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

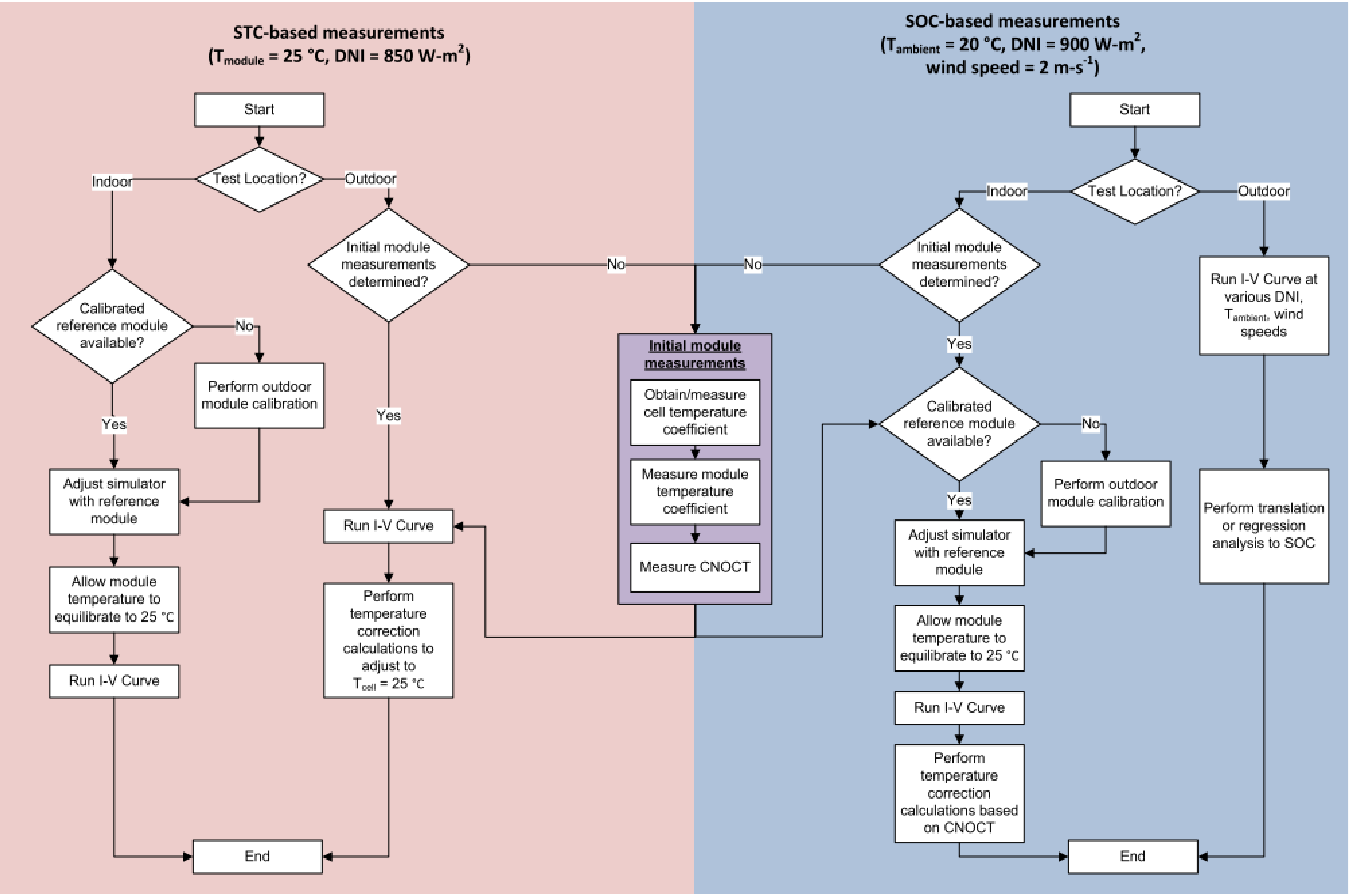
NREL CPV Testbed & Outdoor Power Ratings

- 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, Tambient, Tmodule, 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)
Tambient (20C), 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

$$P_{max}=DNI(a_1+a_2DNI+a_3T_{ambient}+a_4Wind)$$

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

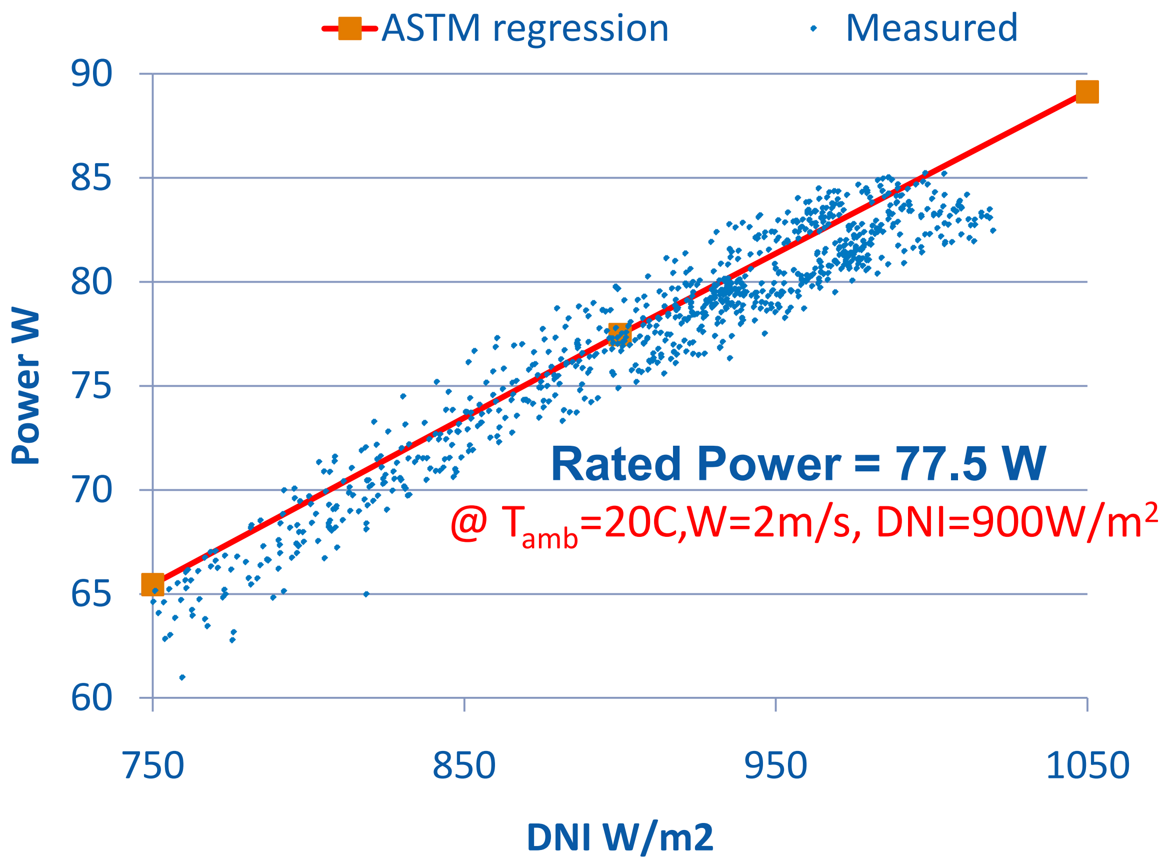
- In this presentation CSOC or $(T_{amb}=20C, W=2m/s, DNI=900W/m^2)$ is used

- ASTM calls for the following restrictions on data for the regression
  - $10C \le T_{amb} \le 30C$
  - $DNI \ge 750W/m^2$
  - The average wind speed for the 5 minutes prior to a measurement is <= 5m/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 > $140W/m^2$
  - Reject if Tracking error is > 0.15 degrees

ASTM 2527 Applied to Sept 2010 data

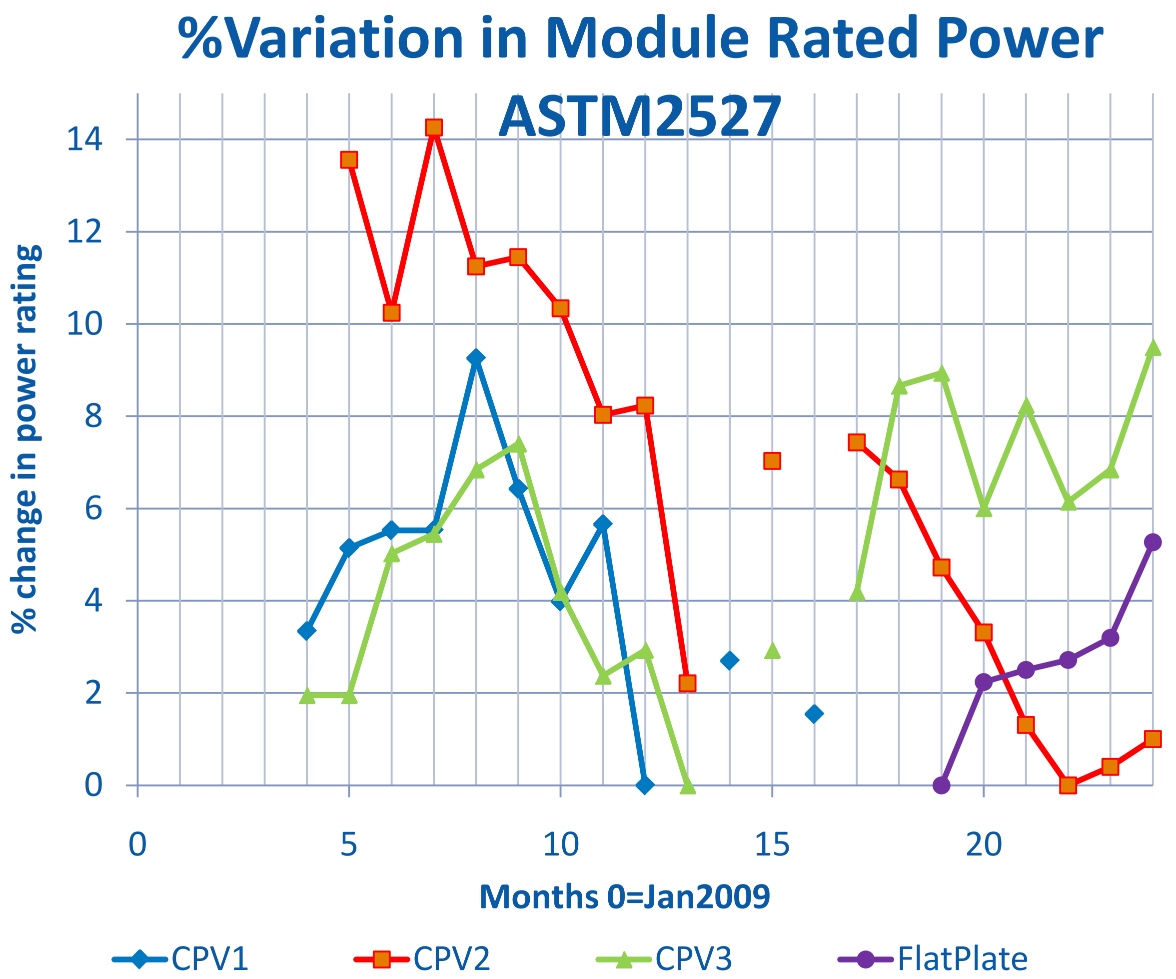


- **How much will the Rated Power for a CPV module if this procedure is applied over multiple months??**
- **The answer not only depends on outdoor conditions but also on the module technology!**

• 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?

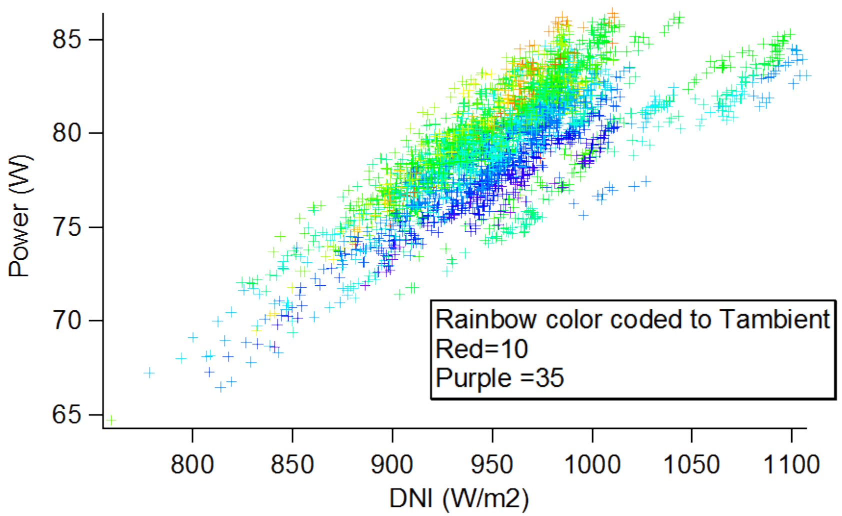
•Lens performance neglected?

•Moisture in modules, soiling, alignment varies?

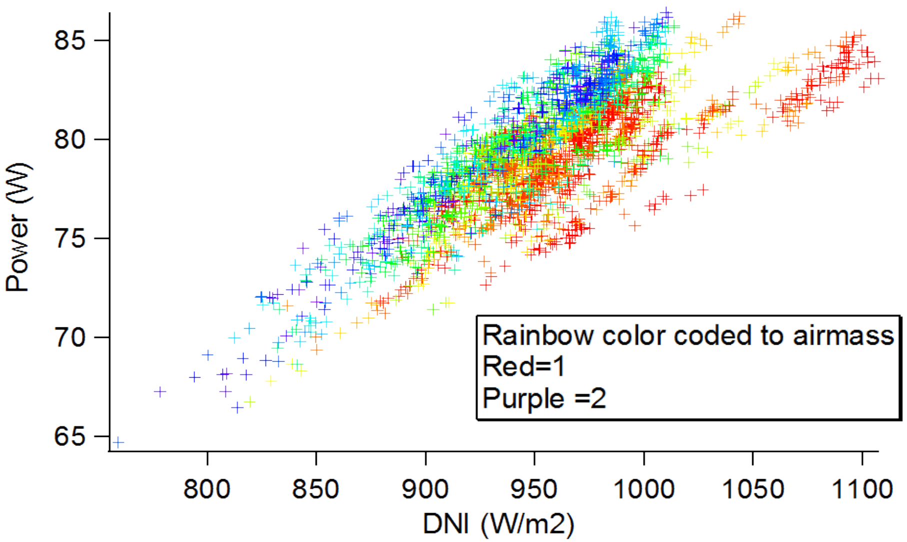
•Regression gives too much weight to outliers?

Can other variables improve the regression?

Efficiency correlates with the following
- Tambient
- Tmodule
- 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 Tambient, consistent with lenses that go out of alignment at low temperatures



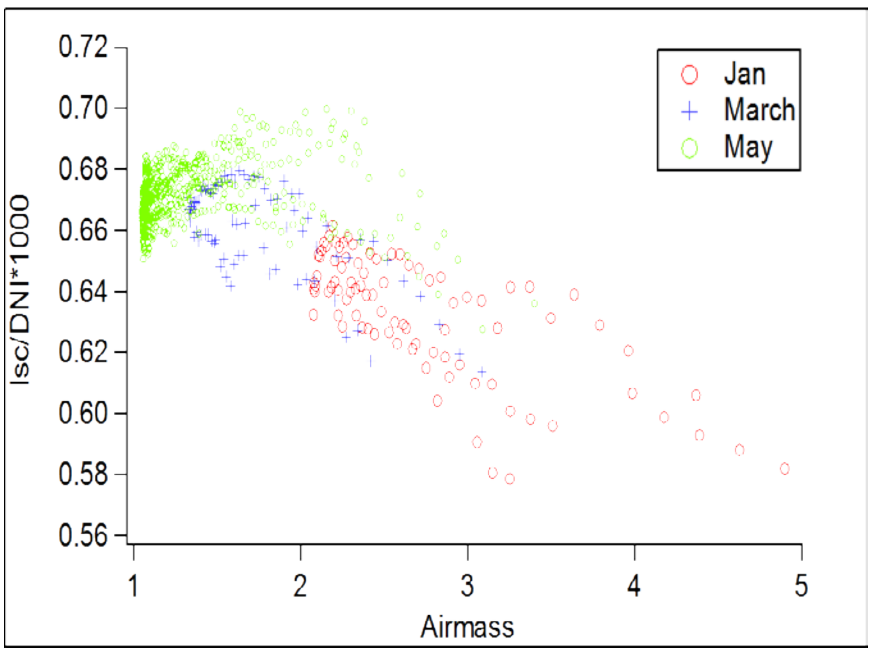
Regressions examined

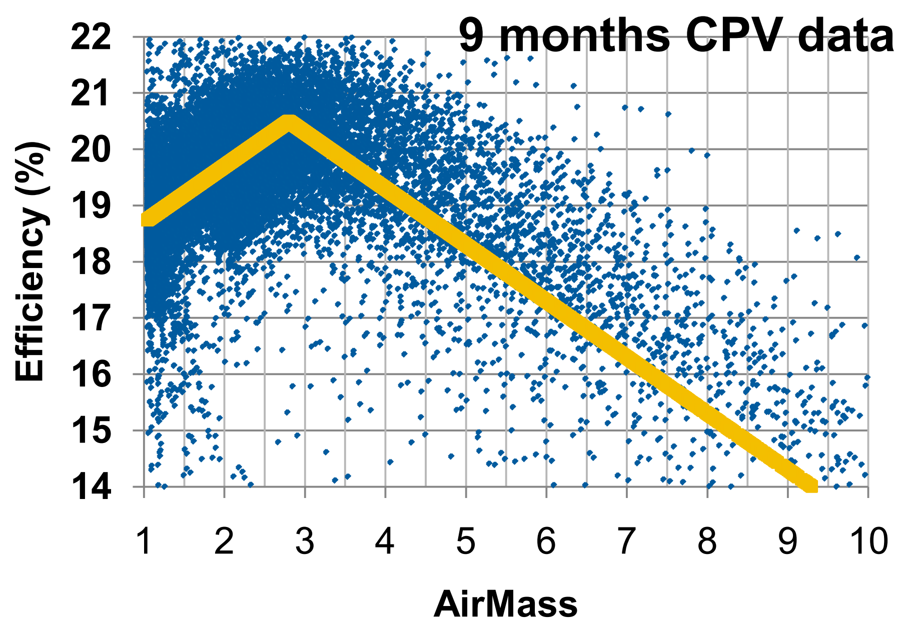
•New regressions were tested on yearly data sets using linear and nonlinear combinations of the variables on the previous slide

•The "best fit" for yearly data, judged by lowest standard error and the Tstat on the included variables, was $Power_{temp\ corrected} = a_1 DNI + a_2 DNI^2 + a_3 AM + a_4 WaterVapor$

• 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)





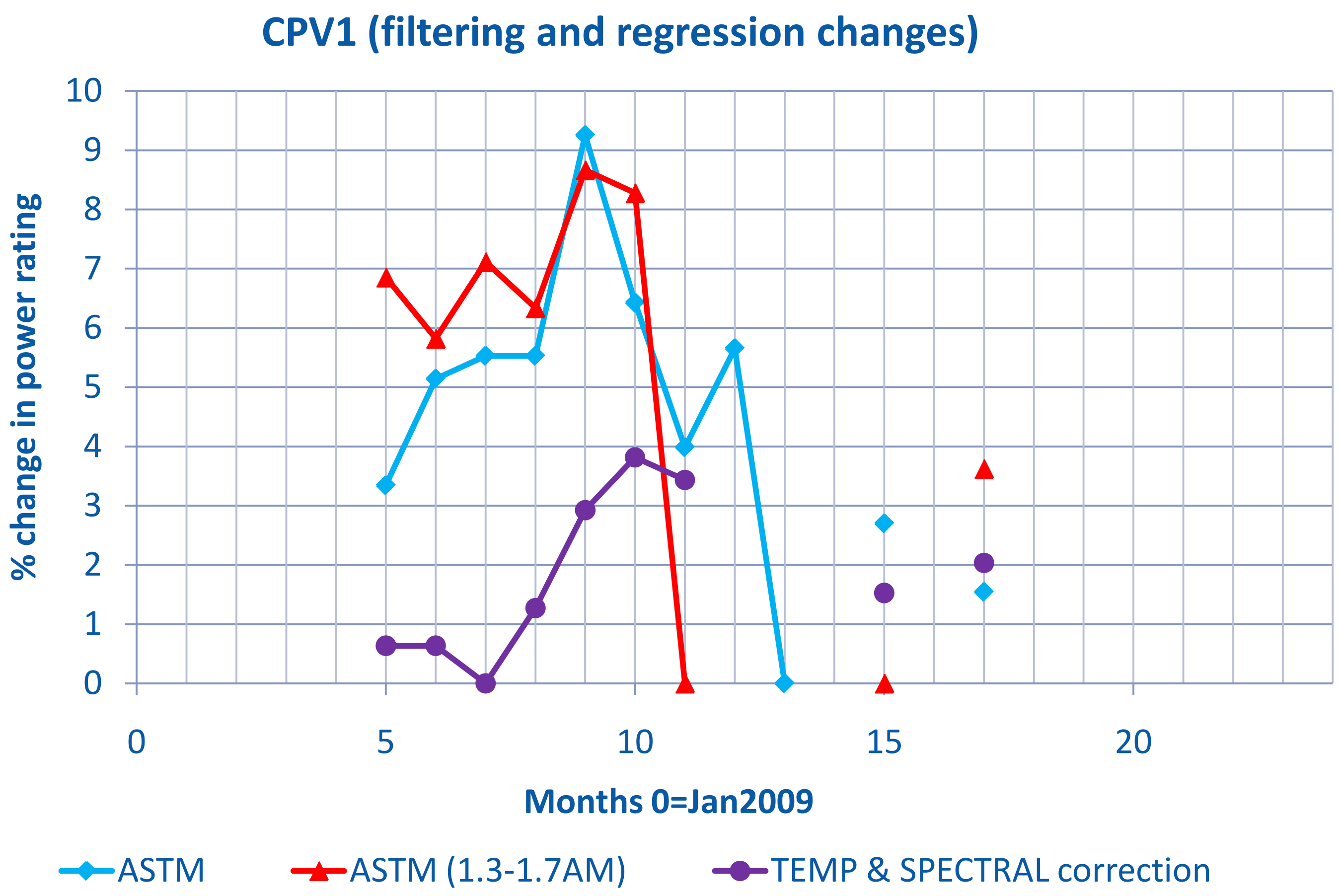
- The graphs on the previous slide show how monthly regressions can fail to accurately model spectral performance variations

- As an alternative, can spectral filtering (specifically limitting 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

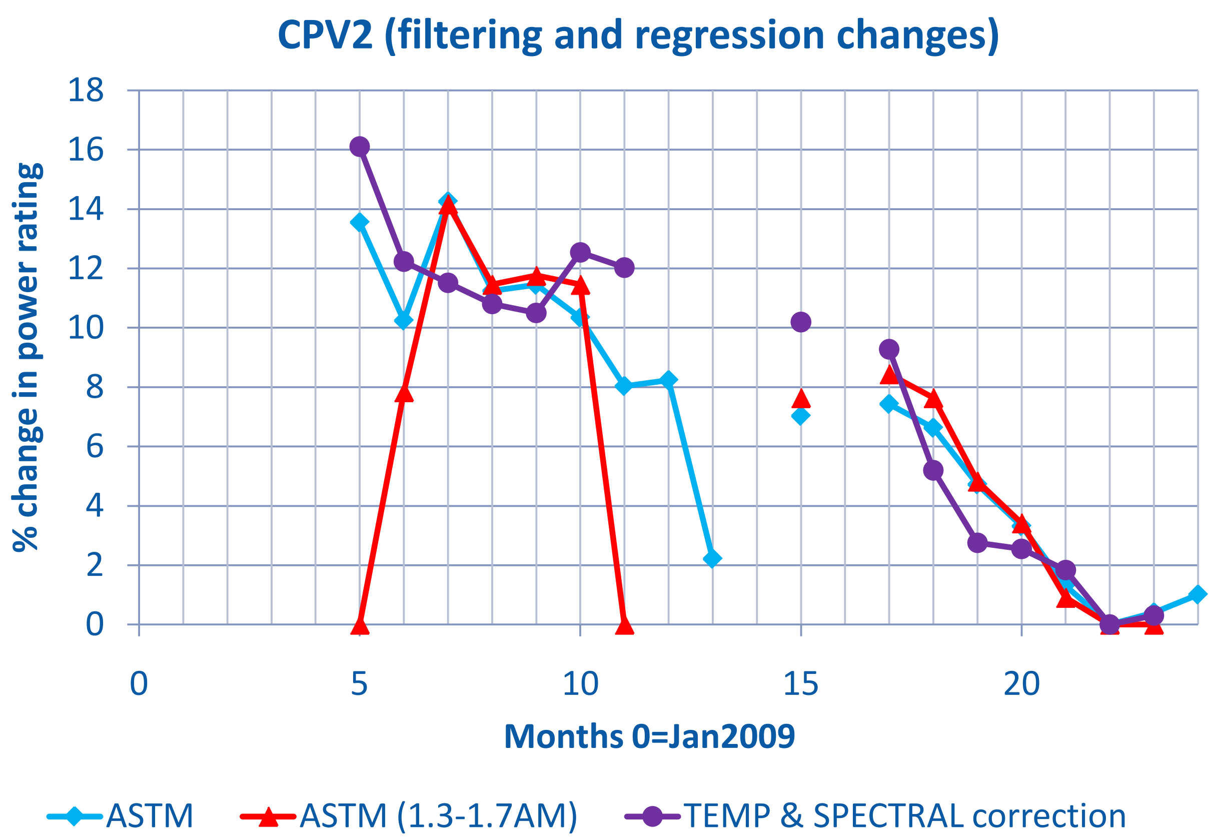
Regression modification results CPV1

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



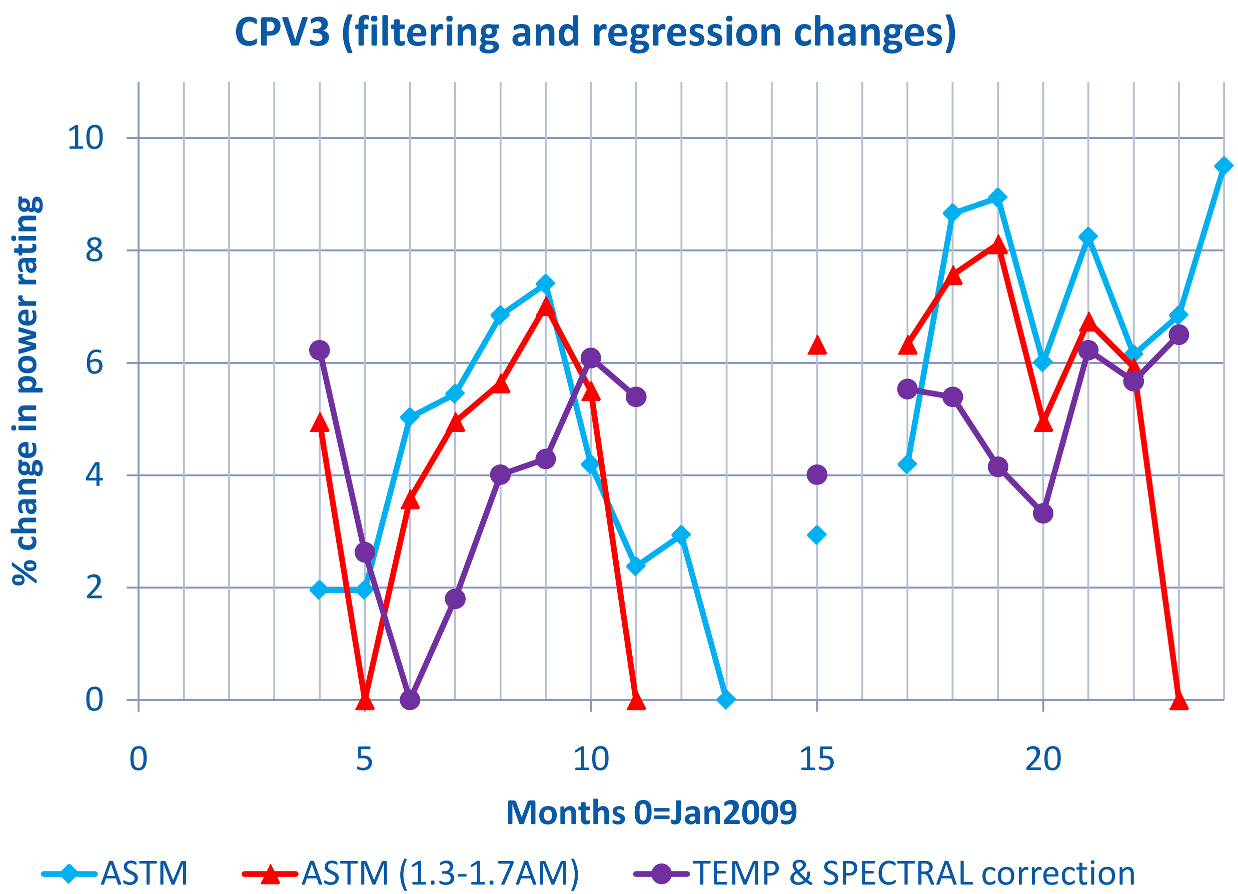
Regression modification results CPV2

- 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.