Side-by-side Comparison of Subhourly Clipping Models

Matt J. Prilillman[1], Janine M.F. Keith[1], and William B. Hobbs[2]

1. National Renewable Energy Laboratory
2. Southern Company

June 11, 2024

IEEE Photovoltaic Specialists Conference 51
Seattle, WA
6/9/2024 – 6/14/2024
NREL/PR-7A40-90237

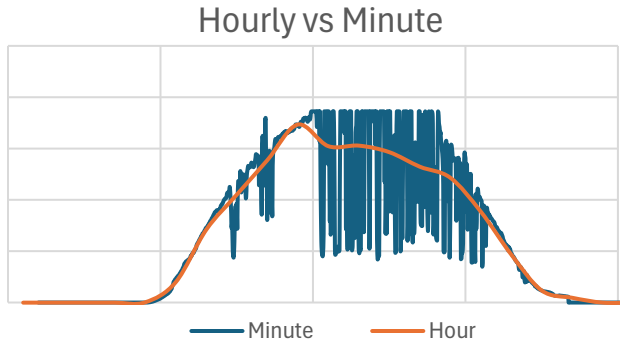
Photo by Dennis Schroeder, NREL 55200

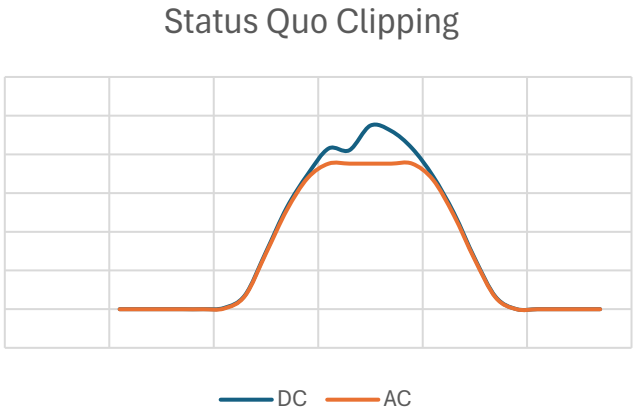
Agenda

1. Introduction and Motivations
2. Subhourly Clipping Correction methodologies
3. Comparison results
4. Conclusions

Introduction

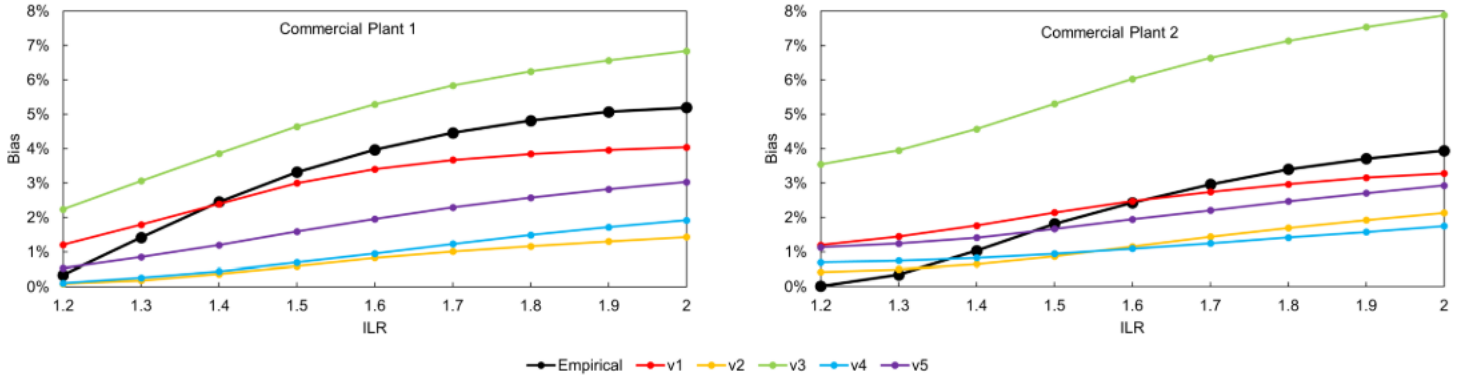
- PV performance models often run with hourly average weather data
- Hourly weather fails to always account for performance variation within the hour
- Inverter clipping: power lost due to the input power to inverter exceeding the maximum power limit of the inverter
- Hourly performance models have been shown to consistently underpredict clipping losses





Prior Work

- Models compared here are not a comprehensive list
- Models here are applied only in performance model, do not include corrections to resource data



W. B. Hobbs, C. L. Black, W. F. Holmgren and K. S. Anderson, "Evaluation of Irradiance Variability Adjustments for Subhourly Clipping Correction," 2023 IEEE 50th Photovoltaic Specialists Conference (PVSC), San Juan, PR, USA, 2023, pp. 1-4, doi: 10.1109/PVSC48320.2023.10359541.

Anderson, Kevin and Kirsten Perry. 2020. Estimating Subhourly Inverter Clipping Loss From SatelliteDerived Irradiance Data: Preprint. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5K00-76021. https://www.nrel.gov/docs/fy20osti/76021.pdf

Bowersox, David & MacAlpine, Sara. (2021). Predicting Subhourly Clipping Losses for Utility-Scale PV Systems. 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC), 2507-2509. 10.1109/PVSC43889.2021.9518956.

Townsend, Tim and Sauer, Kenneth. (2023). Triple-C: Clouds, Capacity, and Clipping - A Method to Correct Traditional Hourly-Based PV Simulations to Account for Subhourly Clipping Loss. White Paper.

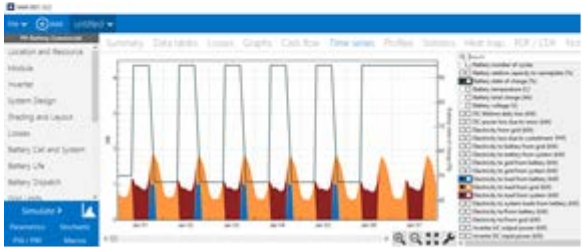
Adrien Villoz, Bruno Wittmer, André Mermoud, Michele Oliosi, Agnes Bridel-Bertome. (2022). A Model Correcting The Effect Of Sub-hourly Irradiance Fluctuations On Overload Clipping Losses In Hourly Simulations. WCPEC8.

Motivations

- Not many direct comparisons between different modeling methods
- Interest in investigating trends in model predictions across inverter loading ratios (ILR), years of weather data in different climates
- ILR = rated DC power / rated AC power

System Advisor Model (SAM)

- Free software for modeling renewable energy projects
- Desktop app for Windows, Mac, Linux; PySAM Python package
- Allen method available in desktop app, matrix can be modified in PySAM
- Walker method available through PySAM, available in user interface in upcoming release

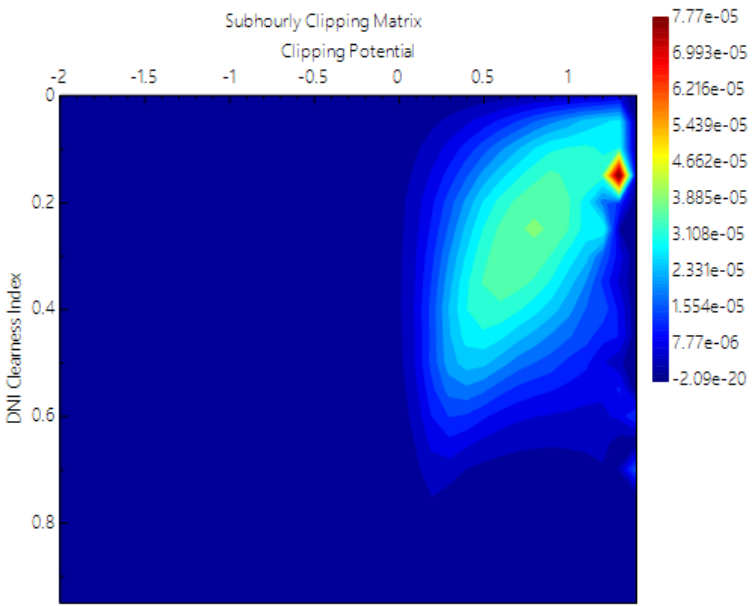


https://sam.nrel.gov

Allen Method

- 9 sites modeled for 1-7 years of data
- Hourly clip bias estimated, correlated to Direct Normal Irradiance (DNI) Clearness index, clipping potential
- Matrix of bias correction indexed each timestep, scaled by nominal annual AC output
- Losses calculated in addition to AC power limit clipping

$$\gamma_{DNI} = \frac{DNI}{DNI_{DryClean}} \qquad CP = \frac{P_{dc,DryClean} - P_{ac,0}}{P_{ac,0}}$$



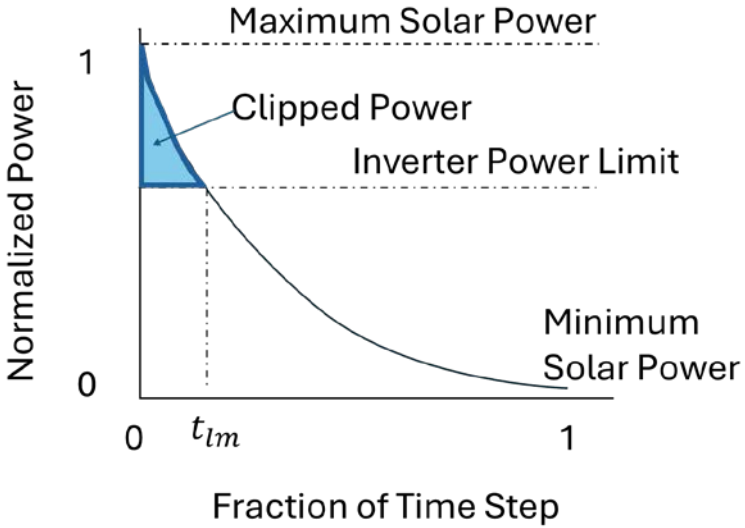
Walker Method

- Model PV output over the timestep as a distribution
- Maximum PV output: Based on clearsky model
- Minimum PV output: dependent on atmospheric thickness
- Integrate under inverter power limit, portion of curve over limit is counted as clipping loss

$$P_{solar} = P_{solar,min} + \left(P_{solar,max} - P_{solar,min}\right) * \left(1 - \left(\frac{t}{T}\right)^{\frac{CF}{CF-1}}\right)$$

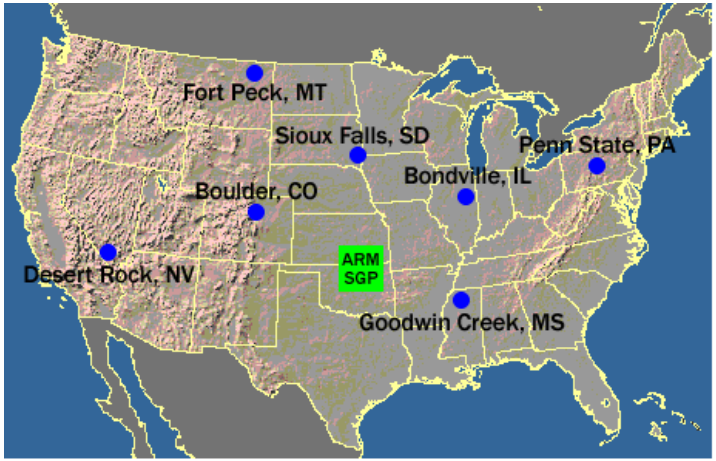
$$CF = \frac{P_{solar} - P_{solar,min}}{P_{solar,max} - P_{solar,min}}$$

$$t_{lm} = Te^{\left[\frac{\ln\left(1 - \frac{L - P_{solar,min}}{P_{solar,max} - P_{solar,min}}\right)}{\frac{CF}{CF-1}}\right]}$$



Comparisons

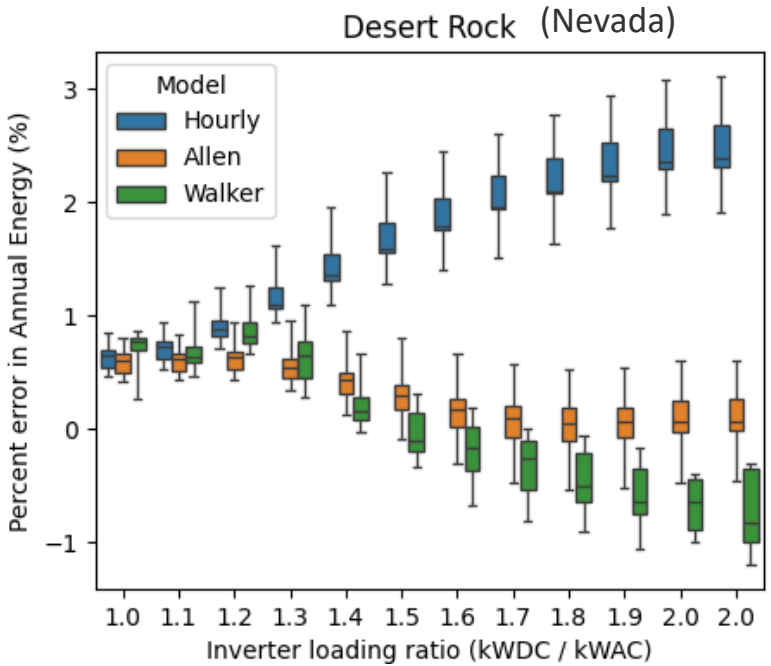
- 7 SURFRAD sites modeled for 2010-2020
- 1 minute resource data, aggregated to 60 minute data
- PySAM used to model 1-minute results for 1 MW E-W tracking system for increasing ILR
- Hourly model ran in PySAM for status-quo clipping, Allen method, Walker method
- Clipping losses, annual energy yield compared against 1-minute truth

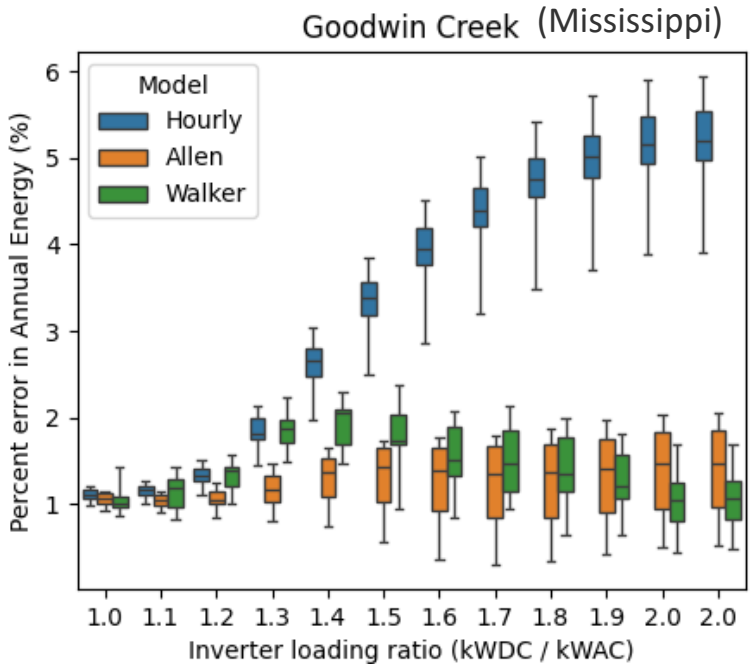


https://gml.noaa.gov/grad/surfrad/sitepage.html

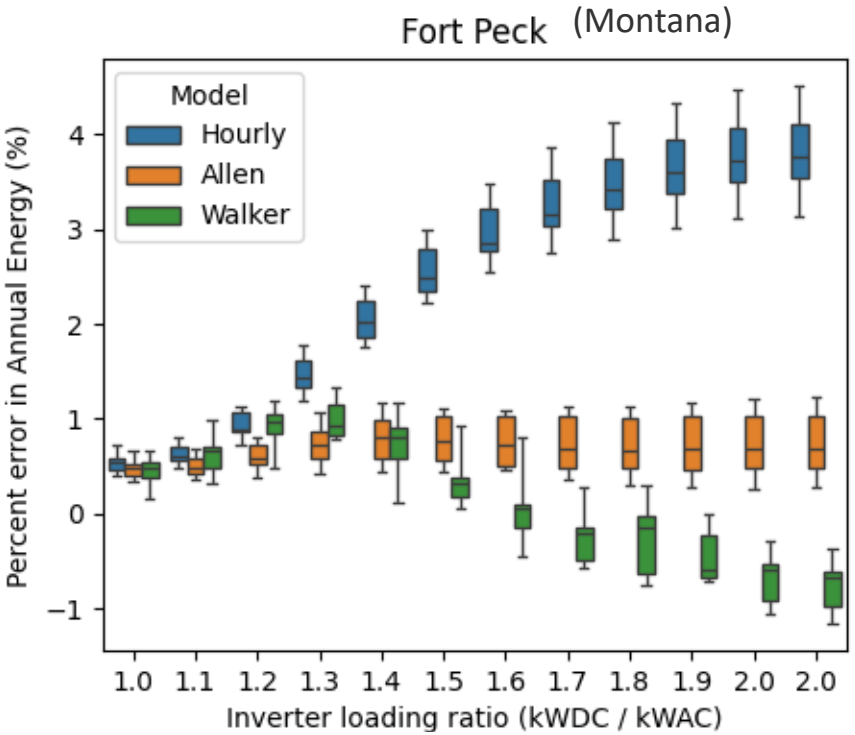
Results

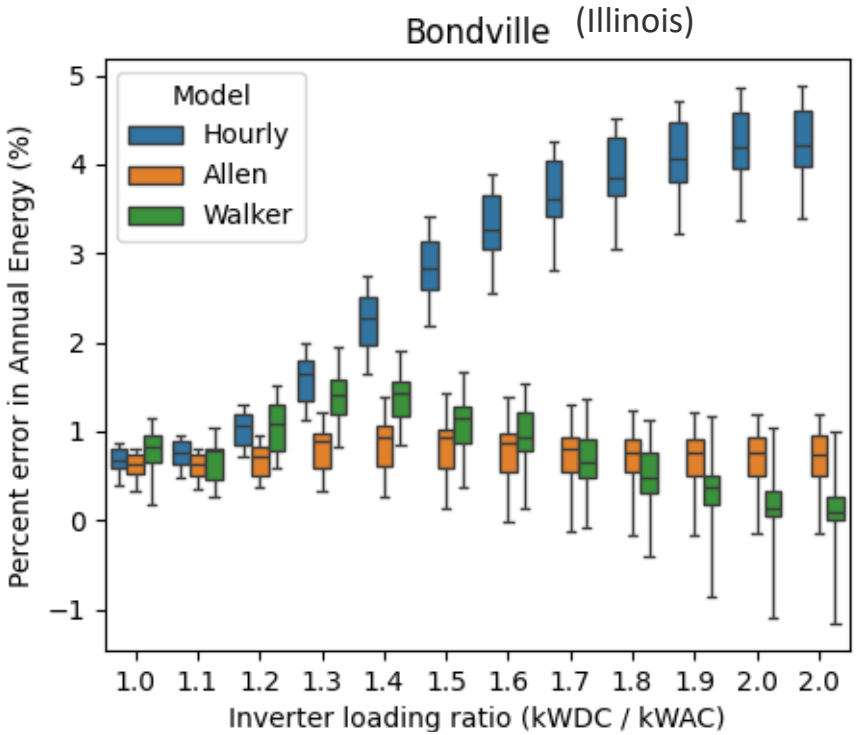
- Percent error (model – minute) 2-5% for higher ILR
- Bias error from solar position assumptions – to be investigated further





Results

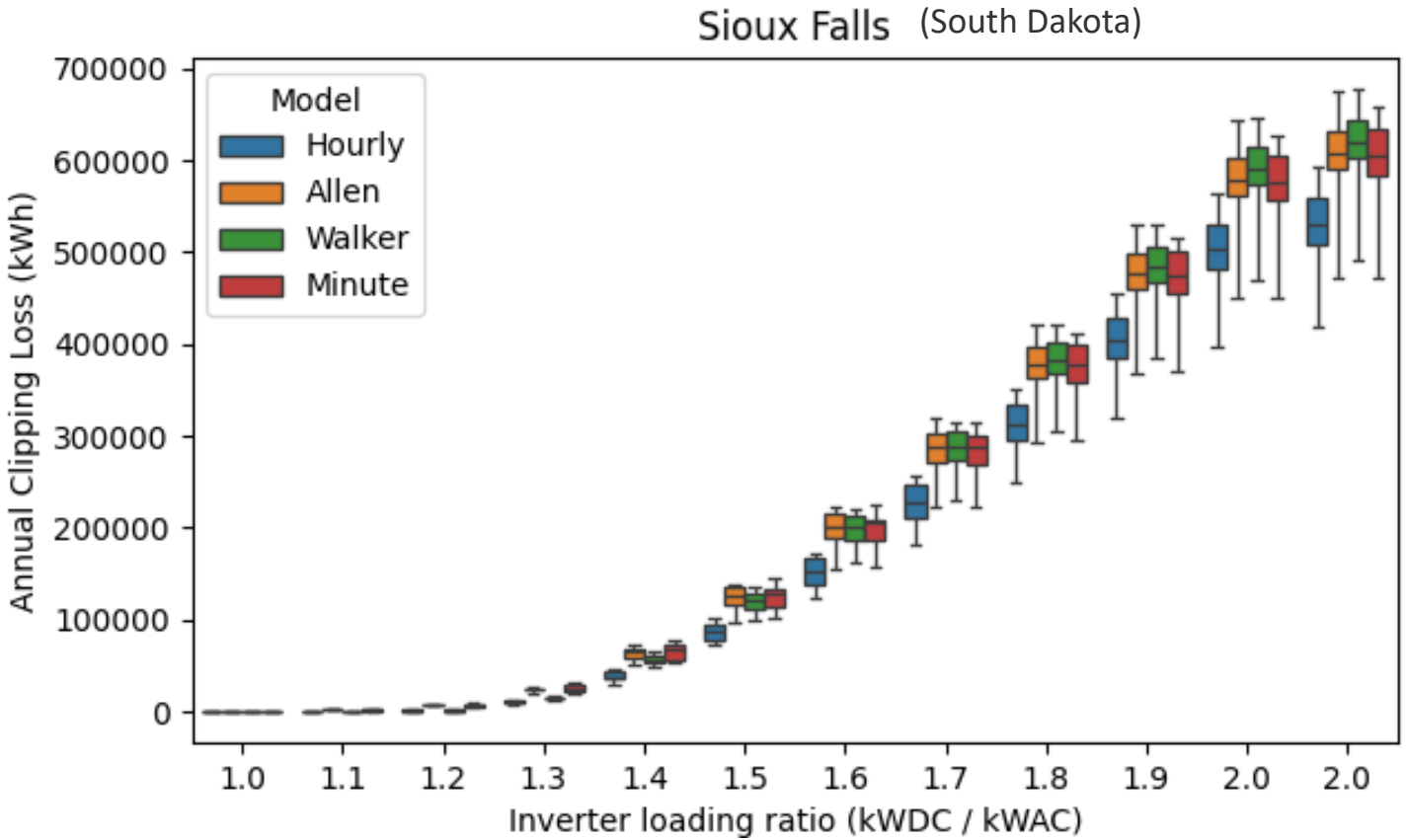

Fort Peck (Montana)
Model
Hourly
Allen
Walker
Percent error in Annual Energy (%)
4
3
2
1
0
−1
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.0
Inverter loading ratio (kWDC / kWAC)


Bondville (Illinois)
Model
Hourly
Allen
Walker
Percent error in Annual Energy (%)
5
4
3
2
1
0
−1
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.0
Inverter loading ratio (kWDC / kWAC)

Percent Error in Annual Energy (%)

	Bondville (IL)			Boulder (CO)			Desert Rock (NV)			Fort Peck (MT)			Goodwin Creek (MS)			Penn State (PA)			Sioux Falls (SD)		
ILR	H	A	W	H	A	W	H	A	W	H	A	W	H	A	W	H	A	W	H	A	W
1	0.67	0.61	0.77	0.71	0.65	0.72	0.63	0.59	0.71	0.54	0.48	0.47	1.12	1.06	1.07	0.82	0.76	0.84	0.94	0.89	0.93
1.1	0.75	0.61	0.67	0.86	0.71	0.89	0.71	0.61	0.69	0.63	0.51	0.62	1.15	1.05	1.14	0.93	0.80	0.82	1.01	0.89	0.93
1.2	1.02	0.66	1.07	1.24	0.85	1.12	0.92	0.63	0.88	0.93	0.60	0.92	1.34	1.07	1.32	1.27	0.96	1.24	1.24	0.92	1.17
1.3	1.58	0.78	1.40	1.85	1.01	0.75	1.19	0.57	0.64	1.46	0.73	0.99	1.85	1.18	1.85	1.94	1.25	1.74	1.71	1.00	1.48
1.39	2.24	0.85	1.38	2.48	1.08	0.44	1.46	0.43	0.20	2.05	0.79	0.72	2.61	1.30	1.92	2.76	1.53	1.68	2.30	1.05	1.37
1.49	2.84	0.82	1.10	3.03	1.10	0.36	1.71	0.31	-0.04	2.56	0.78	0.37	3.33	1.32	1.81	3.51	1.71	1.45	2.78	1.03	1.23
1.59	3.31	0.76	0.96	3.45	1.09	0.19	1.90	0.17	-0.19	2.96	0.76	0.05	3.91	1.26	1.55	4.12	1.79	1.25	3.18	0.99	1.00
1.69	3.66	0.71	0.69	3.79	1.07	0.10	2.07	0.09	-0.33	3.26	0.73	-0.23	4.36	1.23	1.49	4.59	1.85	1.14	3.49	0.96	0.76
1.78	3.92	0.68	0.48	4.07	1.10	0.08	2.22	0.06	-0.46	3.48	0.72	-0.26	4.71	1.25	1.39	4.96	1.90	0.96	3.73	0.95	0.63
1.88	4.10	0.68	0.32	4.31	1.14	-0.05	2.36	0.07	-0.59	3.65	0.72	-0.46	4.96	1.31	1.29	5.24	1.95	0.85	3.90	0.94	0.38
1.98	4.24	0.69	0.15	4.51	1.21	-0.20	2.47	0.11	-0.67	3.78	0.73	-0.68	5.14	1.38	1.04	5.44	1.98	0.68	4.03	0.94	0.26
2.01	4.27	0.69	0.08	4.56	1.23	-0.20	2.50	0.13	-0.73	3.80	0.73	-0.76	5.18	1.40	1.06	5.48	1.98	0.62	4.06	0.94	0.20

Annual Clipping Loss (kWh)



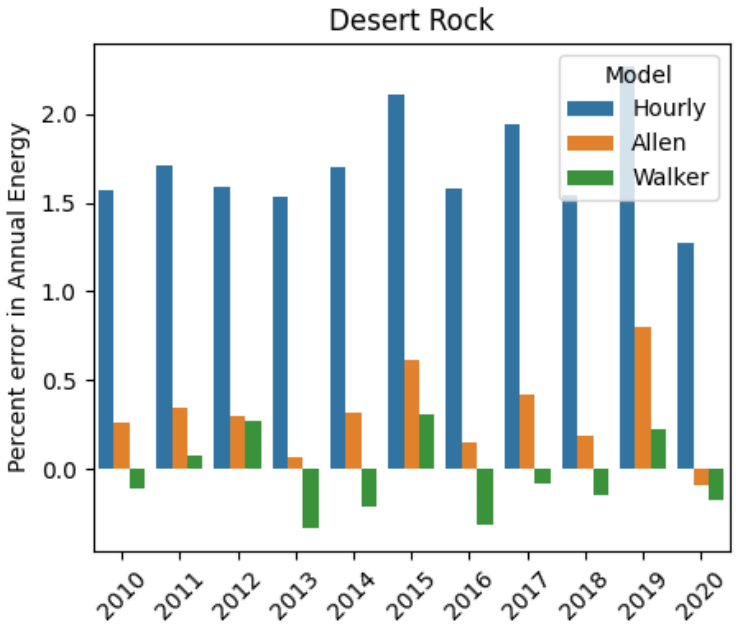
Annual Clipping Loss (% Error)

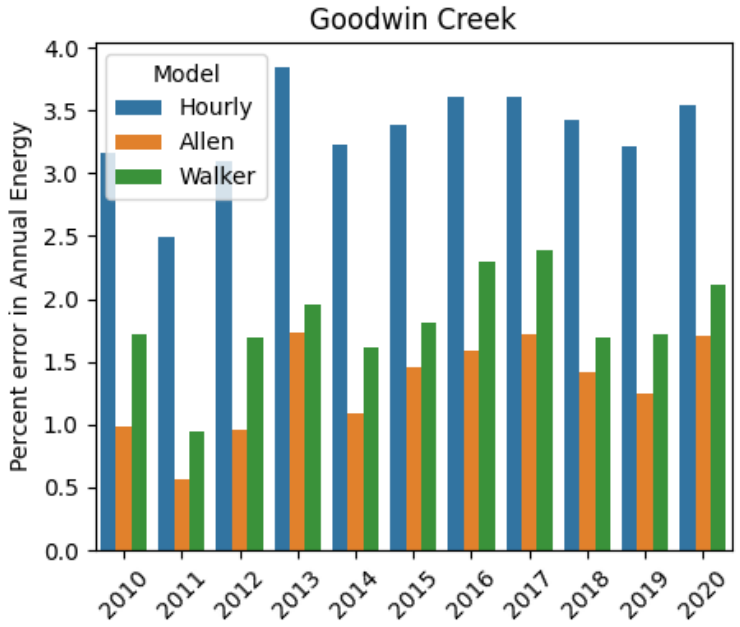
- At low ILR, high percentage losses due to low magnitude of clipping losses
- Converges to low percent difference as clipping increases

	Sioux Falls		
ILR	Hourly	Allen	Walker
1	-100.00	314.93	-100.00
1.1	-97.82	48.57	-97.82
1.2	-82.56	2.26	-82.06
1.3	-59.31	-4.80	-44.01
1.39	-41.63	-3.26	-13.58
1.49	-30.62	-0.96	-3.90
1.59	-24.04	0.06	-0.35
1.69	-19.70	0.48	1.25
1.78	-16.57	0.66	2.07
1.88	-14.17	0.74	2.52
1.98	-12.27	0.78	2.78
2.01	-11.83	0.79	2.83

Inter-annual Variability

- ILR = 1.5, Yearly results
- Highest error, lowest error occur in same year for both models





Conclusions

- Both models improve yield estimates by ~2-3% for higher ILR
- > 1% difference in error across weather years, important to allow for modeling inter-annual variability effect on clipping
- Difference between hourly and minute models is mostly from underprediction of clipping
- Future Work: Further incorporation into SAM desktop tool, open-source scripts from analysis

Thank you! Questions?

Contact: Matt Prilliman
Matthew.Prilliman@nrel.gov
https://sam.nrel.gov/

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38407. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from iStock-627281636