17th Annual PV Performance Modeling Collaborative

Gap-Filling Ground Measurements of Solar Irradiance

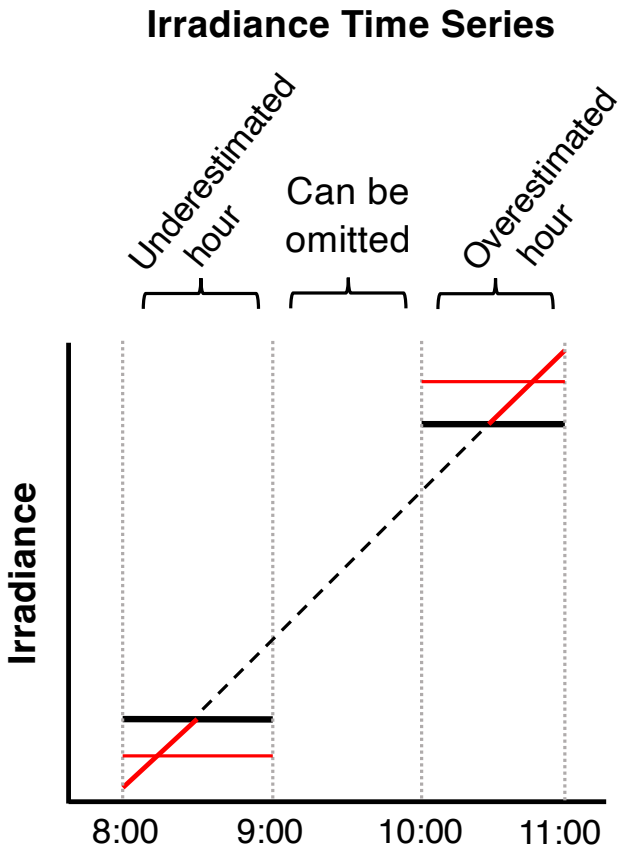
Alex Bryan, Josh Peterson, Julie Chard

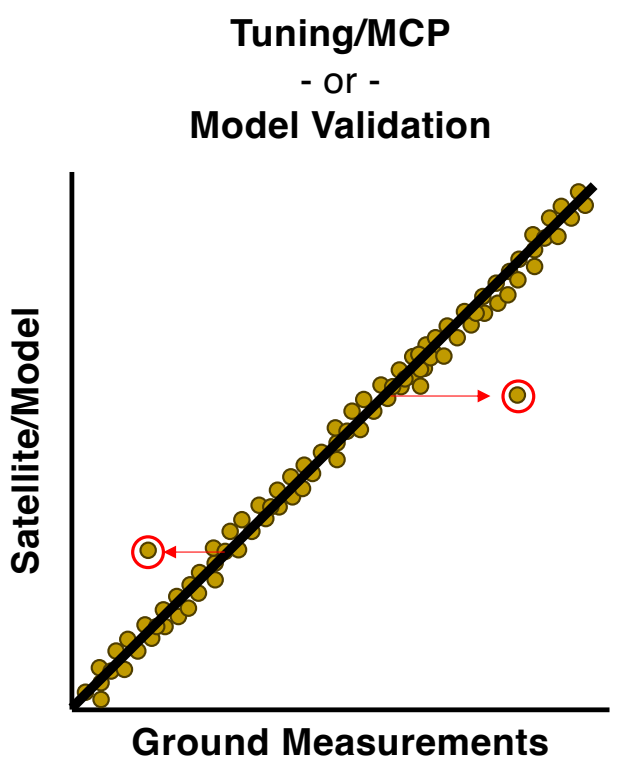
May 8, 2024



© GroundWork Renewables, Inc. | All Rights Reserved

IMPACTS OF GAPS IN RESOURCE ASSESSMENT





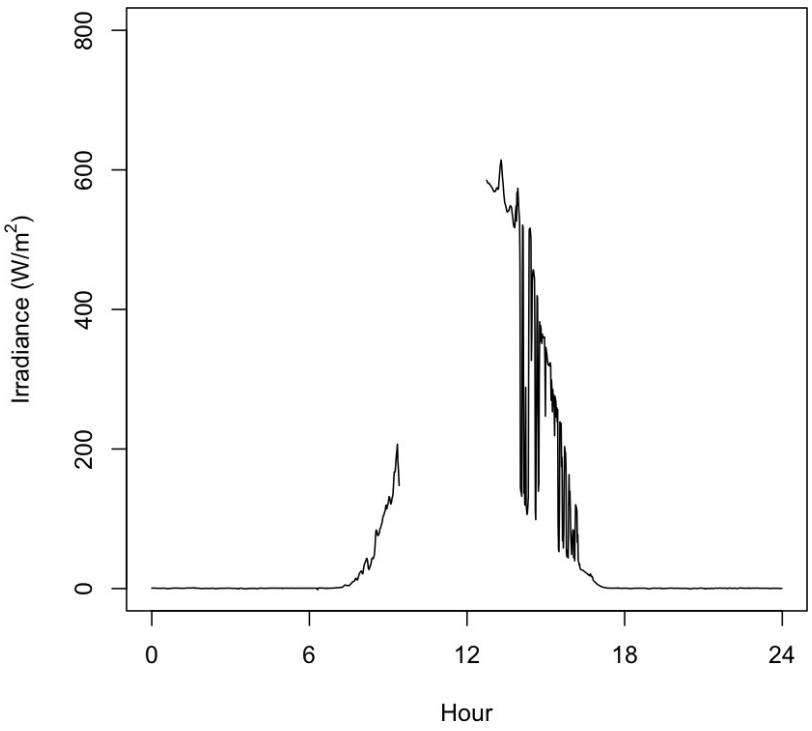
© GroundWork Renewables, Inc. | All Rights Reserved

Gap-Filling Ground Measurements of Solar Irradiance

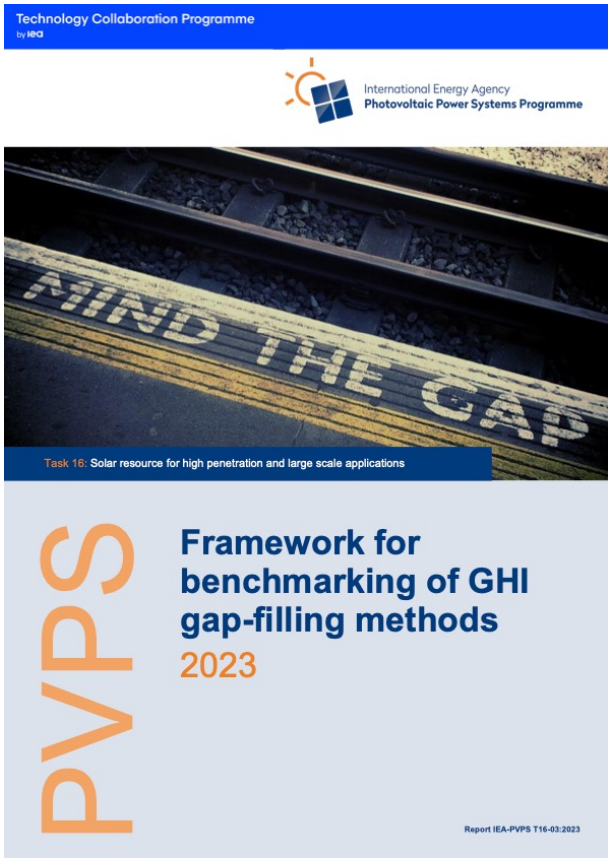
01 Current state of gap-filling methodologies

02 Proposed improvement to the current state-of-the-art gap-filling methodologies

03 Fleetwide assessment of GroundWork campaigns



© GroundWork Renewables, Inc. | All Rights Reserved



International Energy Agency (IEA)
Photovoltaic Power Systems Programme

Task 16: Solar Resource for High Penetration and Large-Scale Applications

June 2023

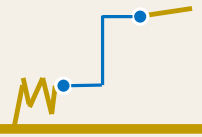
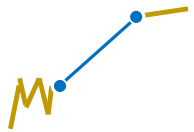
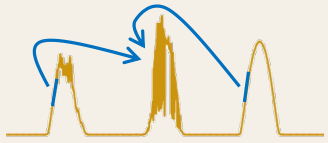
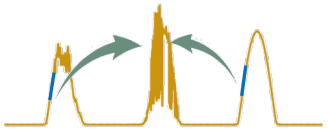
[1] IEA-PVPS T16:2023 *Framework for Benchmarking of GHI Gap-Filling Methods.*

© GroundWork Renewables, Inc. | All Rights Reserved

IEA GAP-FILLING METHODS

GroundWork

Increasing Complexity ↓

GF0	Step-wise K_t	
GF1	Linear K_t	
GF2	k-Nearest Neighbor	
GF3	Kernel regression	
GF4	Supplemental data (e.g., nearby station / sensor, satellite)	

Best for **short**-term gaps (< 30 mins)

Best for **long**-term gaps (> 2 hrs)

Best overall*

** Nearby sensor currently used in GroundWork Hourly Aggregation when passing data available. Satellite data not appropriate for use in satellite tuning studies.*

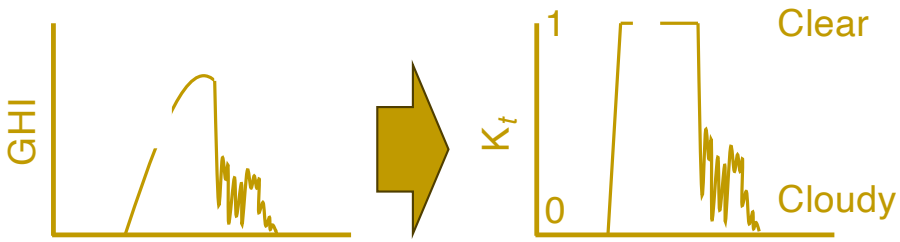
© GroundWork Renewables, Inc. | All Rights Reserved

GF1: LINEAR INTERPOLATION OF K_T

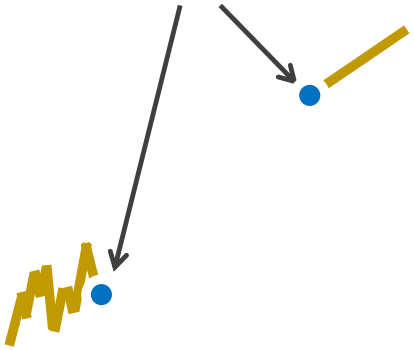
GroundWork

1 Calculate Clearness Index (K_t)

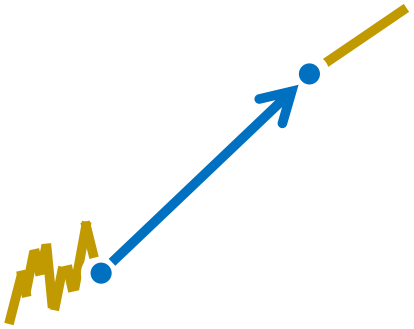
$$K_t = \frac{GHI_{ground}}{GHI_{top-of-atmosphere}}$$



2 Find nearest valid K_t data points

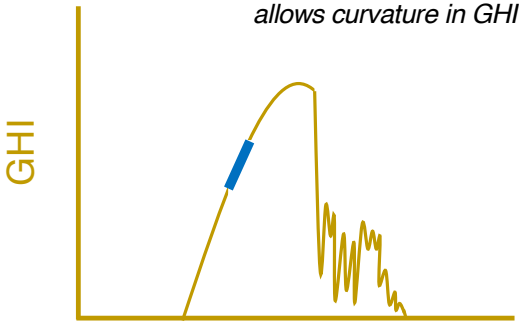


3 Linearly interpolate along K_t



4 Return to GHI

** Note: Conversion to K_t allows curvature in GHI data*



[1] IEA-PVPS T16:2023 *Framework for Benchmarking of GHI Gap-Filling Methods*. Section 3.2.2.

© GroundWork Renewables, Inc. | All Rights Reserved

Expand gap boundary from 1-minute to variable window sizing with gap size

1-minute (IEA GF1)

Variable window (GroundWork)

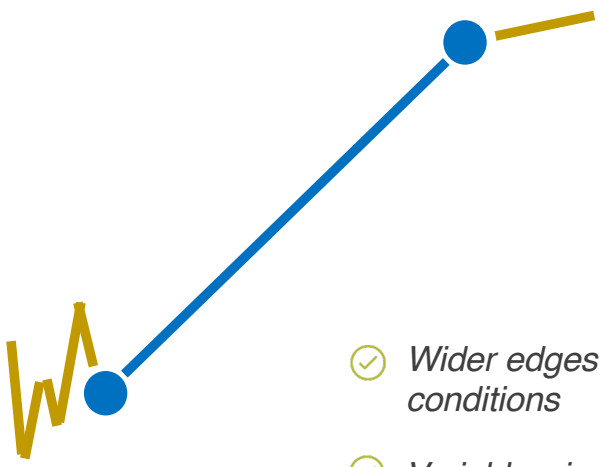
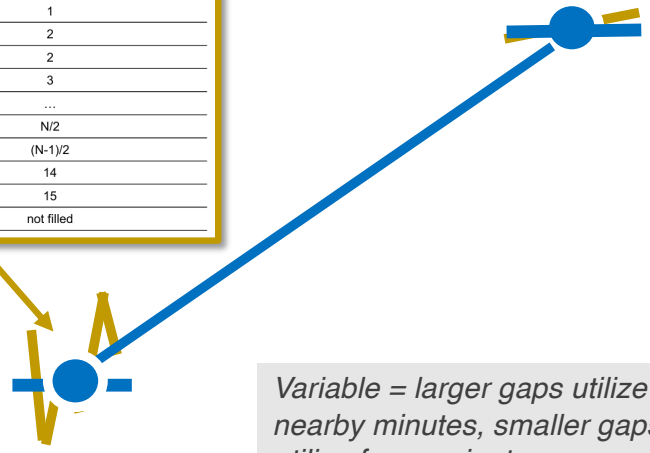


Table 4. Examples of various irradiance gap sizes and the number of nearby minutes used in the linear fit.

Gap Size (minutes)	Nearby Minutes Used in Linear Fit
1	1
2	1
3	1
4	2
5	2
6	3
…	…
N (even gaps)	N/2
N (odd gaps)	(N-1)/2
29	14
30	15
31	not filled

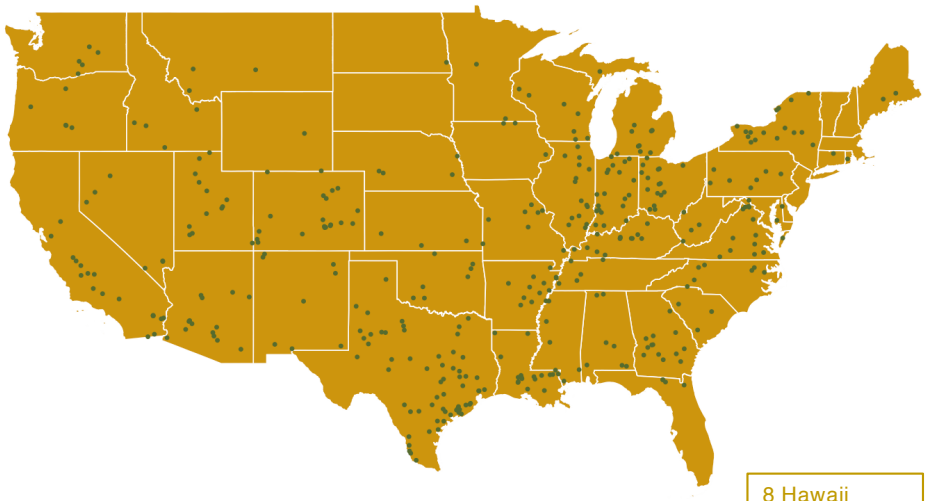


- *Wider edges account for variable sky conditions*
- *Variable window does not overweight distant data points under short gaps*

Variable = larger gaps utilize more nearby minutes, smaller gaps utilize fewer minutes

© GroundWork Renewables, Inc. | All Rights Reserved

FLEETWIDE ASSESSMENT



8 Hawaii
4 Canada
2 Mexico
1 Alaska
1 Puerto Rico
1 Yucatan
1 Chile

410 Resource Assessment campaigns

Diversity geographically, temporally, risks due to soiling, station outages, etc.

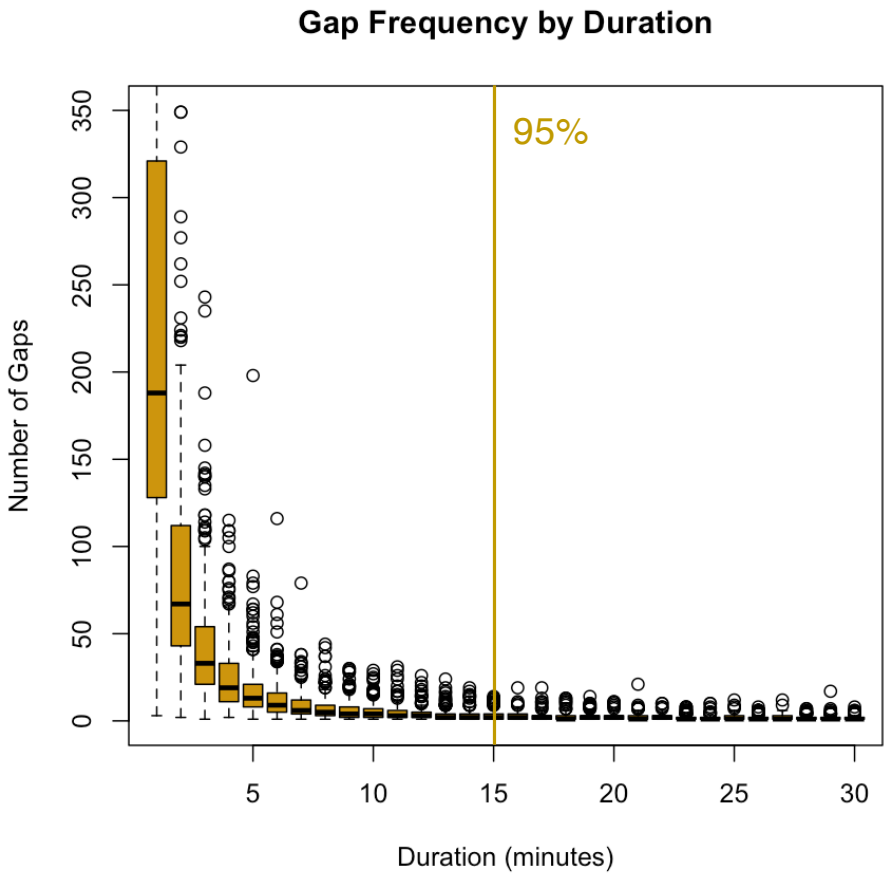
→ 7 years covered (2017 – 2024)

→ ≥ 1-year campaigns

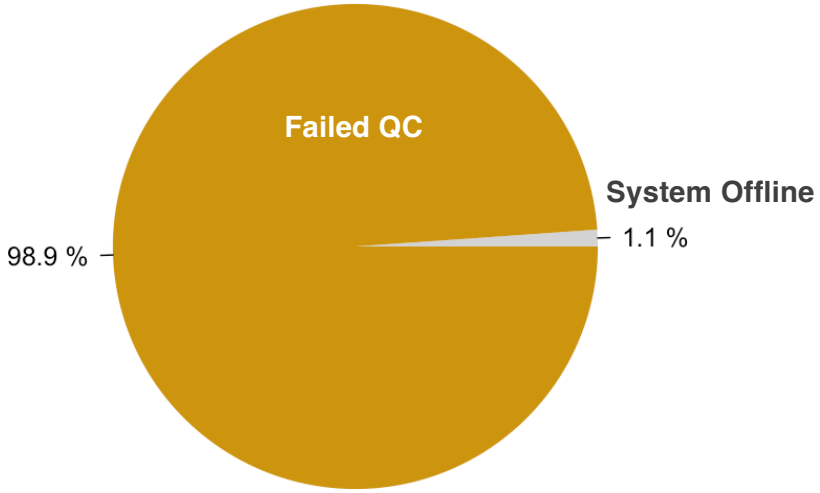
→ Maintained weekly, robust systems minimize outages, protocols for minimizing soiling (e.g., bird deterrents), daily data monitoring/alarming

© GroundWork Renewables, Inc. | All Rights Reserved

CHARACTERIZATION OF GAPS



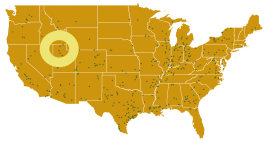
- **95%** of gaps are less than 15 minutes in length
- **99%** of gaps are caused by failed QC — not by system failures



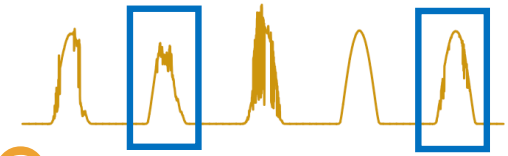
© GroundWork Renewables, Inc. | All Rights Reserved

METHODOLOGY: TESTING OF GAP-FILLING METHODS

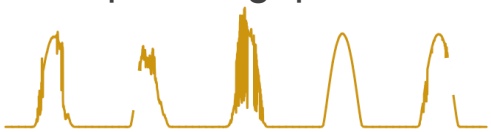
1. Pick a station



2. Pick 20 random days within that campaign

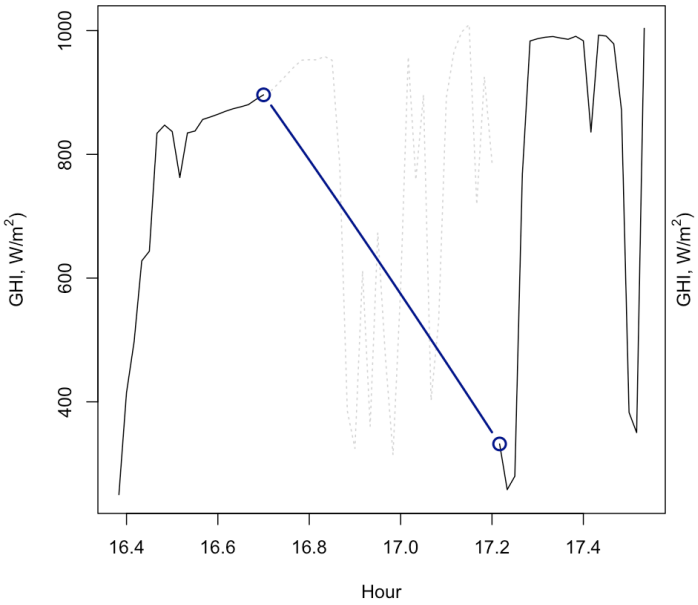


3. Pick 1 random time within each day; impose a gap

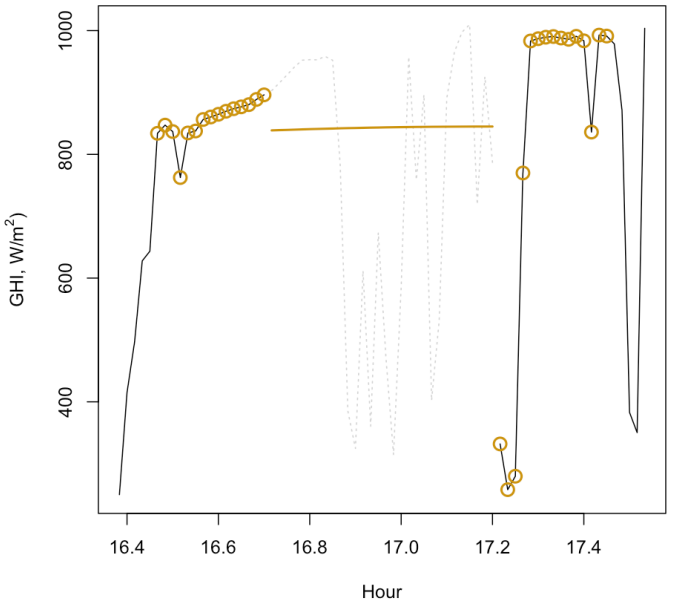


4. Apply both methods (at right) to time period

1-minute



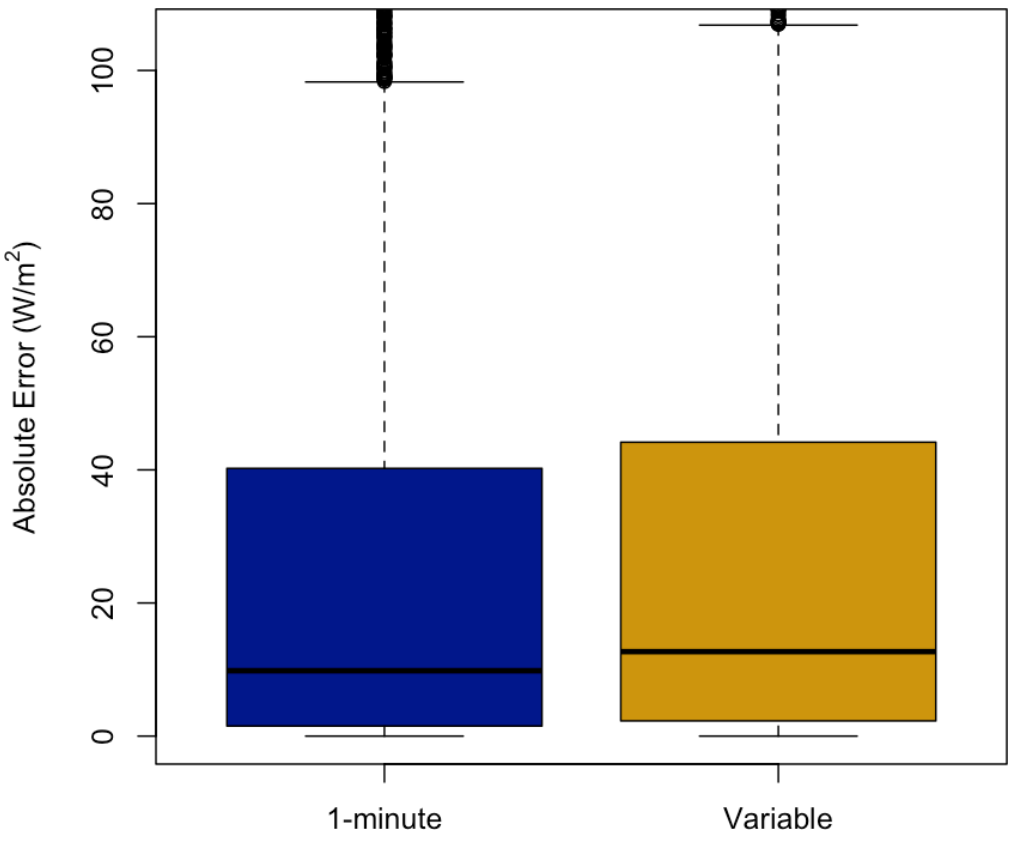
Variable window



Evaluation: Compare both methods against measured data during gap

© GroundWork Renewables, Inc. | All Rights Reserved

RESULTS: IMPROVEMENT LED BY EXPANDING GAP BOUNDARIES



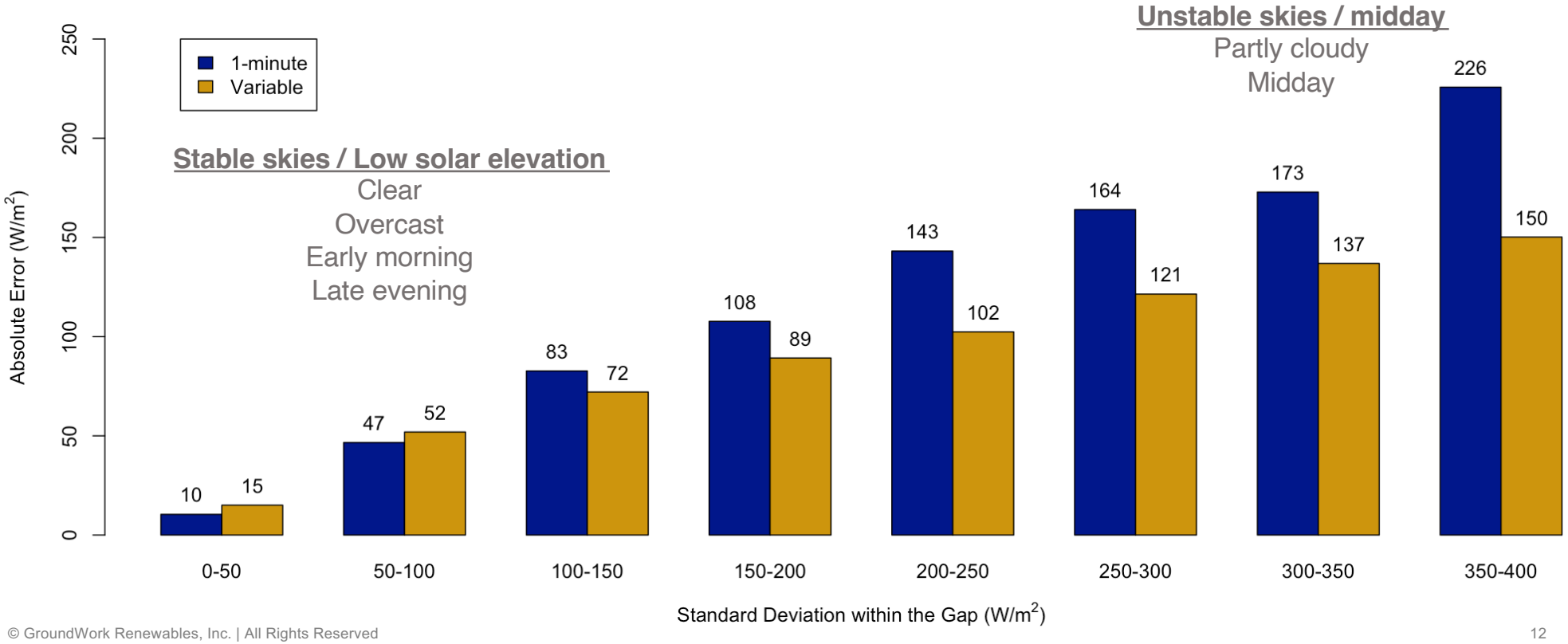
- *Overall,* **1-minute** and **Variable** methods yield similar results in terms of absolute error looking holistically at all imposed gaps

- Absolute error, on average, no more than **10 – 15 W/m^2**

$$\text{Abs. Err.} = \left| GHI_{actual} - GHI_{gap-filled} \right|$$

© GroundWork Renewables, Inc. | All Rights Reserved

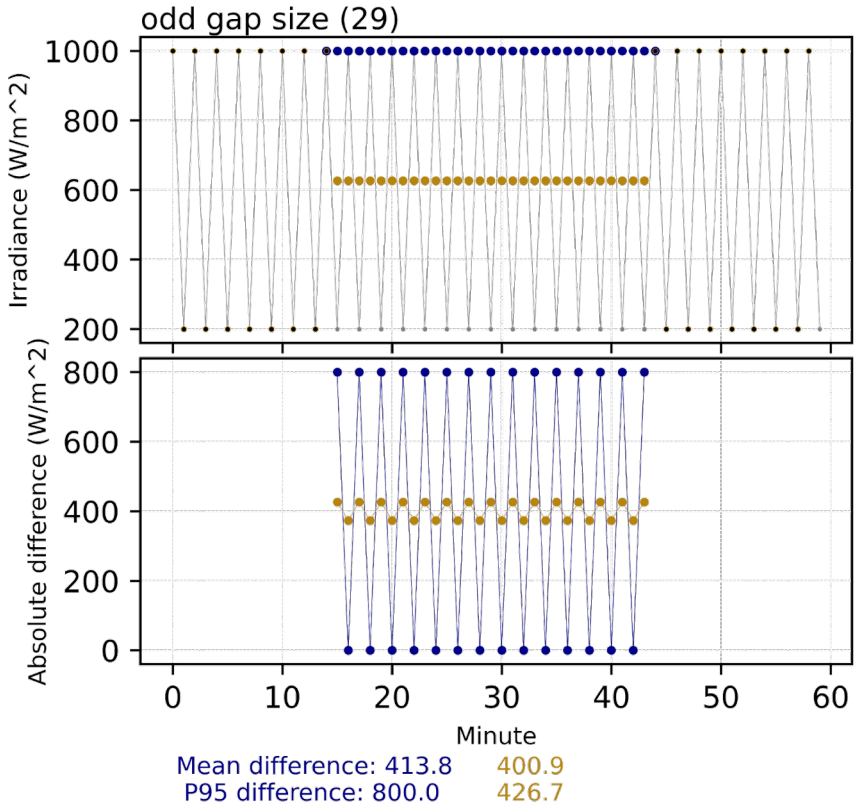
Improvement increases with increasing standard deviation of the gap



© GroundWork Renewables, Inc. | All Rights Reserved

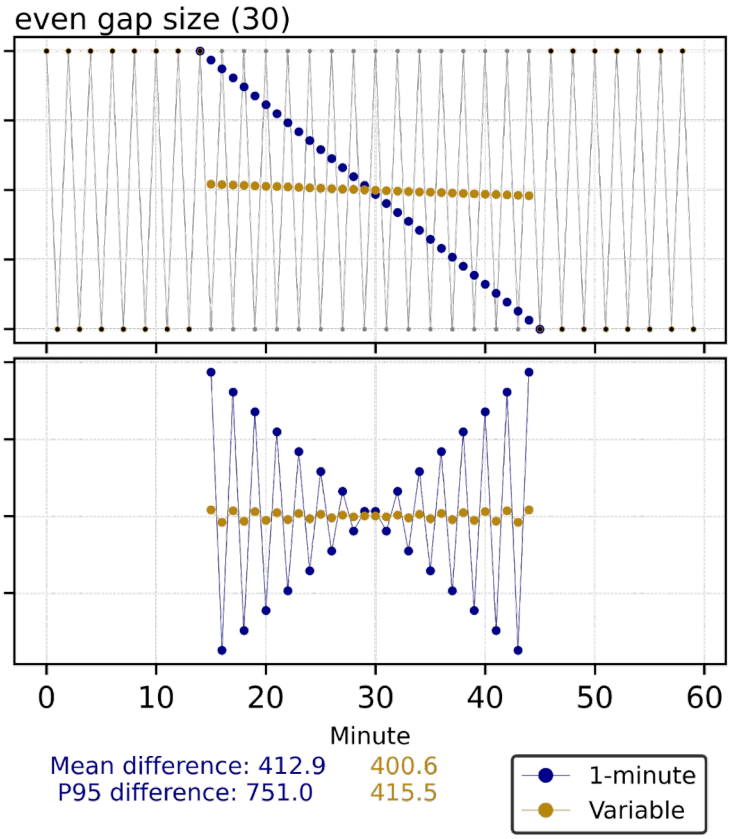
DIVING INTO THE PARTLY CLOUDY RESULTS

Both Neighboring Minutes Not Cloud-Covered



Mean difference: 413.8 400.9
P95 difference: 800.0 426.7

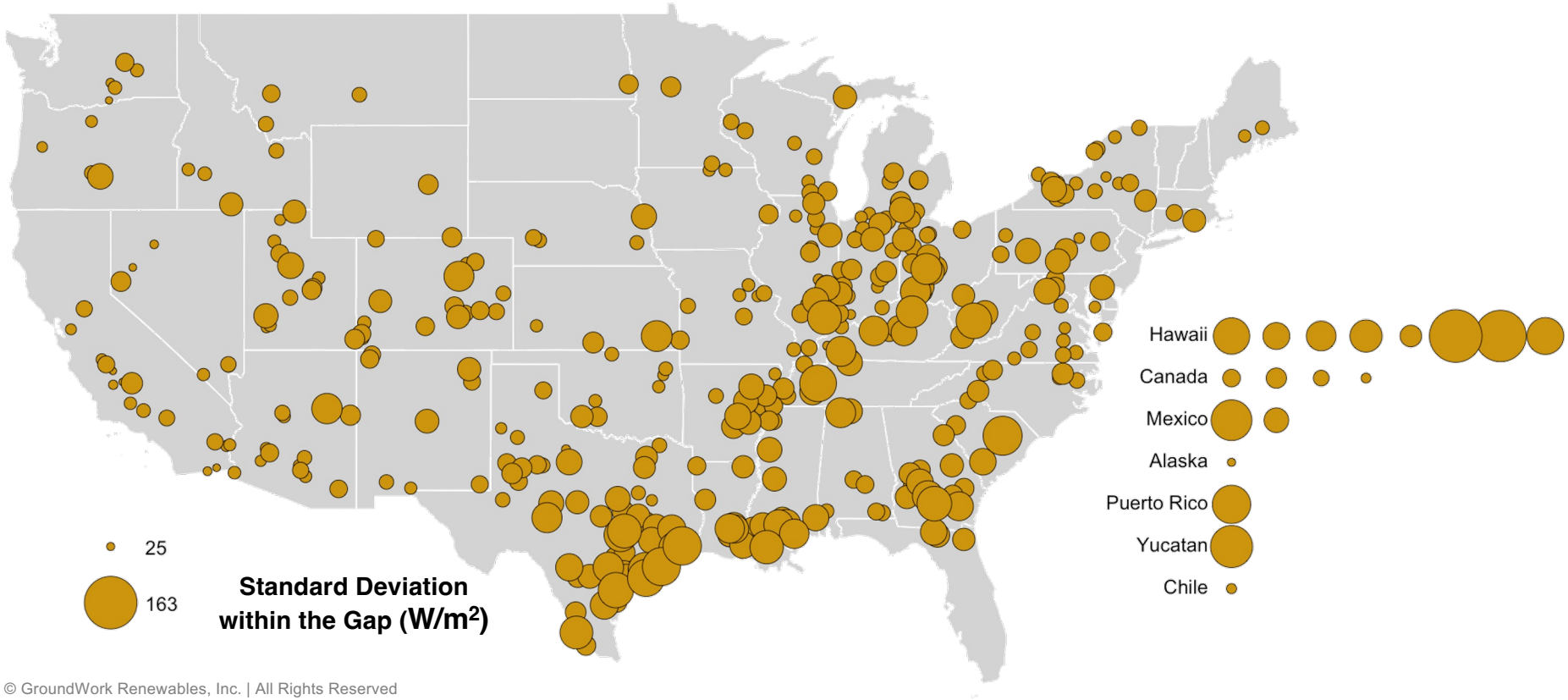
One Minute Cloud Covered, Other Not



Mean difference: 412.9 400.6
P95 difference: 751.0 415.5

© GroundWork Renewables, Inc. | All Rights Reserved

Most important at sites prone to boundary layer cumulus (e.g., coasts, mountains).



© GroundWork Renewables, Inc. | All Rights Reserved

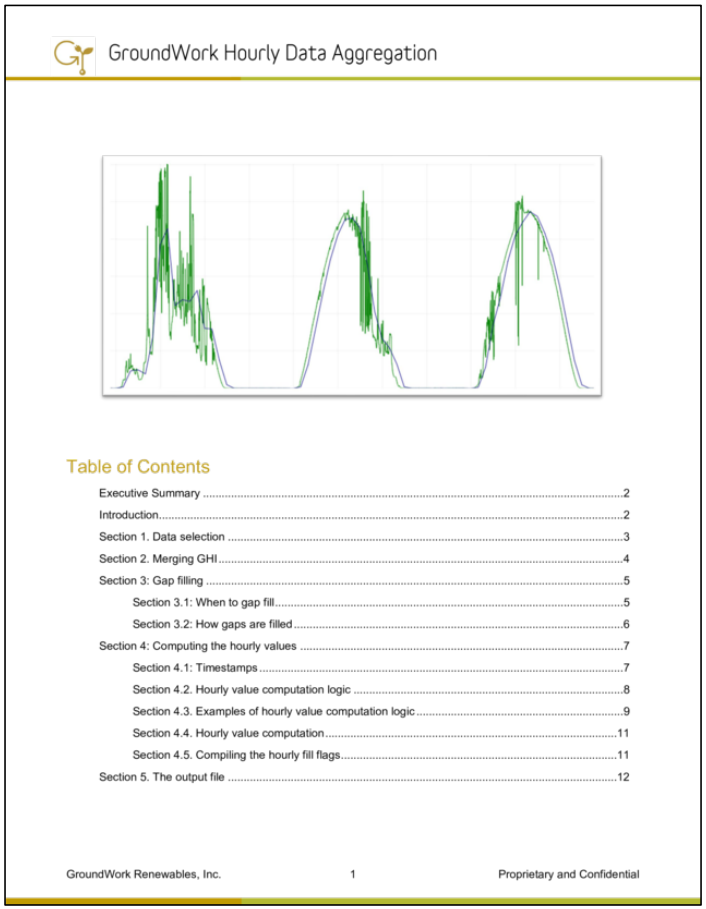
CONCLUSIONS

- Characterization of gaps in the field
  - → 95% of gaps are less than 15 minutes
  - → 99% of gaps are due to failed QC
- 1-minute and variable window methods yield similar results, except under partly cloudy skies midday when variable method shows large improvement
  - → Wider gap boundaries better inform cloud conditions during gap
  - → Increased window most important in partly cloudy regions (e.g., warm coastal environments due to the sea breeze effect, downwind of Great Lakes due to lake effect, mountains)



© GroundWork Renewables, Inc. | All Rights Reserved

- Gap-filling is one component of a new GroundWork offering: an Hourly Aggregation file, a post-processing of GroundWork data that ***also*** includes:
  - → Filtering of unqualified data
  - → Merging of redundant measurements
  - → Hourly statistics



GroundWork Hourly Data Aggregation

Table of Contents

Executive Summary 2
Introduction 2
Section 1. Data selection 3
Section 2. Merging GHI 4
Section 3: Gap filling 5
Section 3.1: When to gap fill 5
Section 3.2: How gaps are filled 6
Section 4: Computing the hourly values 7
Section 4.1: Timestamps 7
Section 4.2. Hourly value computation logic 8
Section 4.3. Examples of hourly value computation logic 9
Section 4.4. Hourly value computation 11
Section 4.5. Compiling the hourly fill flags 11
Section 5. The output file 12

GroundWork Renewables, Inc. 1 Proprietary and Confidential

© GroundWork Renewables, Inc. | All Rights Reserved

THANK YOU!

A

Contact me: abryan@grndwork.com



standard.co.uk

© GroundWork Renewables, Inc. | All Rights Reserved