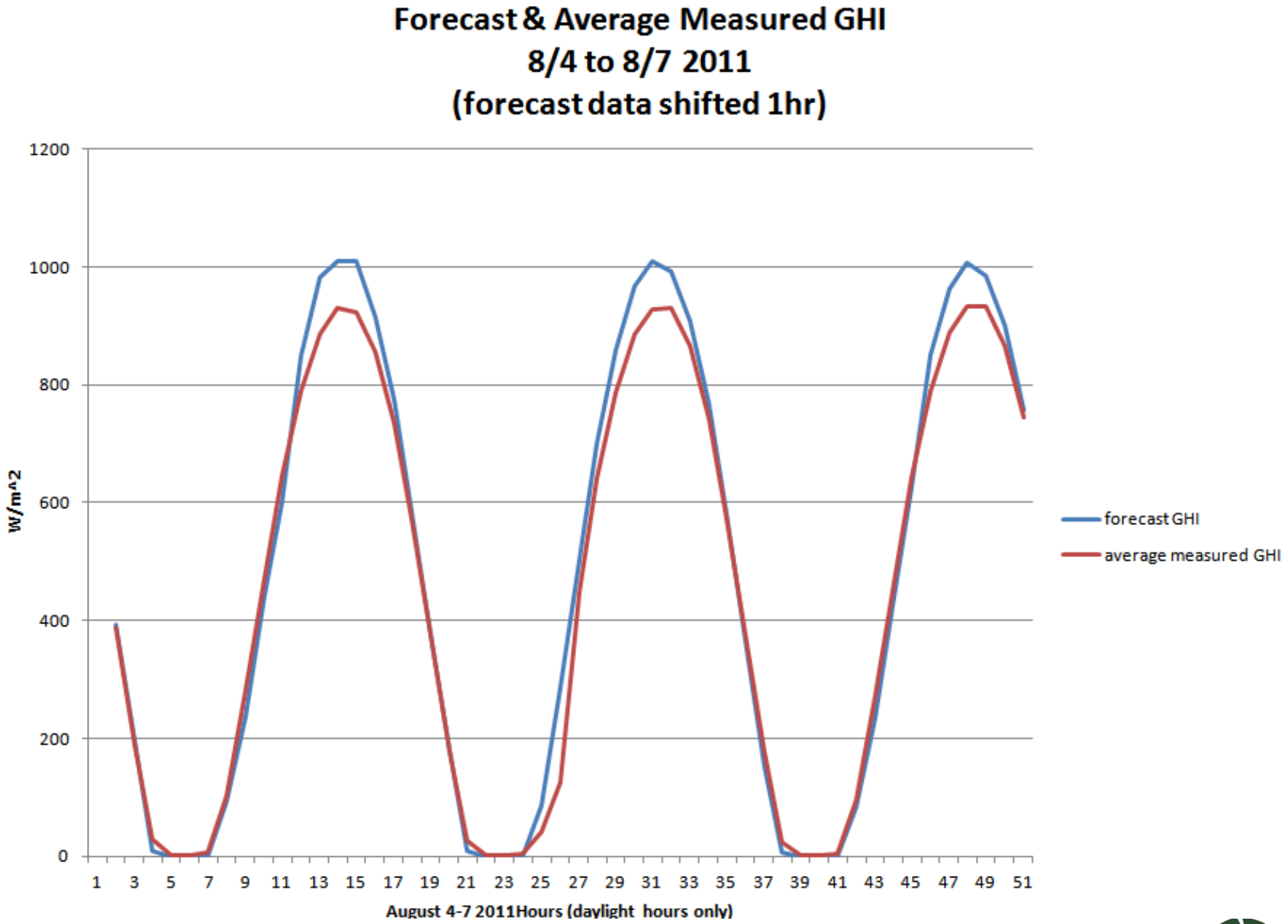

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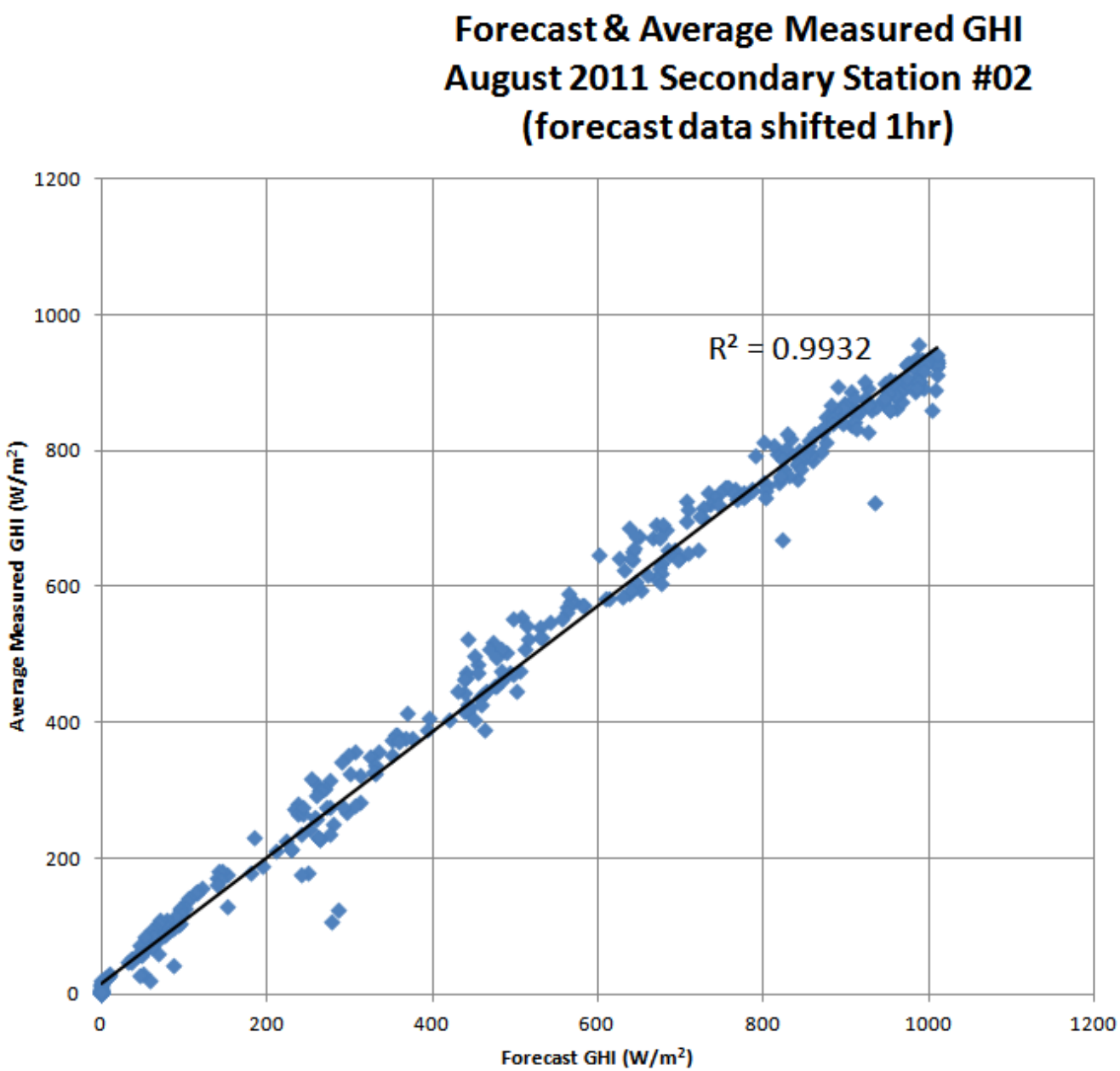

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Status of Subtask 5.4

- Validation program for Irradiance & PV production 20-36 Hour Forecast Model started
- Validation of Irradiance 1-3 Hour Forecast Model not yet started
- Validation of Modified Load Forecast Model not yet started

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Unforeseen Issues, Problems, Remedies, Lessons Learned

- Shadows cast by overhead lines and crossbars causing “artifacts” in secondary station GHI data
  - Working on algorithm to filter data for these
- Training historical forecasts (“Hindcasts”) from NOAA were difficult to acquire
- Data logger flash memory errors
  - NEO downloaded program patch via cell link to 54 units
  - NEO downloaded wire link 6 units
  - NEO replaced 4 failed units
- Reference PSP for data verification

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NEO's Data Retrieval QC

- Data from the 66 secondary stations and 5 RSRs are scheduled for daily automatic data collection on two separate machines. The result is a complete data set existing on two separate machines. Daily checks of the success of the automatic downloads are performed, and in the event of a failed automatic download, a manual download is attempted.

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NEO's Data Retrieval QC

- The current percentage of our dataset is 96.27%. I define the following terms for the calculation:

- Duration of deployment (days): [Last data of deployment or present] – [date of deployment on pole]
- Duration of good data set (days): [Last date of good data collection or present] – [date of deployment on pole] – [known data gaps if any]
- Good dataset percentage = [SUM for all units duration of good data set] / [SUM for all units duration of deployment] x 100

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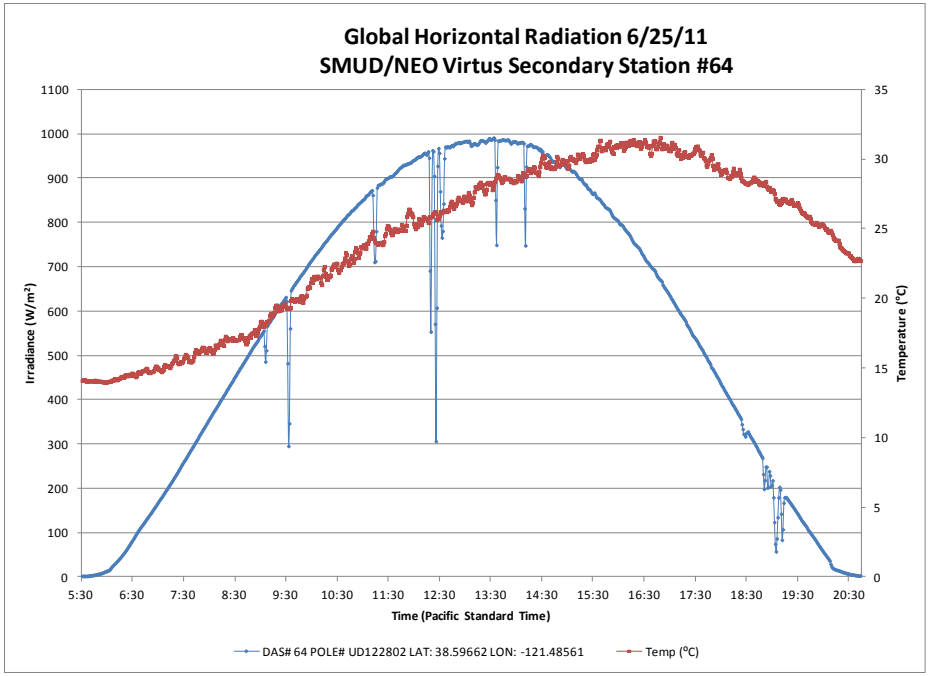
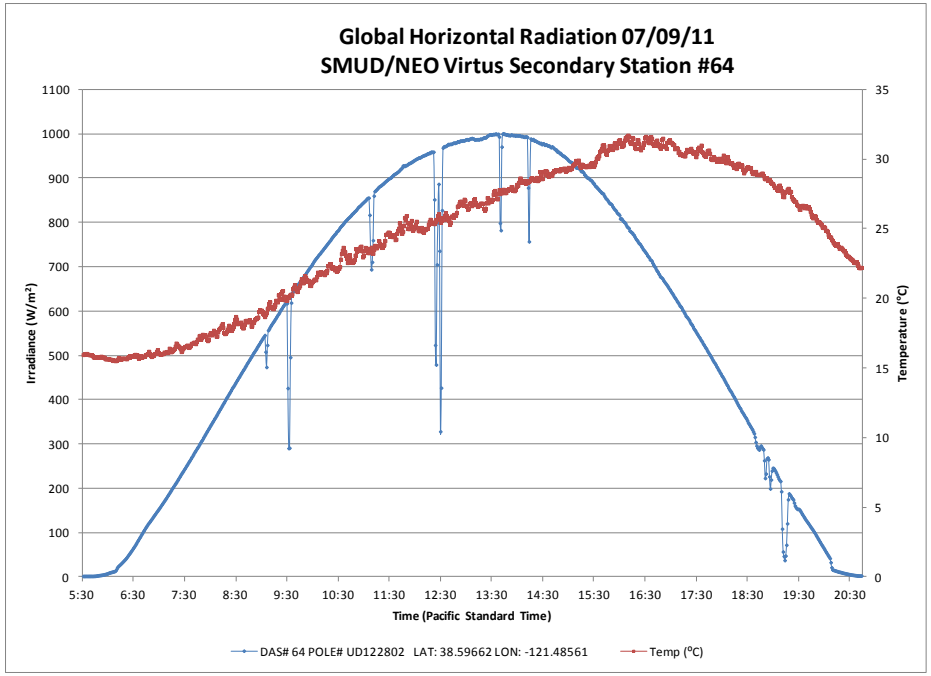
Overhead Wire Shading Anomalies





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Overhead Wire Shading Anomalies

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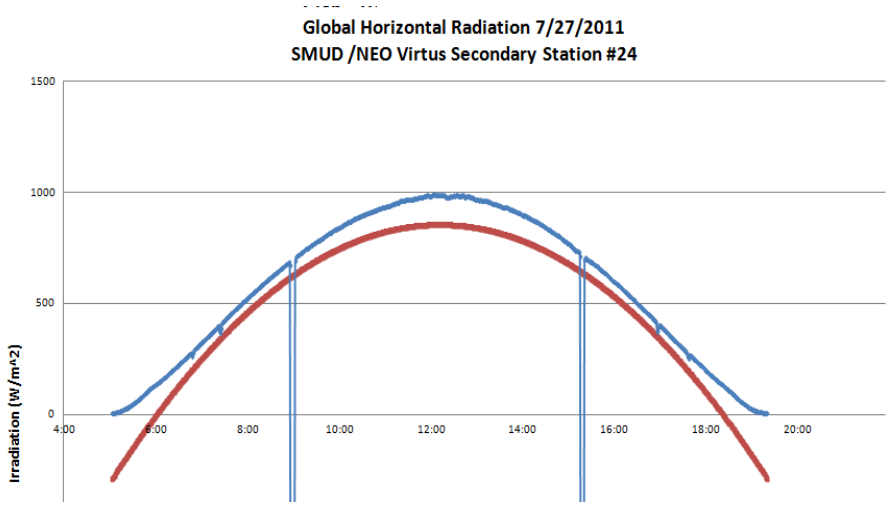
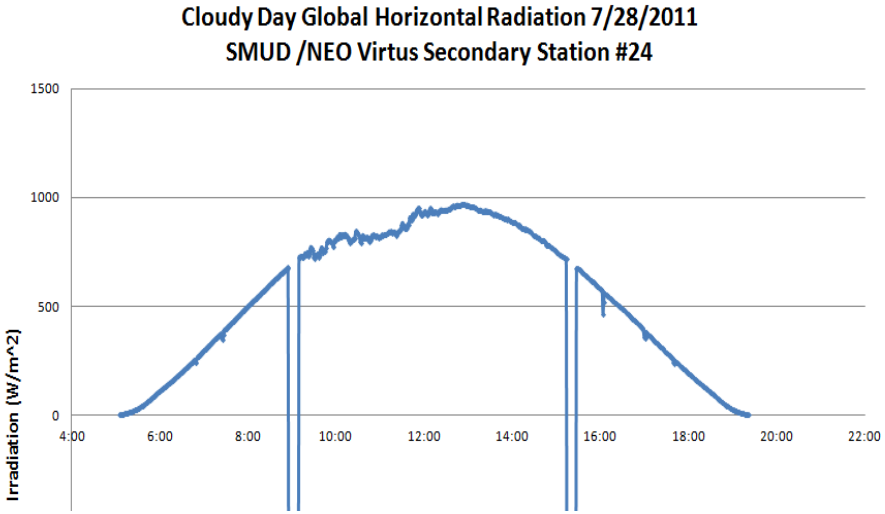
SMUD's Shading Filtering Method





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Global Network Calibration

- Eppley Precision Spectral Pyranometer (PSP)
- 4 PSP calibrated at NREL (BORCAL)
- PSPs installed on project RSRs
- Two week cleaning
- System-wide (“Global”) secondary monitoring unit calibration.

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Presentation & Papers

- Scripps Institute DOE/CPUC kickoff meeting
- ASES 2011 paper & presentation
- Lawrence Livermore National Laboratory lunch presentation
- ASES 2012 paper & presentation (scheduled)
- ASES Resource Applications Division newsletter April 2012
- IEEE PES General Meeting 2012 (scheduled)

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QUESTIONS?

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