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System Loss Considerations

Alex Panchula

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System losses consideration for increased accuracy

- Spectral losses
  - There is a quantifiable mismatch between AM1.5 and all QE curves of PV modules
- Soiling studies
  - This is easily measured, and should be for utility scale power plants
- DC Health
  - It is expected, and normal for the DC side health to not be 100% all the time.

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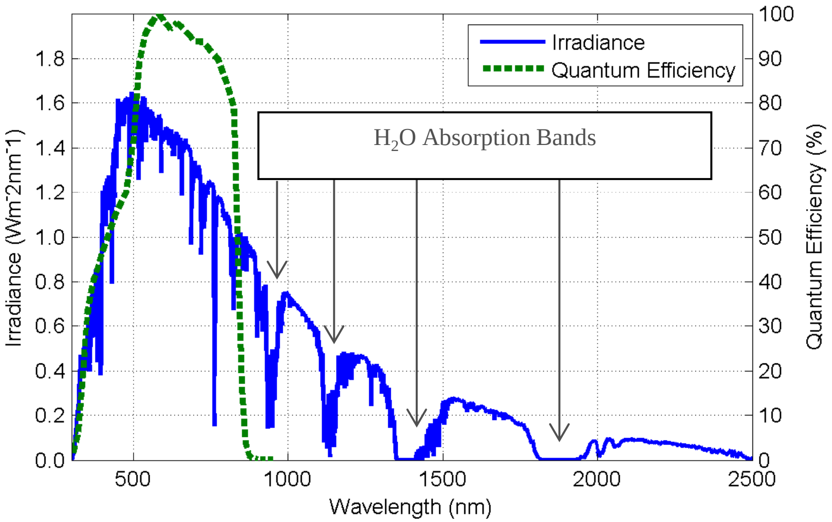
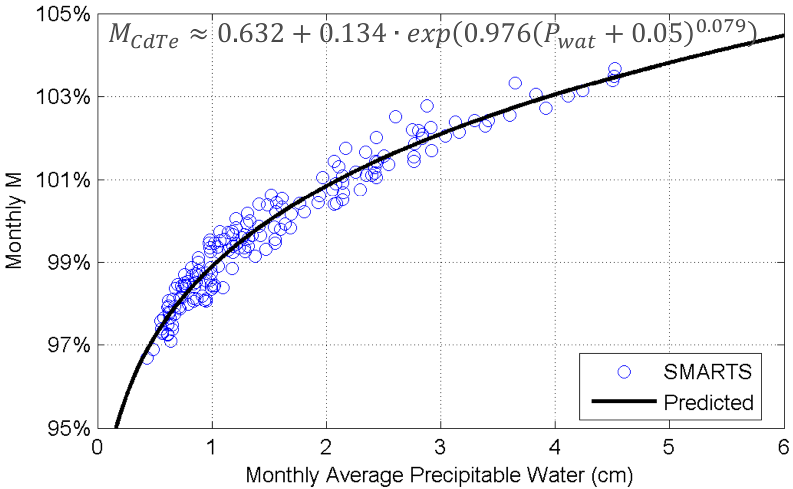
CdTe Spectral Shift

- Module nameplates defined at **AM1.5**
- Real world spectrum doesn't usually match AM1.5
- **Spectral shift** (*M*) is the deviation of module performance from nameplate due to changes in outdoor spectral distribution.
- For CdTe, *M* is primarily driven by the **precipitable water** (P_{wat}) content of the atmosphere.
- Higher P_{wat} → Higher CdTe performance[1]
- Lower P_{wat} → Lower CdTe performance[1]





[1] Relative to a broadband irradiance sensor such as a thermopile pyranometer

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Observed Spectral Performance Trends

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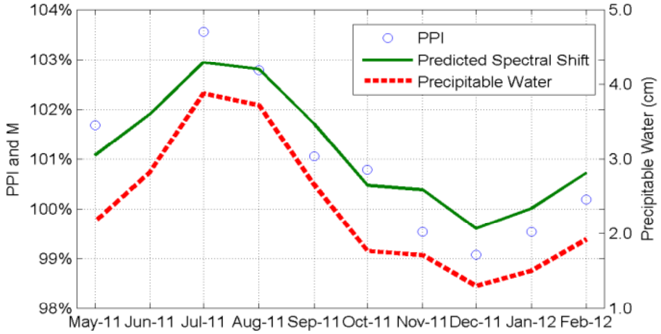
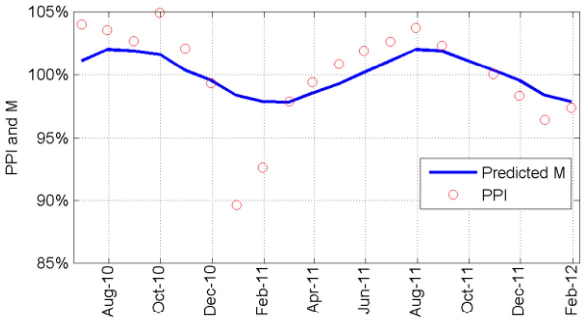
San Antonio, Texas, USA



Improved performance observed in summer months with higher P_{wat}

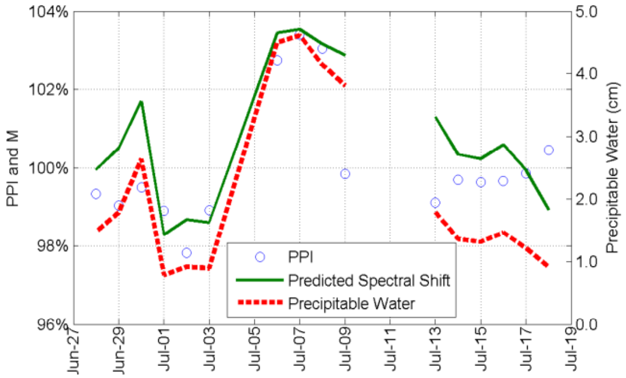
More than 100 MW in 4 different North American climates shows correlation between M and CdTe Performance

Ontario, Canada



Diminished performance observed and predicted in dry winter months. Improved performance in wet summer months

Blythe, California, USA



Improved performance after thunderstorm in the desert.

PPI is temperature corrected DC power regressed to 1000 W/m[2]

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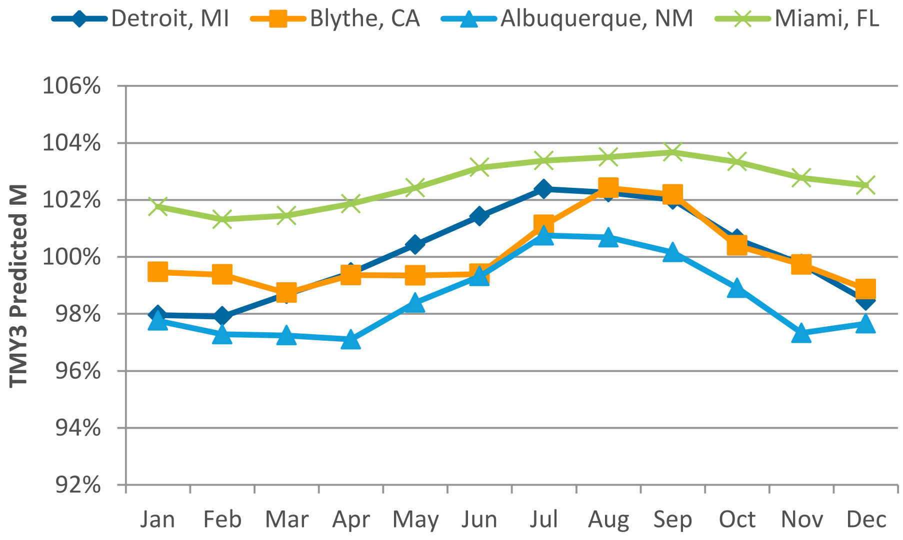
Predicting CdTe Spectral Shift in the United States

- All PV manufacturers will be subject to shifts in performance due to non AM1.5 spectrum.
- First Solar improved prediction accuracy in 2012 by incorporating spectrum into PV system modeling.

Location	Annual M
Detroit, MI	100.2%
Las Animas, CO	99.2%
Blythe, CA	100.2%
Las Vegas, NV	99.2%
El Paso, TX	99.4%
Phoenix, AZ	99.5%
San Antonio, TX	101.8%
Lancaster, CA	99.4%
Miami, FL	102.6%
Massena, NY	100.6%



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For more Information…

- Best Poster Award Winner- IEEE PVSC 38 2012
- Published in Journal of Photovoltaics. Vol 3(1). Jan 2013.

Changes in Cadmium Telluride Photovoltaic System Performance due to Spectrum

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Abstract **— Seasonal and short-term weather related changes in the solar spectrum can induce shifts in performance of PV systems which affects both annual energy predictions and system characterization. The spectral shift factor, a metric indicative of how much the performance of a PV system will vary from nameplate due to deviations from the ASTM G173 spectrum ("AM1.5"), is predicted using TMY3 data and the SMARTS model and is correlated to CdTe PV system performance in four different climates. The predicted spectral shift factors for CdTe systems show improved performance in the late summer and early fall and diminished performance in the winter. These intra-annual variations can be as large as +/- 3%, but annual spectral shift factors are typically within +/- 1% of nameplate. The spectral shift factor of CdTe systems was found to be most sensitive to the precipitable water content of the atmosphere. Consequently, a parameterization of CdTe spectral shift factor as an exponential function of precipitable water is derived using the outputs of the SMARTS model in 11 locations. This parameterization is shown to predict observed monthly and daily fluctuations in CdTe PV performance. Future efforts will incorporate this methodology into energy predictions which will reduce uncertainty.**

Index Terms **– photovoltaic systems, spectrum, Cadmium Telluride, modeling**

number of charge carriers generated per incident photon of a given wavelength – of a device:

$$SR_\lambda = QE_\lambda \cdot \lambda \cdot \frac{e}{hc} \qquad (1)$$

where e is the fundamental charge, h is Plank's constant and c is the speed of light.

A QE curve for CdTe normalized to 100% is shown in Fig. 1. The range of operation for CdTe is approximately 280 to 900 nm, while a broadband device such as a thermopile pyranometer has a theoretical SR of 100% from 280 nm to 3000 nm, and is therefore resilient to changes in spectrum.

The solar spectral irradiance distribution (also shown in Fig. 1) describes light intensity as a function of wavelength. The reference spectral irradiance distribution under which PV module nameplate ratings are defined is given by the global spectrum in ASTM G173, which is considered to be representative of the average spectrum in the 48 contiguous United States [4]. A number of input variables are used to derive ASTM G173 such as: a tilt of 37 degrees, a perceptible water vapor column of 1.42 cm, and an absolute air mass of 1.5 ("AM1.5") which corresponds to a solar zenith angle of 48.19°. Note that with regards to PV modules and systems

Why do we monitor soiling?

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Before

After ~8 mm rain event

- Back-out the impact of soiling on power plant performance
  - We can account for external factors affecting power plant performance such as irradiance, temperature, availability, and need to add soiling to the list
- Long term energy projections: measure soiling ramp rates directly and apply to energy generation estimates
- Provide a means of evaluating the threshold when cleaning might be economically advantageous to recover lost energy
  - Cleaning costs (labor, velocity, automated, dry vs. wet)
- Correct capacity tests for soiling effect

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Methodology

Close-up of water dispensing nozzle, programmed for daily pre-dawn washing

- Control modules washed at regular intervals
  - Weekly or semi-weekly if cleaned by hand (prospecting stations and power plants)
  - Daily at power plants with modules equipped with automated washing systems
- Daily ratio of module current sums are plotted to assess long-term soiling trend
- Differential measurement; by symmetry all modules are located in the same location within the array or relative to structures (PCS buildings) or are simply co-located; temperature effects are common-mode
- Pair-wise cross-comparisons between different reference module pairs if more than two modules available (e.g. 6 clean vs. 6 dirty)

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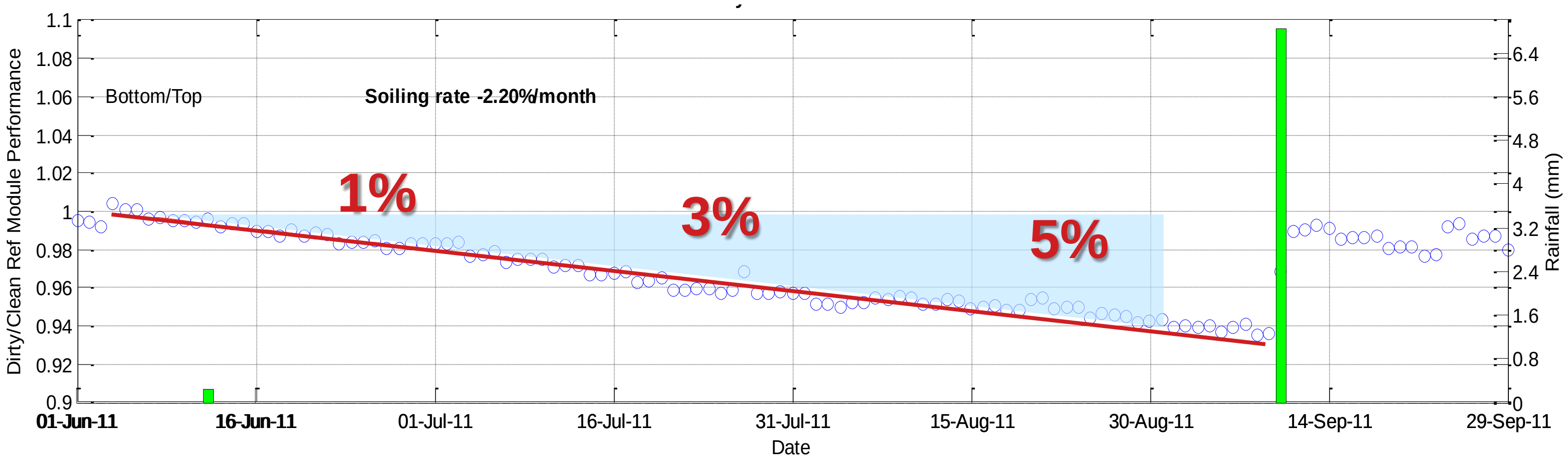
Soil Rates vs. Soil Levels



Soiling Rate	Slope of the line	How quickly dust accumulates between cleaning events
Soiling Level	Area above the line	% loss fed into energy estimation model

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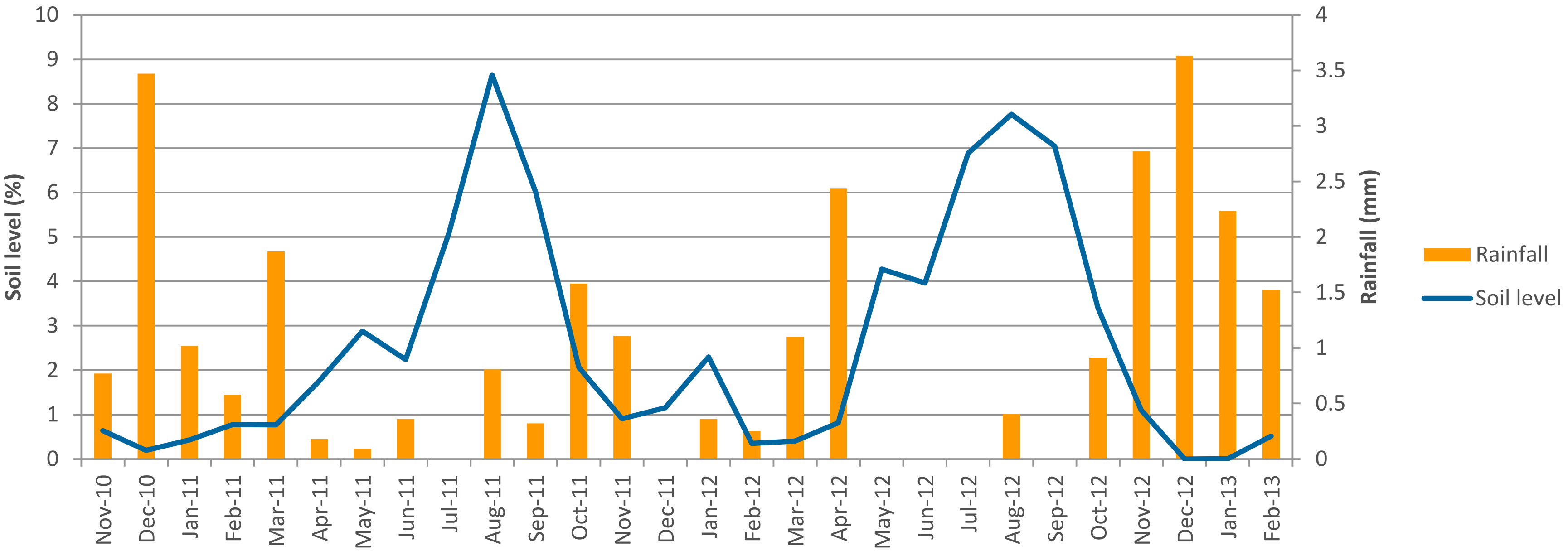
Monthly soiling level and rainfall for period of record

- Average soiling level: 2.6%
- Monthly soiling level does not exceed 8.7%



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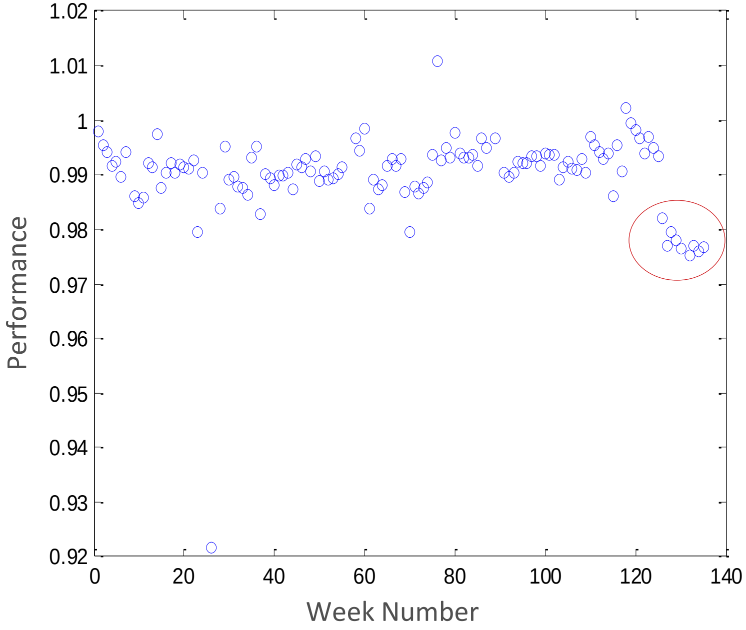
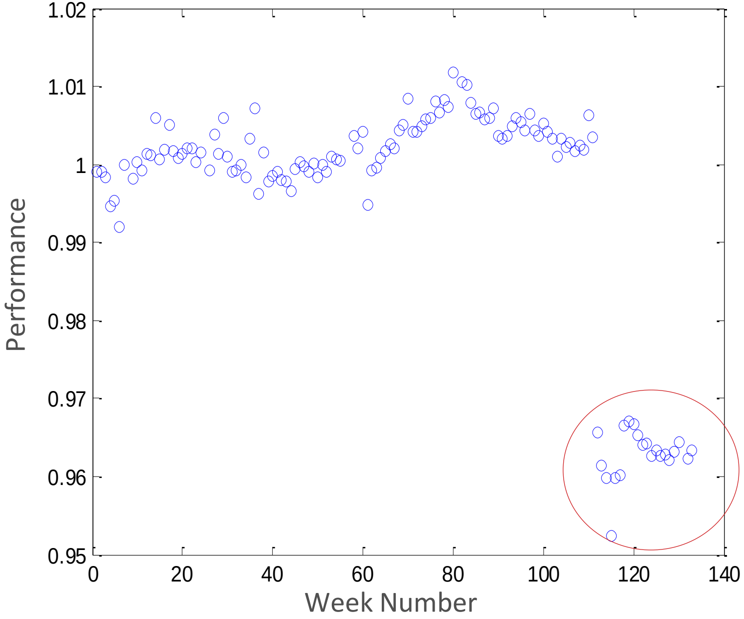
DC Health - CT trends over time, field checked



* Found 3 disconnected strings



* Found harness outage

Data trending over a multiyear period shows a small percentage of CT errors than be directly attributed to fuses, wildlife or human interactions

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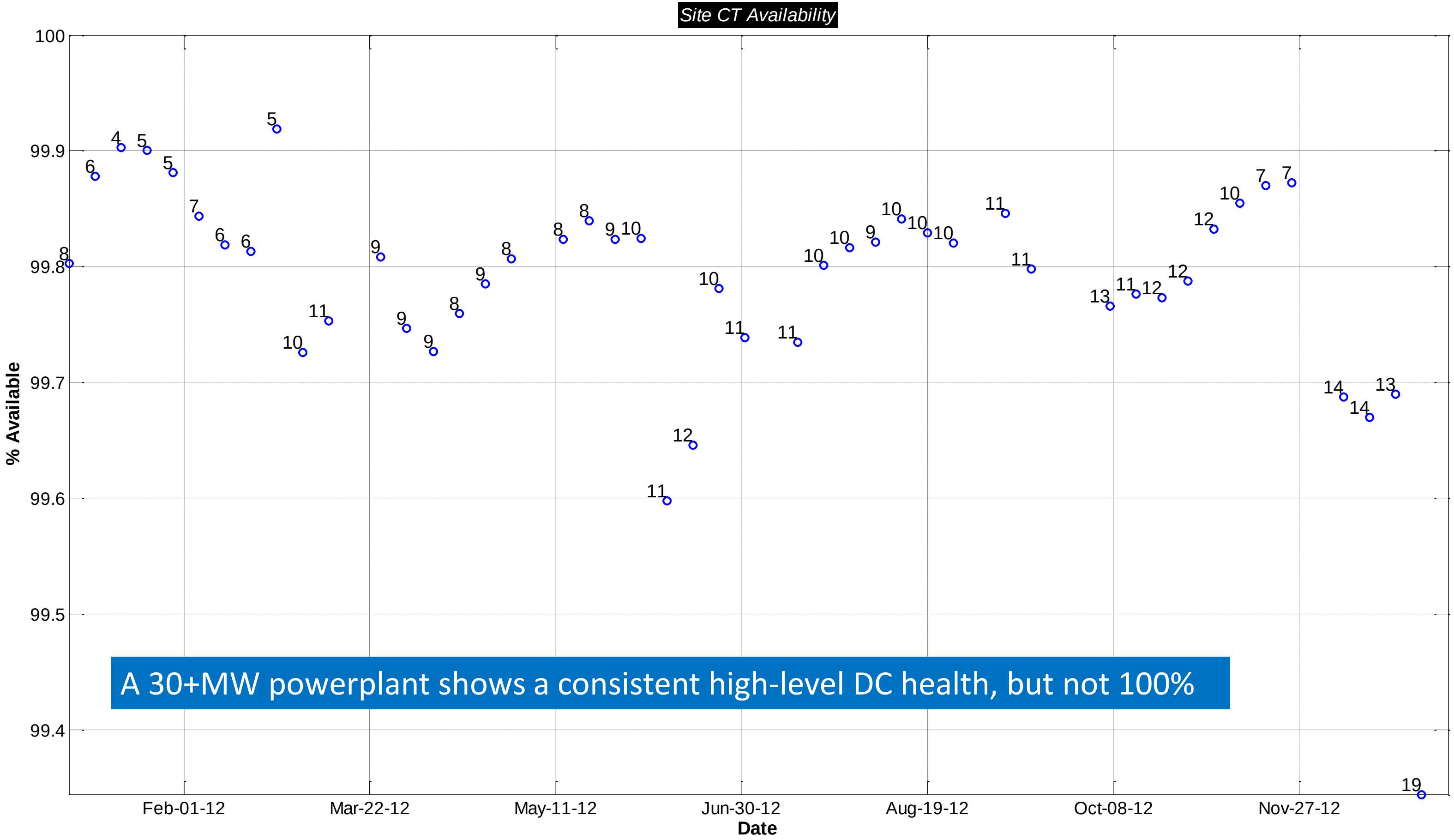
Site-wide trends in DC Health



A 30+MW powerplant shows a consistent high-level DC health, but not 100%

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