

Minimizing Variation in Outdoor CPV Power Ratings



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Outline

- NREL CPV testbed and its use in examining outdoor CPV power ratings
- IEC 62670 ,outdoor CPV power ratings, motivations and challenges
- ASTM E2527, a method for rating CPV module power outdoors
- Month to month variation in power ratings using ASTM method
- Attempts to improve the ASTM regression or develop an alternative
- Results to modifications to regression filtering and additional approaches
- Conclusions/Recommendations

NREL CPV Testbed & Outdoor Power Ratings

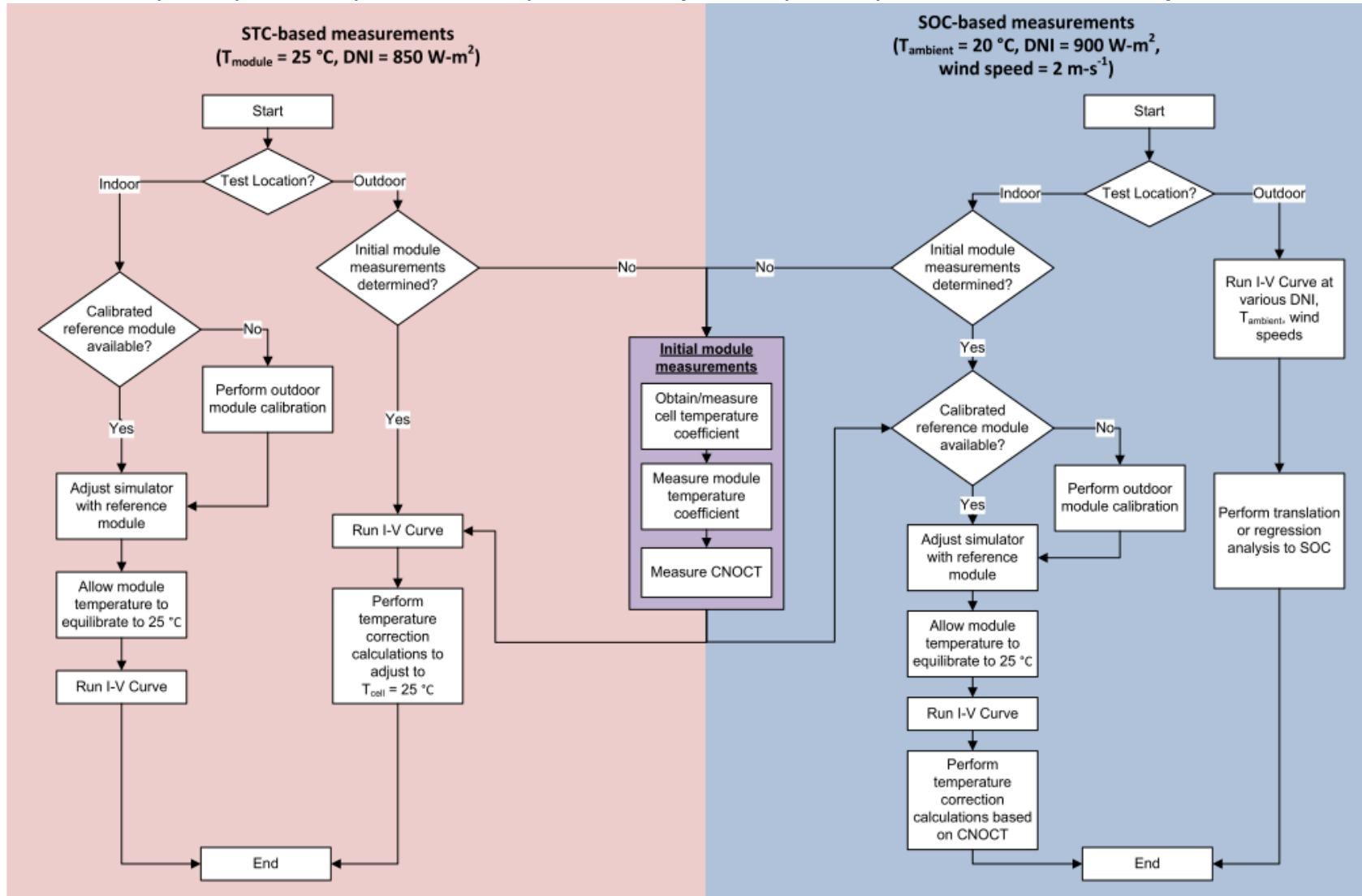
- 2-axis tracker (± 0.15 degree sun pointing error)
- Data acquisition provides module peak power tracking
- IV sweeps, 5 minute intervals
- DNI, GNI, wind speed, T_{ambient} , T_{module} , and tracking error are measured
- Spectral data (SRRL)
- A unique data set of various CPV lens and module architectures
- Understanding CPV performance variation and supporting standards development



IEC 62670 and Outdoor CPV Power Ratings

Concentrator Standard Operating Condition (CSOC)

T_{ambient} (20°C), DNI (900W/m²), Wind speed (2m/s) G173/AM 1.5 Spectrum



Outdoor Power Ratings, WHY? HOW?

- A need to characterize module thermal performance
 - Flat plate, ~25C above ambient at 1sun
 - CPV , ?? Degrees C above ambient
 - 300-1300X concentration varies the heat dissipation needed
 - Not all heat sinks are created equal
 - Outdoor temperatures → module/lens expansion/contraction
 - Does this impact performance?
- A need to characterize module spectral performance
 - It is well know that performance of triple junction cells is dependent on spectrum but how does this play out in a module and can it be quantified without specialized data
- If the above is the WHY? What about HOW?
 - IEC62670 describes CSOC but has not established a clear method
 - Method must provide consistent results from lab to lab (<5% variation)
 - Method must work for various CPV architectures without specialized information from the manufacturer

ASTM E2527, An Existing Method

CPV Module Power Rating Outdoors

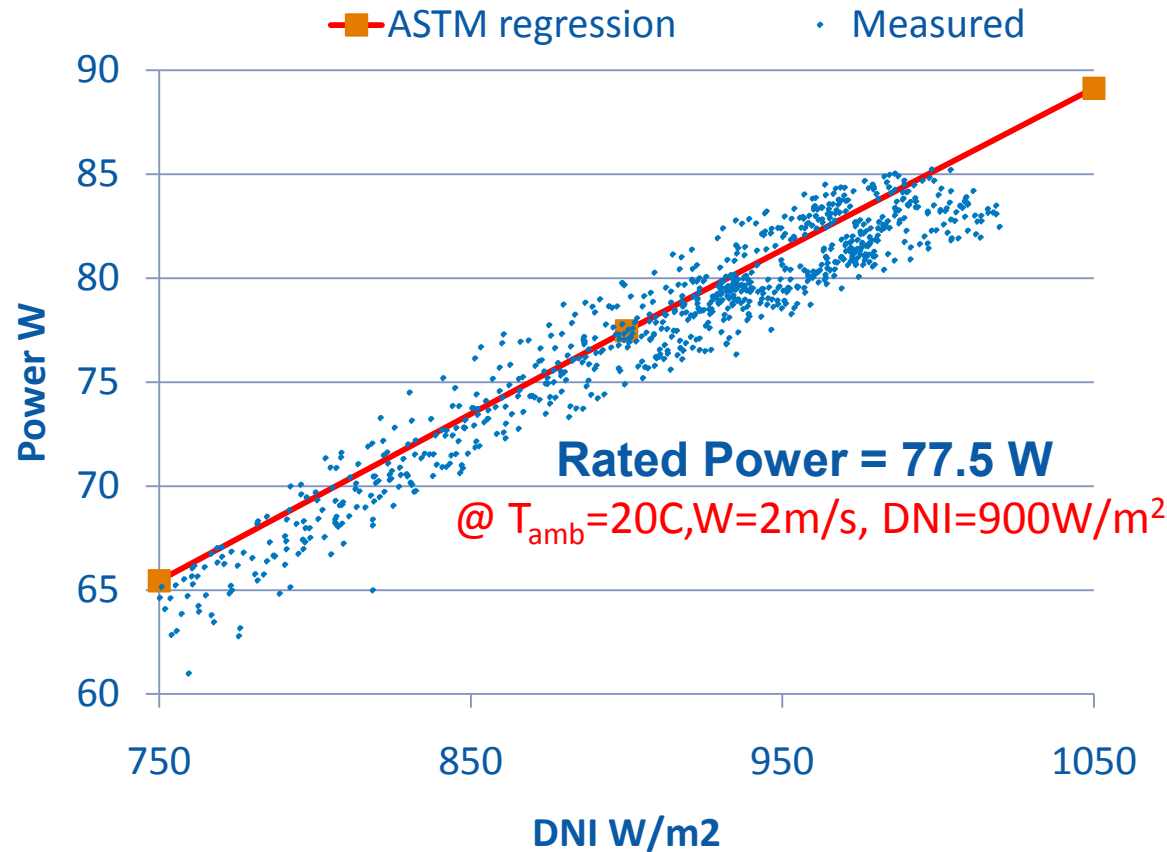
- Measure module maximum power and meteorological parameters
- Apply the following regression to the data set, reject if standard error too high

$$P_{\max} = \text{DNI}(a_1 + a_2 \text{DNI} + a_3 T_{\text{ambient}} + a_4 \text{Wind})$$

Report Pmax @ ($T_{\text{amb}}=20\text{C}$, $W=4\text{m/s}$, $\text{DNI}=850\text{W/m}^2$)

- In this presentation CSOC or ($T_{\text{amb}}=20\text{C}$, $W=2\text{m/s}$, $\text{DNI}=900\text{W/m}^2$) is used
- ASTM calls for the following restrictions on data for the regression
 - $10\text{C} \leq T_{\text{amb}} \leq 30\text{C}$
 - $\text{DNI} \geq 750\text{W/m}^2$
 - The average wind speed for the 5 minutes prior to a measurement is $\leq 5\text{m/s}$
 - Reject if visible clouds are within 10 degrees of sun
- Cloud restriction is approximated by rejecting a 10 minute DNI deviation $>2\%$
- Other restrictions applied above and beyond ASTM criteria
 - Reject if Diffuse radiation is $> 140\text{W/m}^2$
 - Reject if Tracking error is > 0.15 degrees

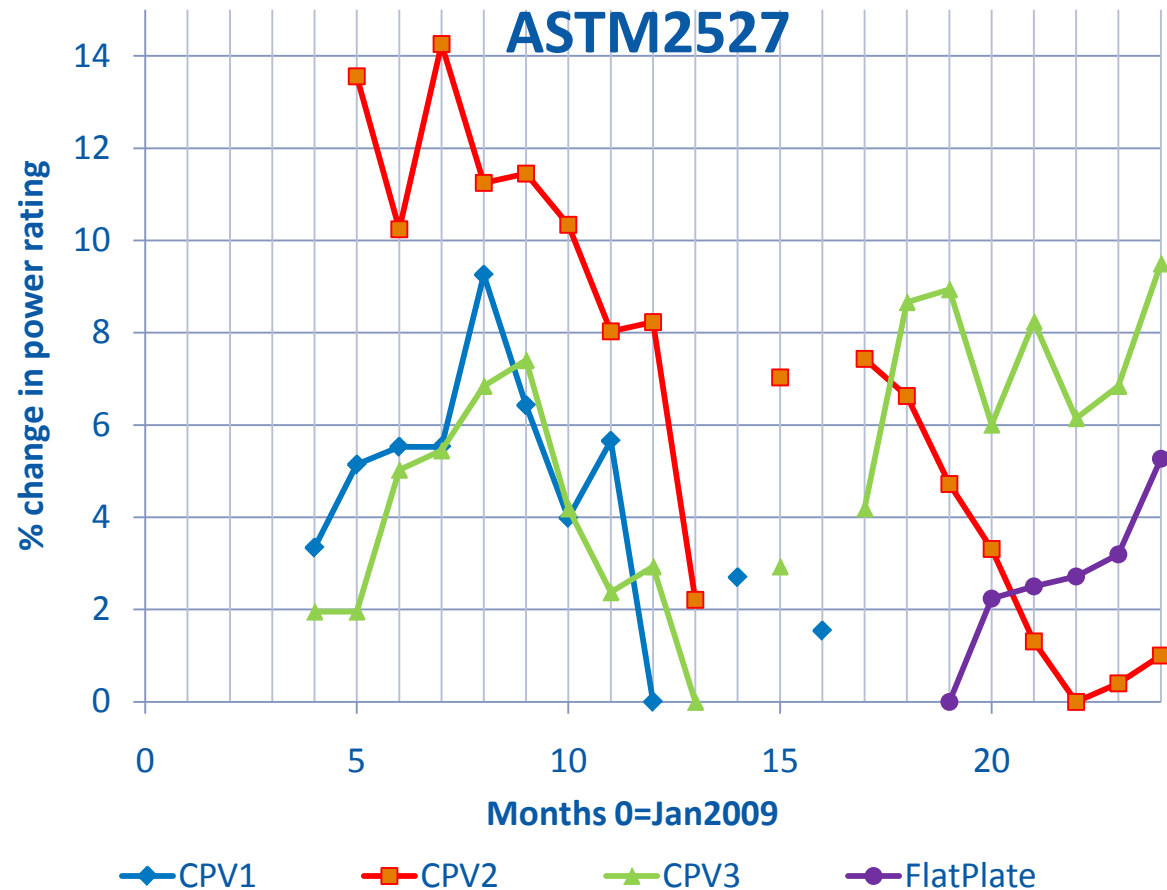
ASTM 2527 Applied to Sept 2010 data



- ❑ How much will the Rated Power for a CPV module if this procedure is applied over multiple months??
- ❑ The answer not only depends on outdoor conditions but also on the module technology!

%Variation in Module Rated Power

ASTM2527



- The graph shows the % variation in a modules monthly power rating as compared to lowest monthly rating over the 2 years

- For example, CPV1 had its lowest rating in month 12, while the rating in month 11 was almost 6% greater

- Note that CPV2 appears to be degrading in the 2nd year.

- WHY so much variation with the regression results?

- AM neglected?
- Lens performance neglected?
- Moisture in modules, soiling, alignment varies?
- Regression gives too much weight to outliers?

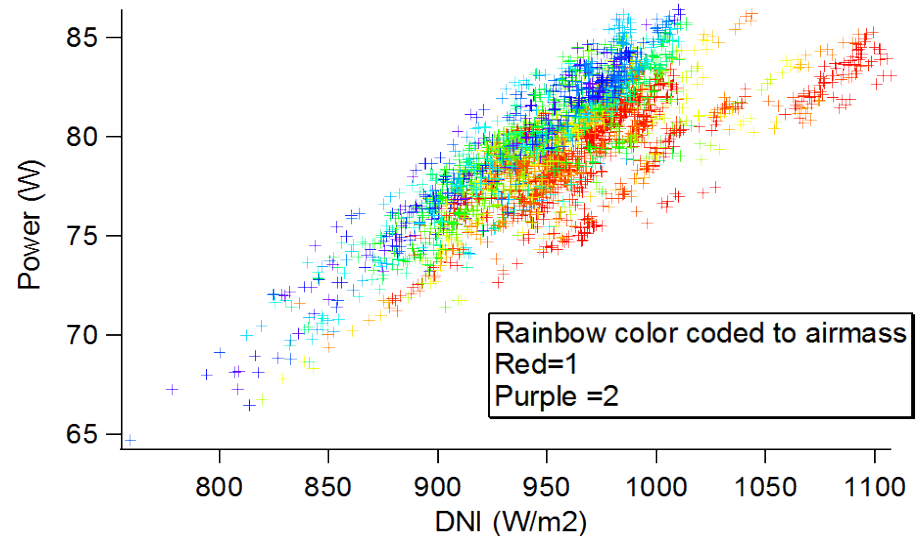
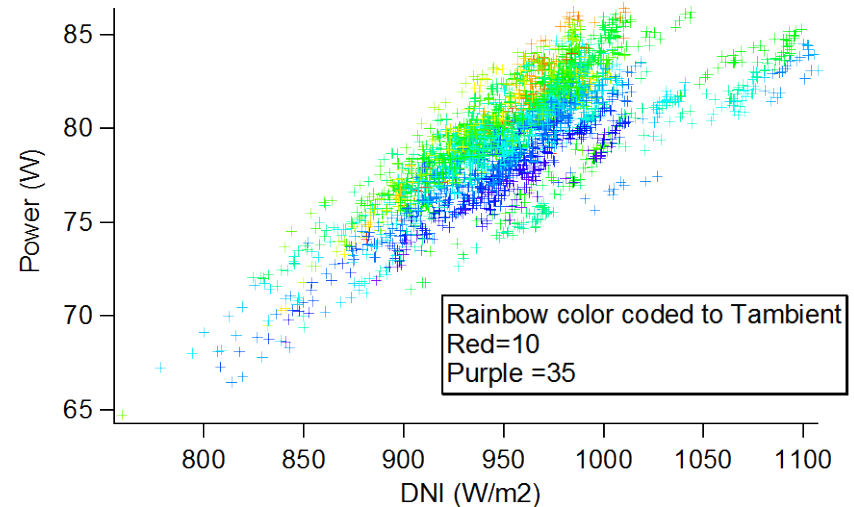
Can other variables improve the regression?

Efficiency correlates with the following

- T_{ambient}
- T_{module}
- DNI and GNI
- AM

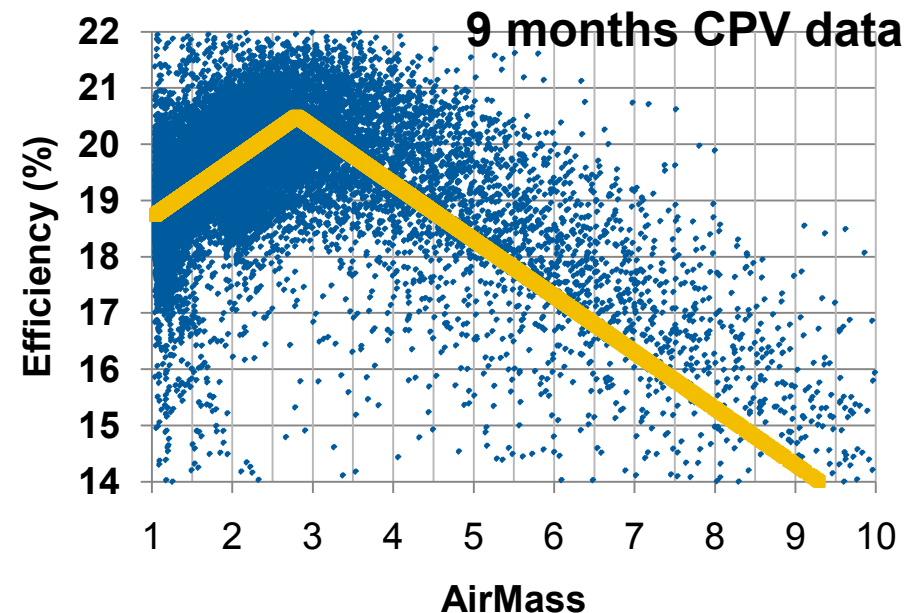
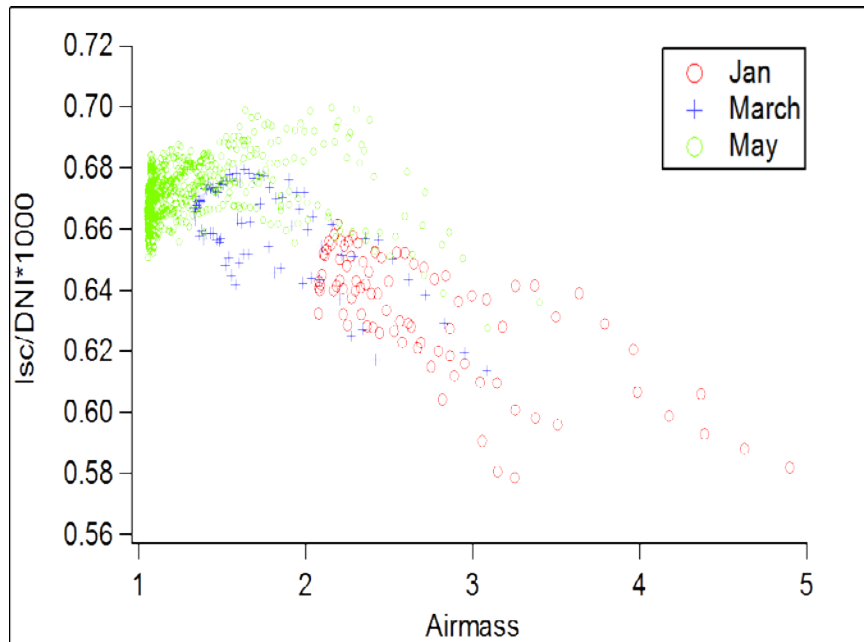
Efficiency (after temp correction) correlates with

- DNI and GNI
- AM
- Precipitable water vapor (moderate to weak)
- Turbidity (weak)
- In some cases there is positive correlation with T_{ambient} , consistent with lenses that go out of alignment at low temperatures



Regressions examined

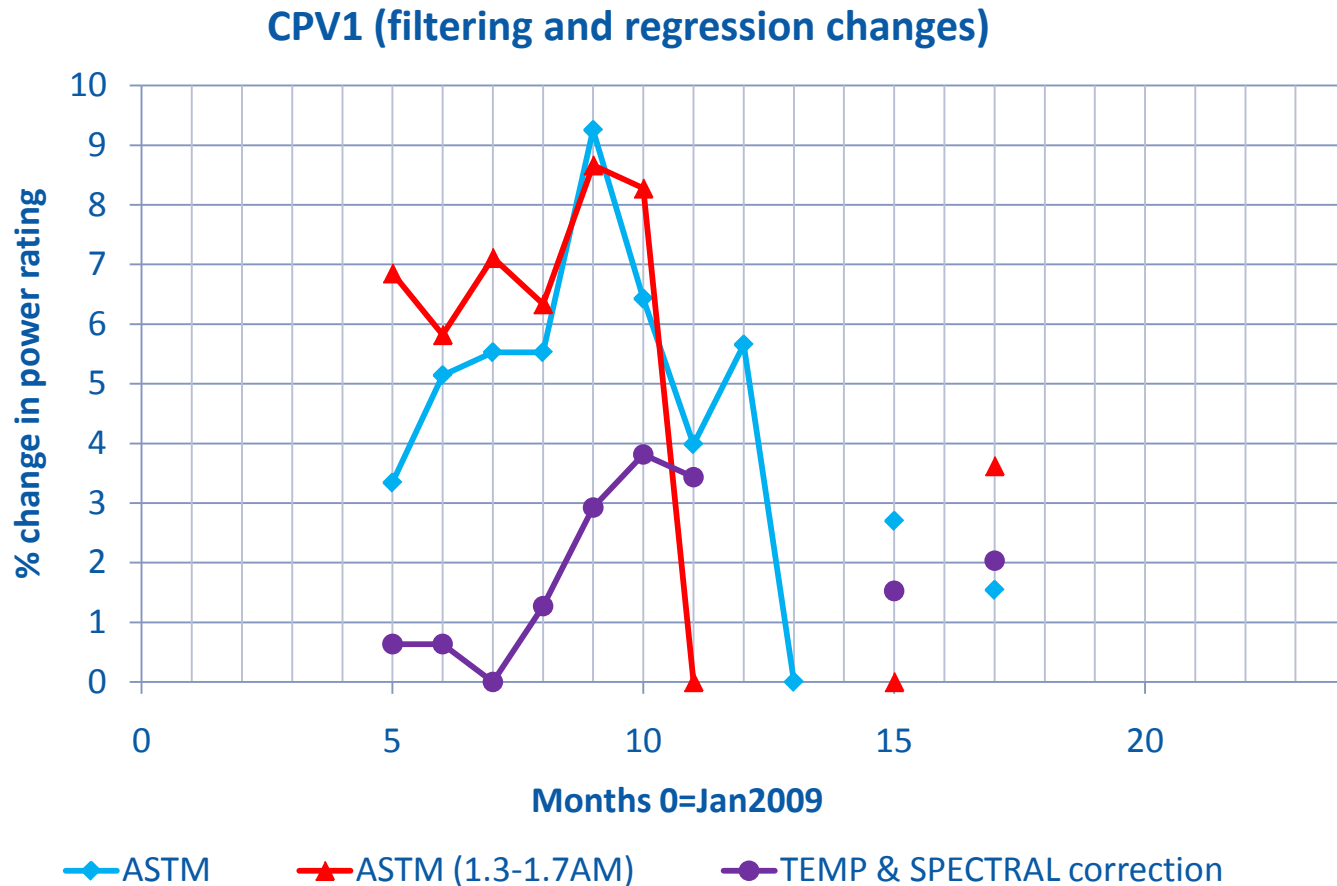
- New regressions were tested on yearly data sets using linear and nonlinear combinations of the variables on the previous slide
- The “best fit” for yearly data, judged by lowest standard error and the Tstat on the included variables, was $\text{Power}_{\text{temp corrected}} = a_1 \text{DNI} + a_2 \text{DNI}^2 + a_3 \text{AM} + a_4 \text{WaterVapor}$
- The existing ASTM regression with AM included also performed well.
- When the “best fit” and the modified ASTM regression were tested on monthly data the monthly variation in power became worse. (Graphs show one reason why)



- The graphs on the previous slide show how monthly regressions can fail to accurately model spectral performance variations
- As an alternative, can spectral filtering (specifically limiting airmass from 1.3 to 1.7) reduce variation in the ASTM power rating?
- As another alternative, would variation be reduced if monthly data is corrected for temperature, airmass, and precipitable water vapor before running a simple regression using DNI and DNI^2 ?
 - Only accept airmass values less than 2
 - Assume efficiency increases 1% absolute per unit of AM
 - Assume efficiency increases 0.6% per cm of PWV
 - Exclude any data points that have a PWV below 0.4cm
 - Exclude ambient temperatures below 15C

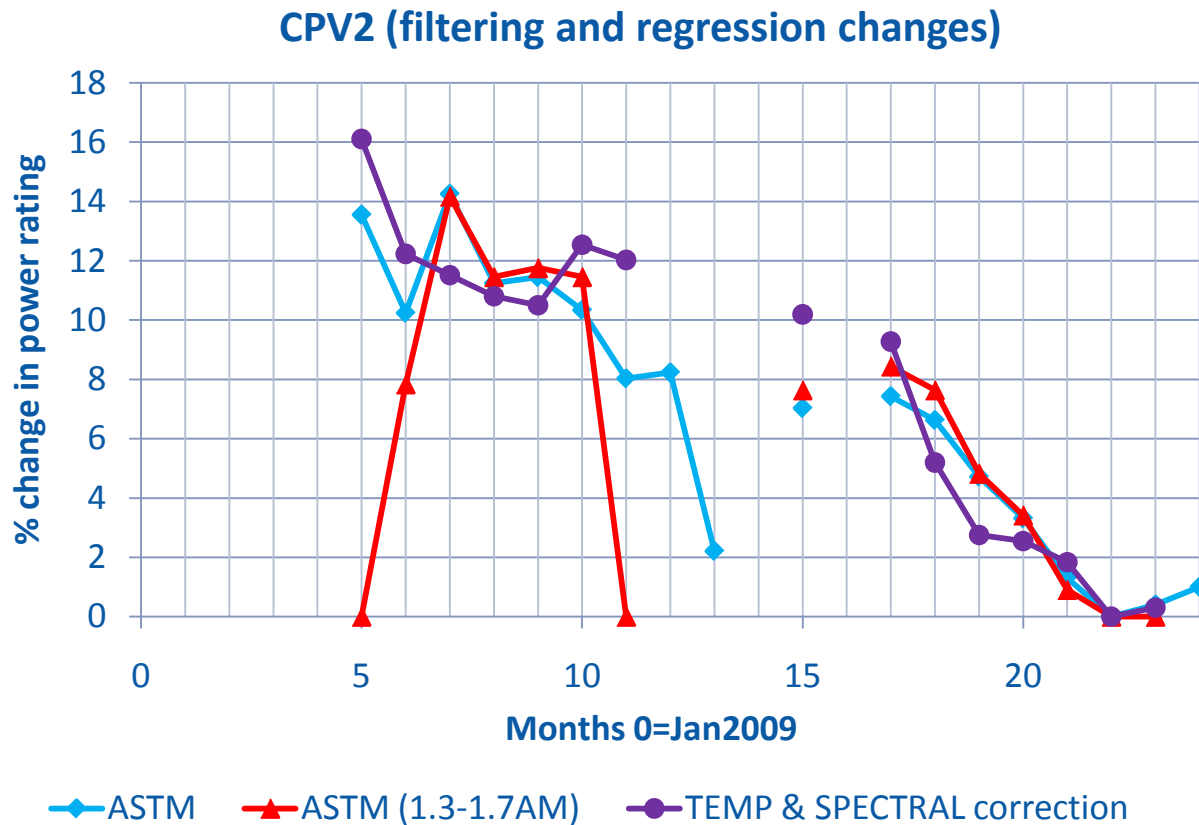
Regression modification results CPV1

- The tight filter on airmass eliminates Dec ,Jan but there is still ~9% variation
- The simple regression with corrected data reduces variation to ~4%



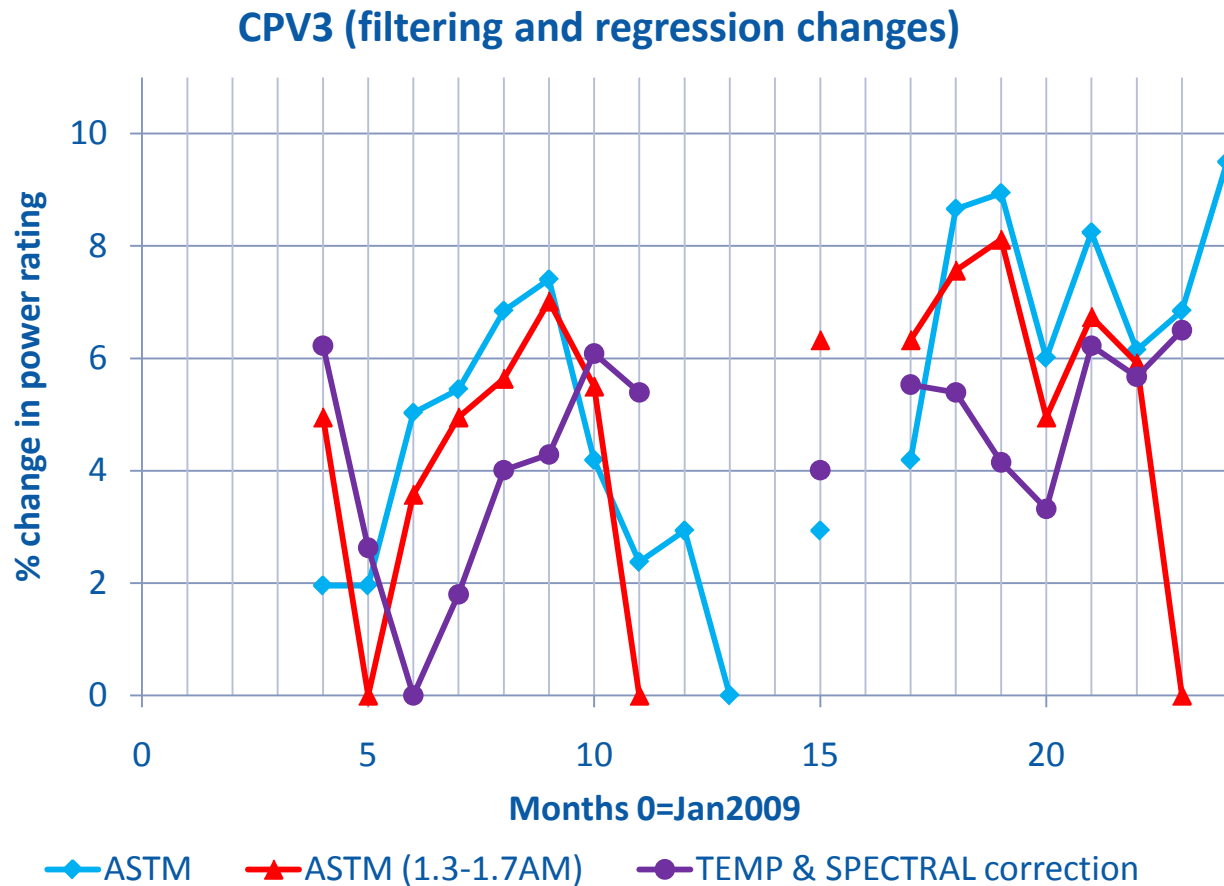
Regression modification results CPV2

- Airmass filtering again removes Dec, Jan but variation is still high
- Ignoring 2010 degradation, corrected data has a variation of ~6%



Regression modification results CPV3

- Again airmass filtering removes Dec, Jan with only a slight reduction in variation
- Corrected data still has a variation of 6.5%, June 2009 looks questionable



Conclusions and Recommendations

- Data sets for outdoor CPV power ratings should not include data points with a geometric airmass greater than 2
 - Performance begins to decline at airmasses greater than 2 or 3
 - This does little to help predict performance at AM1.5
- Ambient temperatures below 15 C have the potential to skew power ratings due to lens misalignment at low temperatures (true for some modules)
- Monthly regressions as a method for calculating CPV outdoor power ratings show too much variation (At least for data collected in Golden Colorado)
- Correcting outdoor data for temperature and spectral variation shows some potential to reduce month-to-month variation in outdoor CPV power ratings.