Assessing Complementarity of Wind and Solar Energy for Optimising Reliability of Future Hybrid Projects Across Brazil

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September 14th, 2018

Introduction and Background

As of May 2017, 61.27% of Brazil Electrical Power Matrix is met by largescale hydroelectric power (Pereira 2017). This represents the third largest installed capacity of hydroelectric power in the world. While hydroelectricity will no doubt feature heavily in Brazil's electricity mix, the Ministry of Mines and Energy aims, along with significant backing from the private sector, to diversify the power mix in order to reduce the risk of power shortages caused by droughts and thereby increasing energy security (Global Data 2017). The diversification and energy security strategies for the near future will increase the share of thermal, nuclear, and alternative renewable energy sources in particular onshore wind and PV solar capacities are expected to grow at an Compound Annual Growth Rate of 15% and 47% respectively in the period from 2015 to 2025 (Global Data 2017).

With the goals in mind of: electrical power security and reliability, grid optimisation and local supply-demand matching, as well as the expected growth in previously untapped solar and wind resources in the energy mix, this preliminary study takes wind speed and irradiance data measured as part of the SWERA project in three locations across Brazil from 2012 to 2014 to produce power generation data. It then assesses the possible complementarity of these energy resources by examining their anti-correlation at a variety of timescales. Before finally looking at hypothetical hybrid solar-wind energy projects and varying the mix of the two resources to optimise the reliability of the resultant power generation. The reliability of power generation is judged by a range of metrics informed indirectly by the needs and demands of consumers, grid operators and governmental energy security goals.

This short report, along with a presentation made by Joshua Gowdy to employees at the CCST at the Institute of Space Research, concludes this study and summarises its findings.

Results

The study encountered a general principle of great importance when investigating complementarity of energy resources - a strong dependence on the timescale between data points influences the anticorrelation value and variability of the resources. This also influences the minimal variance combination of wind and solar since, as found in the study using simple addition of variance formulae, this optimum can be predicted from correlation and relative variance alone[1]. The study found that correlation strength is reduced from weak to zero as the timescale is made finer from monthly to daily to hourly for Petrolina and Brasilia, while for Sao Martinho a moderate to weak anticorrelation of wind and solar persists at all timescales. For all location's variability of the

[1] See Figure A showing the dependence of the optimal solar fraction on the correlation and relative variance of wind and solar energy as implied by variance addition formulae

resource increases as the timescale is made finer which is an indication of volatility. This dependence on timescale asks the question: 'what reliability goal is the stakeholder interested in? And, crucially, at what timescale?' this study identifies this as a key consideration for justifying a particular resource balance for a hybrid energy project.

The study used four different metrics evaluated on a monthly basis to estimate the reliability of power supply of a hypothetical hybrid energy plant of varying fraction of solar and wind power. These were:

1. Monthly standard deviation of hourly data
2. Monthly standard deviation of daily data
3. Number of days per month with less than 0.5 times the annual mean power
4. Number of occasions per month of 7 or more consecutive hours with less than 0.1 times the annual mean power

These reflect the timescale dependence mentioned earlier and also reflected the multifaceted definition of reliable energy born out of the vary needs of energy stakeholders. Metrics 1 and 2 measure variability at hourly and daily timescales respectively while 3 and 4 measure the frequency of power shortages; either a significant mismatch in average power over a day (metric 3) or a sustained period in a day with essentially zero power generation (metric 4).

The results of this part of the study are presented in Figures 1 to 4 - a figure for each metric evaluated over the year for each location and at each solar fraction in the power balance (from 0 to 1 coloured dark to light). The solar optimal solar fraction(s) are highlighted and labelled.

This study found that wind was less variable than solar at the hourly level but more variable at the daily timescale, compare Figures 1 and 2. At the hourly timescale solar energy potential varies greatly due to the day-night cycle much more so than wind, at the daily timescale this variation is not captured but instead there is a much greater difference in wind potential between days than solar. These facts are born out in the optimal solar fractions for minimising standard deviation at each timescale; at the hourly level the optimal solar fraction is much lower, so that the hybrid project favours wind energy to minimise variance, than at the daily level where it favours solar energy. This is because the relative variability is different at each timescale.

The study also found that at both timescales Sao Martinho da Serra had a variety of optimal solar fractions over the year and that it favoured more even shares of wind and solar compared to Petrolina or Brasília. Both facts may be explained by Sao Martinho's greater anticorrelation of wind and solar. As found in this study and implied by simple variance addition formulae, stronger anti-correlation of wind and solar favours more even shares of the two resources in the minimal variance solution[2]. The anticorrelation means the two resources generate power 'out of phase' creating a less variable power supply when used in tandem. While Sao Martinho had a variety of optimal solar fractions over the year because solar and wind had annual profiles of monthly power with large variation and very different shapes between the two resources that is they were anticorrelated at the monthly timescale. Solar was lowest and had least variance during the winter while the opposite was true during the summer meaning during the summer the relative variability of the two resources pushed the solar fraction towards favouring wind while in winter it was moved towards slightly more solar.

[2] See Figure A

Metrics 3 and 4 do not have an easily determinable set of parameters on which they depend and so the trends they exhibit do not have an easy explanation but instead more holistically judge the various solar fractions against the desire of many energy stakeholders to avoid power shortages.

The study found that to avoid low power days it is best to have hybrid energy projects that favour solar over wind, but in all locations the solar only case was not optimal. Some wind was a useful addition particularly for Sao Martinho and autumn time in Brasília. Often for metric 3 there would a host of optimal or nearly optimal solar fractions of a broad spectrum from 0 to 1 indicating that are certain times of the year wind and solar both perform similarly or that around the optimum varying the solar fraction changes the combined variance only slightly.

To avoid sustained periods of almost zero power a variety of solar fractions were selected depending on the location and time of year. Since for on average half the day solar energy generation is zero since it is night time we would expect that for all locations some proportion of wind is included in the optimal solution, this is indeed the case. The exclusively solar solution was always the worst performing for all locations and for all seasons. The study found that Petrolina had the strongest average wind resource potential over the 3 years, while Brasilia and Sao Martinho had many periods recording zero power generation because the wind speed was less than the cut in value and so bringing down their all year average wind power. These trends are reflected in the optimal solar fractions for minimising metric 4; Petrolina favoured wind over solar for all seasons and had very few instances of zero power generation while Brasilia and Sao Martinho included substantial solar power (despite the night time effect observed above) reflecting the weakness of their wind energy potential. Brasília did favour an exclusive wind solution during the wintertime during which solar energy potential is at its minimum.

Further Study

This preliminary study has raised some key questions about the scope for hybrid wind-solar energy projects and their use of complementarity to increase reliability. The timescale at which complementarity is observed and at which reliability of energy supply is required is an important factor and one that will be governed by the needs of the energy stakeholders and investors. To bring in this added dimension and include the needs of consumers or grid operators would require use of demand data and data from other energy sources to inform the reliability of energy supply as matched to energy demand. The presents a clear avenue for further study into this topic. Such an integrated approach to measuring reliability of energy supply and to judging the benefits of hybrid projects reflects the integrated nature of electricity supply but is incomplete until the geographic nature of electricity systems is considered. Hence, further study would include a much greater selection of measuring stations.

Bibliography

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Figure 0

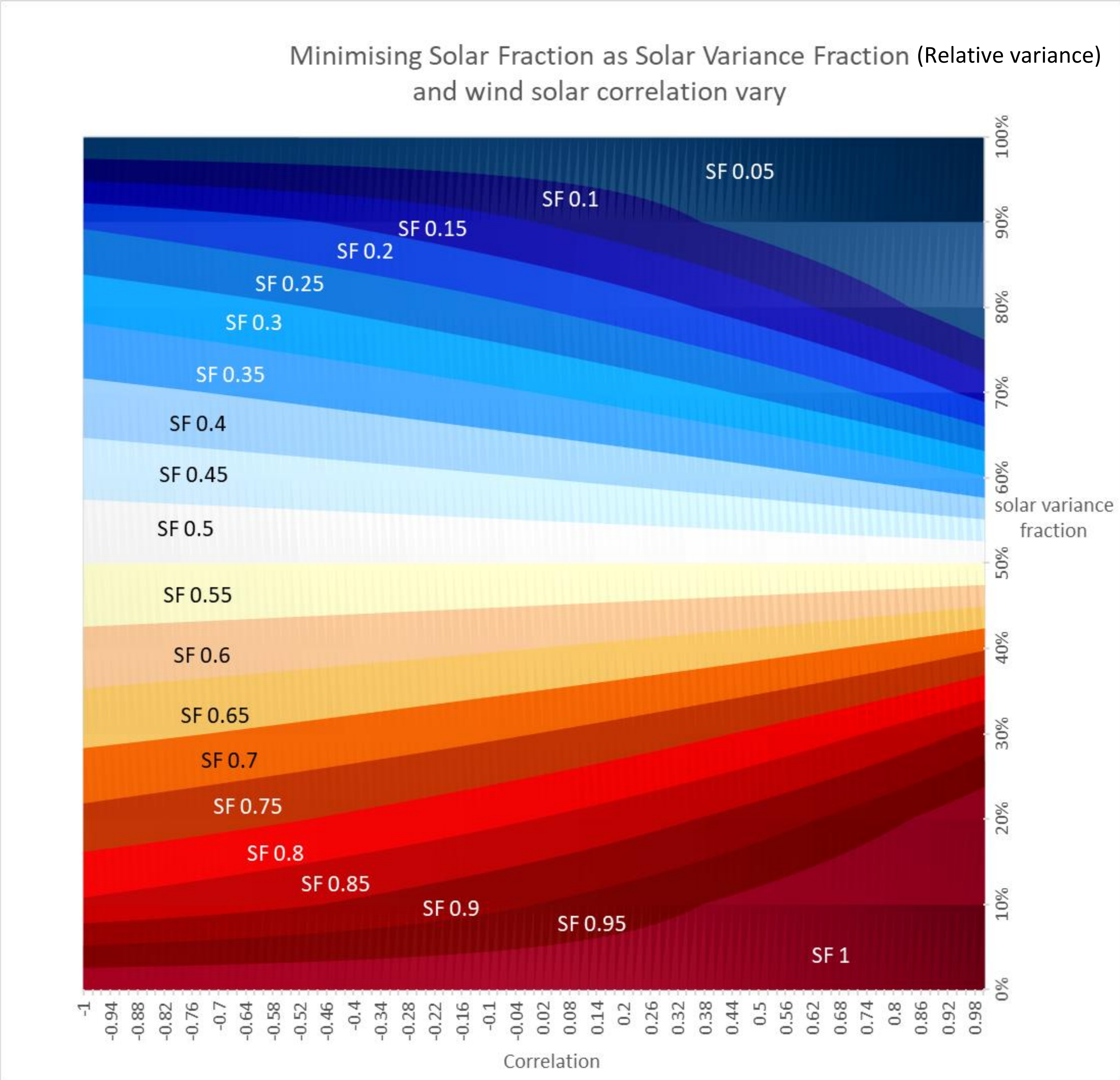

Minimising Solar Fraction as Solar Variance Fraction (Relative variance) and wind solar correlation vary
SF 0.05
SF 0.1
SF 0.15
SF 0.2
SF 0.25
SF 0.3
SF 0.35
SF 0.4
SF 0.45
SF 0.5
SF 0.55
SF 0.6
SF 0.65
SF 0.7
SF 0.75
SF 0.8
SF 0.85
SF 0.9
SF 0.95
SF 1
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
solar variance fraction
-1 -0.94 -0.88 -0.82 -0.76 -0.7 -0.64 -0.58 -0.52 -0.46 -0.4 -0.34 -0.28 -0.22 -0.16 -0.1 -0.04 0.02 0.08 0.14 0.2 0.26 0.32 0.38 0.44 0.5 0.56 0.62 0.68 0.74 0.8 0.86 0.92 0.98
Correlation

Figure 1

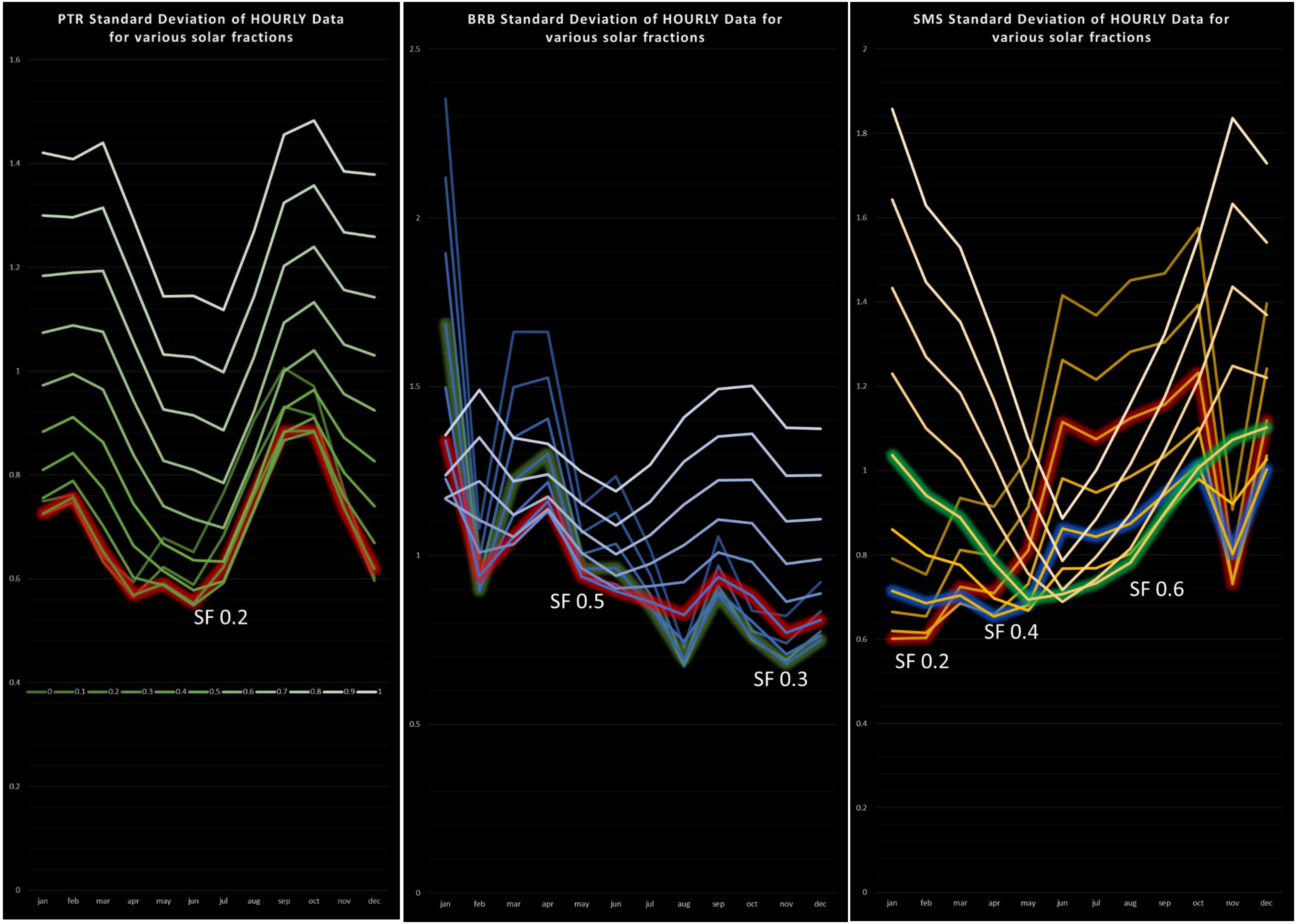
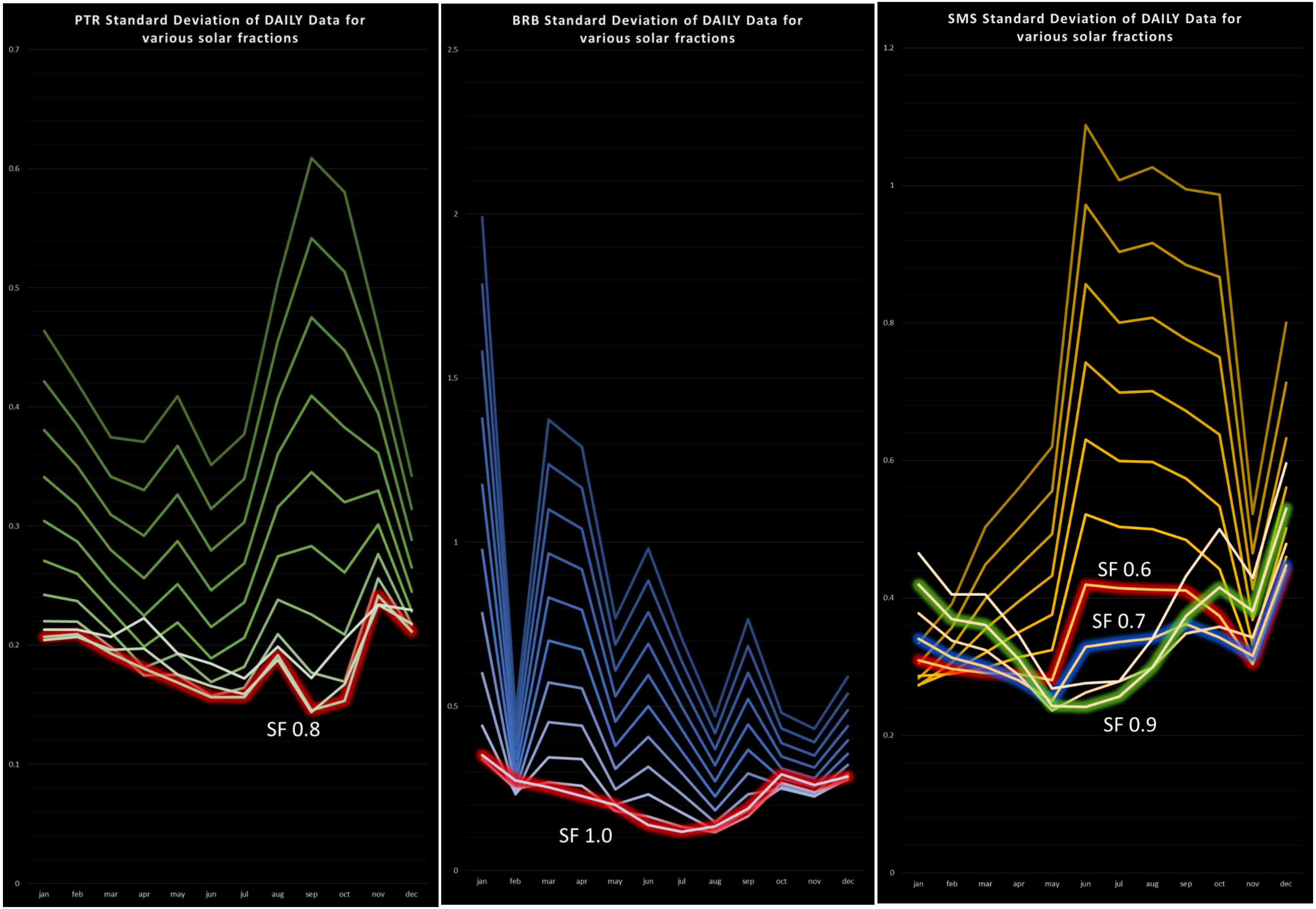
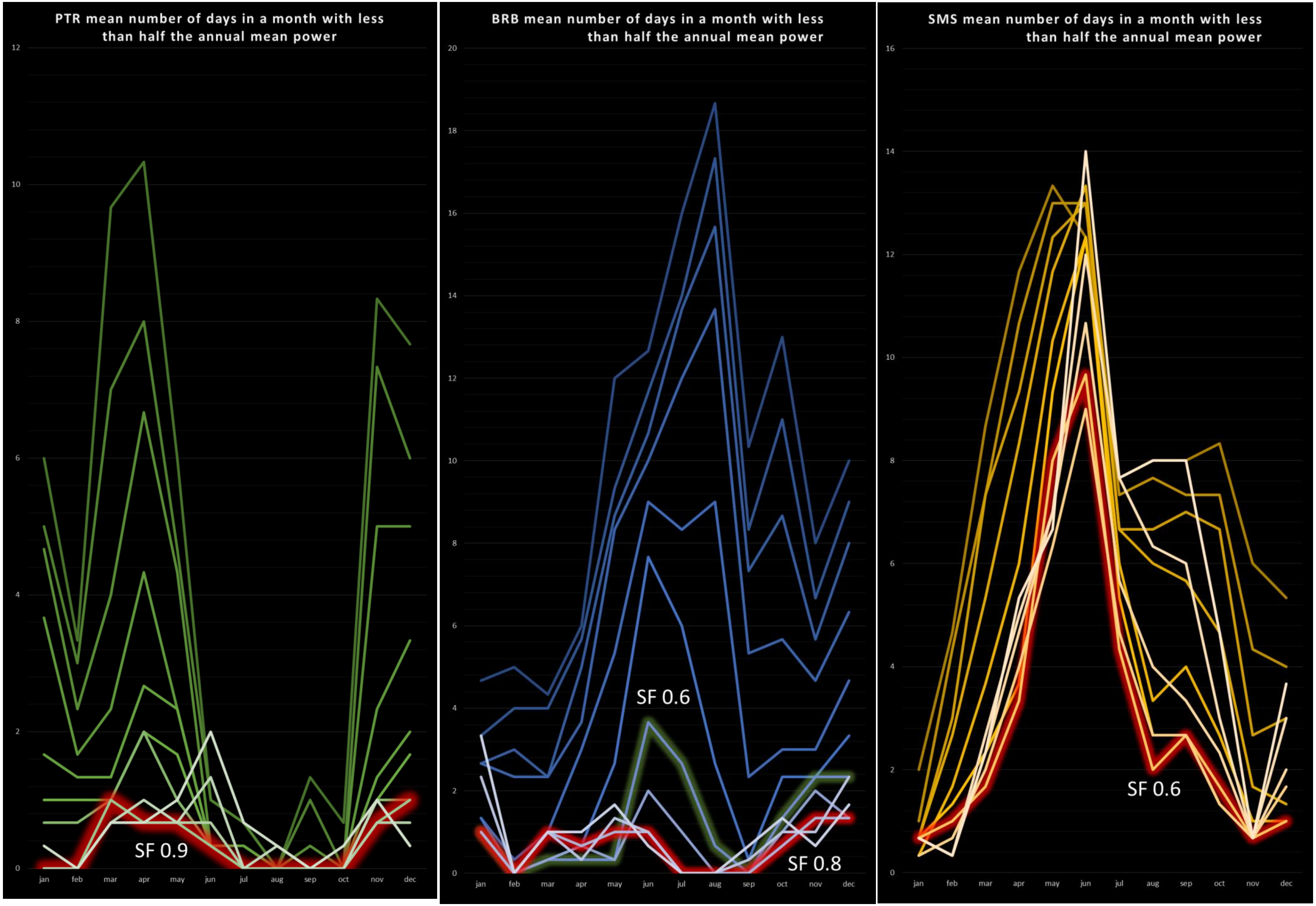

PTR Standard Deviation of HOURLY Data for various solar fractions
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
jan feb mar apr may jun jul aug sep oct nov dec
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
SF 0.2
BRB Standard Deviation of HOURLY Data for various solar fractions
2.5
2
1.5
1
0.5
0
jan feb mar apr may jun jul aug sep oct nov dec
SF 0.5
SF 0.3
SMS Standard Deviation of HOURLY Data for various solar fractions
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
jan feb mar apr may jun jul aug sep oct nov dec
SF 0.2
SF 0.4
SF 0.6

Figure 2



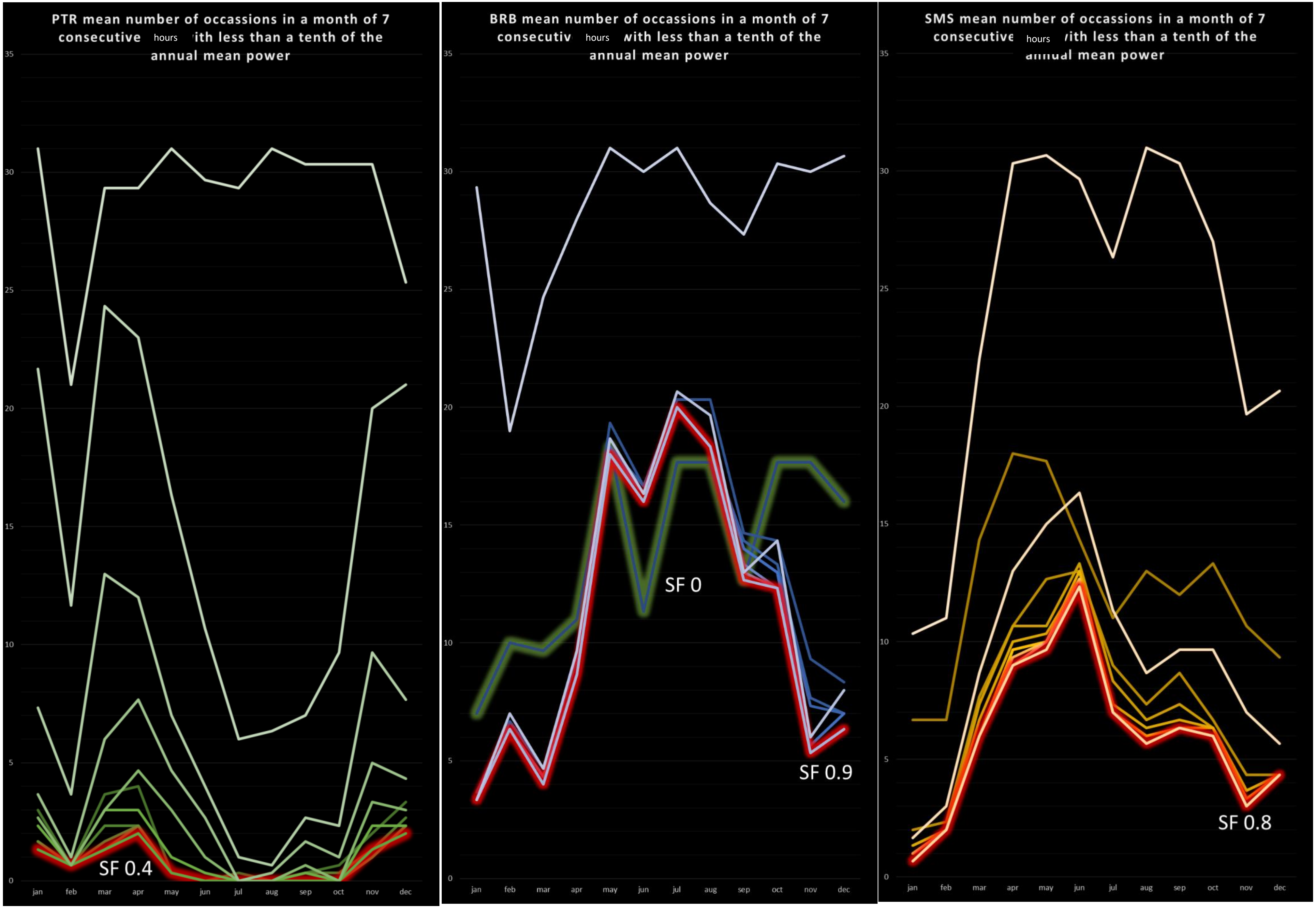
PTR Standard Deviation of DAILY Data for various solar fractions
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
jan feb mar apr may jun jul aug sep oct nov dec
SF 0.8
BRB Standard Deviation of DAILY Data for various solar fractions
2.5
2
1.5
1
0.5
0
jan feb mar apr may jun jul aug sep oct nov dec
SF 1.0
SMS Standard Deviation of DAILY Data for various solar fractions
1.2
1
0.8
0.6
0.4
0.2
0
jan feb mar apr may jun jul aug sep oct nov dec
SF 0.6
SF 0.7
SF 0.9

Figure 3



PTR mean number of days in a month with less than half the annual mean power
12
10
8
6
4
2
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
SF 0.9
BRB mean number of days in a month with less than half the annual mean power
20
18
16
14
12
10
8
6
4
2
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
SF 0.6
SF 0.8
SMS mean number of days in a month with less than half the annual mean power
16
14
12
10
8
6
4
2
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
SF 0.6

Figure 4


PTR mean number of occassions in a month of 7 consecutive hours with less than a tenth of the annual mean power
35
30
25
20
15
10
5
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
SF 0.4
BRB mean number of occassions in a month of 7 consecutiv hours with less than a tenth of the annual mean power
SF 0
SF 0.9
SMS mean number of occassions in a month of 7 consecutive hours with less than a tenth of the annual mean power
SF 0.8