Solar Insolation Micro-Forecasts Using Longwave Infrared Sensors and Artificial Intelligence

Dr. Anthony Menicucci, PhD
University of New Mexico, Research Professor
Department of Mechanical Engineering
amen@unm.edu
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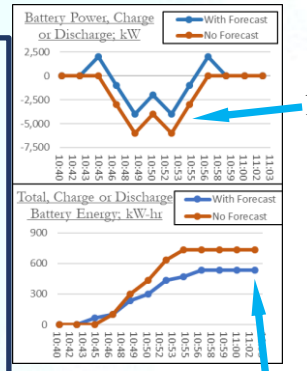
US Energy Industry; Beyond 2021, Solar PV & Nuclear

SCHOOL OF ENGINEERING

PV Solar turns on & off with the following characteristics:

- Within 5 min., deterministically;
- 5 to 120 min., quasi-deterministically;
- day-ahead, statistically; &
- after 5 days, chaotically.

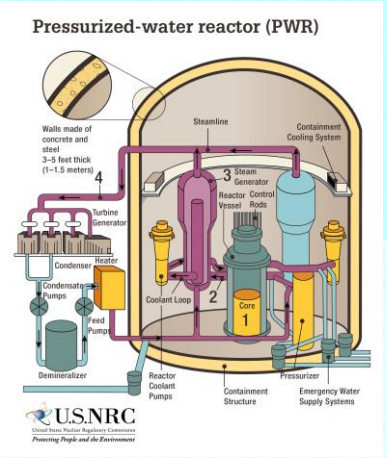


33% Less Battery Wear & Tear W. SIMF

27% Smaller Battery Capacity W. SIMF

Extended Life, Grid-Sized Energy & Battery Storage is The Enabling Energy Technology, by 2040 to 2060

~20 years to innovate &
~20 years to shake off IP from patents



Solar Irradiance Micro-Forecasting SIMF; 0-5 min., LAPART, Velocity Gate

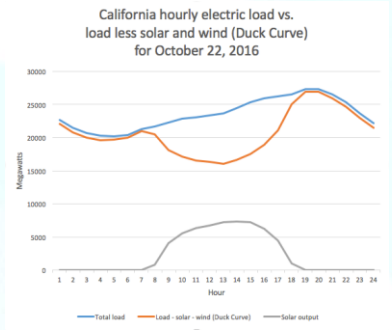
Ground Based

Radar/Satellite

Forecasting; 5-120 min.; LAPART, Velocity Gate

Battery Storage Preservation Technologies are a Current Market Need.

The "Duck Curve" is the Foe of ALL Ohm's Law Believers.



Pumped-Storage Power Station, Germany

Daily:
Nuclear Power does not turn up or down.
&
Nuclear Power does not turn off.

Left: ArnoldReinhold - Own work based on data from caiso.org; CC BY-SA 4.0; File:Duck Curve CA-ISO 2016-10-22.agr.png; Created: 26 October 2016
&
Above: Dr.G.Schmitz; Own work, pumped-storage power station, Rönkhausen, Germany; CC-BY-SA-3.0; Created: 10 May 2008

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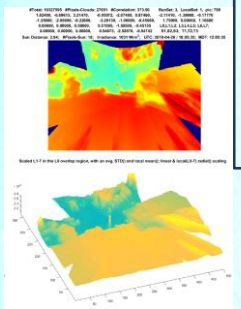
Solar Irradiance Micro-Forecasting (SIMF) for Solar-PV at UNM

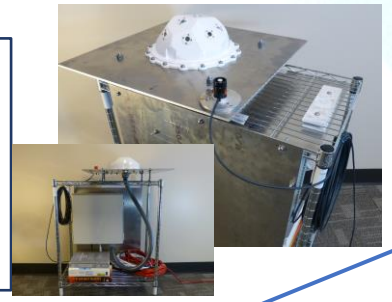
SCHOOL OF ENGINEERING

Benefits of Solar PV Forecasting:

1. ***Grid Sized Battery-Life Preservation;***
2. ***Grid Stability from PV Resources;***
3. ***Arbitrage Opportunities;***
4. ***Investor Confidence in Renewable Portfolio Standards (RPS) Attainment Feasibility***



Fielded Trial of UNM SIMF Tech., for Battery Smoothing; SNL &/or UNM (M2x)



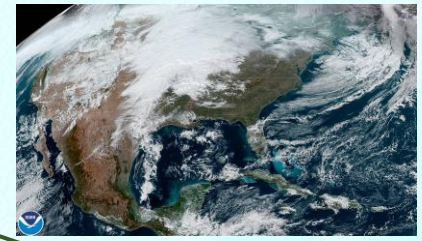
Internet Based Radar Data Inputs
- SIMF; <5 min PIV for Velocity Gate (M1x)
- Forecasting: medium term 5-120 min (M1x)

SIMF, Lens Cleaning System; (M1x)

Solar Irradiance Micro-Forecasting SIMF; 0-5 min., LAPART, Velocity Gate

Solar PV Forecasting at UNM

Short –Term Forecasting; 5-120 min.; LAPART, Velocity Gate



Multi-Sensor Design; FLIR® components

SIMF, UL ® Compliant, Component Selection; (M1x)

Distributed Sensors; Forecasting: medium term 5-120 min (M1x)

Internet Based Satellite Data Inputs
- Forecasting: medium term 5-120 min (M1x)

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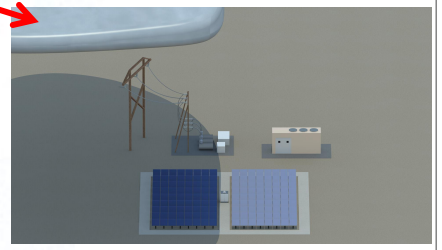
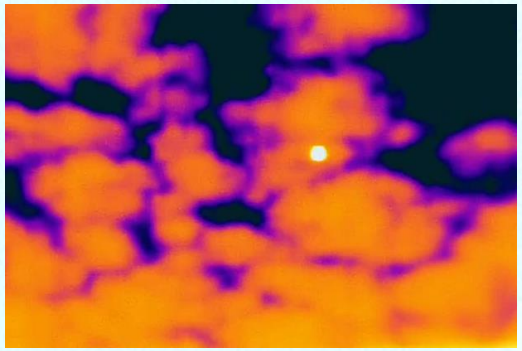
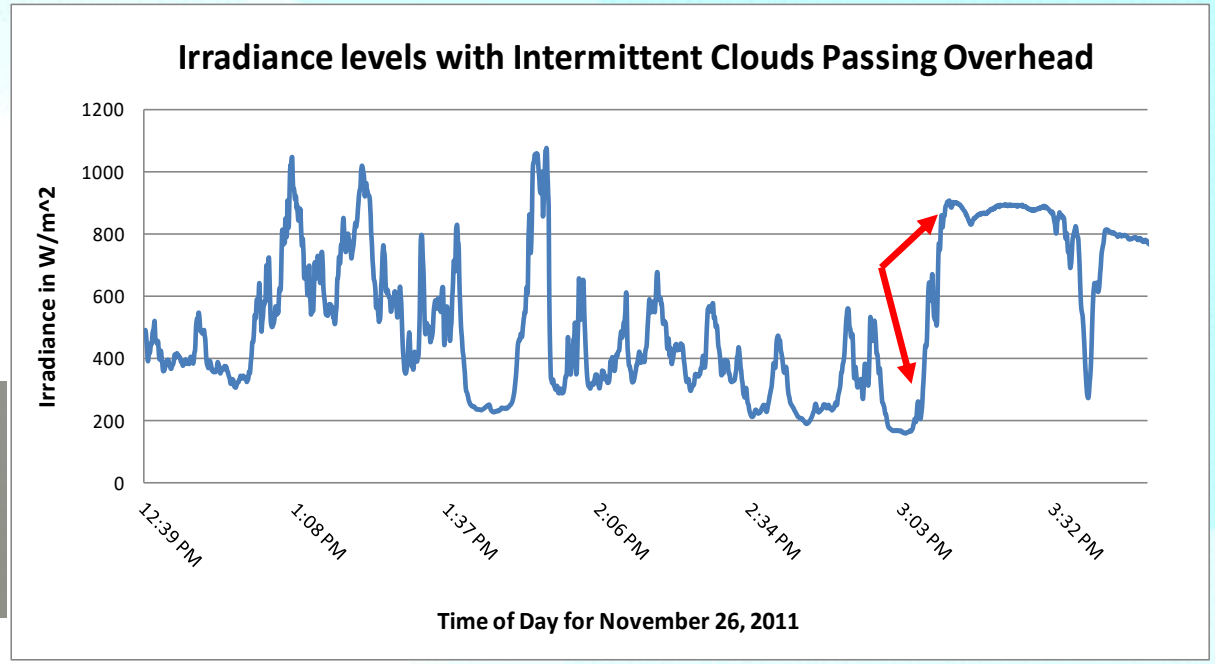
Problem

Solar panels produce intermittent electricity when clouds are present.



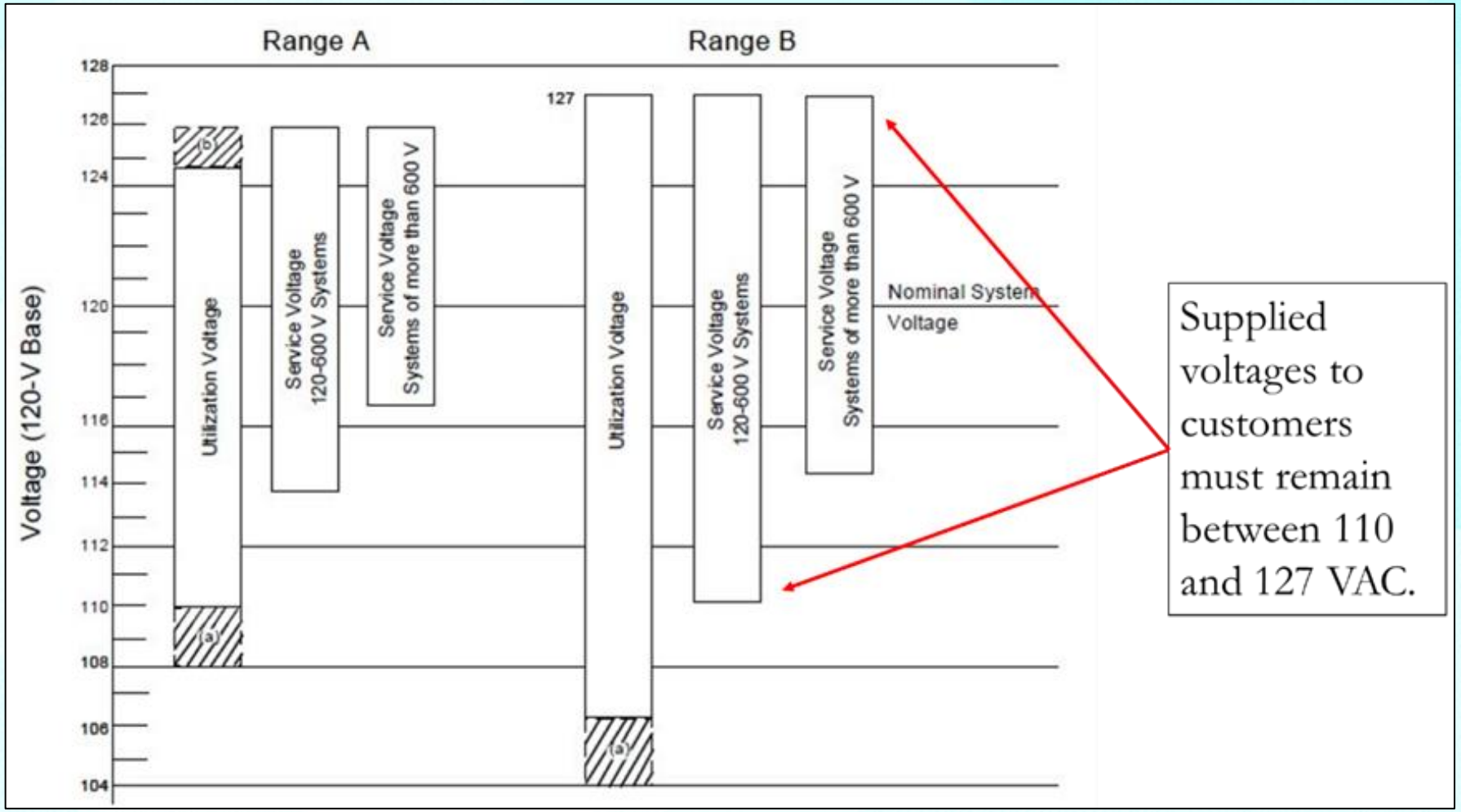


Near &
Far IR Images



Electrical grid operators, known as ISOs/RTOs must match load with supply.

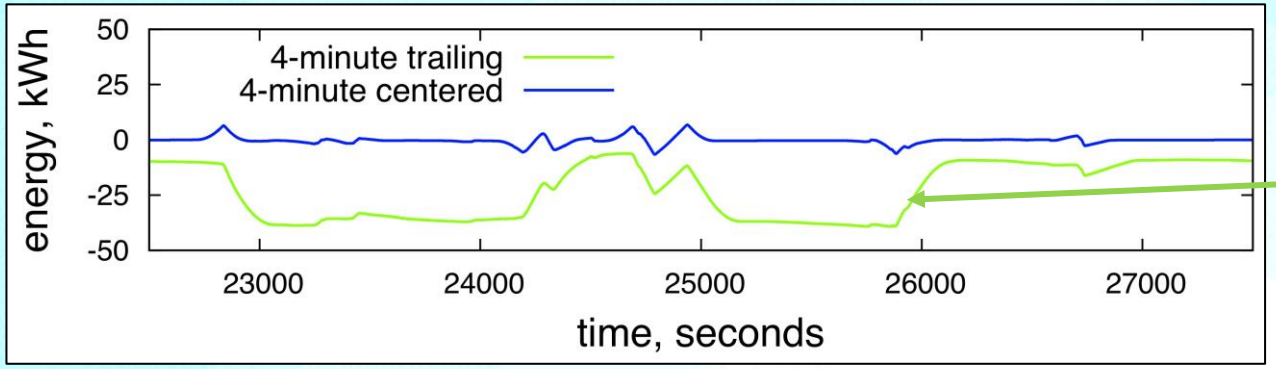
Problem



NEMA-ANSI C84.1 Voltage Ranges

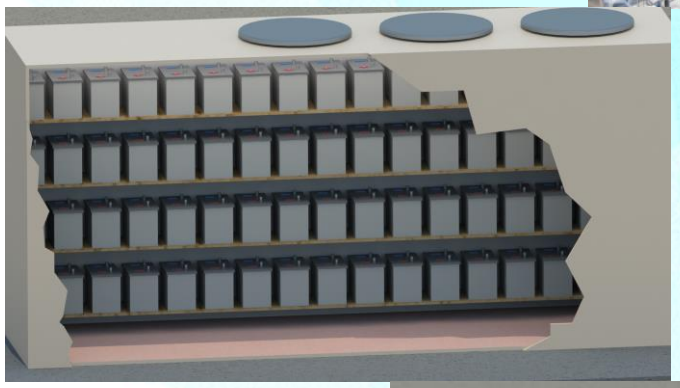
- Voltage Specifications
- CAISO 30 min. $1M frequency specification
- Frequency must be maintained also
- Other…

Problem



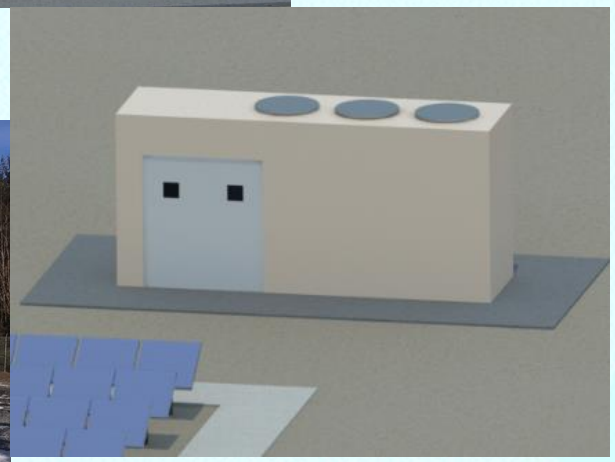
A. Mammoli, et al. Low-cost solar micro-forecasts for improving the efficiency of PV farm output smoothing.

Note how the grid tied smoothing battery is heavily used when there is no 2-minute irradiance forecast.



(CAISO); Because of intermittent clouds and no forecasting, 'we cycle our batteries ten times more than what they are rated to cycle.'

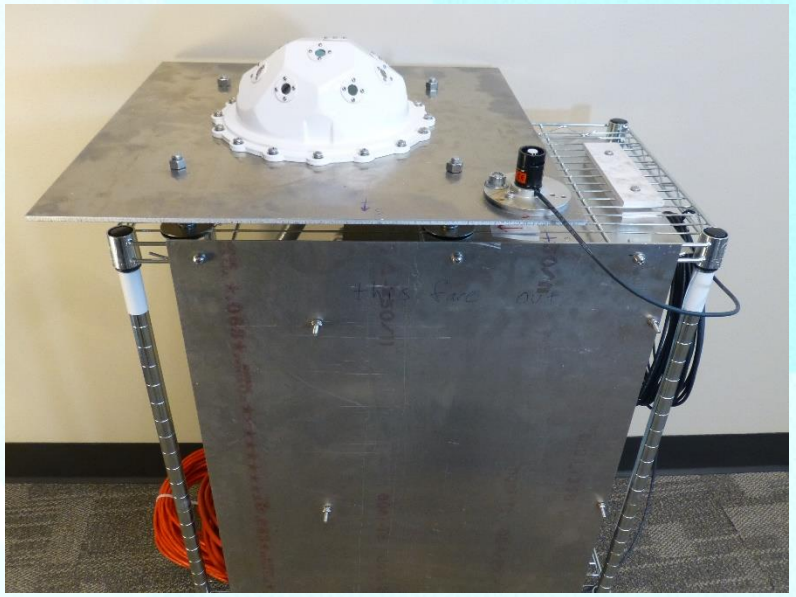
April, 2020



Benefits to Industry:

1. Regulation Support for incoming voltage/frequency, spikes/dips.
2. Reduce smoothing battery project cost by reducing battery capacity size.
3. Prolong smoothing battery lifespan by reducing power utilization.
4. Utilities will be able to meet their Renewable Portfolio Standards (RPS) legislation.
5. Incur less regulatory fines.
6. Utilities can arbitrage the spot market.

**Knowledge of the future always helps.*



Prototype STTR NSF 16-555

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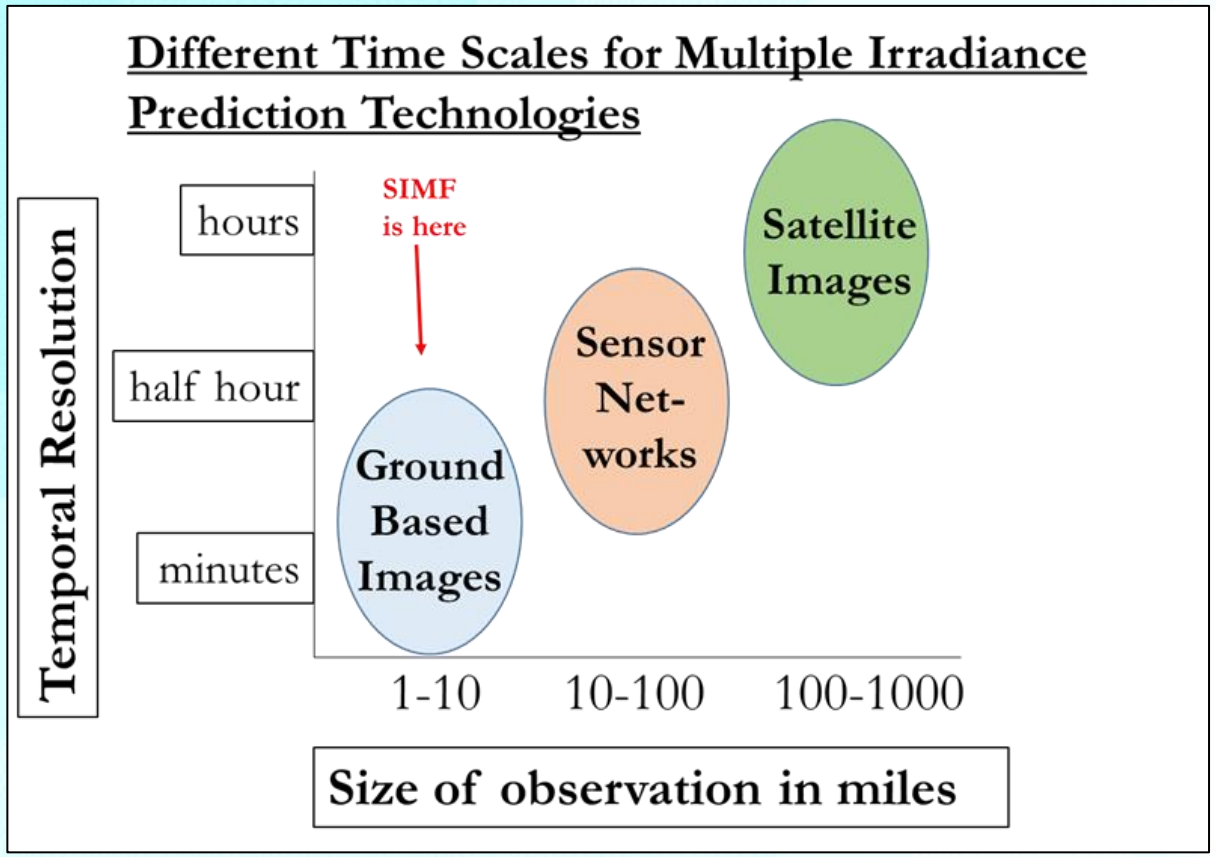
Ground Based Systems



- Lidar, Radar; greater than 20 min.

Older technologies with indirect observation.

ARM

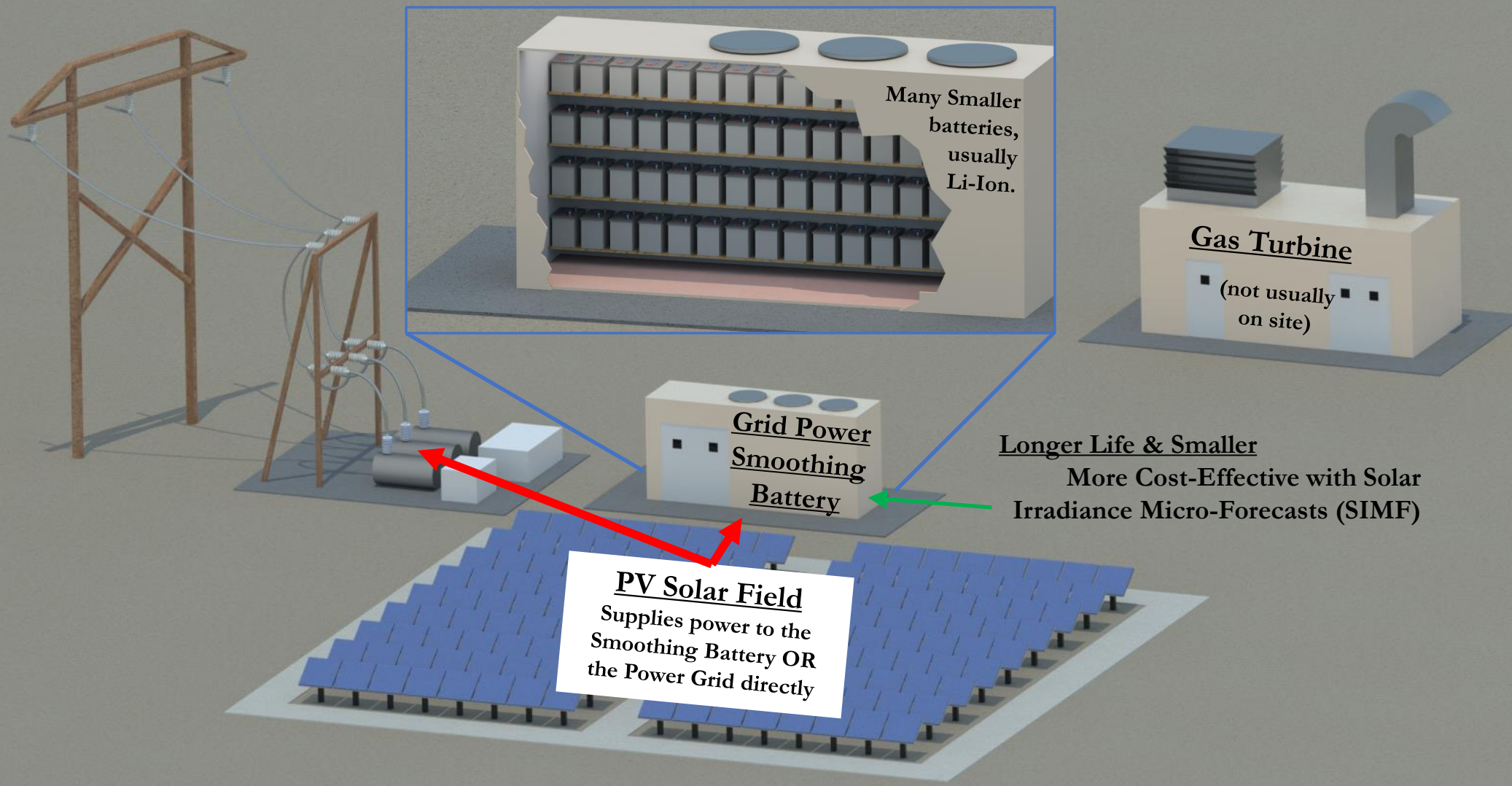
EKO

- We utilizes IR sensors to generate crisp images.
- LAPART Neural Network to predict irradiance accurately, in less than 10 minutes.

Specific Components of a PV Field

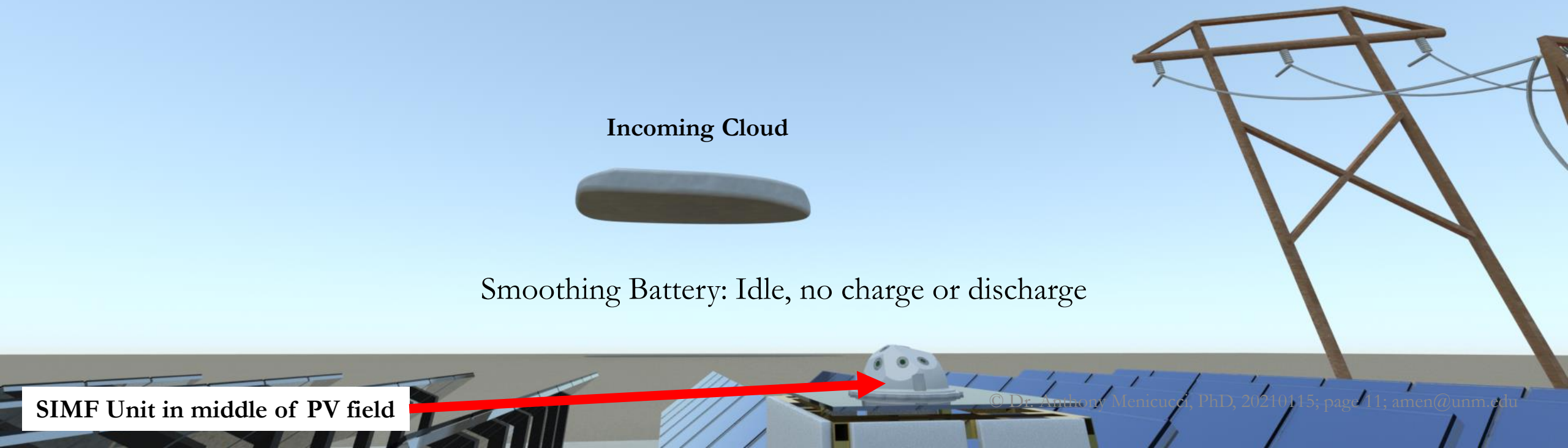
Power Grid.

Remember:
V=I*R;
If Current changes from load OR supply, voltage, frequency & other parameters fall out of specification.



Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

Looking West



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Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

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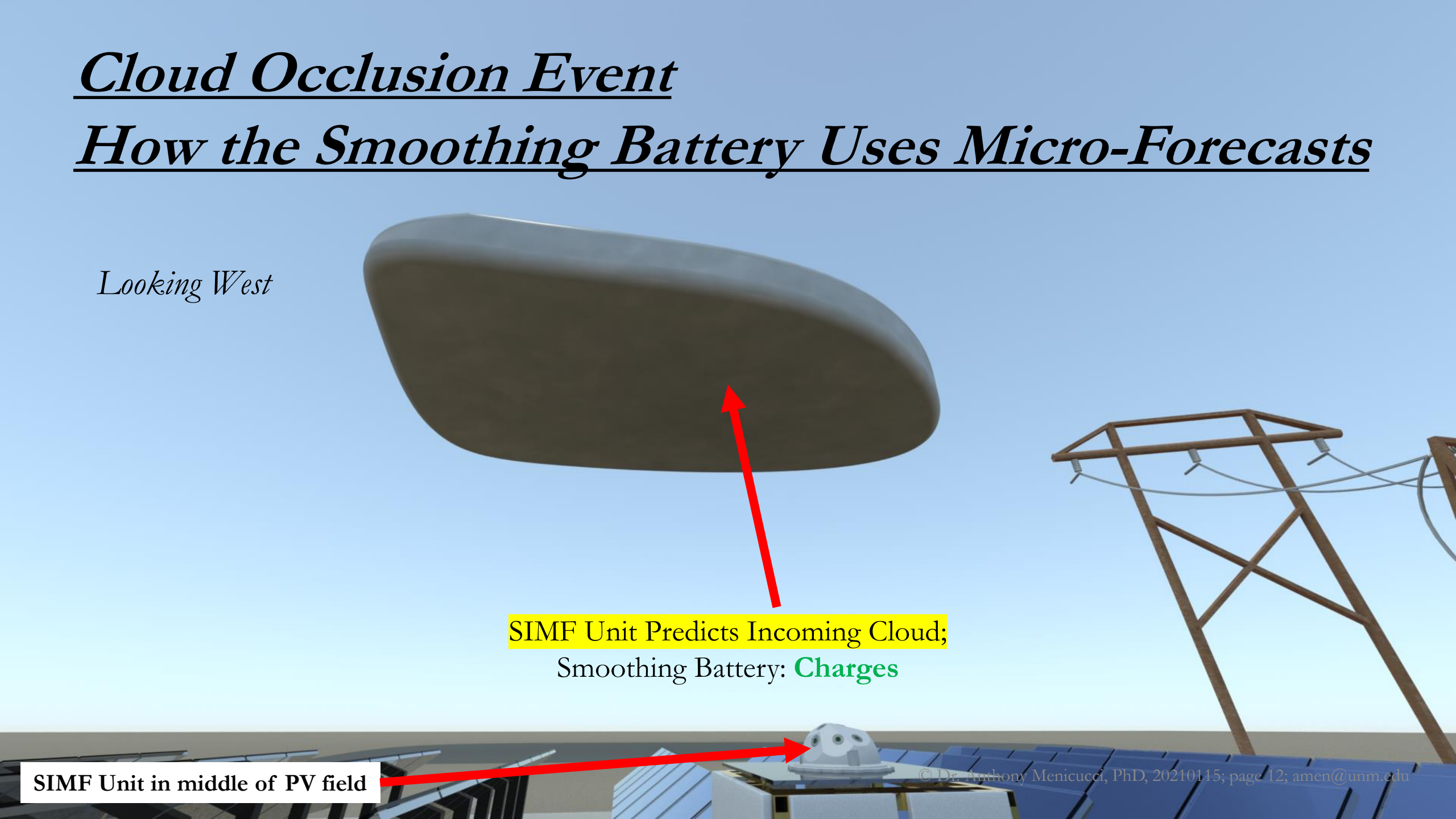

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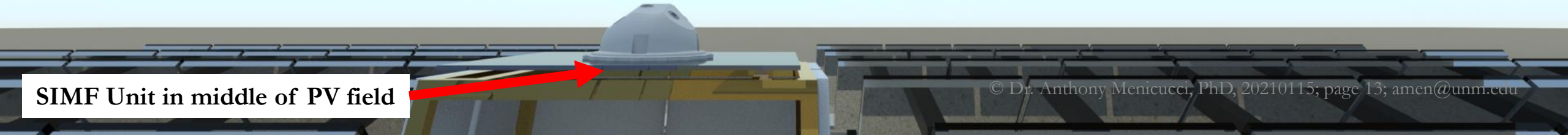
Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

Looking South

Cloud arrives & we switch,
Smoothing Battery: **Discharges**



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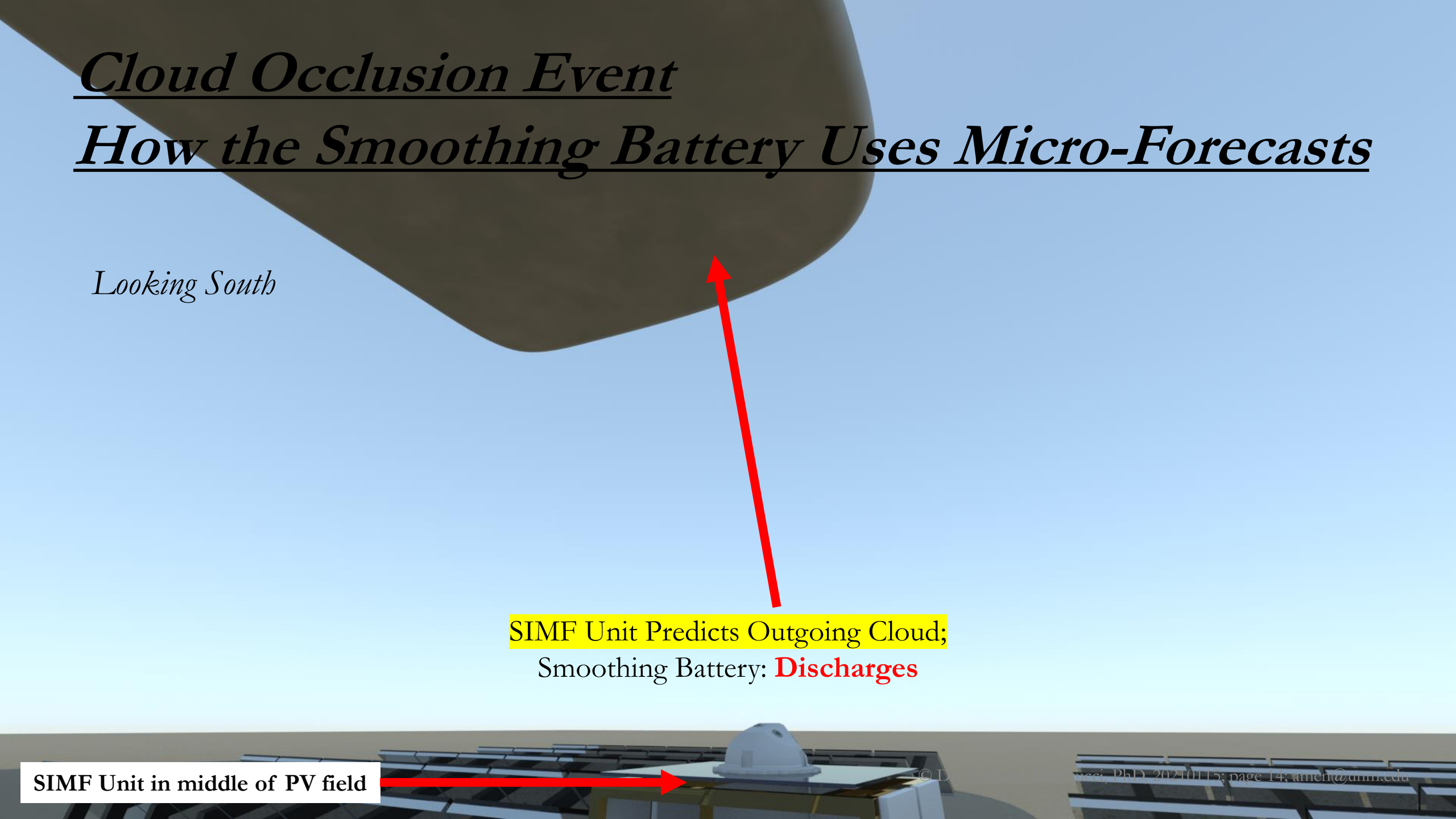
Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

Looking South



Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

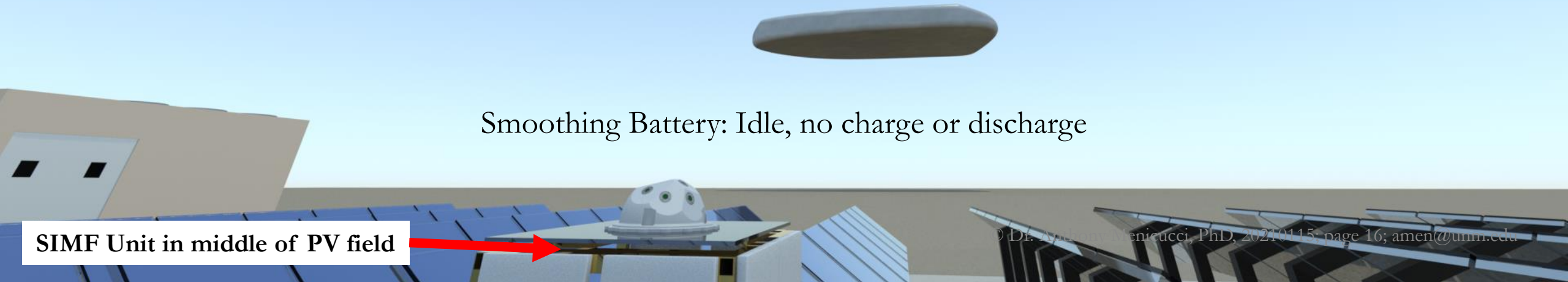
Looking East

Too much power change from recent cloud occlusion:
Smoothing Battery: **Charges**

SIMF Unit in middle of PV field

Cloud Occlusion Event
How the Smoothing Battery Uses Micro-Forecasts

Looking East

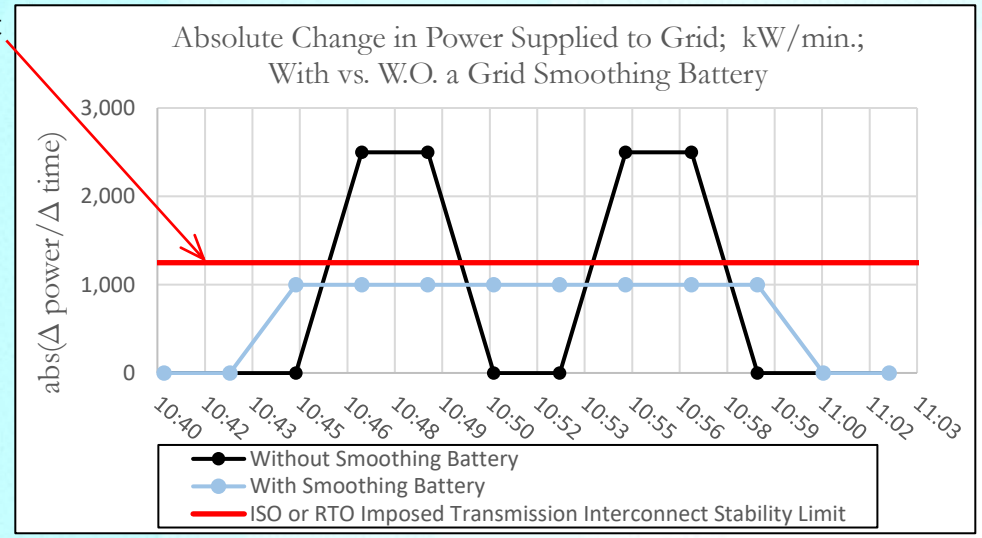


Smoothing Battery: Idle, no charge or discharge

Important to ISOs & RTOs!

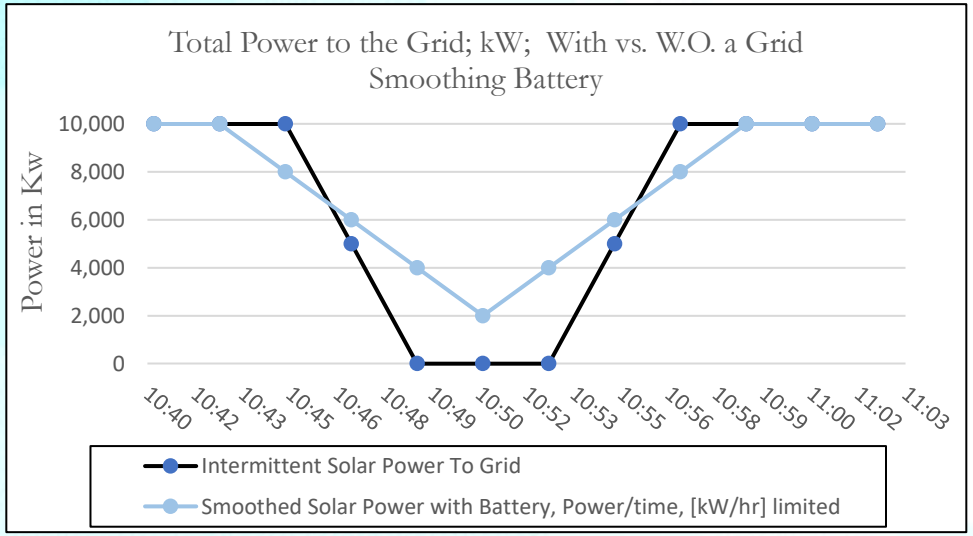
Rate of Power Change

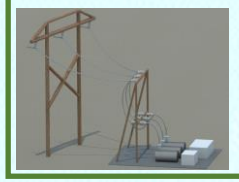
$$\frac{d^2E}{dt^2}$$



Rate of Energy Change; -Power-

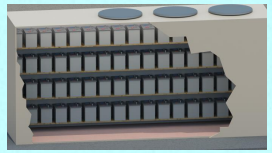
$$\frac{dE}{dt}$$

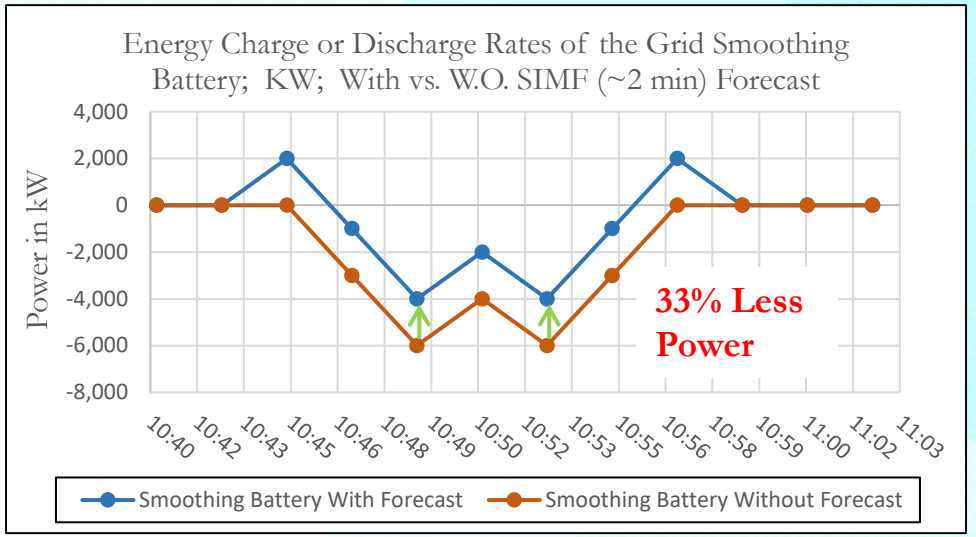




Grid Statistics

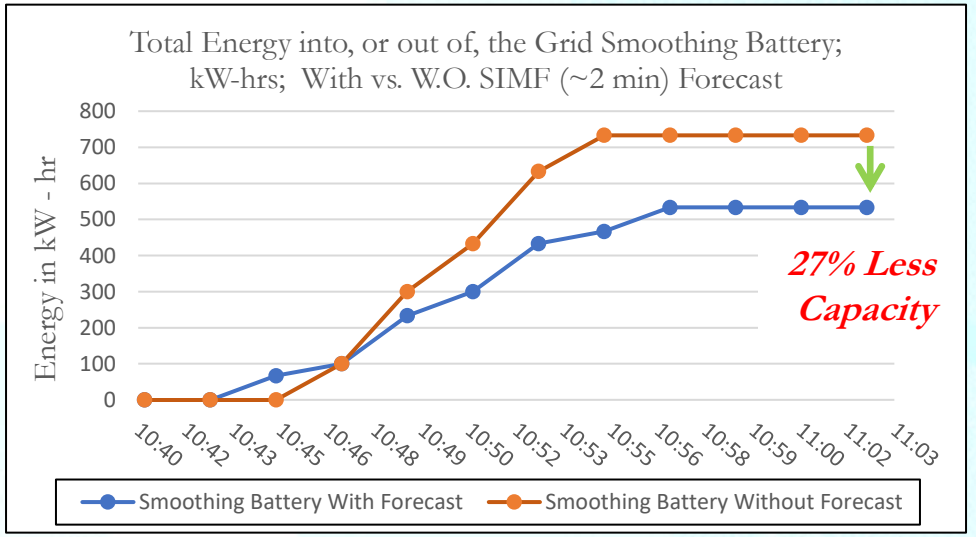
Smoothing Battery Statistics





Rate of Energy Change; -Power-

$$\frac{dE}{dt}$$



-Energy-

$$E$$

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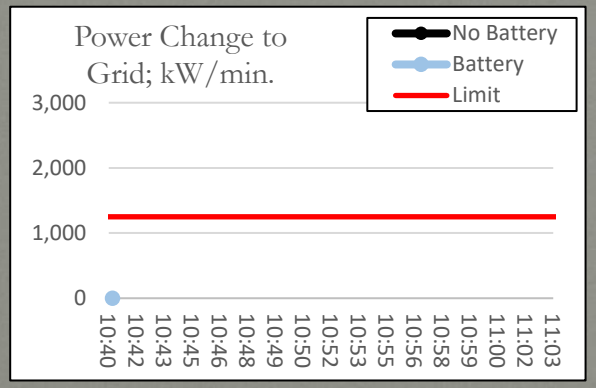
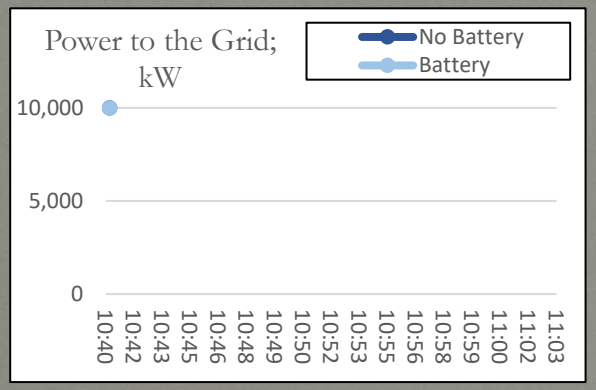
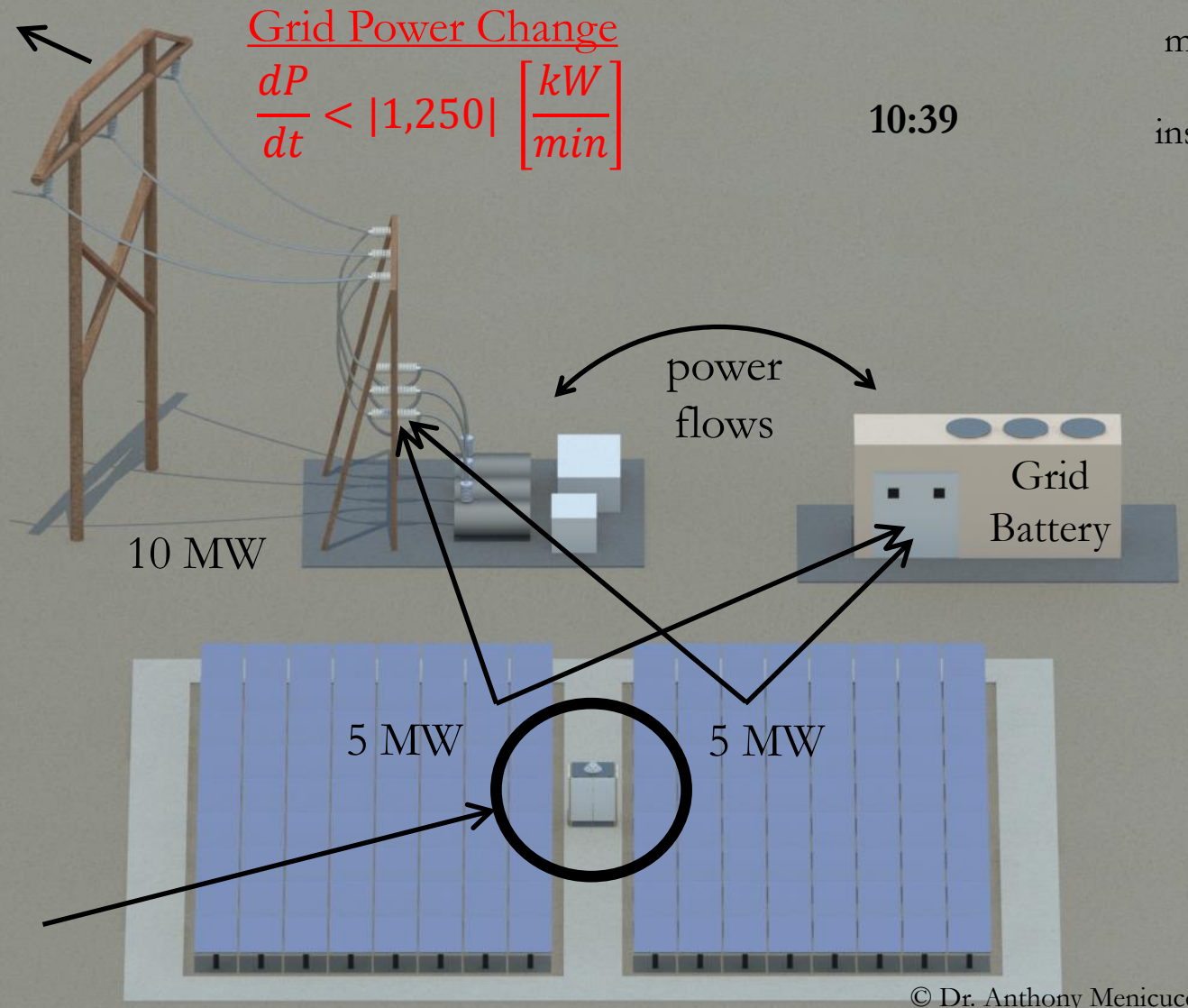
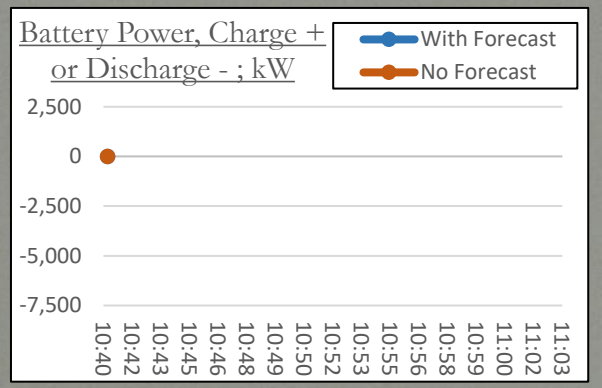
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

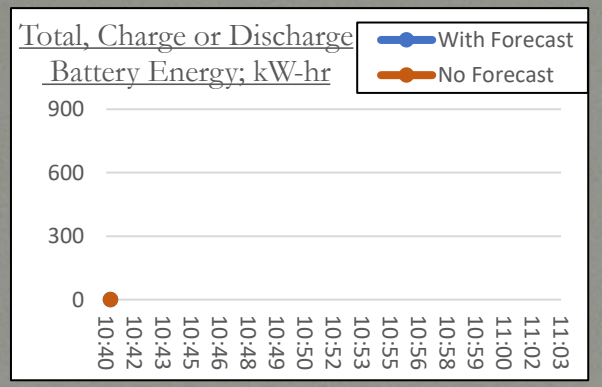






Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





UNM SIMF Unit, USPTO: US9921339, US10345486

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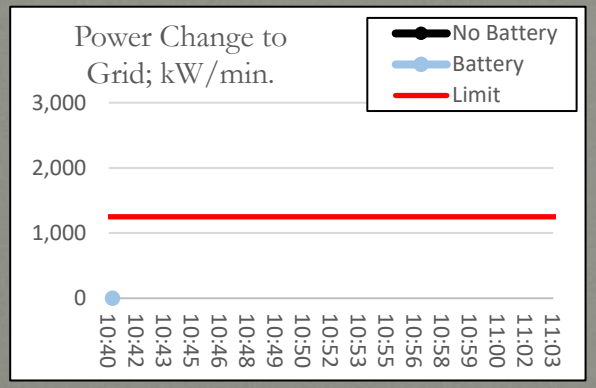
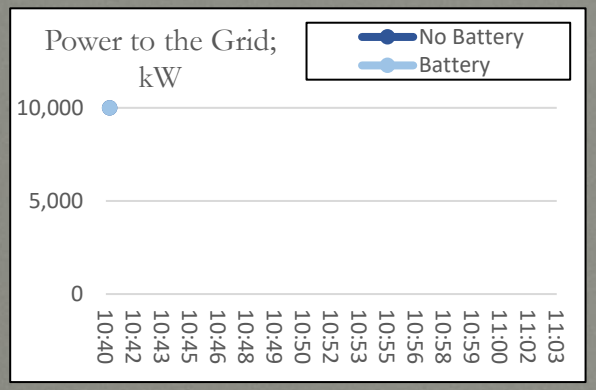
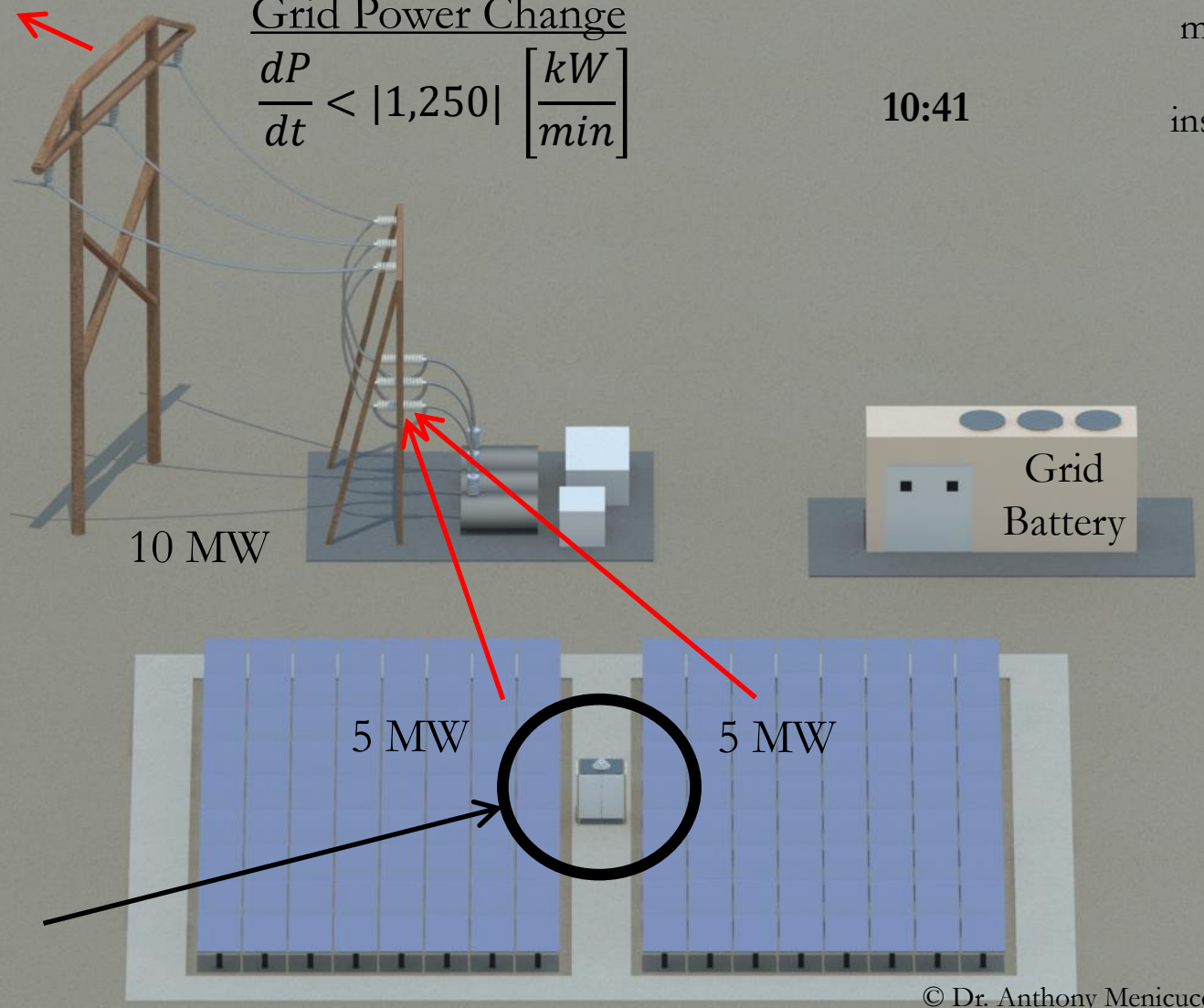




Grid Power Change

$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:41



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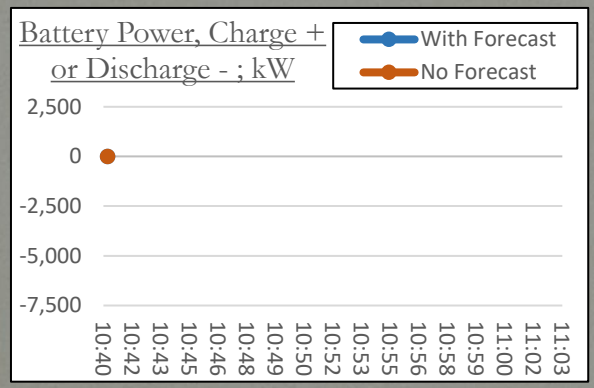

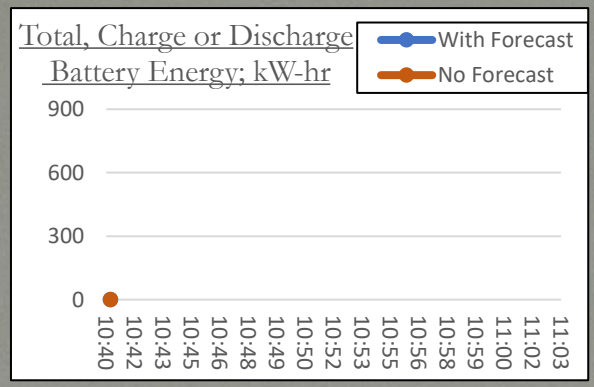

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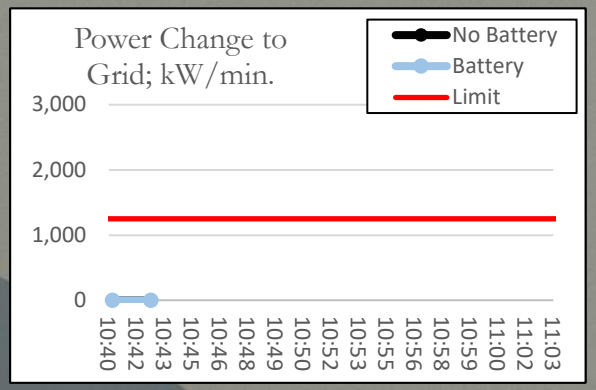
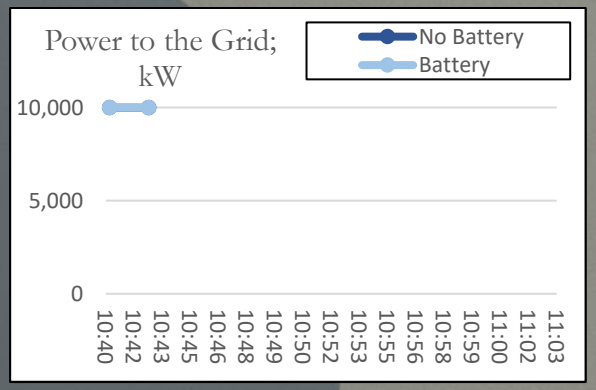
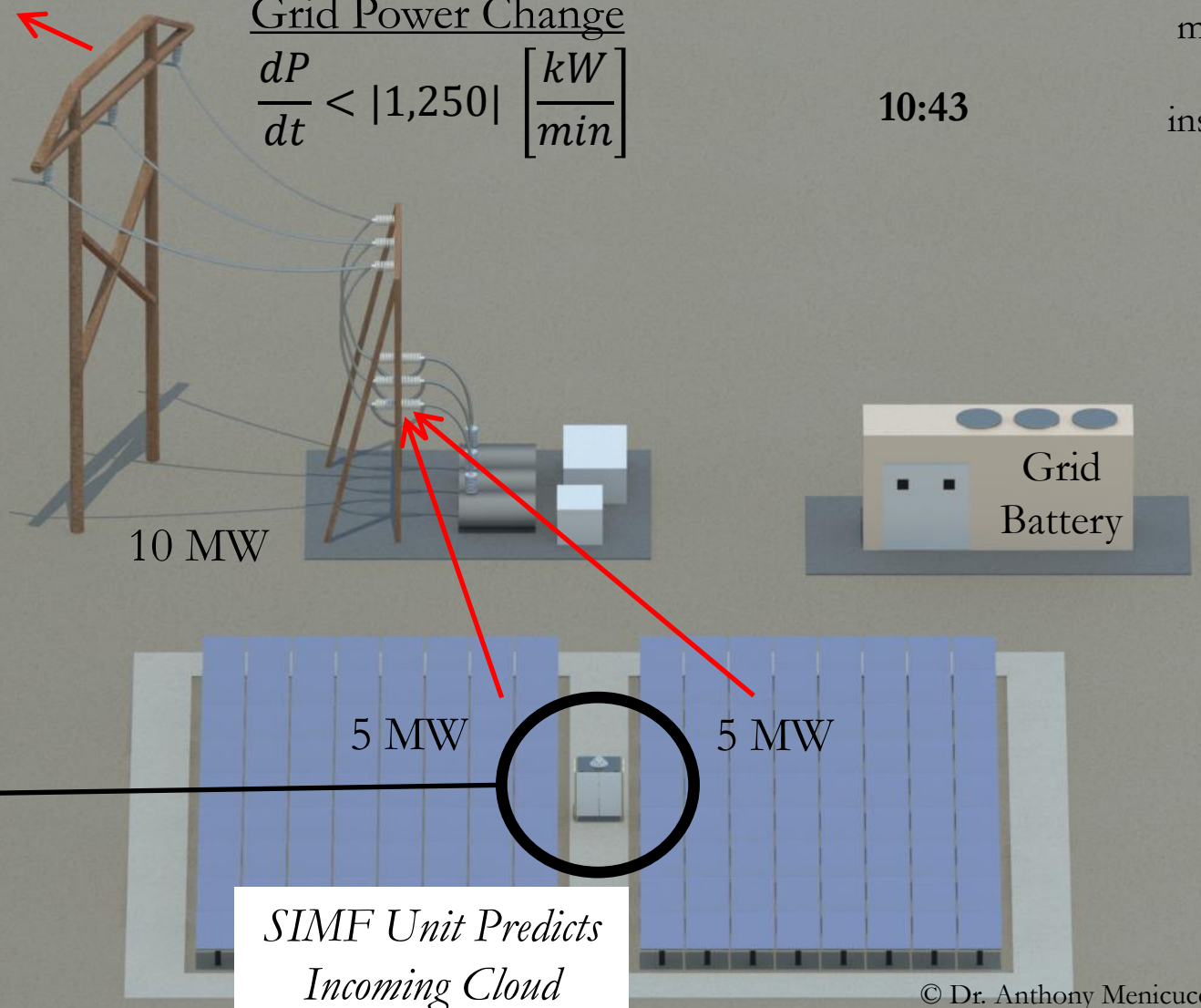




Grid Power Change

$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:43



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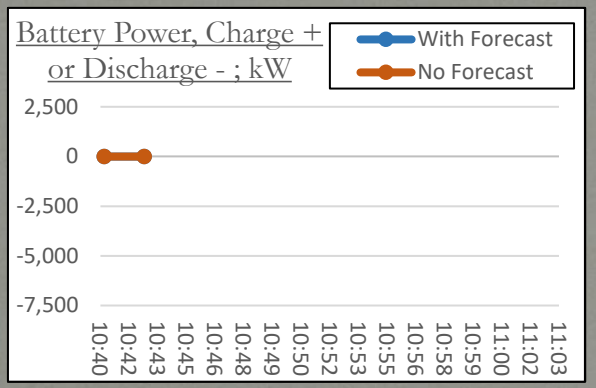

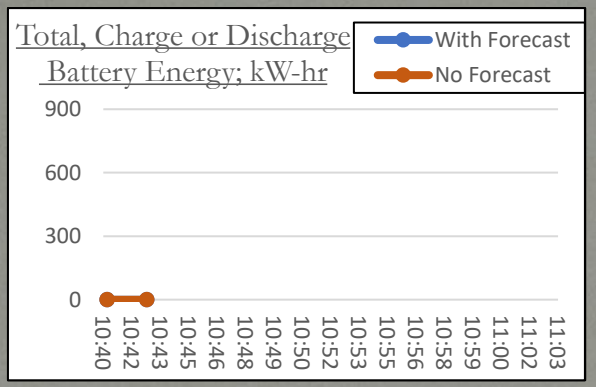

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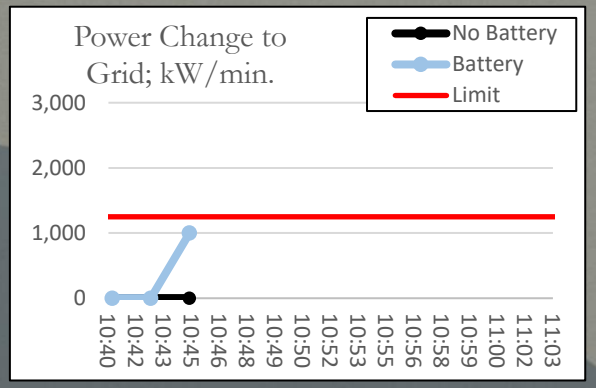
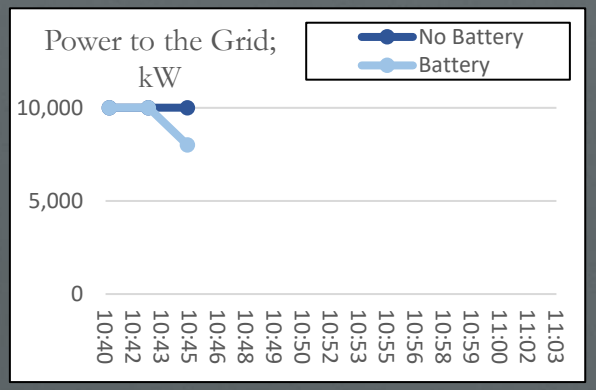
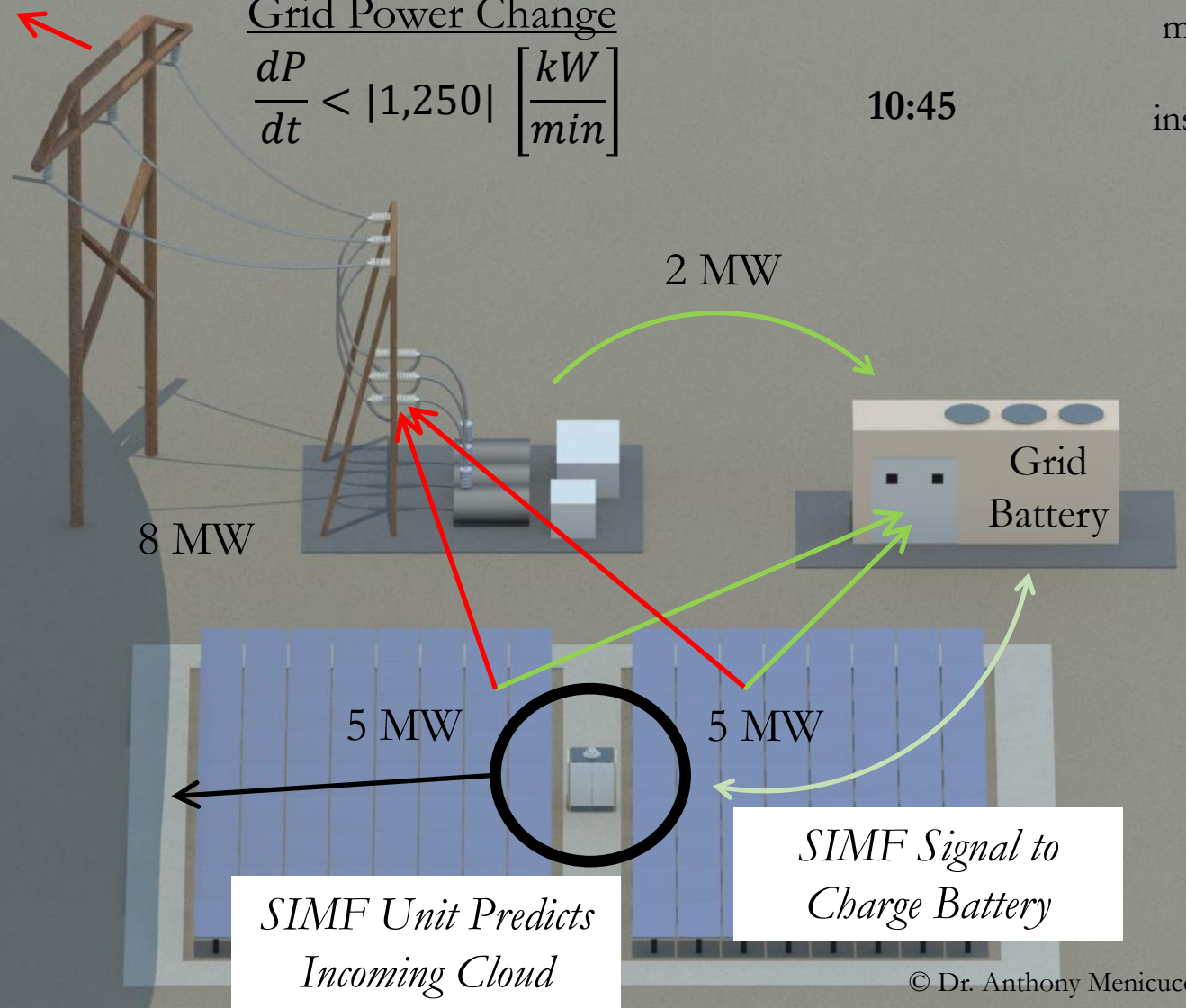




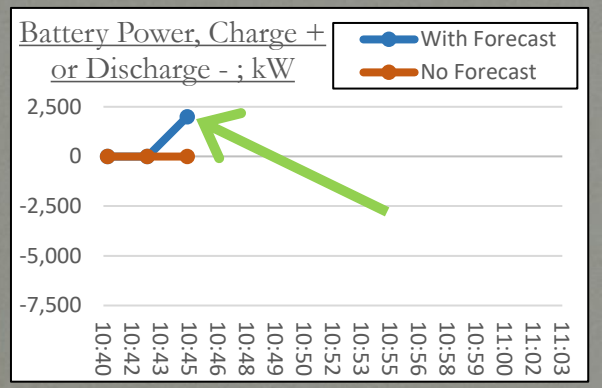
Grid Power Change

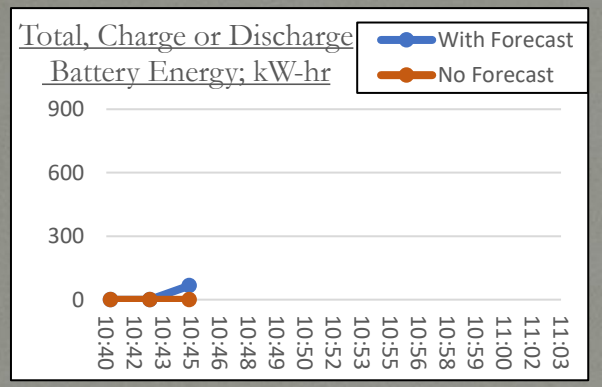
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:45



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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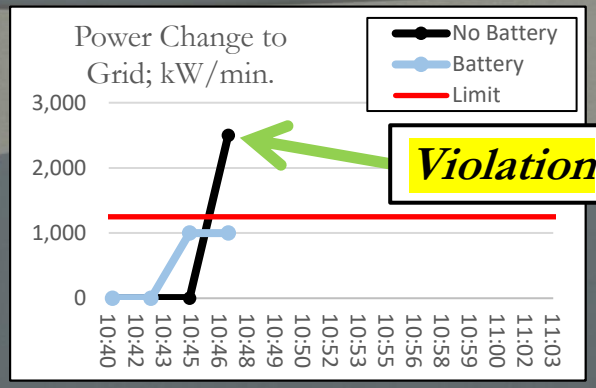
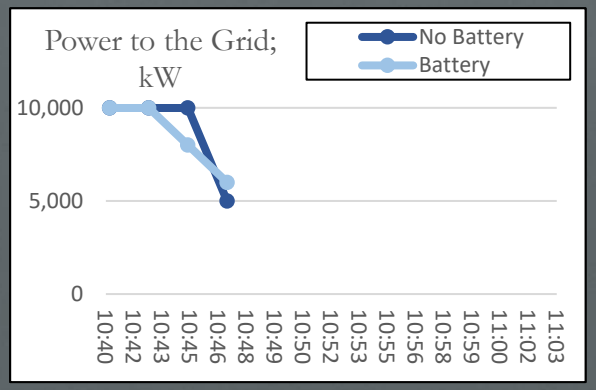
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

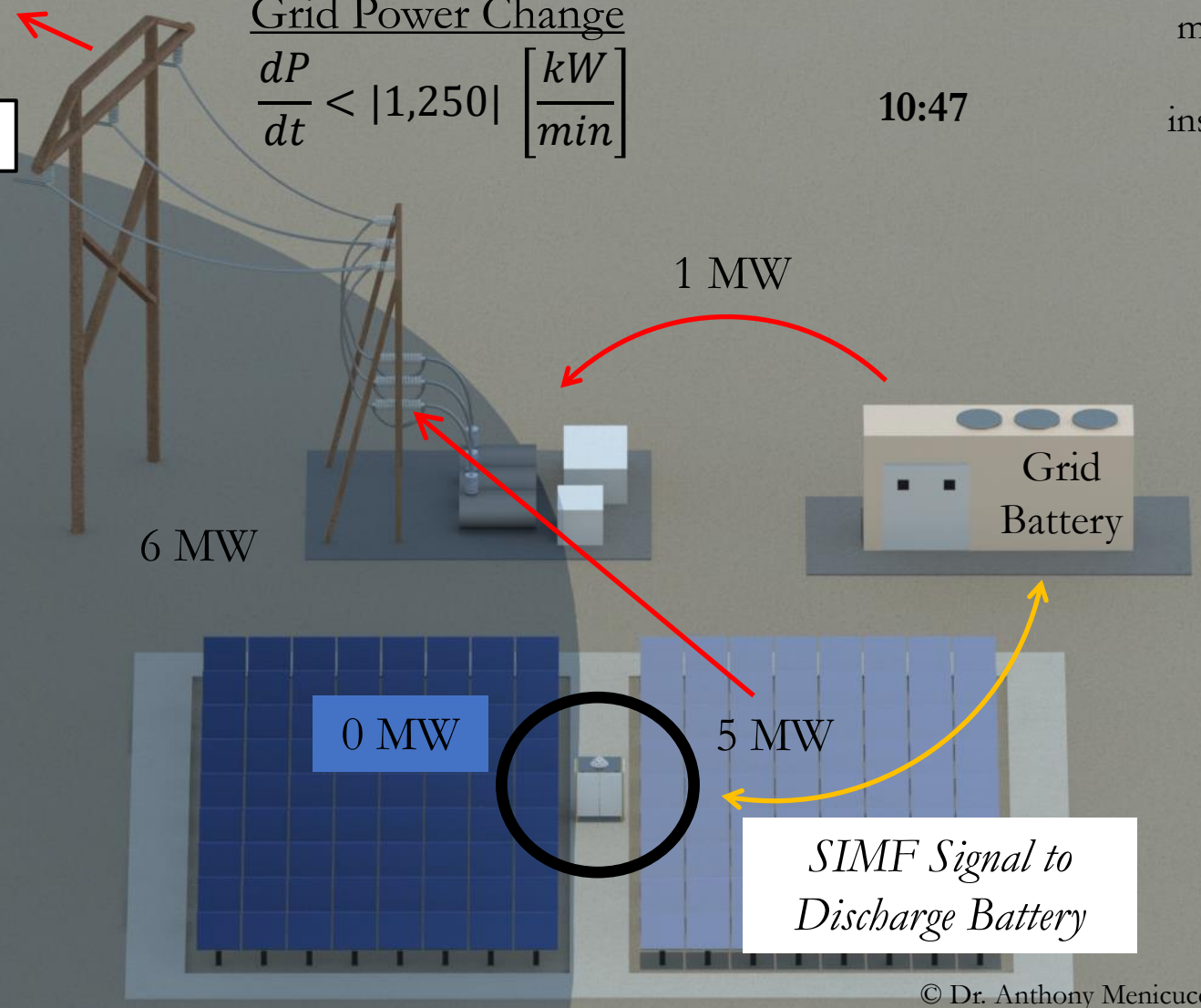




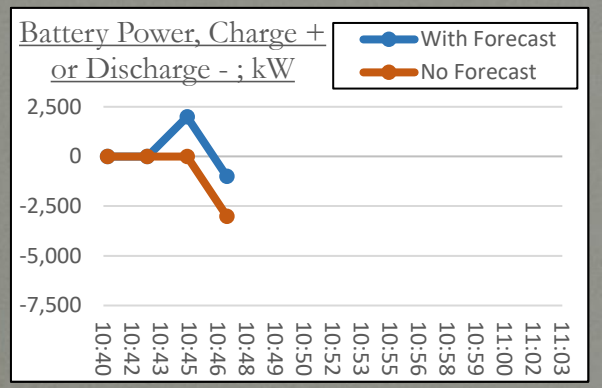
Violation

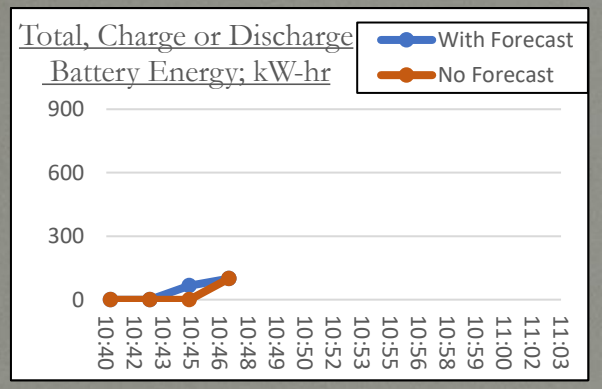
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:47



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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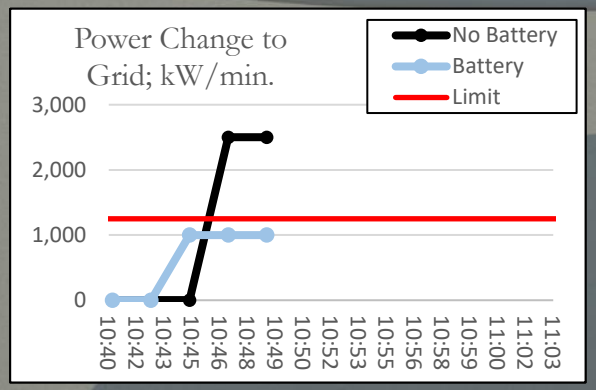
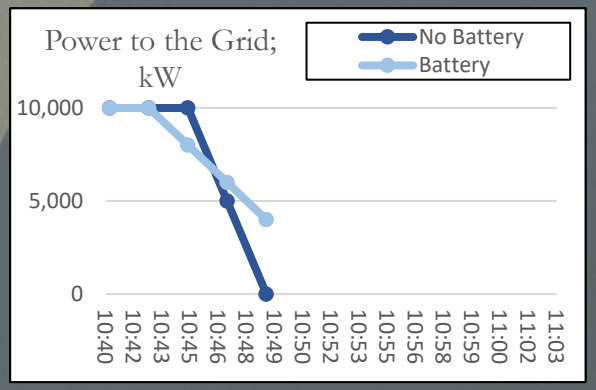
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.





Grid Power Change

$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:49

4 MW

4 MW

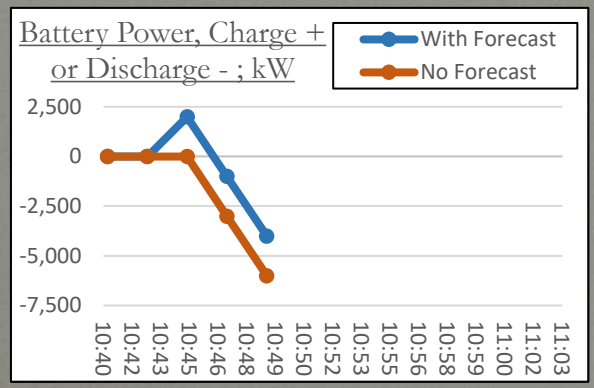
Grid Battery

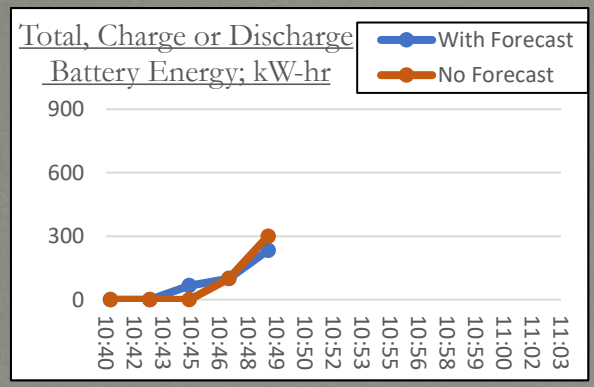
0 MW

0 MW

SIMF Signal to Discharge Battery

Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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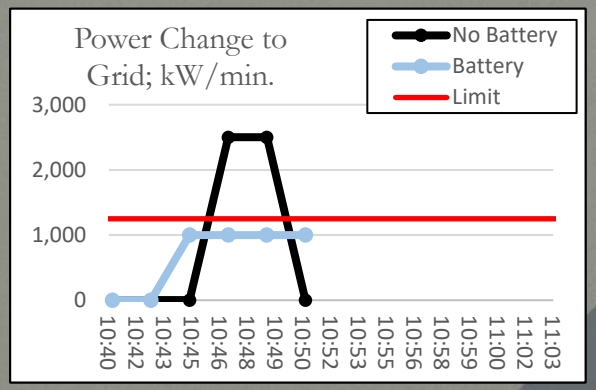
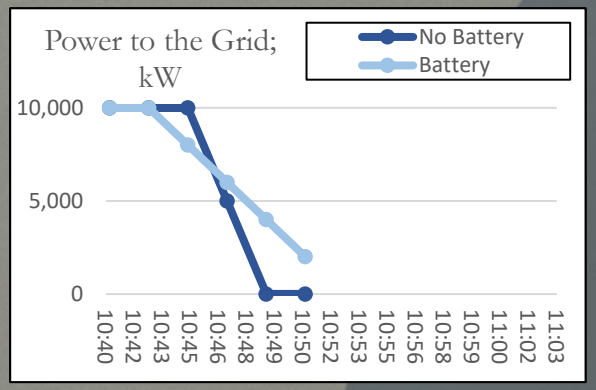
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

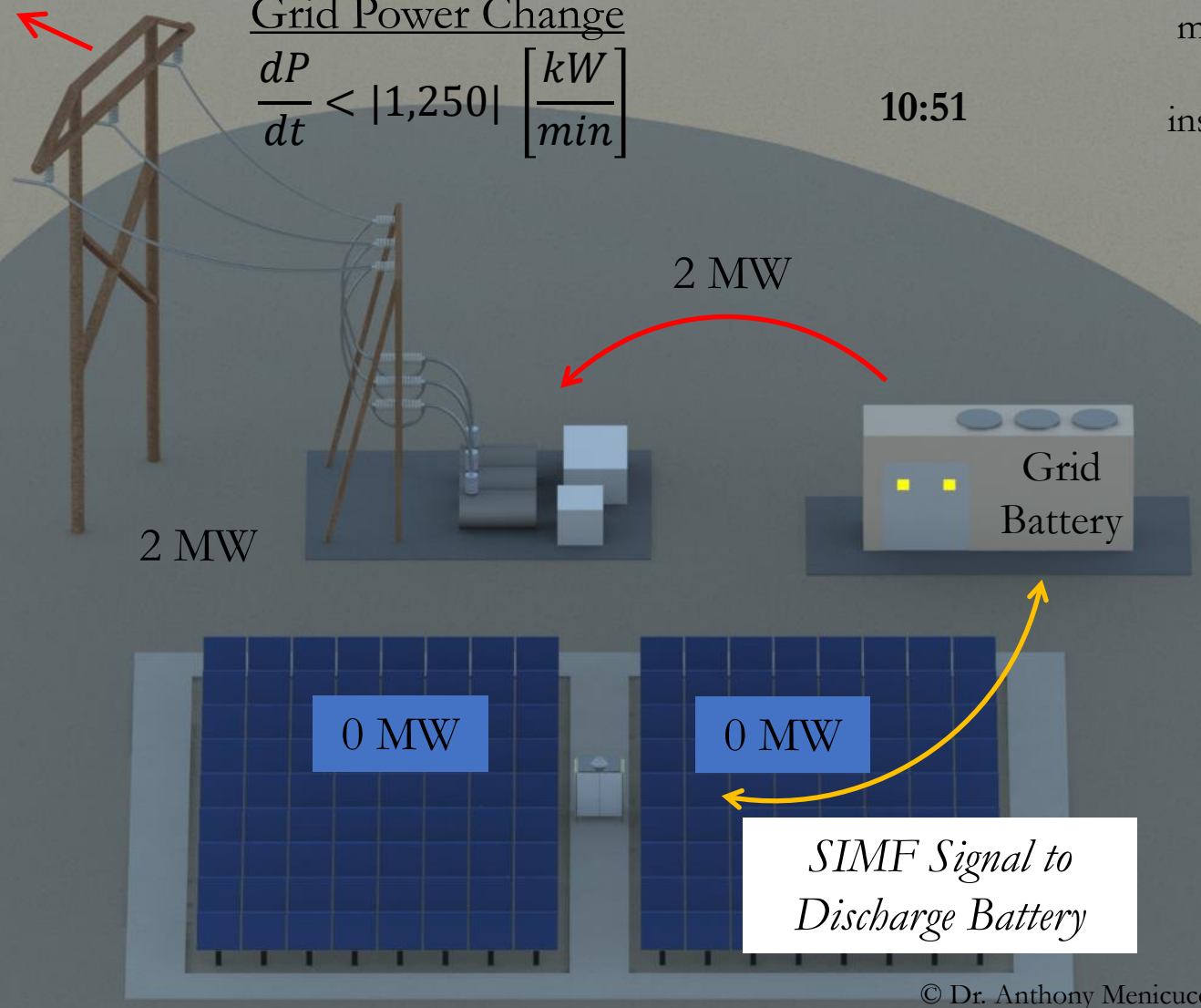




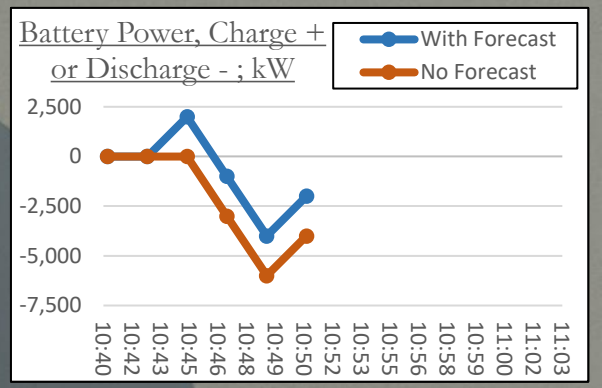
Grid Power Change

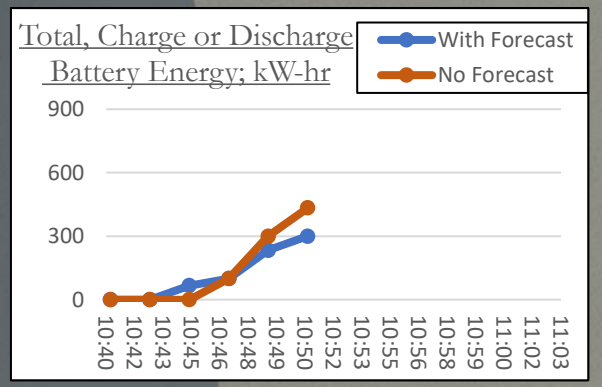
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:51



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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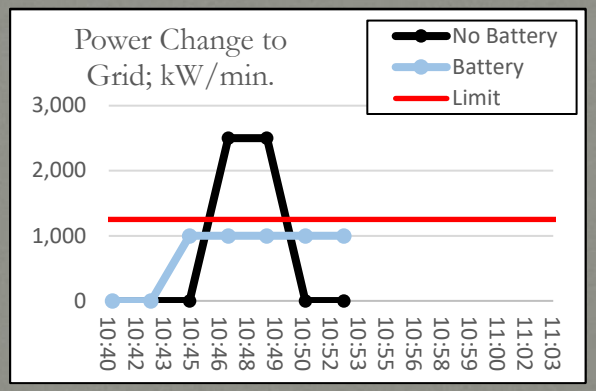
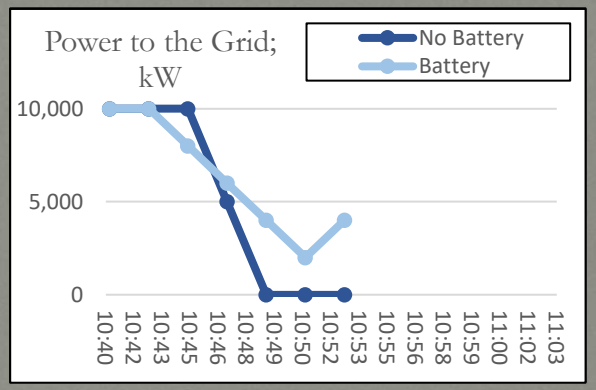
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.

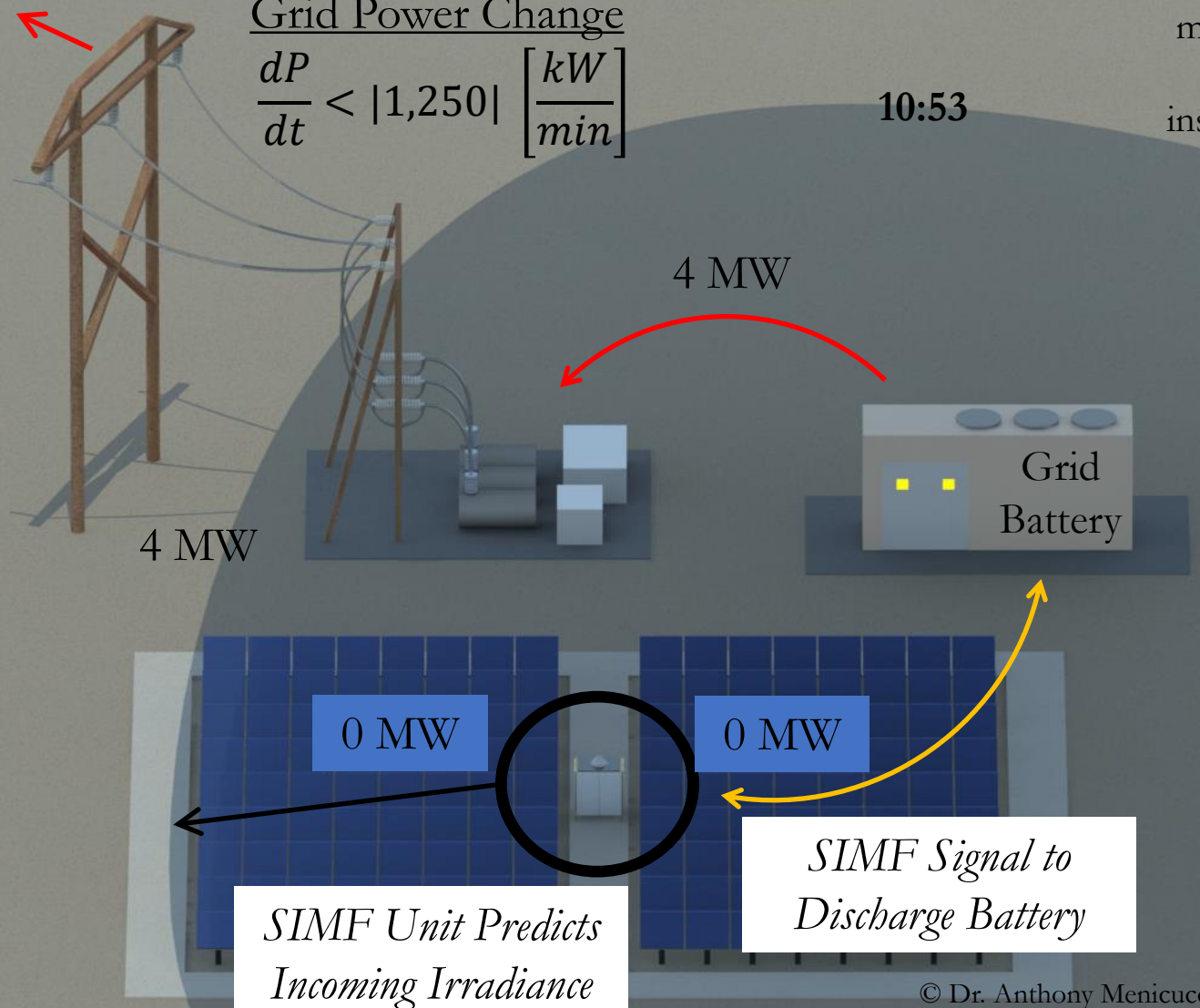


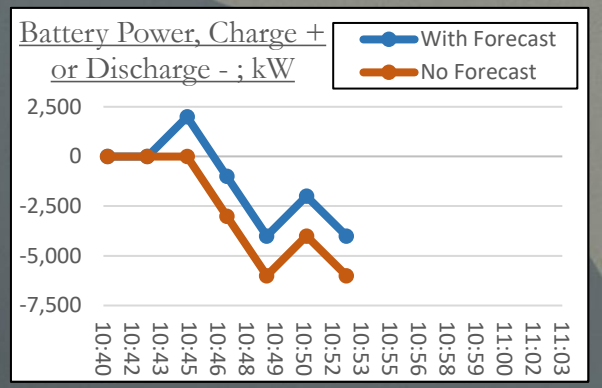


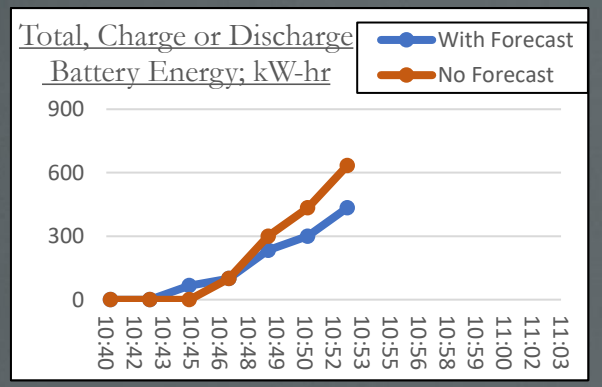
Grid Power Change

$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:53







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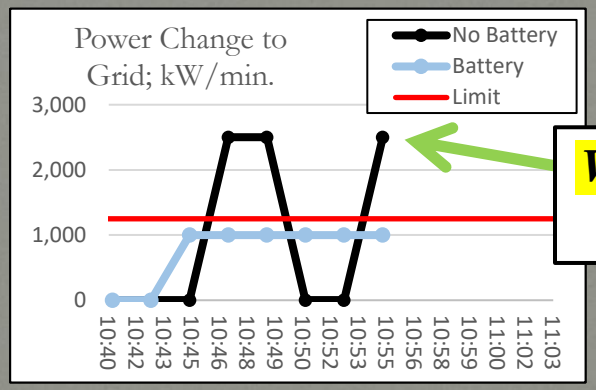
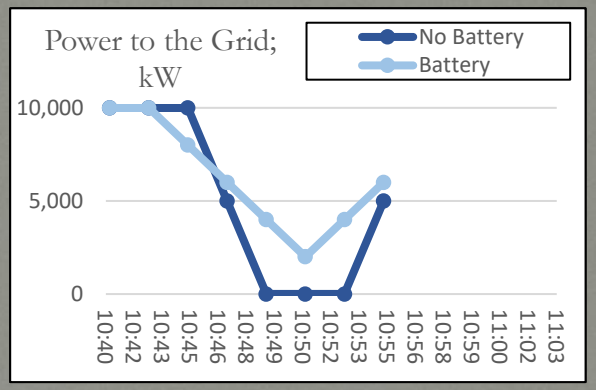
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.



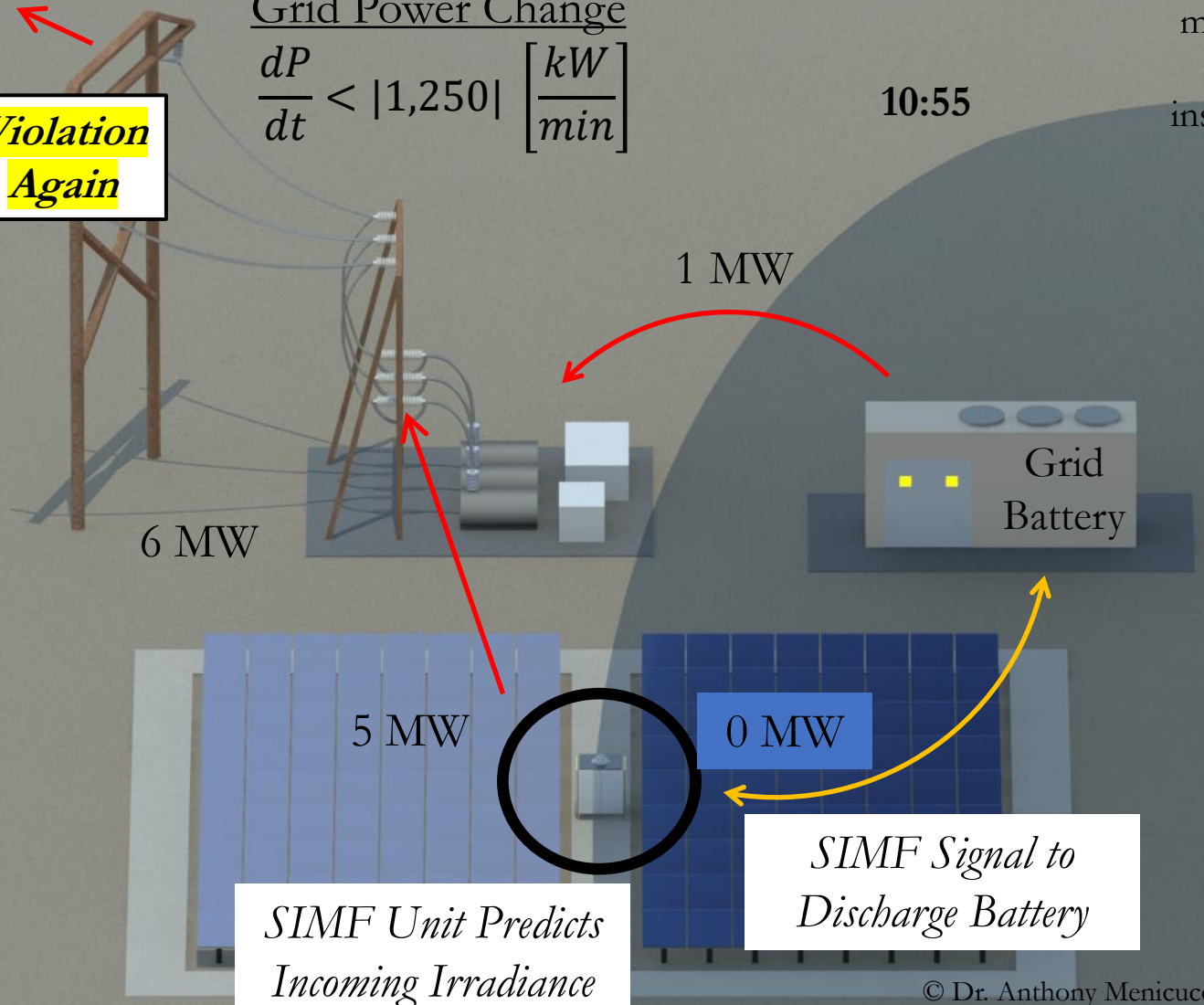


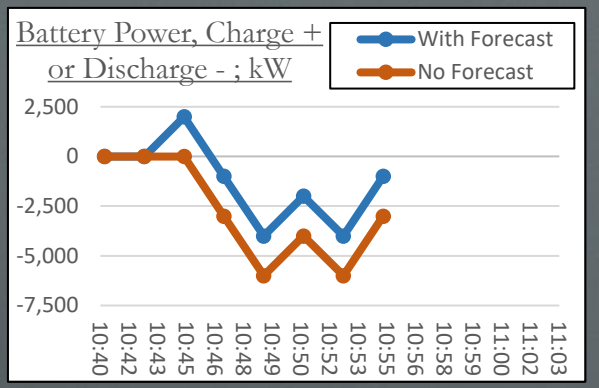
Violation Again

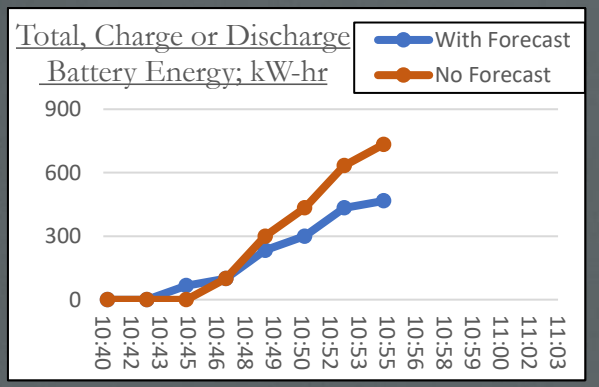
Grid Power Change

$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:55







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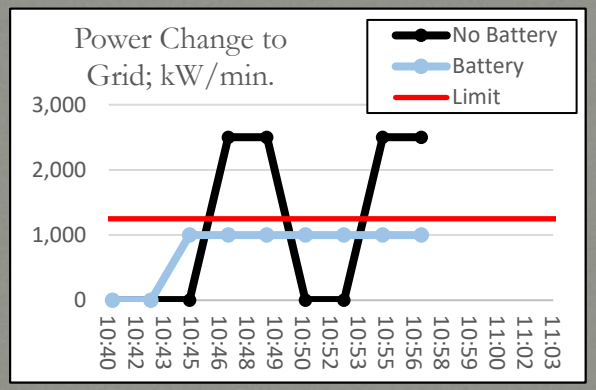
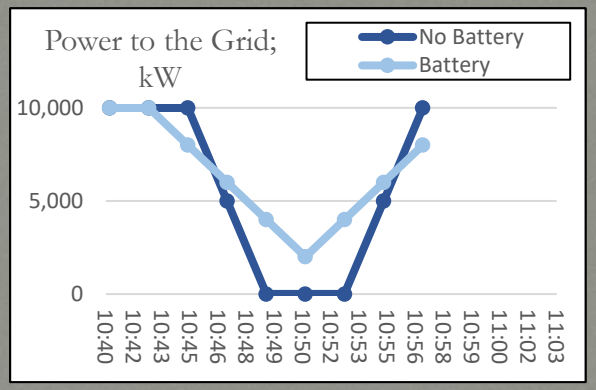
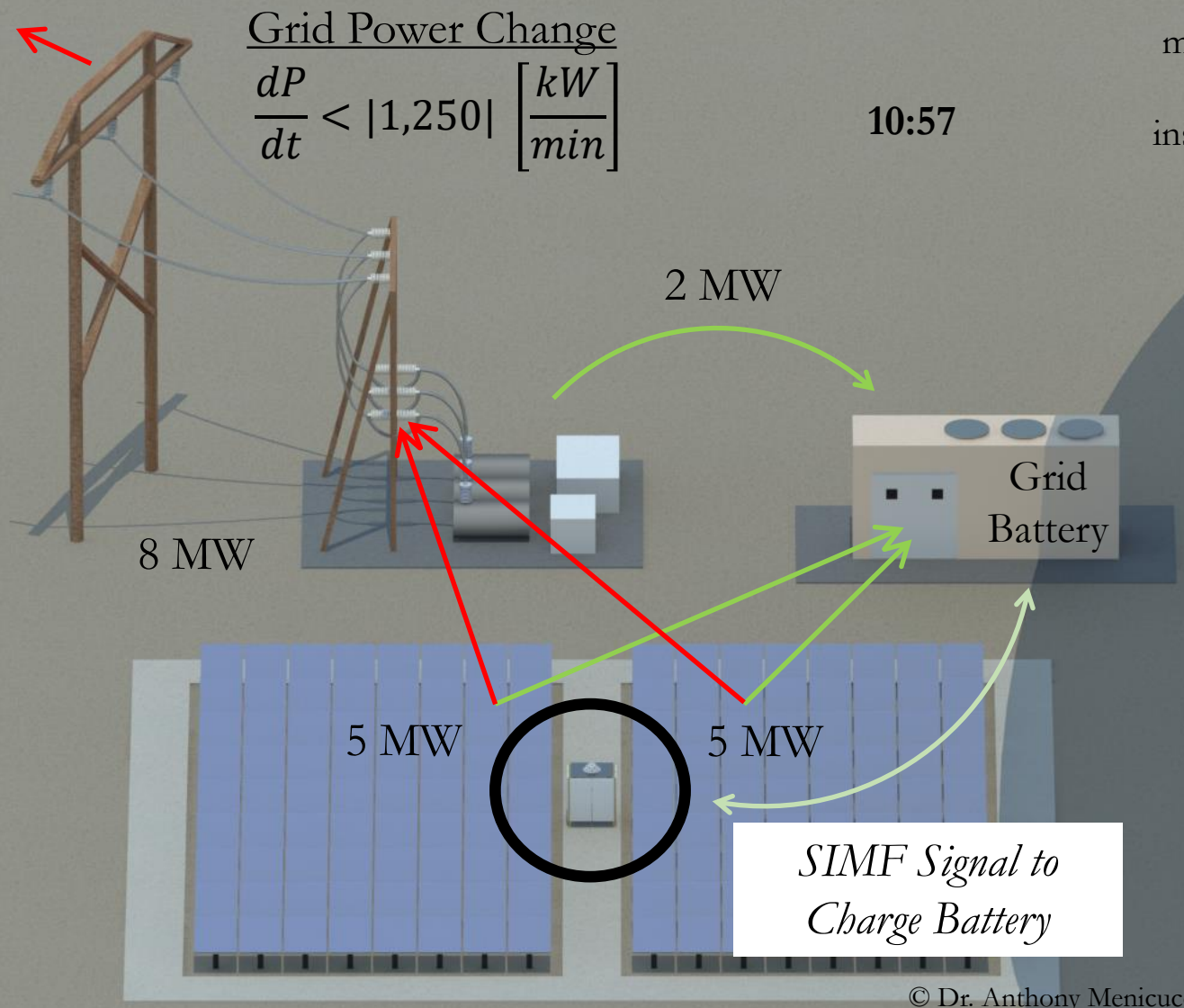
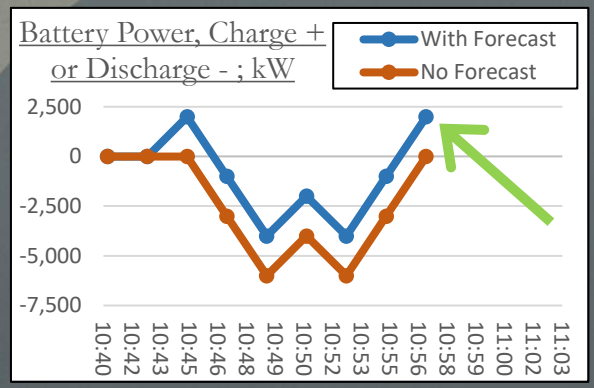
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

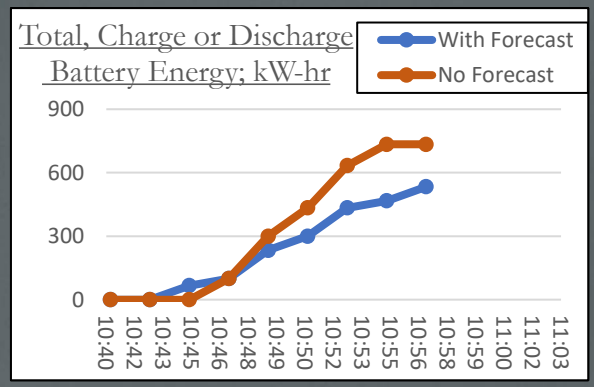






Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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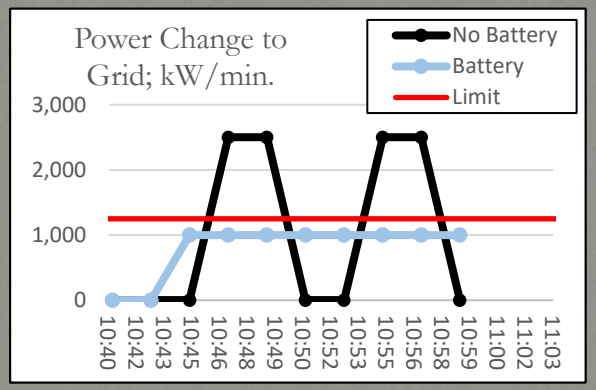
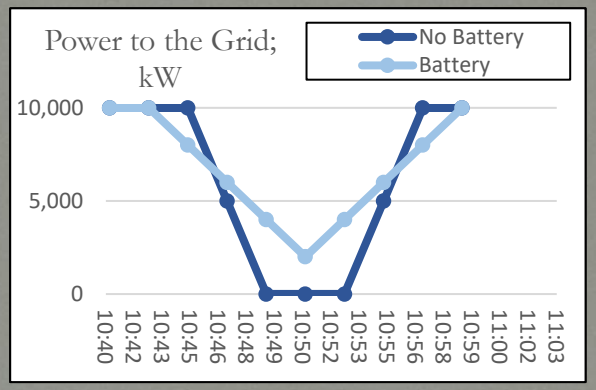
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

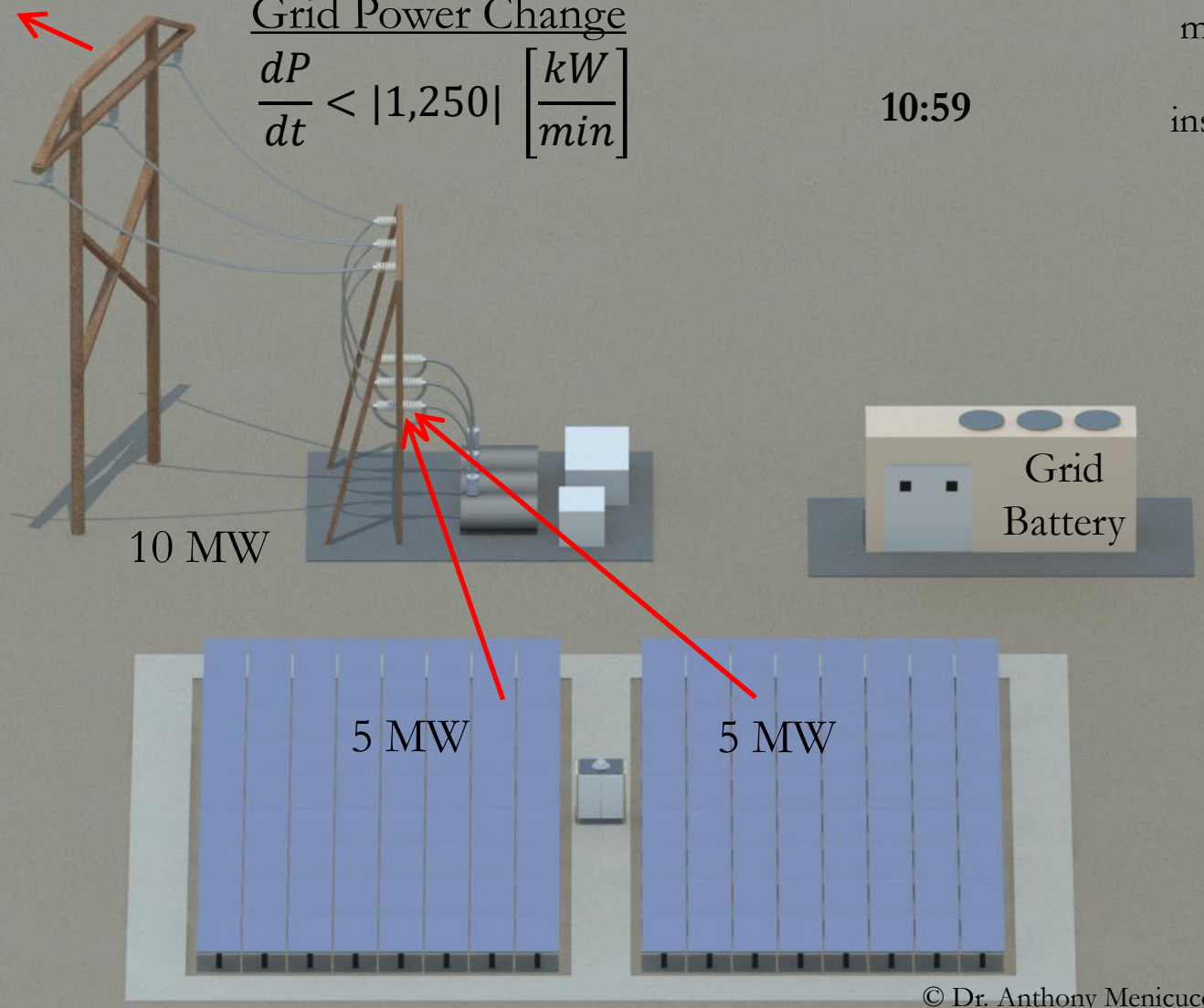




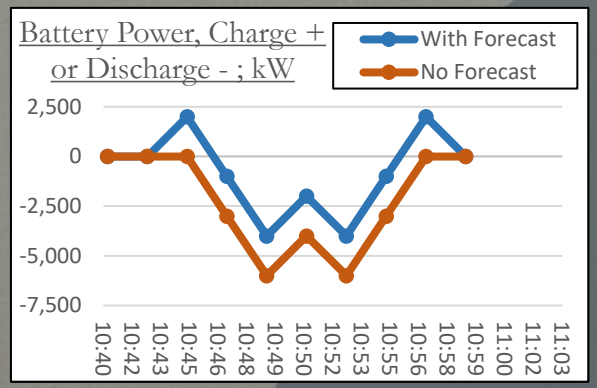
Grid Power Change

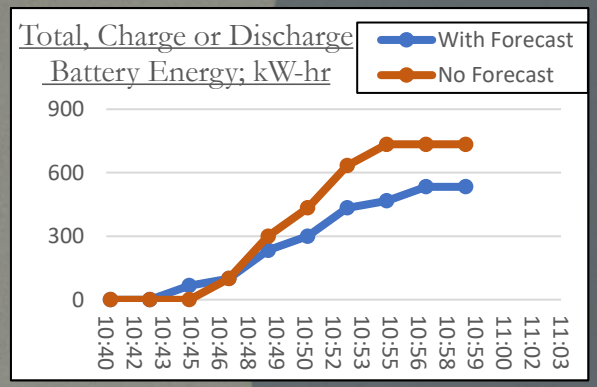
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

10:59



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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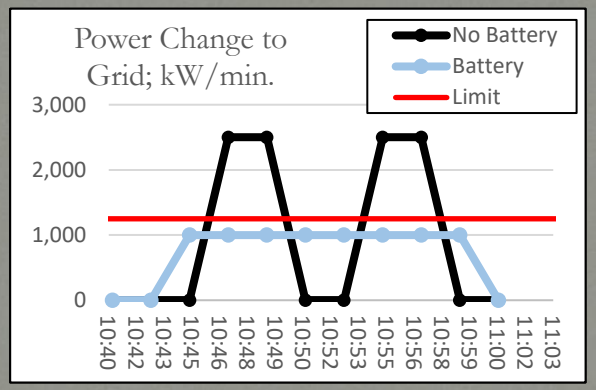
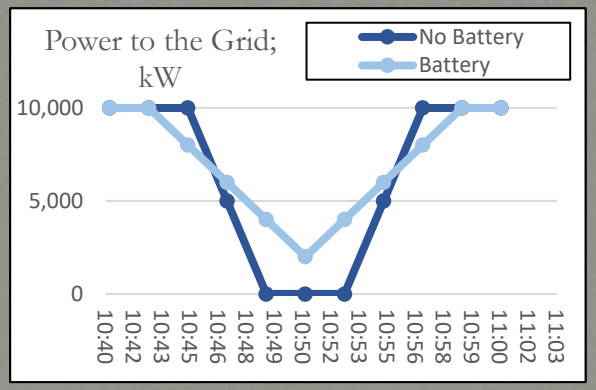
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

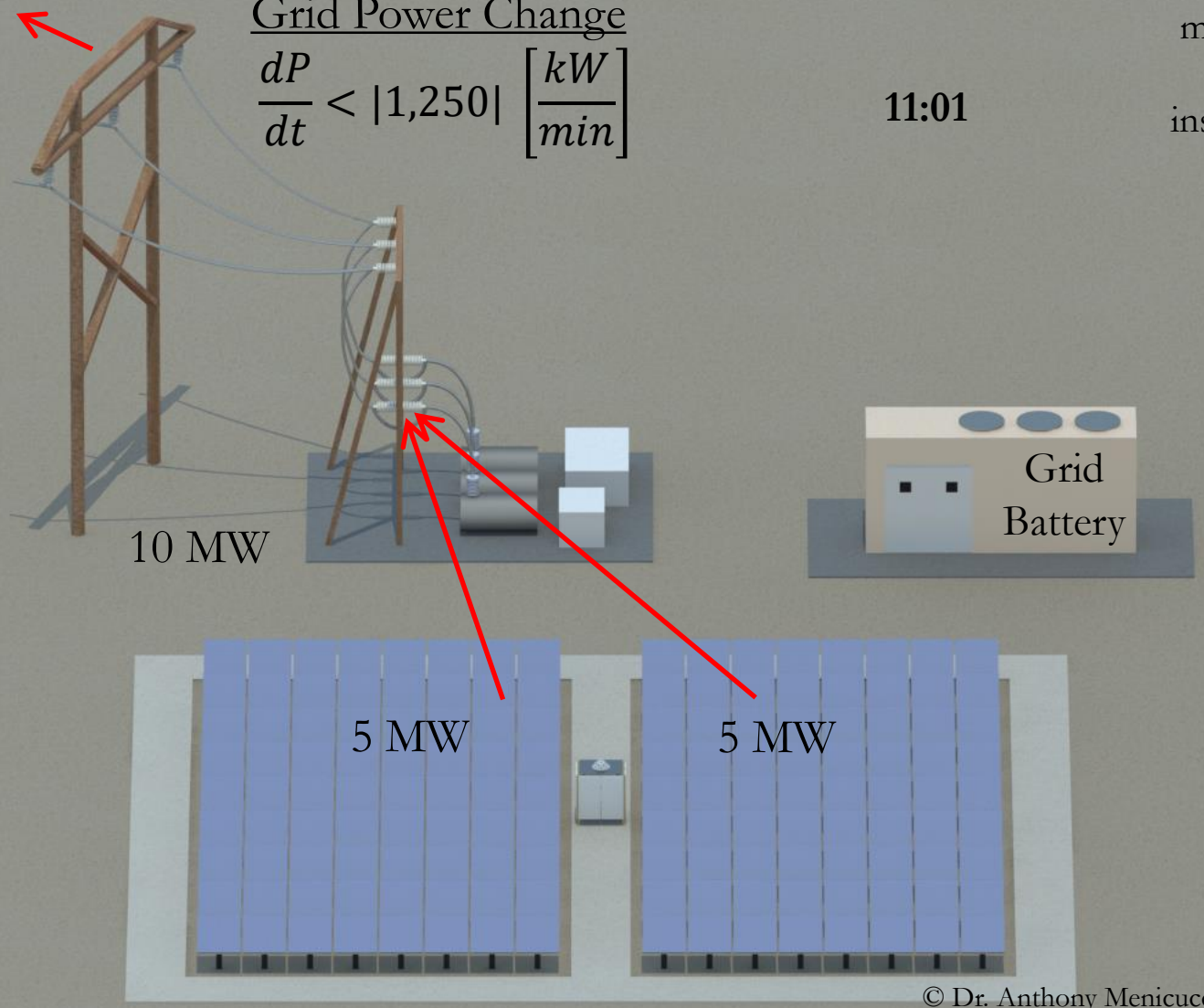




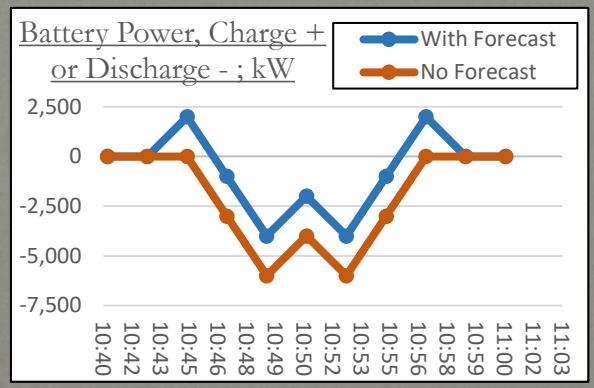
Grid Power Change

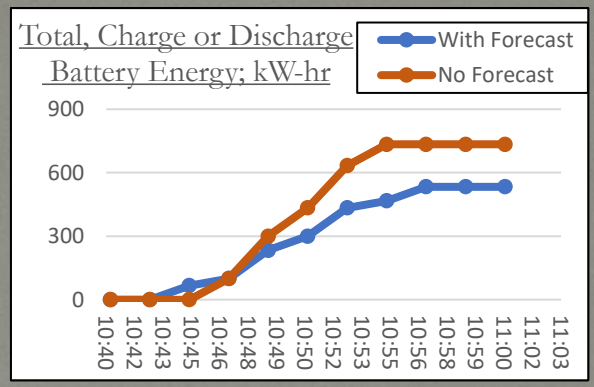
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

11:01



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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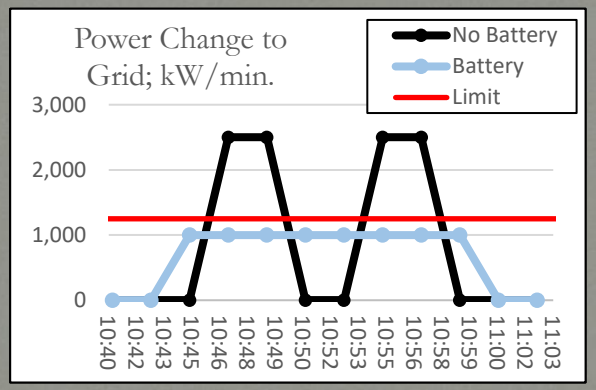
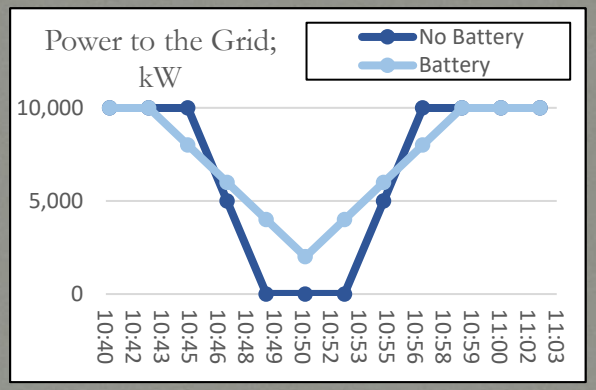
Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

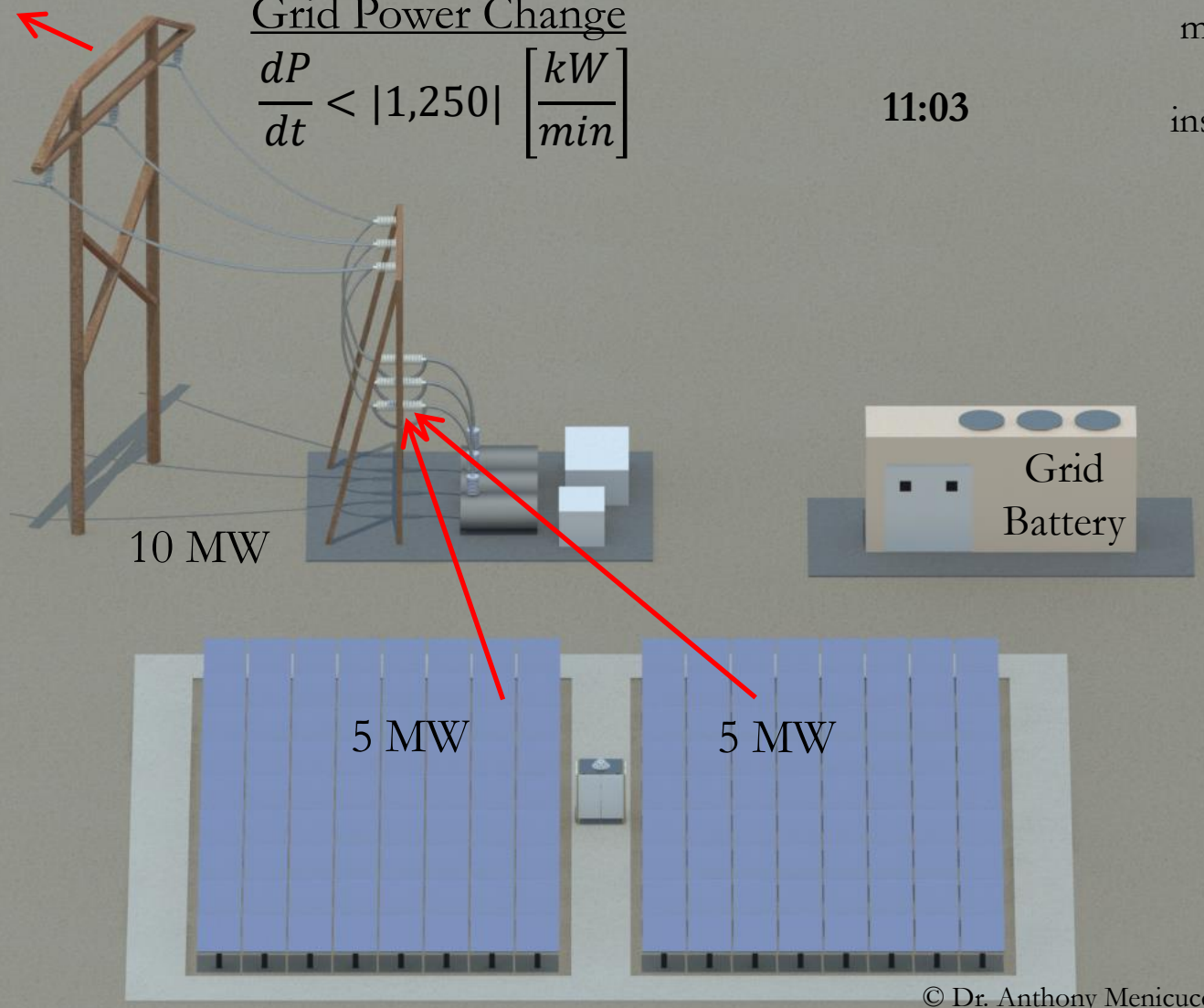




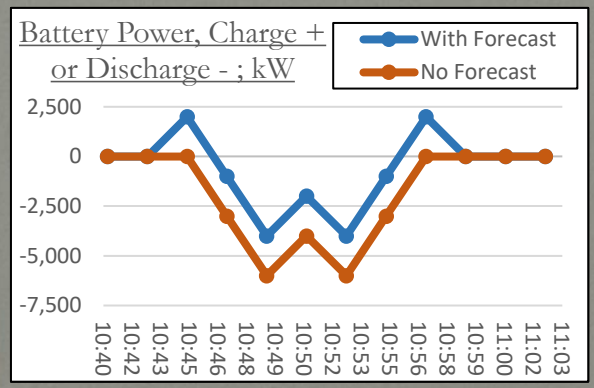
Grid Power Change

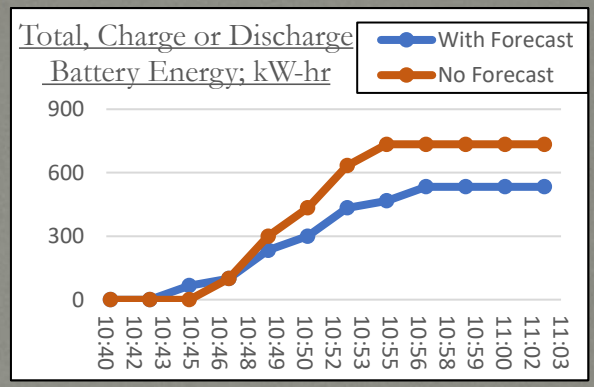
$$\frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

11:03



Note: With this 10 MW PV field, our smoothing battery must maintain a gradual drawdown in electricity for 8 min. after an instantaneous PV field occlusion.





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Design Goal: Maintain Grid Supplied Power Change: Less than 1,250 kW/min.

Success! **->**

Grid Power Change

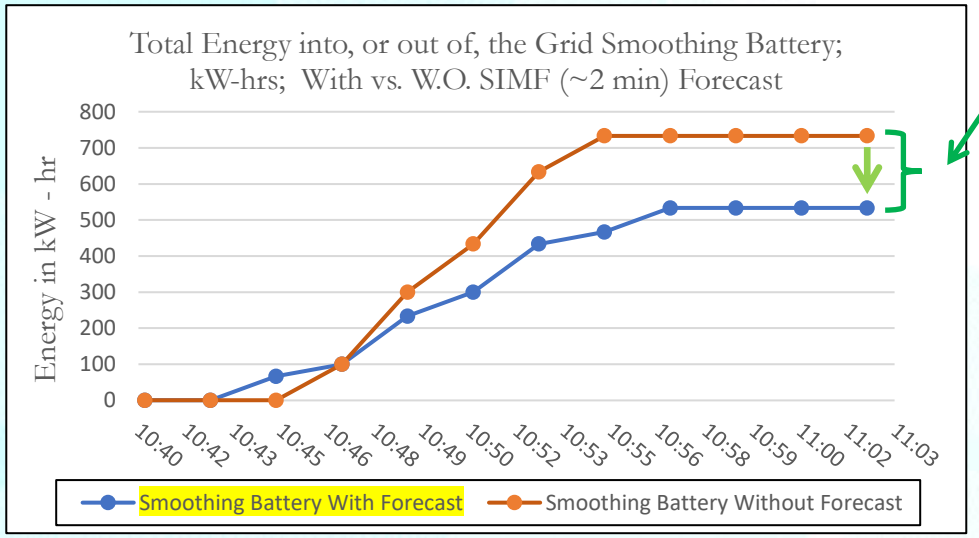
$$\frac{d^2E}{dt^2} = \frac{dP}{dt} < |1{,}250| \left[\frac{kW}{min}\right]$$

With Solar Irradiance Micro-Forecasts, ~2min.

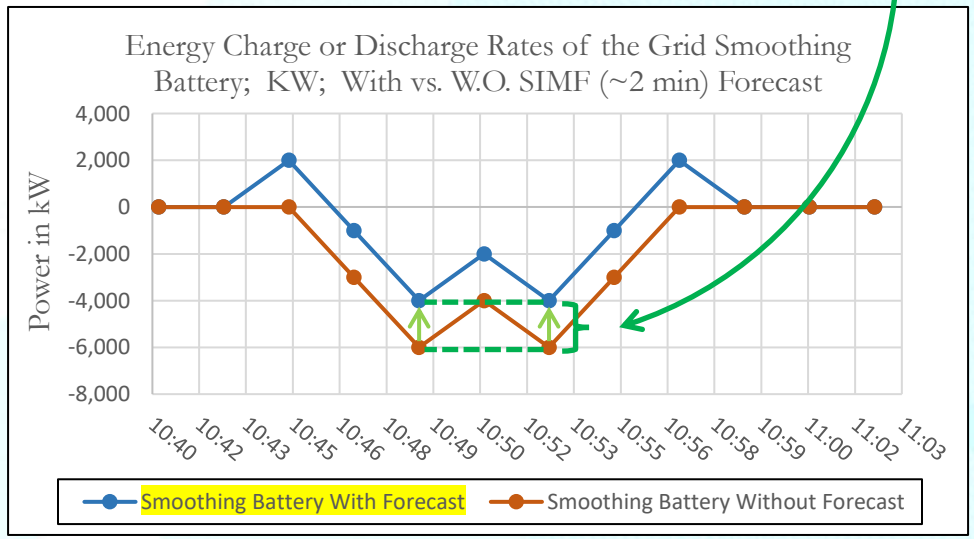
- **27% Less** Smoothing Battery Capacity

- **33% Less** Smoothing Battery Wear & Tear from reduced draw during PV field occlusion events

Smoothing Battery **Energy** Statistics



Smoothing Battery **Power** Statistics



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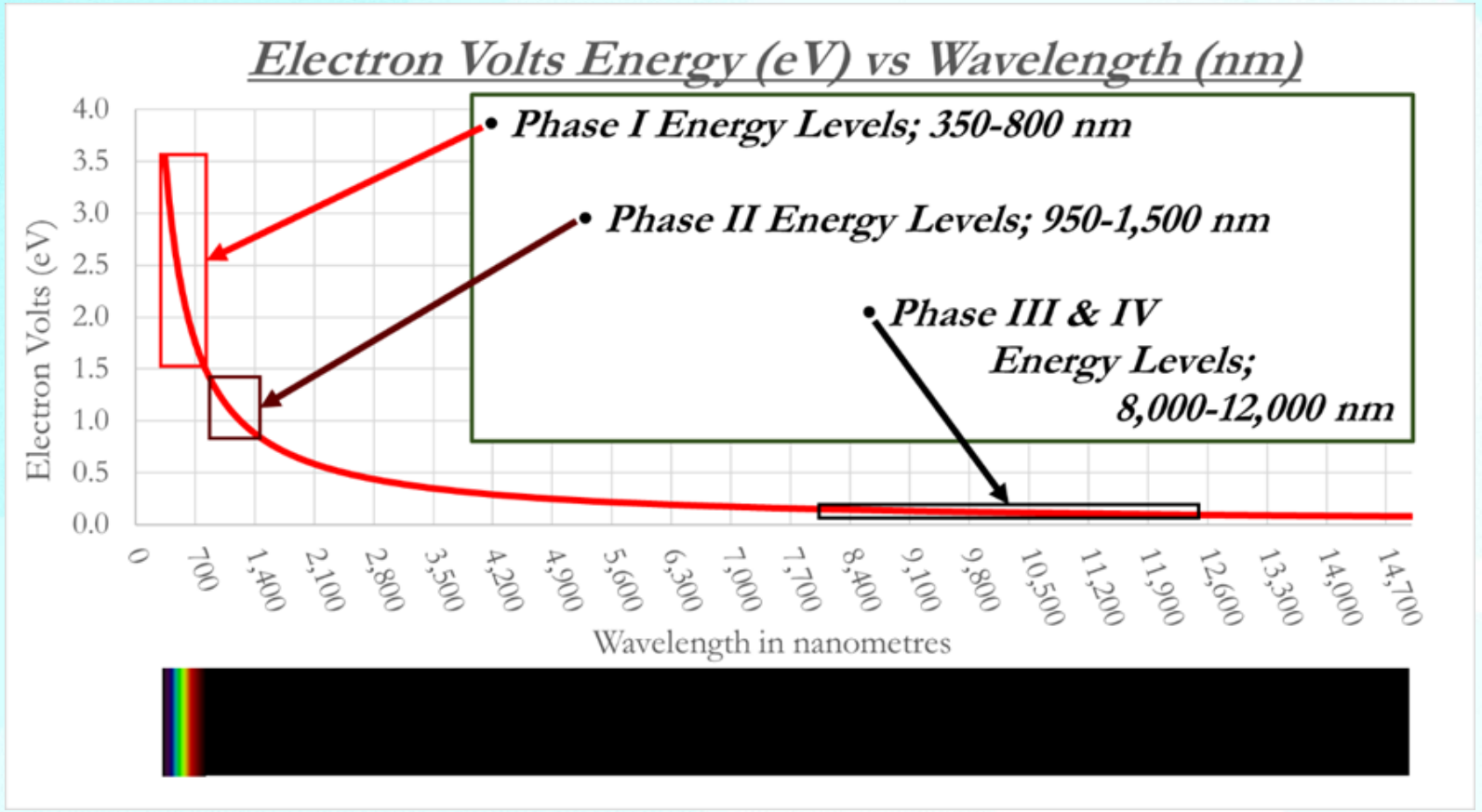
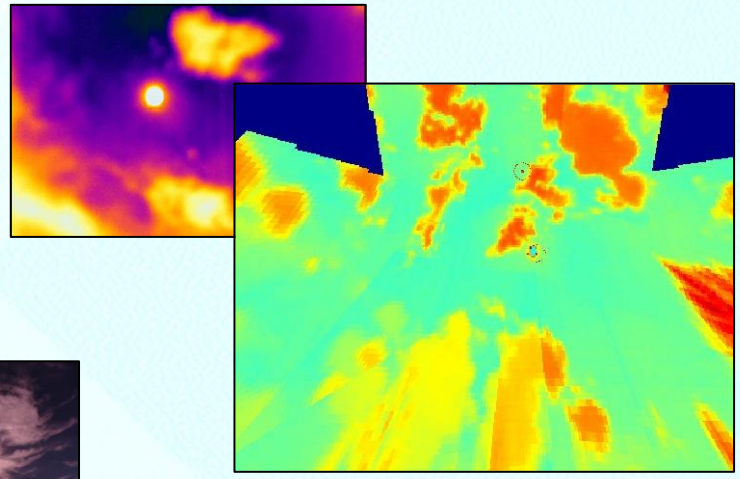
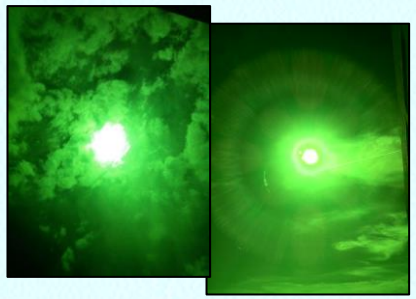
Technological Progression

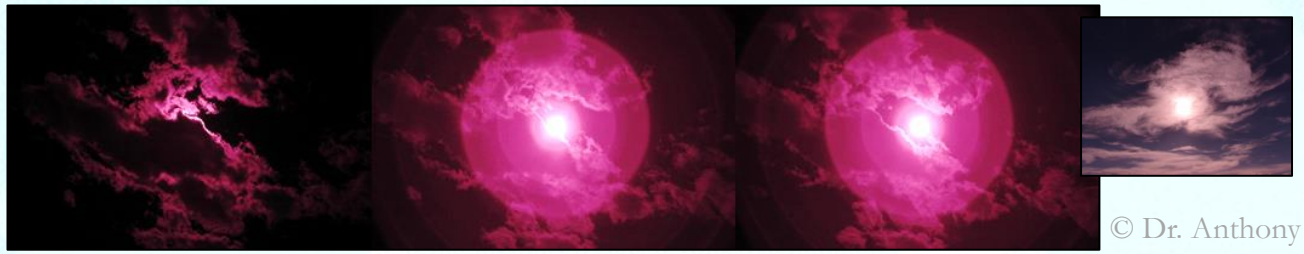


We utilize lower and lower energy wavelengths.

Change the way clouds are imaged.







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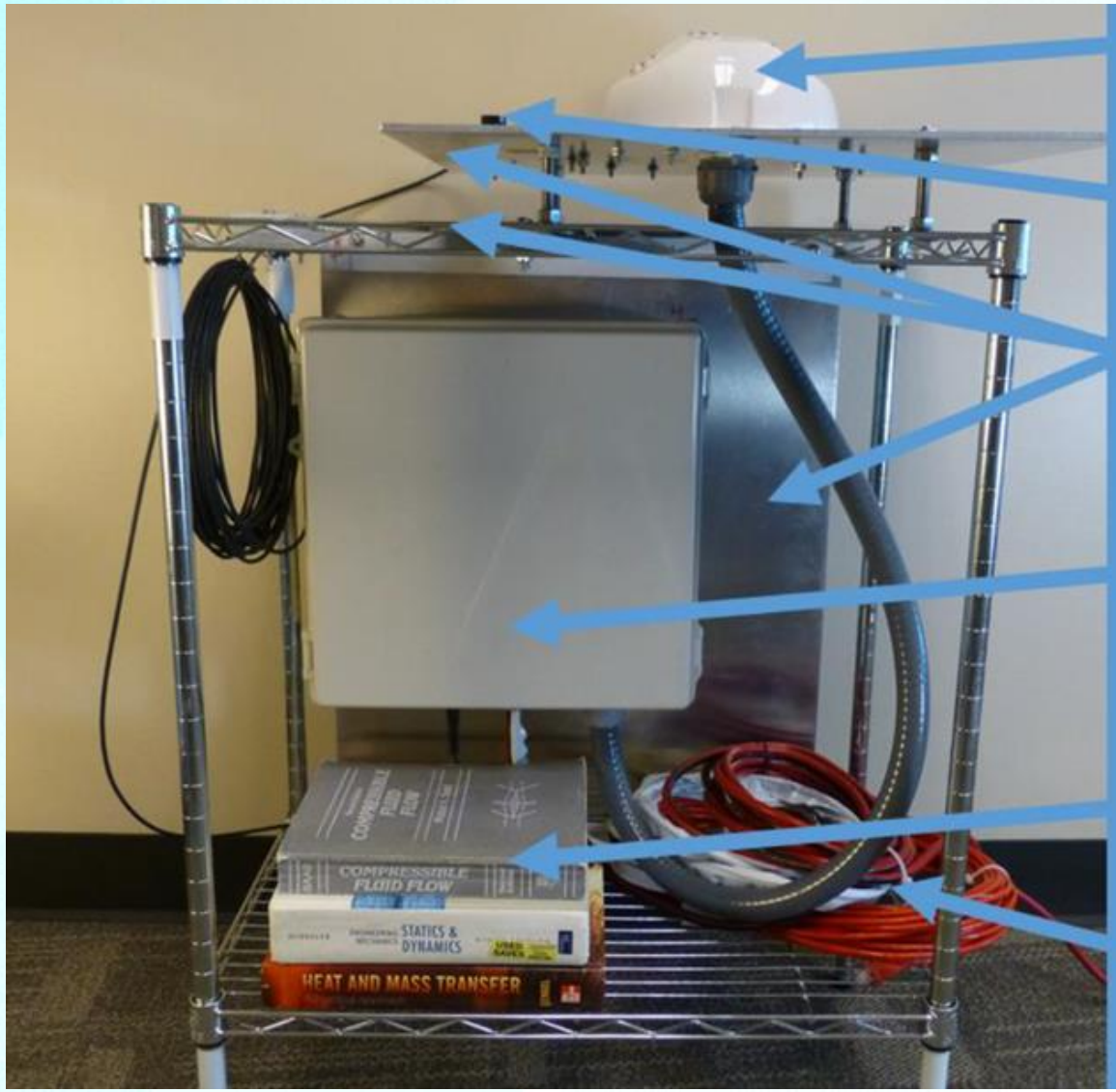
Final Fielded Approach Using IR images



- Outer camera dome
- Irradiance Sensor
- Stainless Steel rain and UV Shields
- Weatherproof electronics box
- Weight for the wind load
- Power and Ethernet

- Two Issued Patents Through UNM (STC) Rainforest Innovation, more to come…
- 75+ hours in a fielded trials, NSF-STTR

(12) **United States Patent**
Menicucci et al.

(10) **Patent No.: US 10,345,486 B2**
(45) **Date of Patent: *Jul. 9, 2019**

(54) **APPARATUS AND METHOD FOR SOLAR ENERGY MICRO-FORECASTS FOR SOLAR GENERATION SOURCES AND UTILITIES**

(71) Applicant: **STC.UNM**, Albuquerque, NM (US)

(72) Inventors: **Anthony Robert Menicucci**, Albuquerque, NM (US); **Thomas P. Caudell**, Edgewood, NM (US); **Andrea A. Mammoli**, Corrales, NM (US)

(73) Assignee: **STC.UNM**, Albuquerque, NM (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/877,167**

(22) Filed: **Jan. 22, 2018**

(52) **U.S. Cl.**
CPC ***G01W 1/10*** (2013.01); ***G01J 5/00*** (2013.01); ***G06Q 10/04*** (2013.01); ***G06Q 50/06*** (2013.01); ***H02J 3/00*** (2013.01); *G01J 2001/4266* (2013.01); *H02J 3/383* (2013.01); *H02J 2003/007* (2013.01); *Y02E 10/563* (2013.01); *Y02E 60/76* (2013.01); *Y04S 10/54* (2013.01); *Y04S 40/22* (2013.01); *Y10T 307/533* (2015.04); *Y10T 307/604* (2015.04)

(58) **Field of Classification Search**
CPC G01W 1/10
USPC 307/49
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2002/0084655 A1 7/2002 Lof et al.
2012/0144828 A1 6/2012 Lazaris
2013/0218355 A1 8/2013 Lazaris
2014/0278108 A1 9/2014 Kerrigan et al.
(Continued)

(12) **United States Patent**
Menicucci et al.

(10) **Patent No.: US 9,921,339 B2**
(45) **Date of Patent: Mar. 20, 2018**

(54) **APPARATUS AND METHOD FOR SOLAR ENERGY RESOURCE MICRO-FORECASTS FOR SOLAR GENERATION SOURCES AND UTILITIES**

(71) Applicant: **STC.UNM**, Albuquerque, NM (US)

(72) Inventors: **Anthony Robert Menicucci**, Albuquerque, NM (US); **Thomas P. Caudell**, Albuquerque, NM (US); **Andrea A. Mammoli**, Albuquerque, NM (US)

(73) Assignee: **STC.UNM**, Albuquerque, NM (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 298 days.

Y02E 10/563 (2013.01); *Y02E 60/76* (2013.01); *Y04S 10/54* (2013.01); *Y04S 40/22* (2013.01); *Y10T 307/533* (2015.04); *Y10T 307/604* (2015.04)

(58) **Field of Classification Search**
CPC G01W 1/00
USPC 307/49
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2002/0084655 A1* 7/2002 Lof F03D 7/0284 290/44
2012/0144828 A1* 6/2012 Lazaris H02J 3/383 60/641.1
(Continued)

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20180331_Anthony_B_Boulder	0	715	715	1.99
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20180404_Anthony_A_Boulder	0	835	835	2.32
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20180430_Anthony_A_Boulder	0	1430	1430	3.97
20180501_Anthony_A_Boulder	0	770	770	2.14
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20180505_Anthony_A_Boulder	100	1615	1515	4.21
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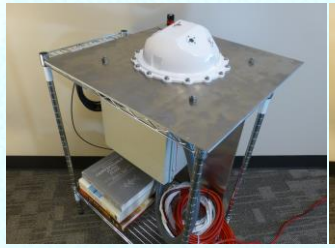
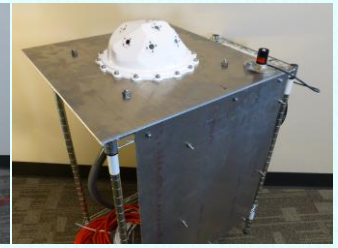
			Total Hours:	78.82





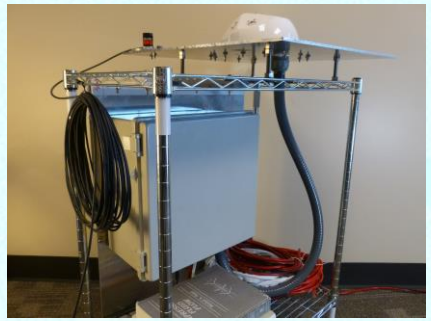


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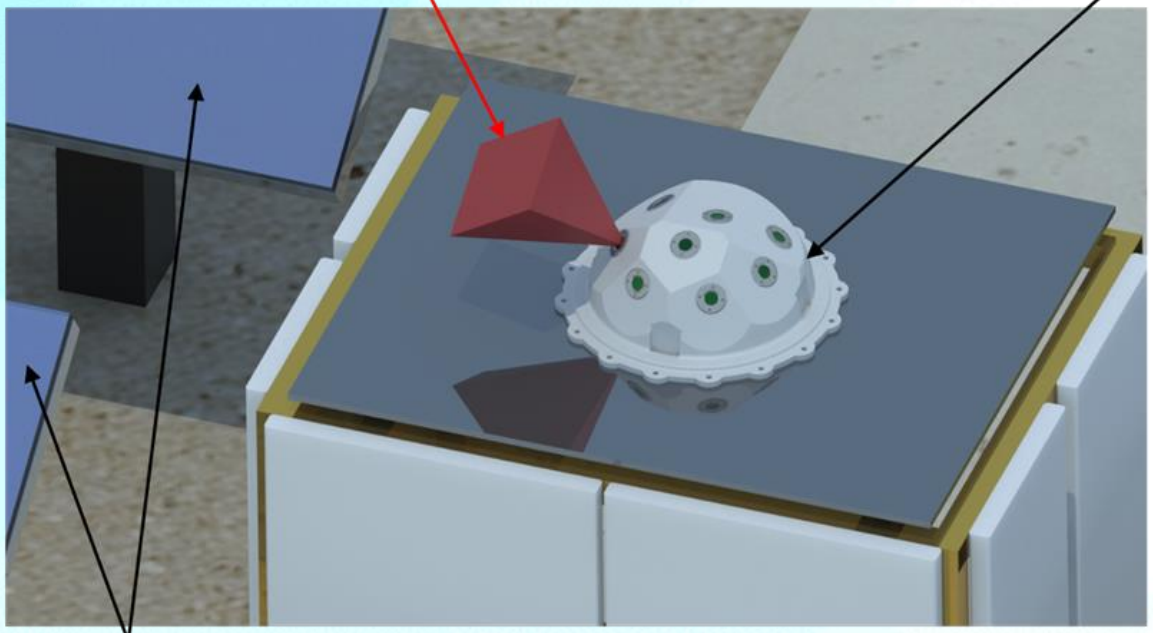
Image Projection Onto Cloud Ceiling

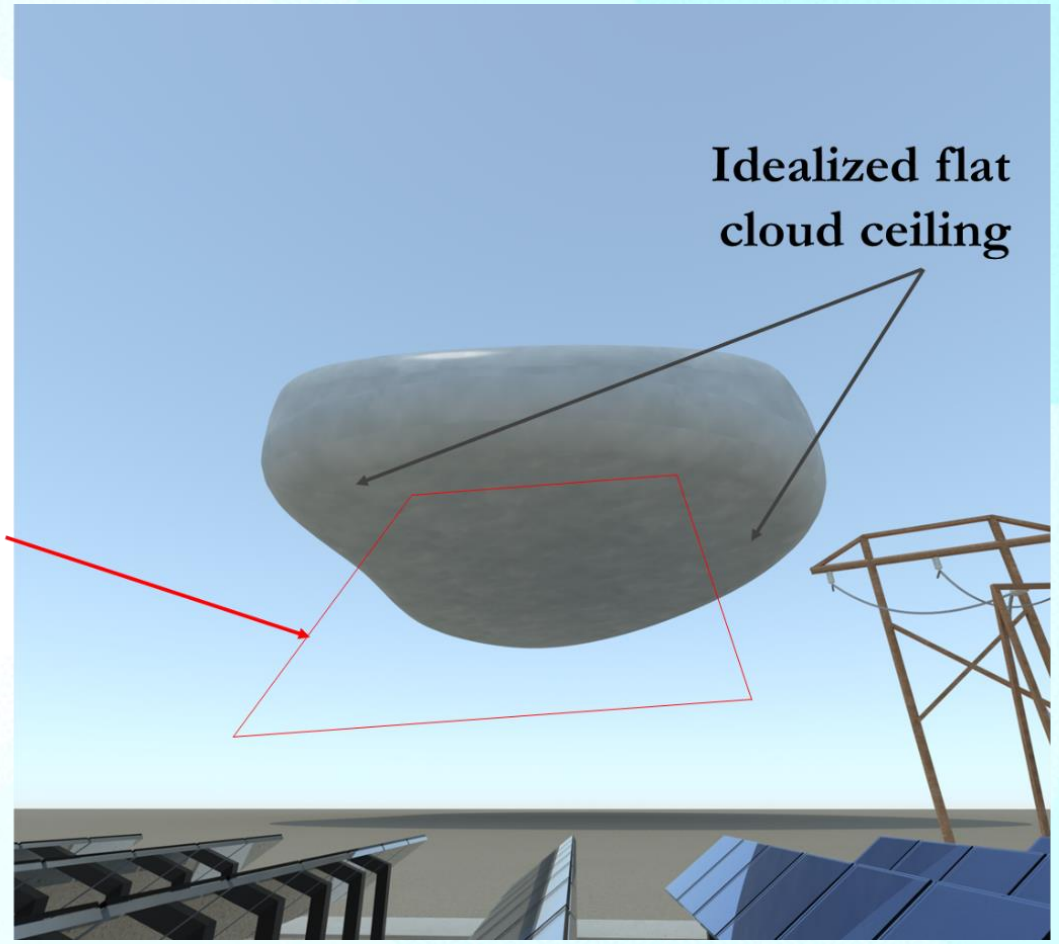
L6 Projected View shown in Red

Ladybug IR sensor apparatus



Solar field

L6 Projected View into the sky, onto an idealized flat cloud ceiling



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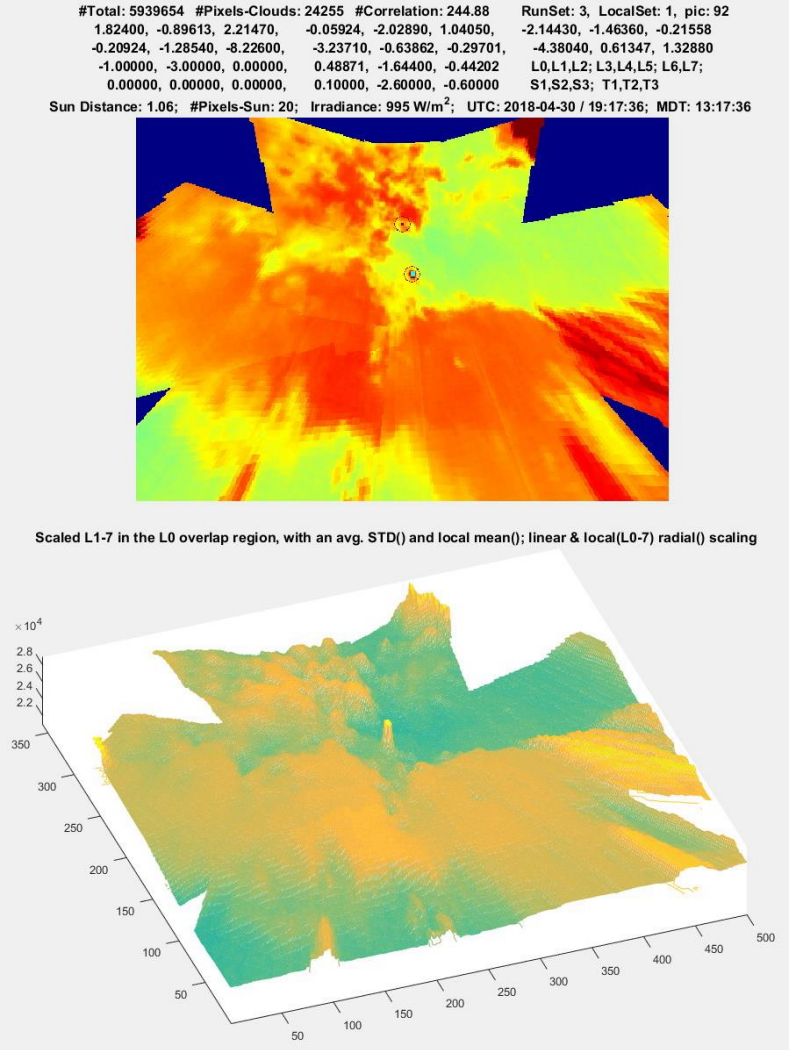
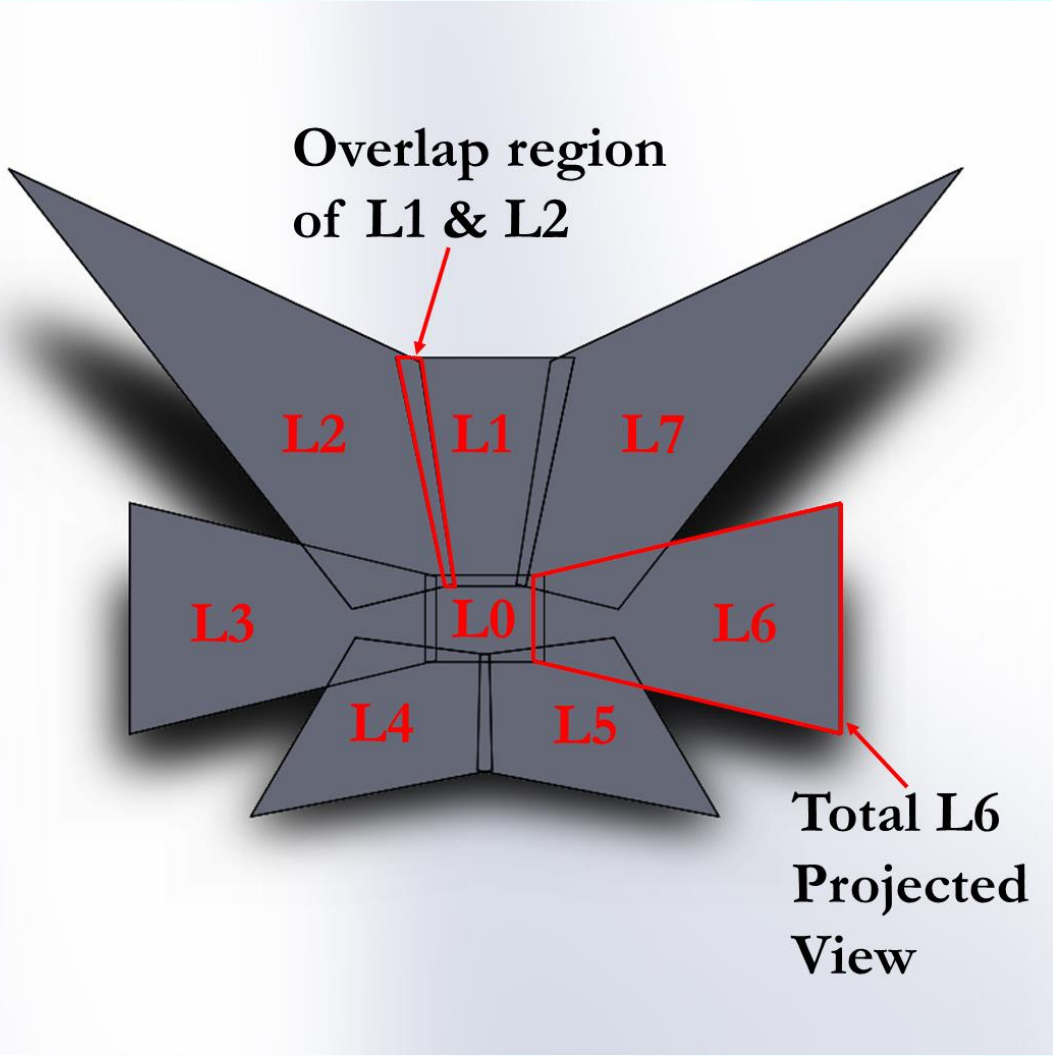
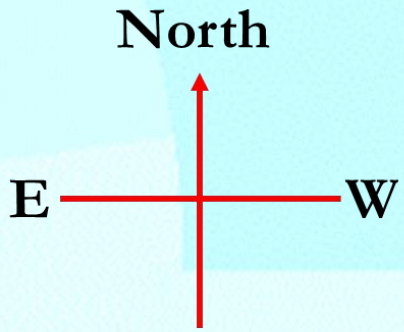
Stitch the Images Together







We were motivated by the contrast of the data.

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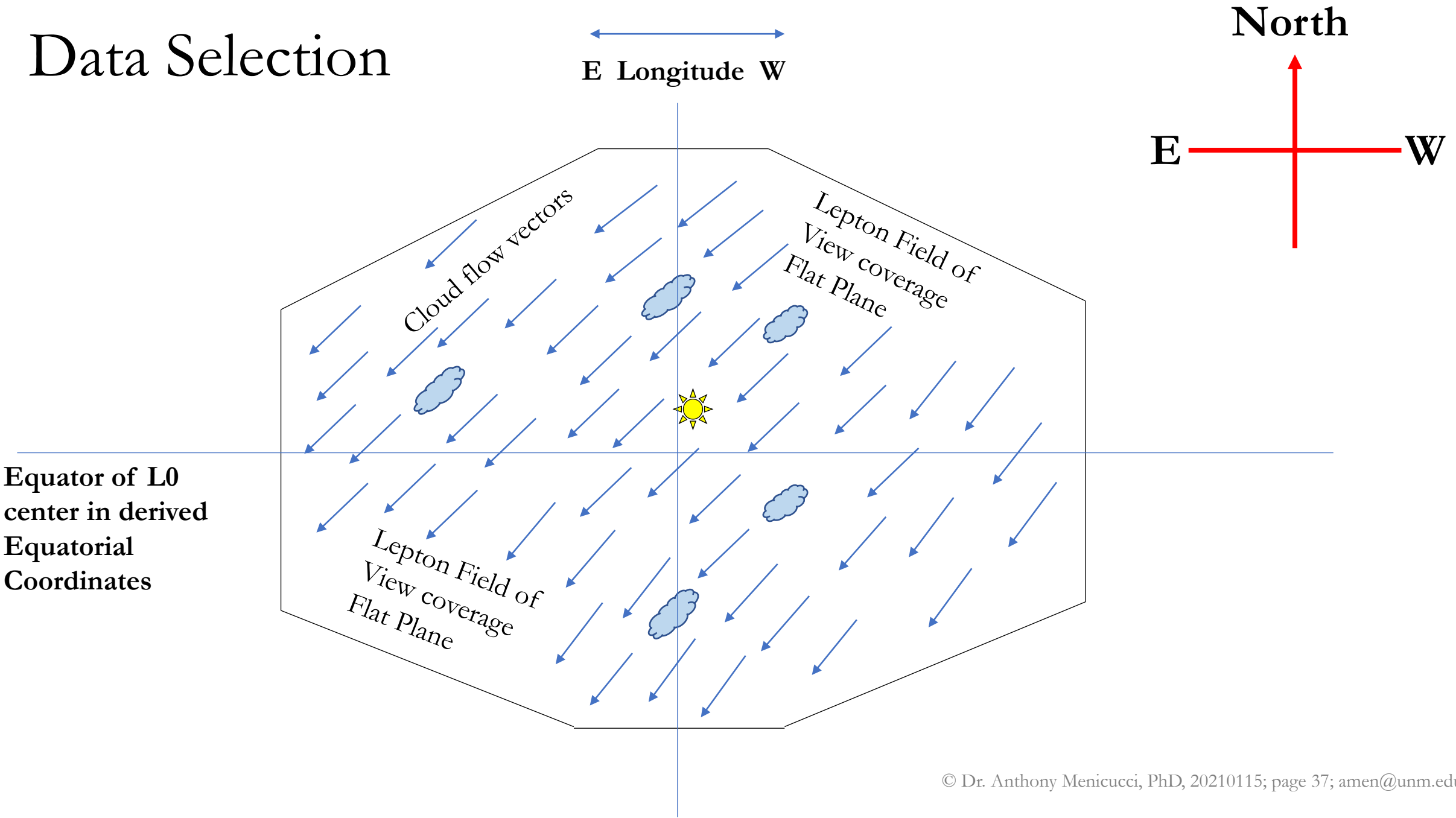
Data Selection



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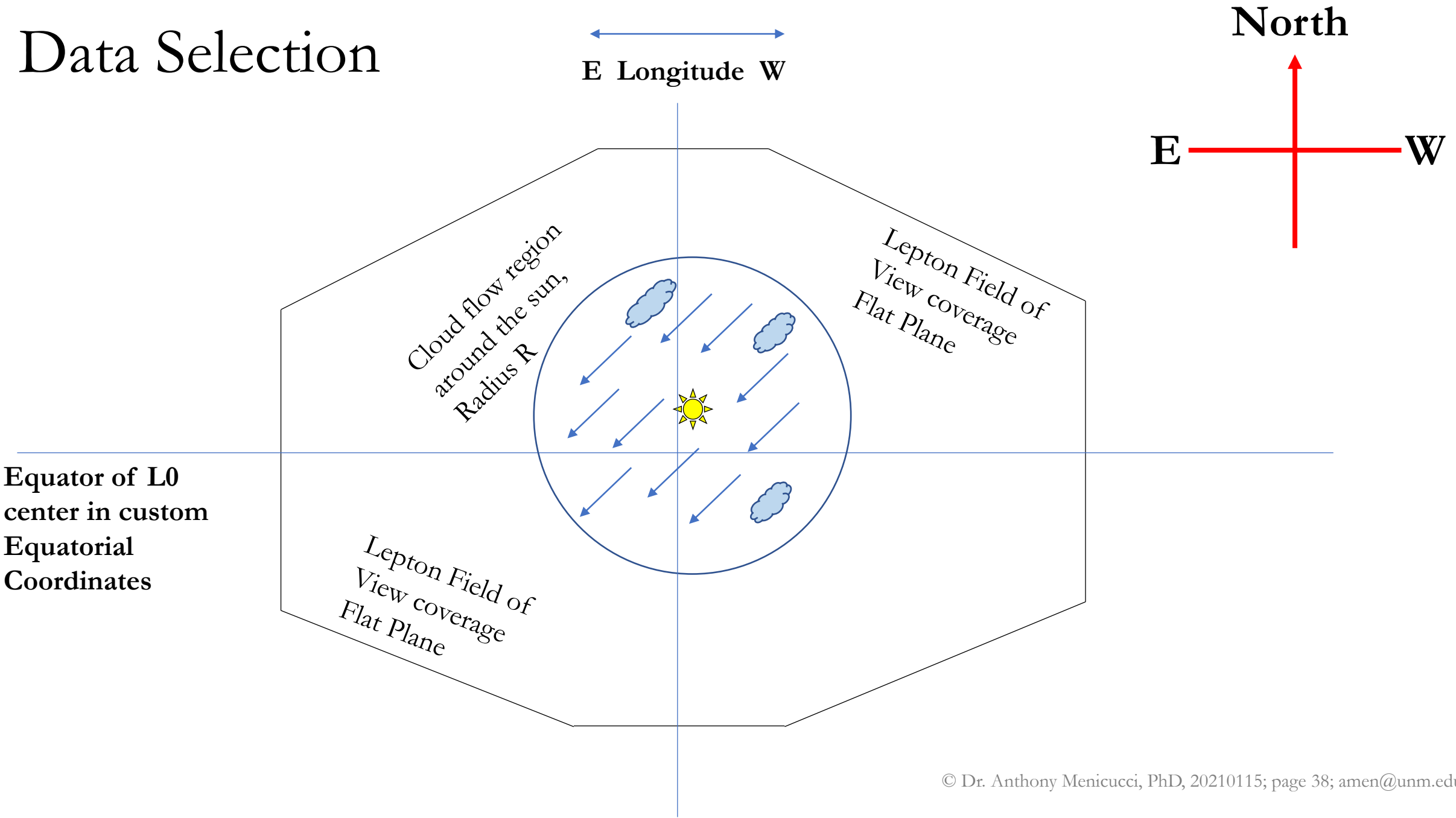
Data Selection



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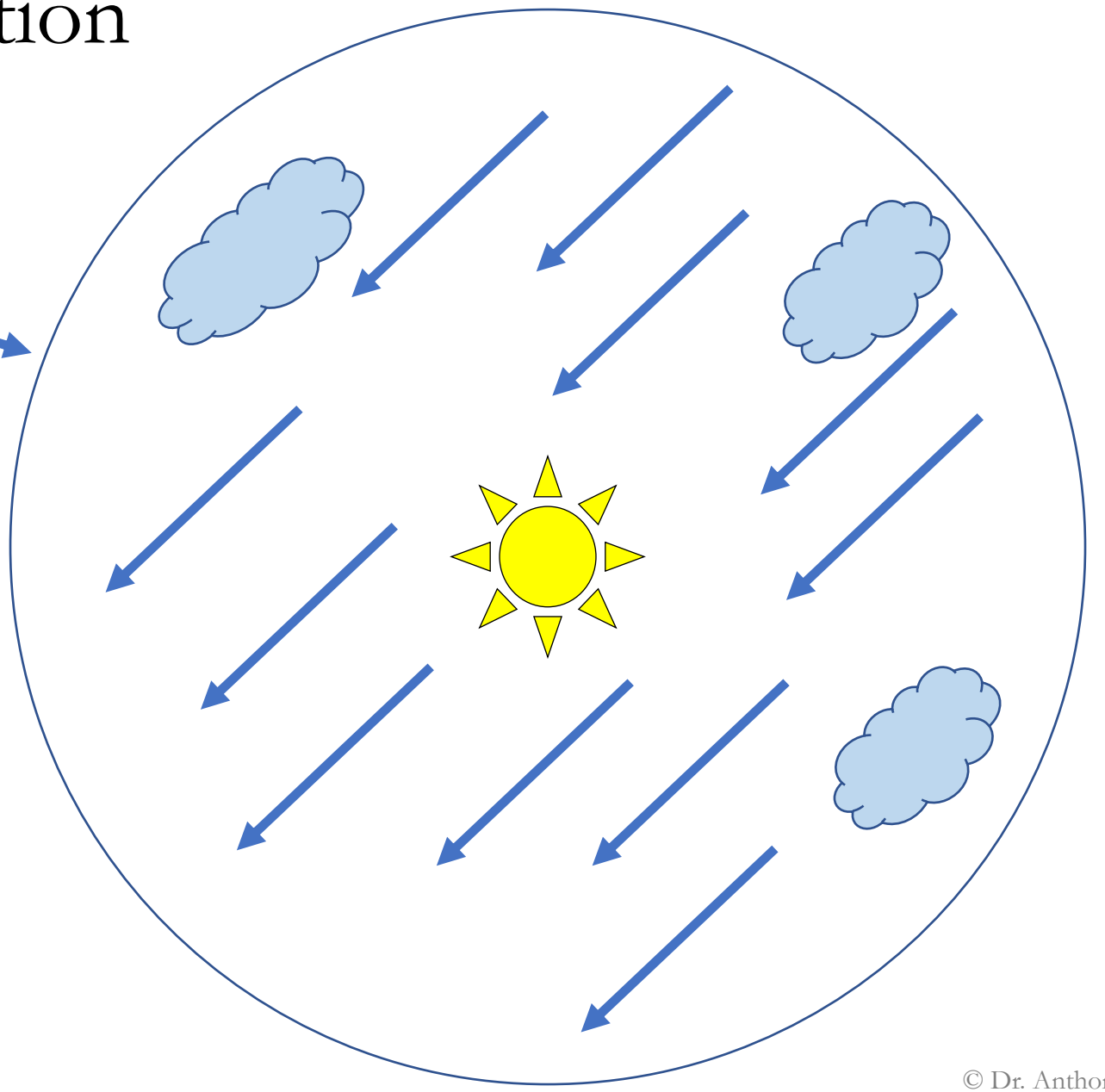
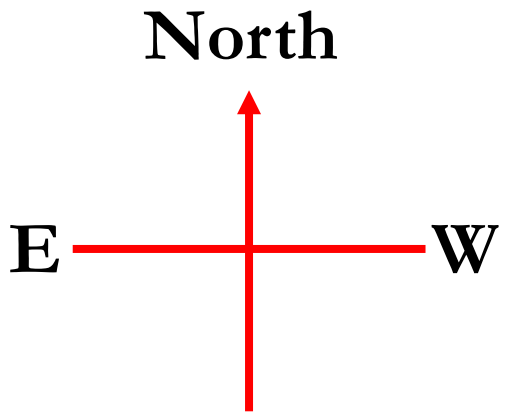
Data Selection

Flow field around the sun, Radius R





Velocities are measured with a Particle Image Velocimetry program, PIVLab and a sequence of images in time.

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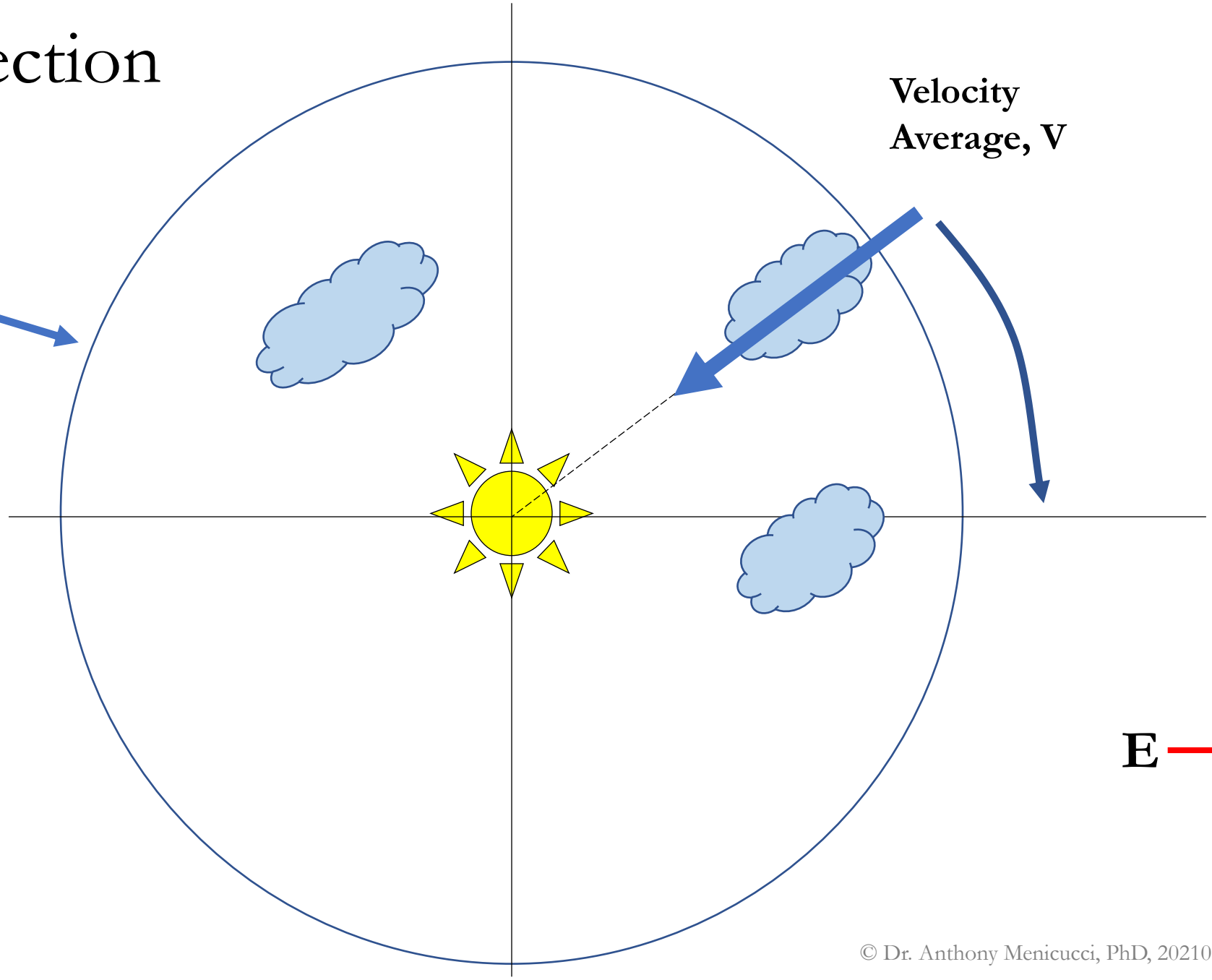
Data Selection

Flow field around the sun, Radius R

Velocity Average, V



North

E **W**

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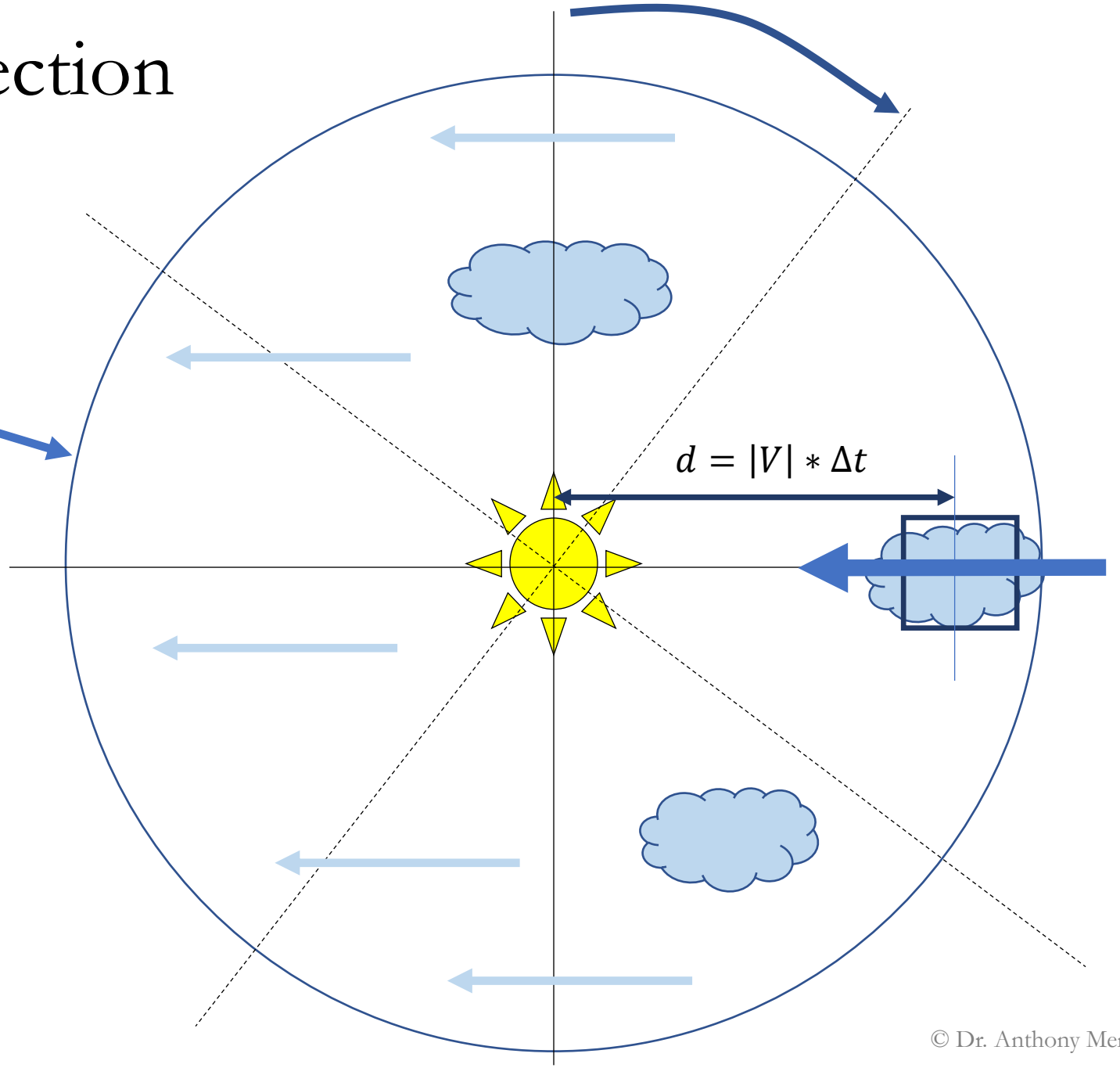
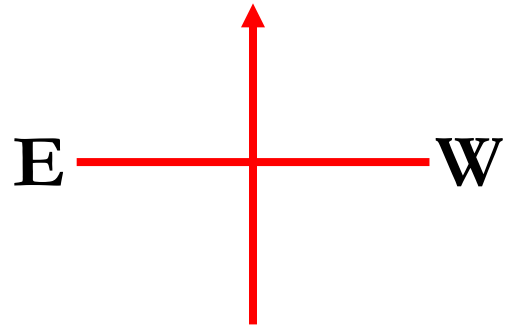
Data Selection -rotation

Flow field around the sun, Radius R



Velocity Average, V



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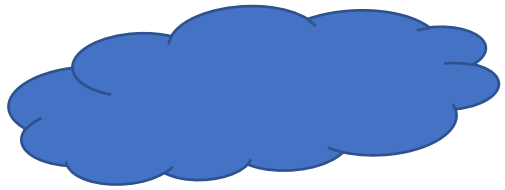
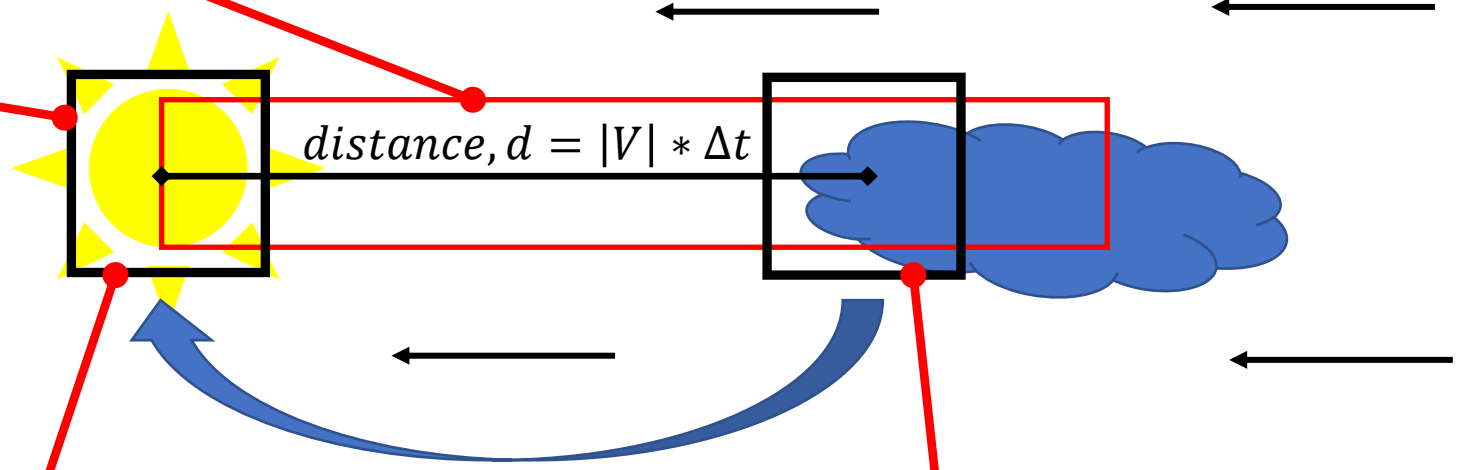
Data flag in line with velocity



The velocity is shown with black arrows

If the velocity is known, then only the data in the red box is relevant to the direct irradiance prediction.

20 X 20 pixel VG region



Location of the Velocity Gate (VG) box at time, t;
LAPART input for prediction at time t $+\Delta t_{prediction}$

Location of the Velocity Gate (VG) box at time, $t + \Delta t_{prediction}$

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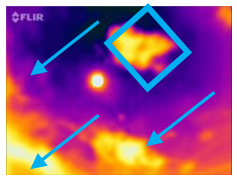
LAPART the AI Neural Network

LAPART Training Phase

Image @ time T

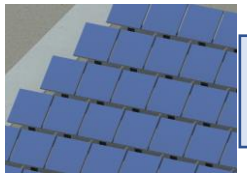


Sky Image Data Timeline

A side Input

LAPART
Training

B side Input

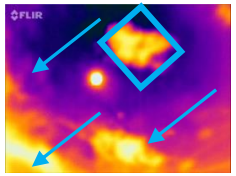


Irradiance Timeline

PV Output data
@ time T+ΔT

LAPART Testing Phase

Image @ time T

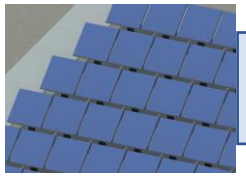


Sky Image Data Timeline

A side Input

LAPART
Testing

B side Output



Irradiance Timeline

PV Output Prediction
for time T+ΔT

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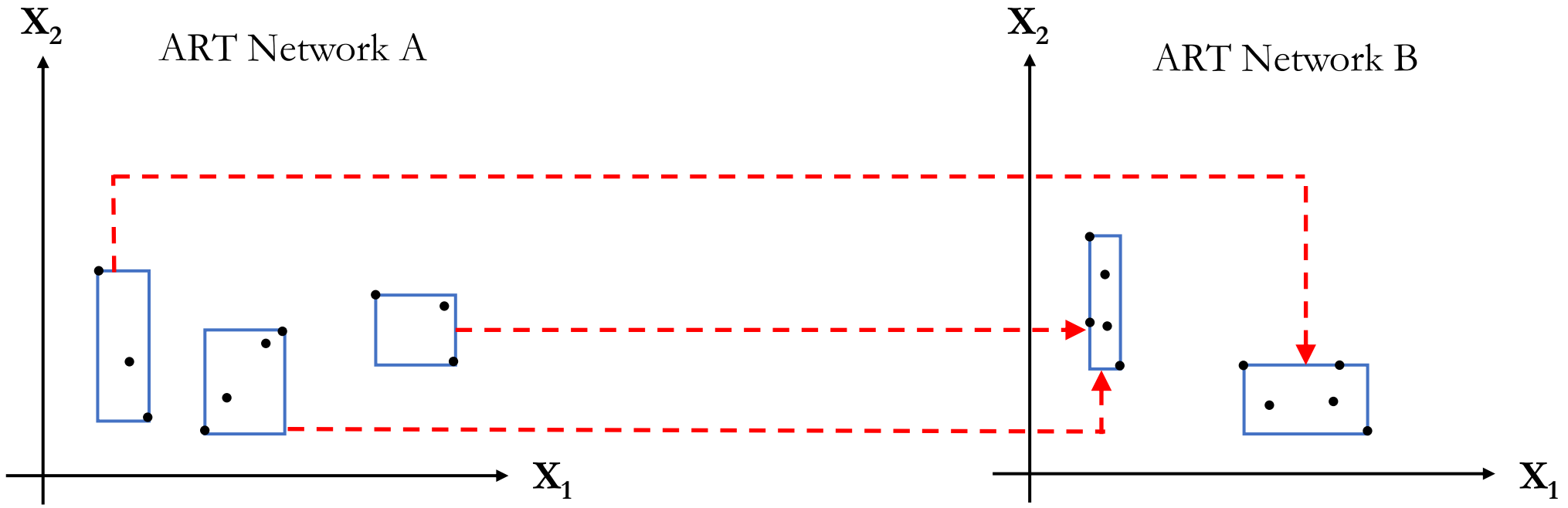
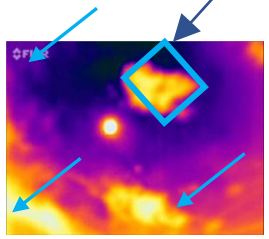
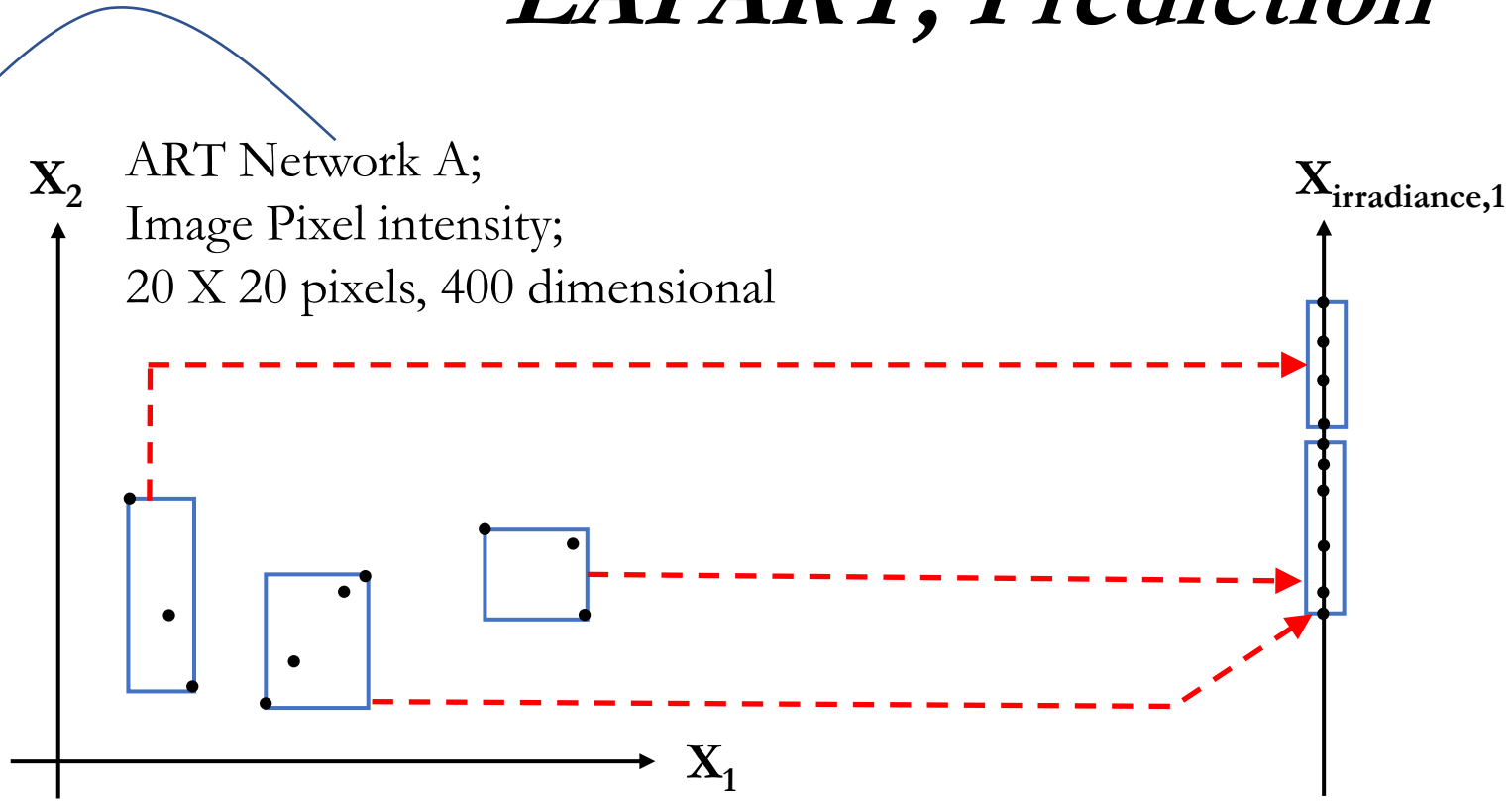
ART and LAPART; Predictive Model Learning



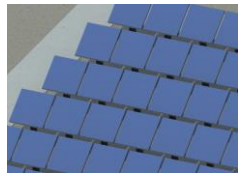
- Learning occurs as lateral weighted connections between hyperboxes.
- Red lines are associators between two ART Networks.
- ρ_A & ρ_B are vigilance parameters and control the size of the hyperboxes.

LAPART; Prediction



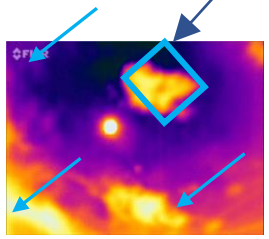


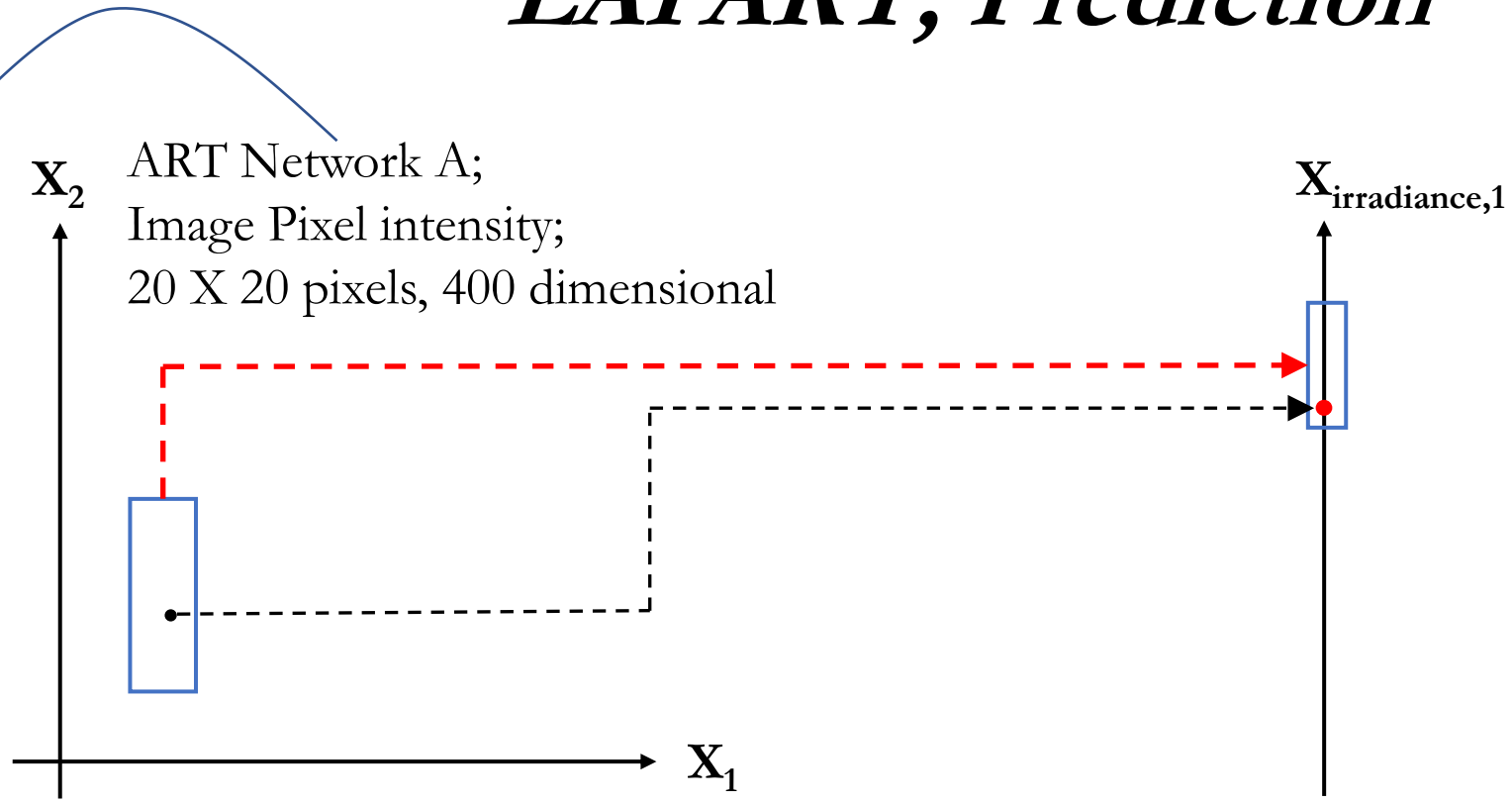
ART Network B;
Single Irradiance
prediction



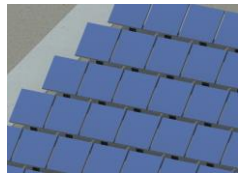
- Learning occurs as lateral weighted connections between pixel intensity and irradiance.
- Red lines are associators between pixel intensity and irradiance

LAPART; Prediction



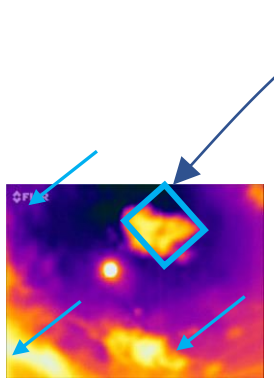


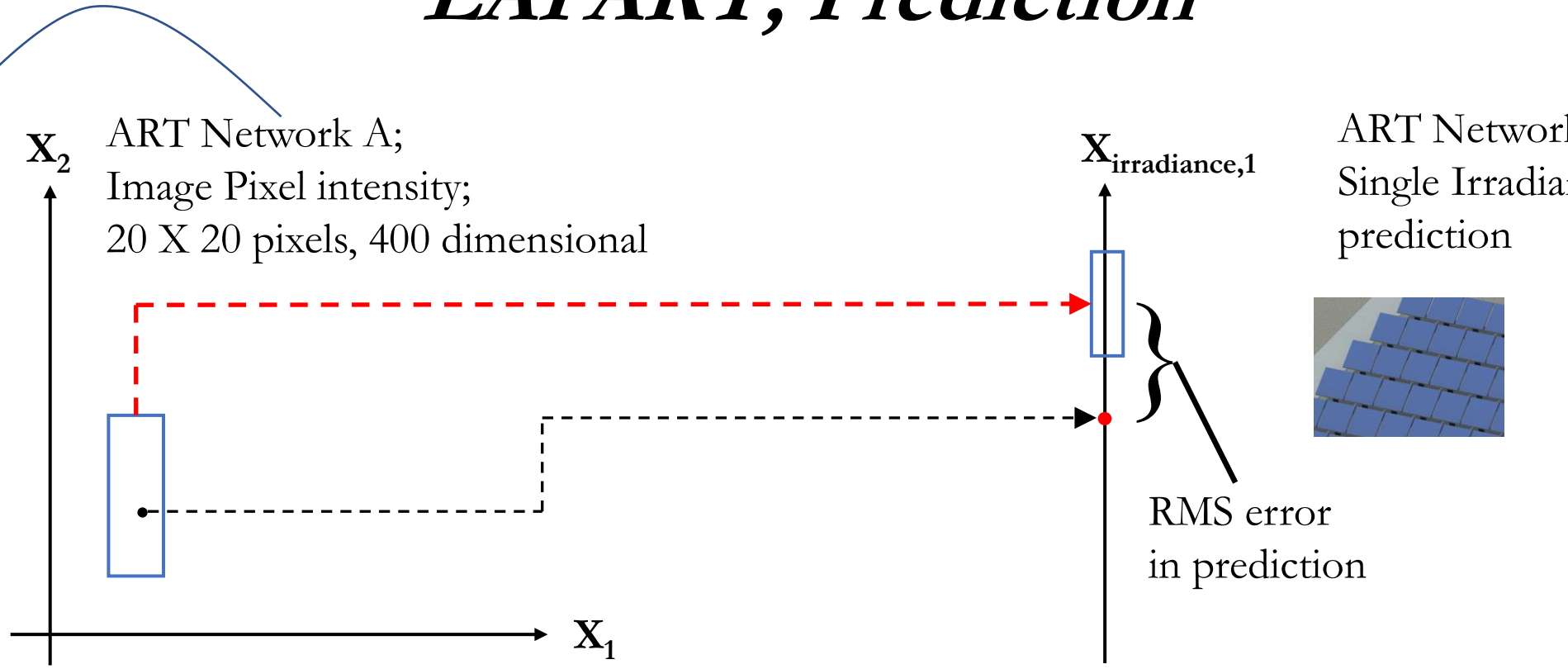
ART Network B;
Single Irradiance prediction



- Associator in red links the irradiance prediction
- The prediction in Red is in the correct category
- Root Mean Squared (RMS) error is measured from the middle of the category

LAPART; Prediction





- Associator in red links the irradiance prediction
- The prediction in Red is outside of the correct category
- Root Mean Squared (RMS) error is still measured from the middle of the category

Two LAPART Testing Scenarios

Leave % out Method

This method leaves out a percentage of data for testing.

Used to Investigate the VG Placement with Altered Average Velocities, Heuristically

Used to investigate High Irradiance Variability, Predictions >250W/m^2

Jackknife Method

This method leaves out one data point & trains on the rest. Then repeats for all of the data.

Used to investigate the Absolute Minimum error in a Prediction expected from LAPART

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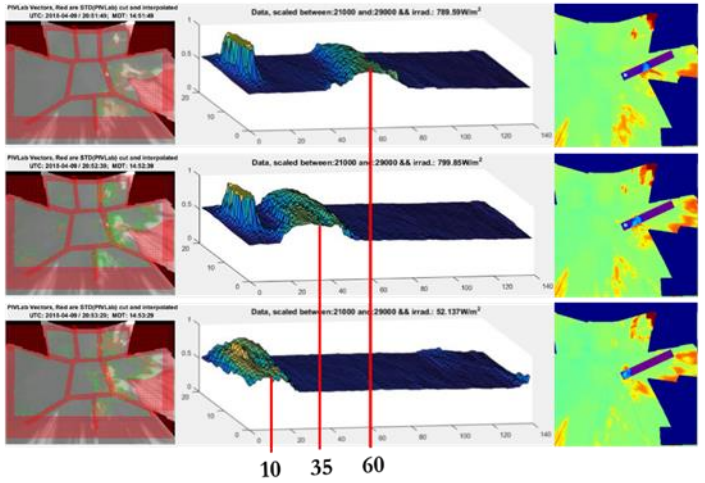
Velocity Gate Heuristic Observation

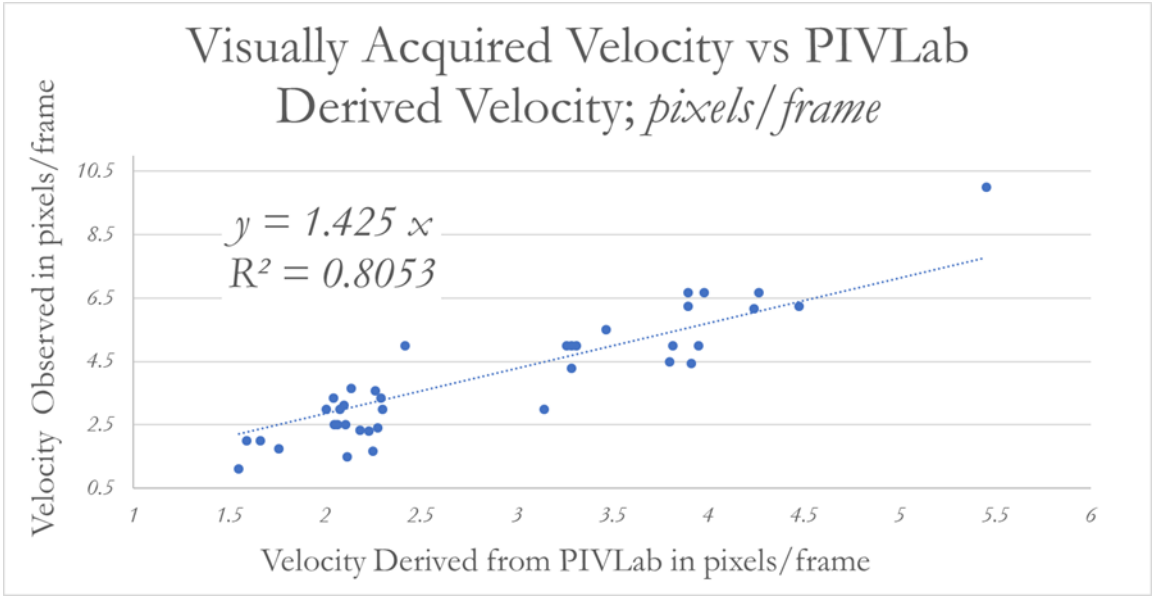
On 4/9/2018 in Boulder, Co., the clouds appeared to be moving approximately
Vel. (V_{PIVLab}) = 50 *pixels* in ***10*** *frames* = ***5*** *pixels/frame* and not ***3.29*** *pixels/frame*
The Automanual correction is V_{PIVLab} **** 152% = V***



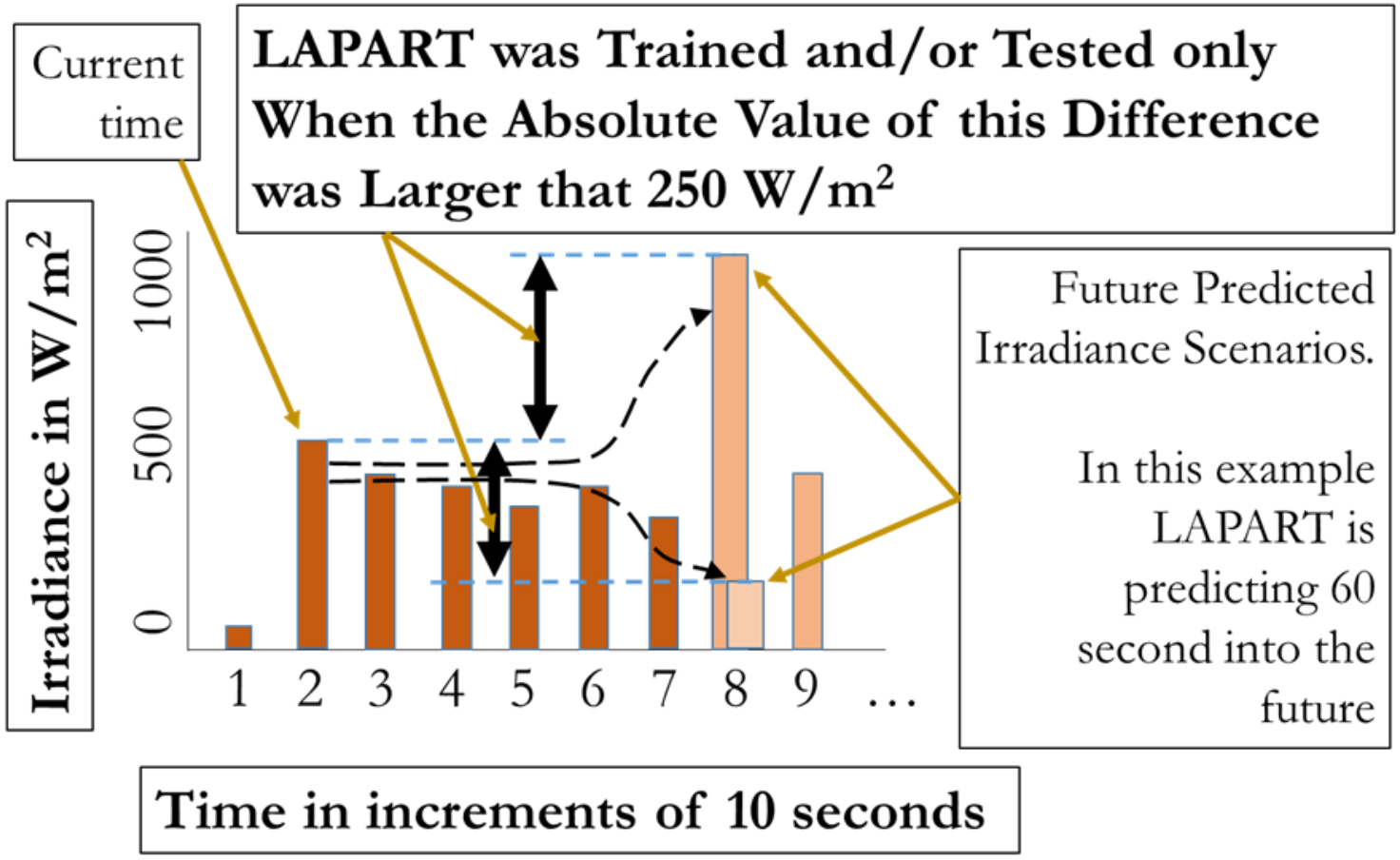
Boulder, CO; 14:51:49 MDT
Cloud @ 60 pixels, 790 W/m^2
PIVLab vel.; 3.29 pxls./frame

Boulder, CO; 14:52:39 MDT
Cloud @ 60 pixels, 800 W/m^2
PIVLab vel.; 3.29 pxls./frame

Boulder, CO; 14:53:29 MDT
Cloud @ 60 pixels, 52 W/m^2
PIVLab vel.; 3.29 pxls./frame



High Variability Data Prediction is greater than 250 W/m²



Leave out 25% for testing

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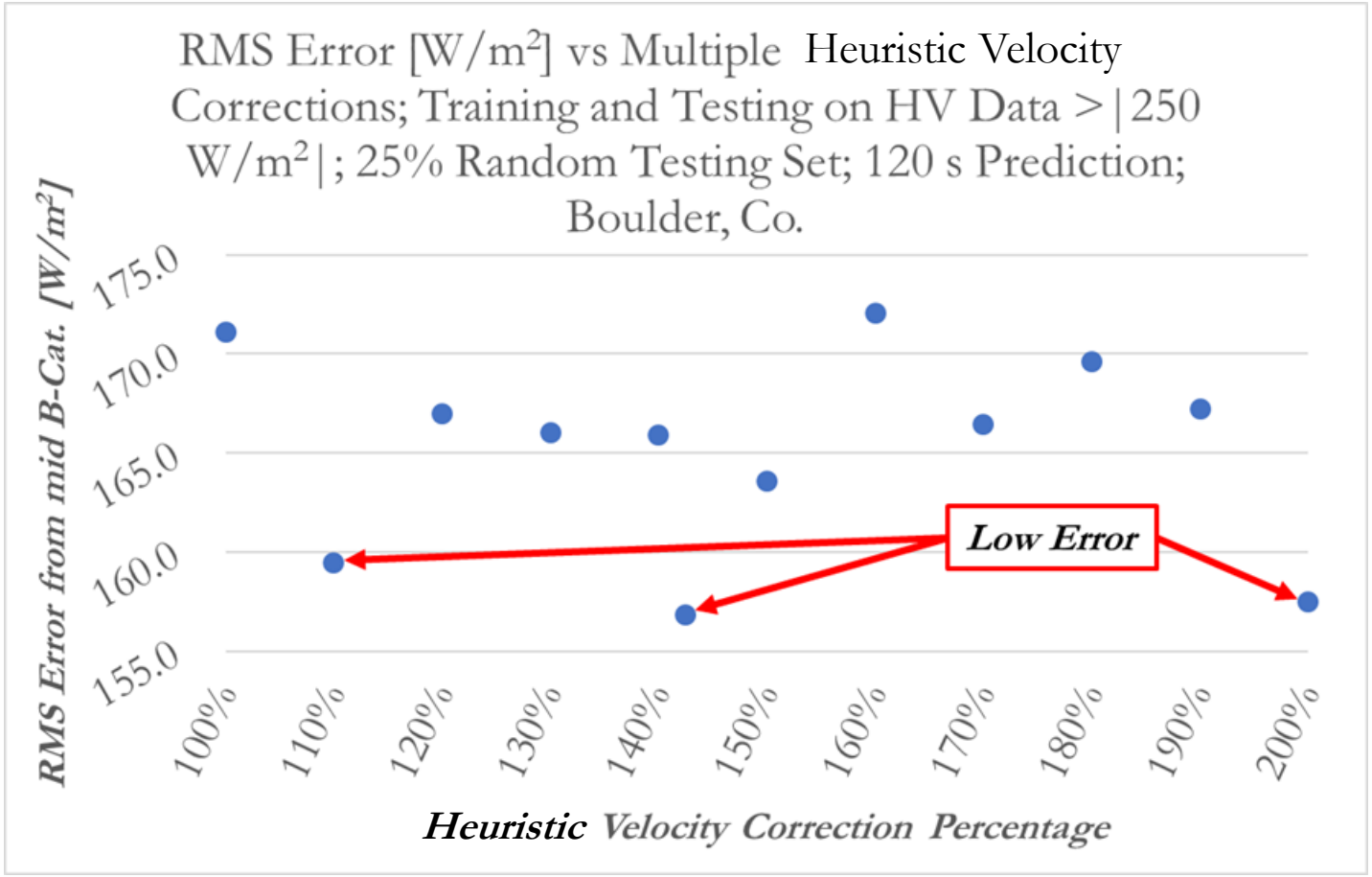
Velocity Gate Heuristic Observation

Prediction Time:	120 s	time interval between pictures:	10 s
ϱA:	98%	Perc. For Testing:	25%
ϱB:	98%	Always predict best choice ?:	YES
High Variability Data Training:	YES	Time restriction on Testing ?:	NO
High Variability Data Testing:	YES	Time restriction Times (24 hrs.):	NA

Folder Name	Auto-manual Velocity Correction	RMS Error from mid cat. W/m^2	# A-Templates	# N Inputs	Percentage (%) # A-Templates / # N Inputs	Percentage (%) passing vigilance
R25_OldV_HV_TrHV_2019071	100%	171.1	850	1,627	52.2%	98.8%
R25_AmVelV_120/12_001_011	110%	159.4	827	1,668	49.6%	99.2%
R25_AmVelV_120/12_001_012	120%	167.0	821	1,621	50.6%	99.6%
R25_AmVelV_120/12_001_013	130%	166.1	800	1,604	49.9%	99.6%
R25_AmVelV_120/12_001_014	140%	165.9	775	1,590	48.7%	99.8%
R25_AMV_HV_TrHV_2019071	142.5%	156.8	829	1,642	50.5%	97.7%
R25_AmVelV_120/12_001_015	150%	163.6	769	1601	48.0%	98.9%
R25_AmVelV_120/12_001_016	160%	172.0	792	1581	50.1%	99.4%
R25_AmVelV_120/12_001_017	170%	166.4	741	1528	48.5%	99.3%
R25_AmVelV_120/12_001_018	180%	169.6	731	1550	47.2%	99.8%
R25_AmVelV_120/12_001_019	190%	167.2	715	1487	48.1%	99.3%
R25_AmVelV_120/12_001_020	200%	157.5	709	1488	47.6%	99.6%

Leave out 25% for testing

Learning may not be completed



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High Variability Data

Prediction Time:	90 s	time interval between pictures:	10 s
ϱA:	98%	Perc. For Testing:	25%
ϱB:	98%	Always predict best choice ?:	YES

Folder Name	Trivial Case	Auto-manual Velocity Correction	High Variability Training > |250| W/m^2	High Variability Testing > |250| W/m^2	RMS Error from mid cat. W/m^2	# A-Templates	# N Inputs	Percentage (%) # A-Templates / # N Inputs	Percentage (%) passing vigilance
9_R25_AmV_HV_TrAll_		YES		YES	271.0	3,037	20,552	14.8%	98.7%
9_R25_AmV_HV_TrHV		YES	YES	YES	153.3	804	1,449	55.5%	97.9%
9_R25_AmV_TrAll_201		YES			70.1	3,047	20,525	14.8%	99.9%
9_R25_Bad_HV_TrAll_2	YES	YES		YES	281.8	3,066	20,532	14.9%	99.4%
9_R25_Bad_HV_TrHV_	YES	YES	YES	YES	480.0	793	1,400	56.6%	99.4%
9_R25_Bad_TrAll_20190	YES	YES			70.3	3,071	20,453	15.0%	99.8%
9_R25_OldV_HV_TrAll_				YES	259.7	4,078	20,648	19.8%	99.0%
9_R25_OldV_HV_TrHV			YES	YES	150.3	881	1,440	61.2%	95.7%
9_R25_OldV_TrAll_201					63.8	4,034	20,502	19.7%	99.6%

Leave out 25% for testing

Learning may not be completed

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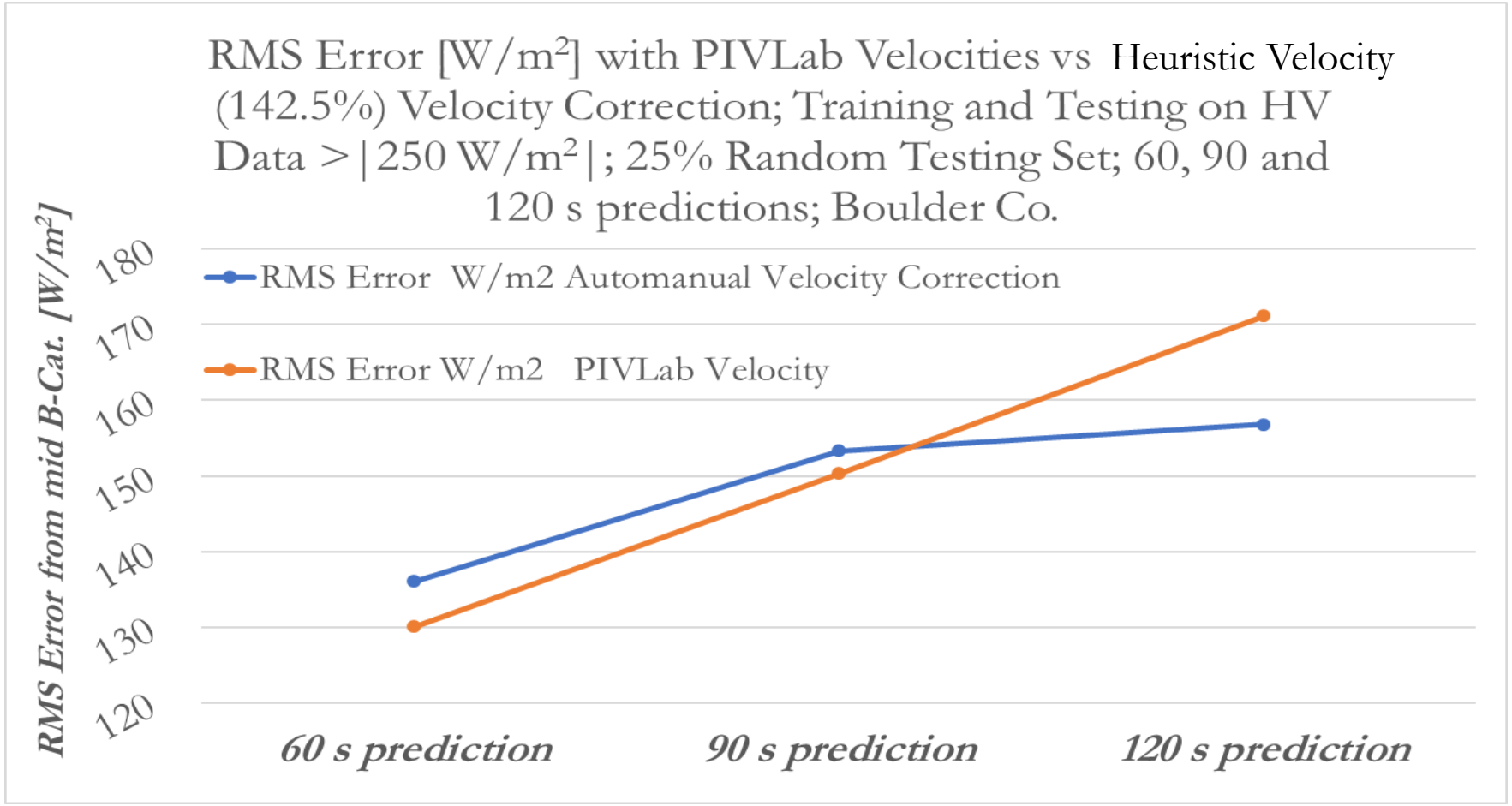
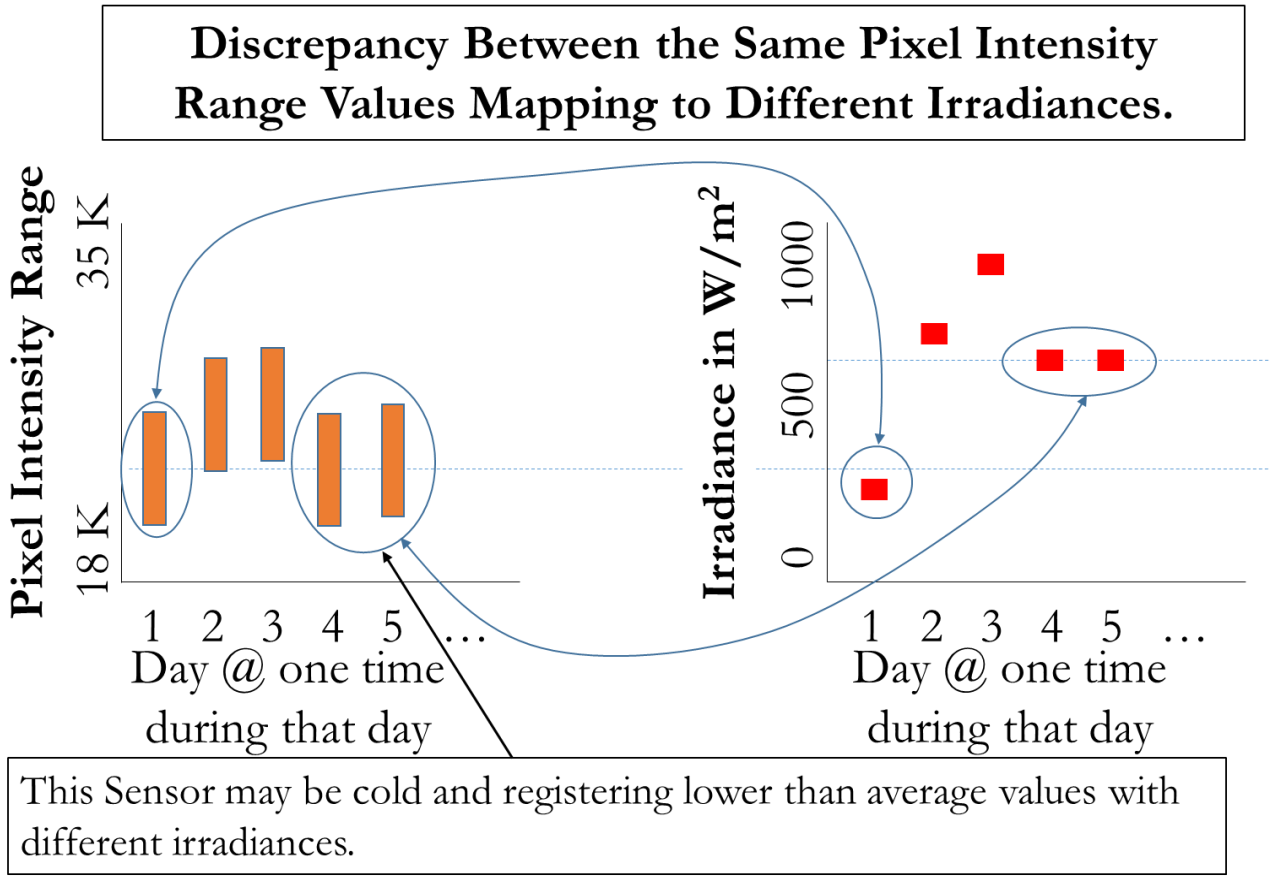
High Variability Data



Reducing Variability in the Inputs



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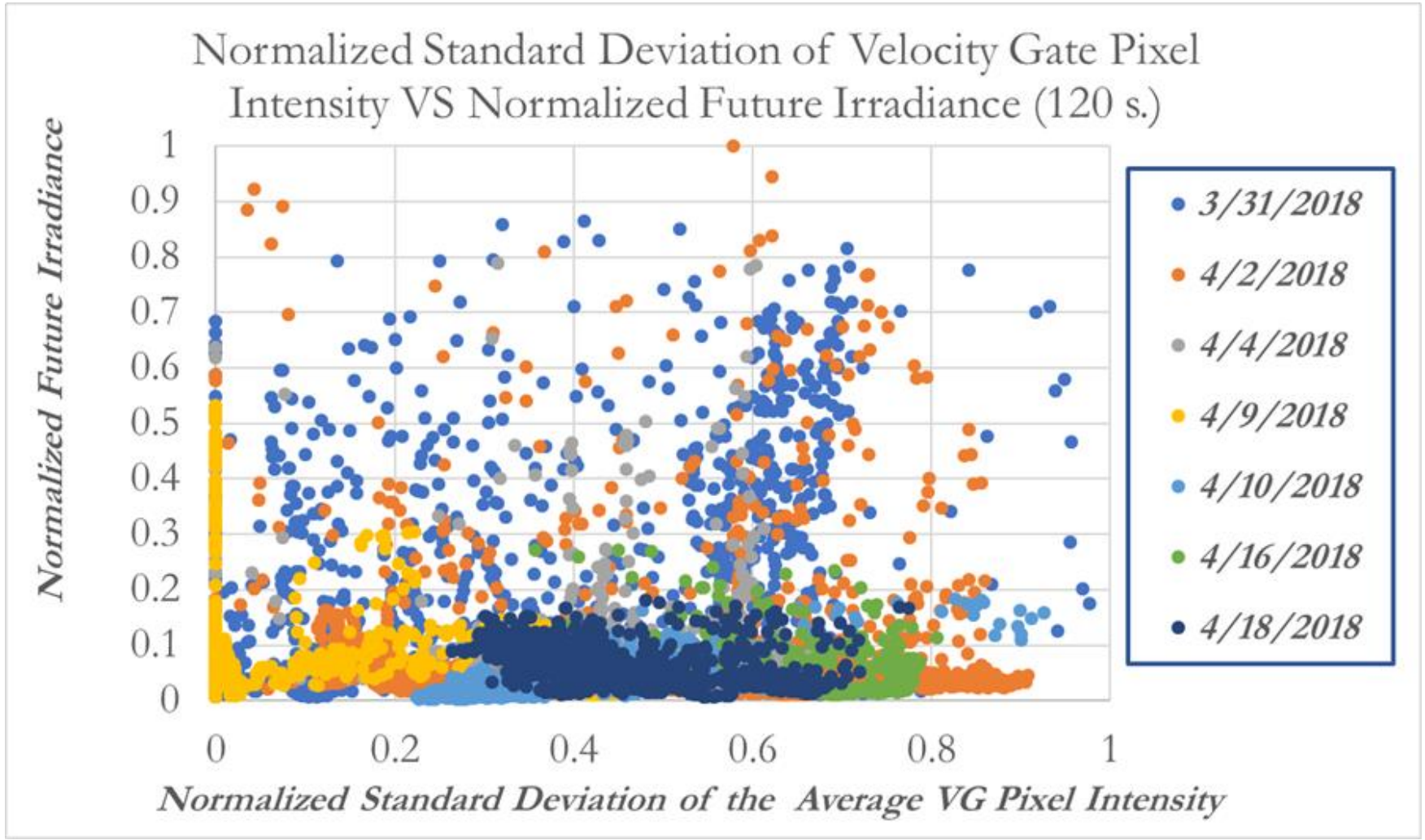
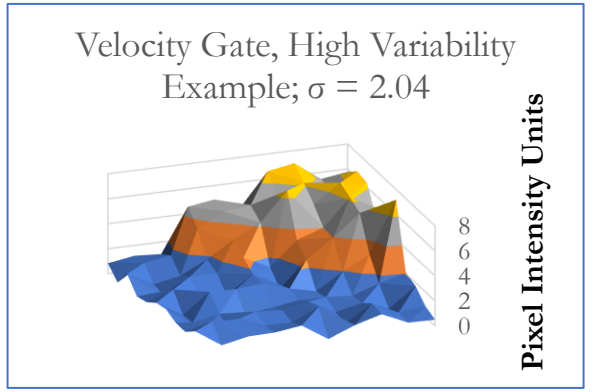
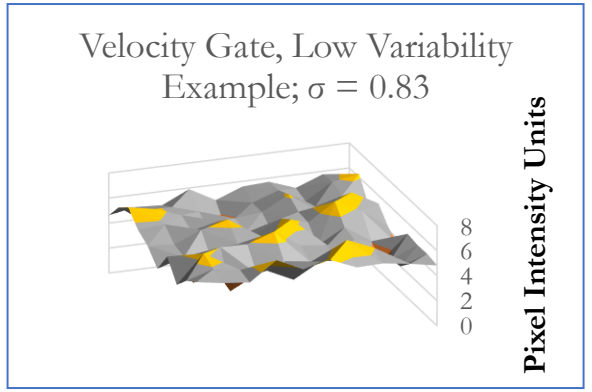
Velocity Gate Observation, High vs Low Variability





Examples of Velocity Gates Containing High (above) & Low Variability (below) data



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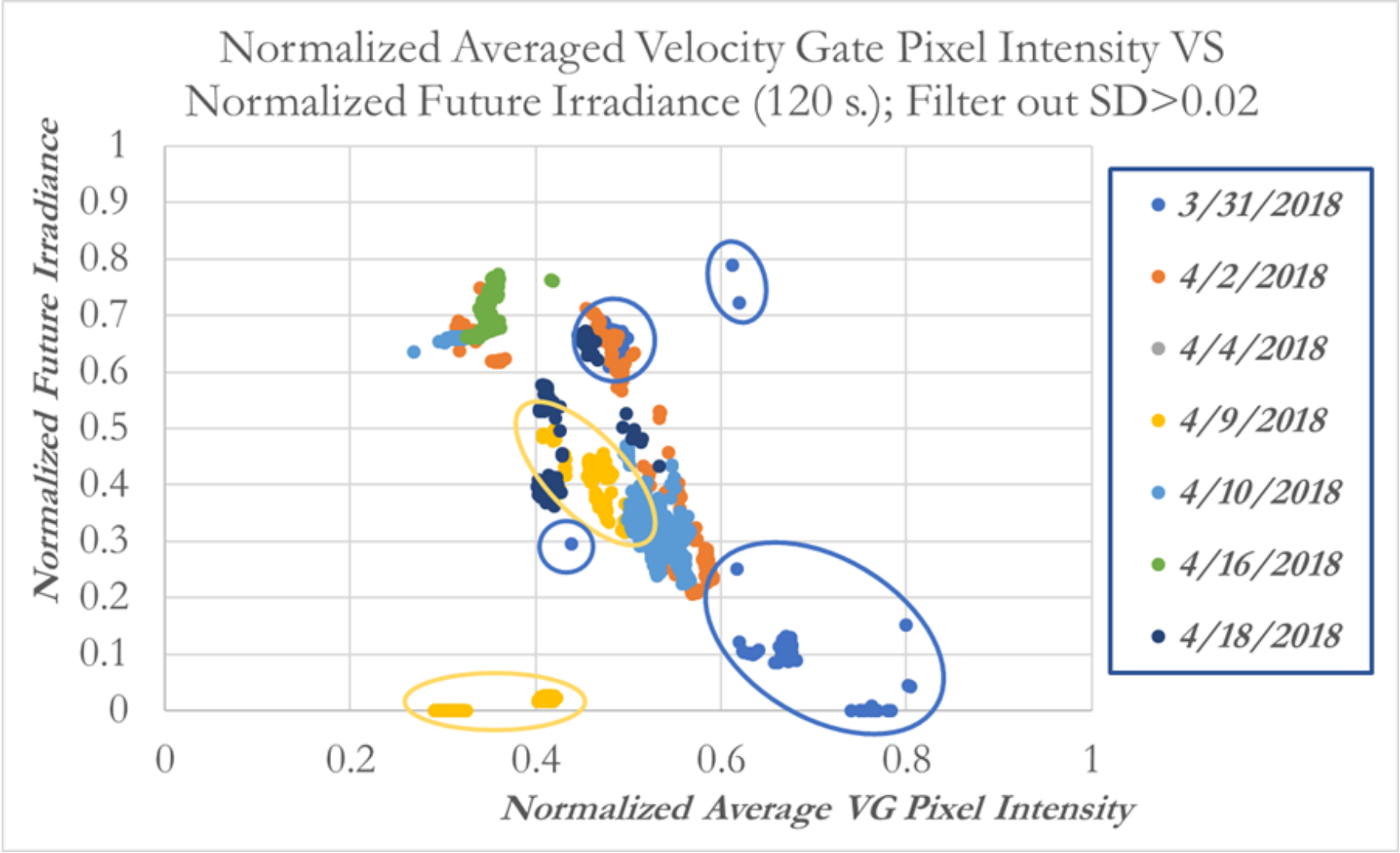
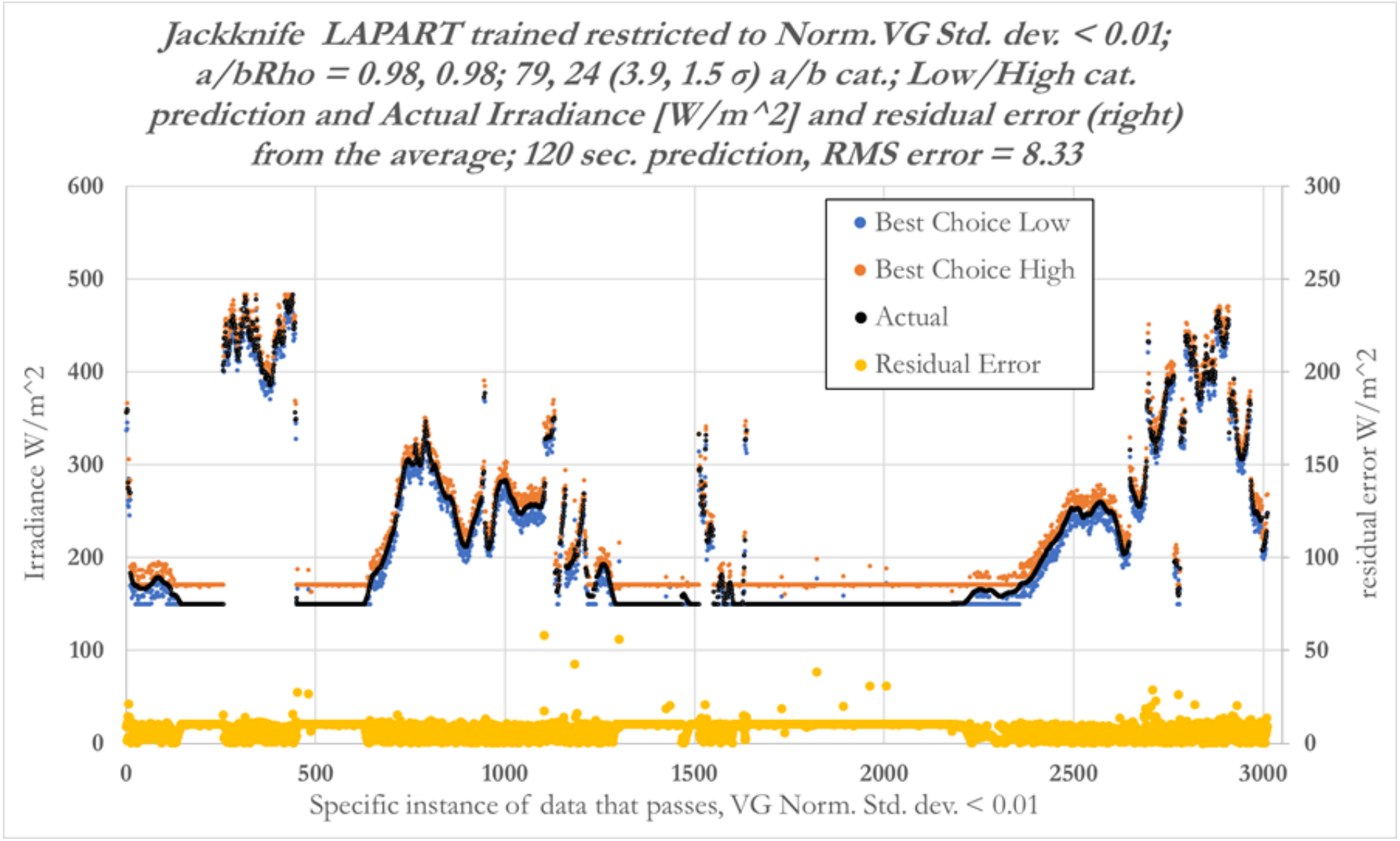
Reducing Variability in the Inputs

We expect that thicker and warmer clouds will block more solar irradiance.

Negative slope correlation



Reducing Variability in the Inputs



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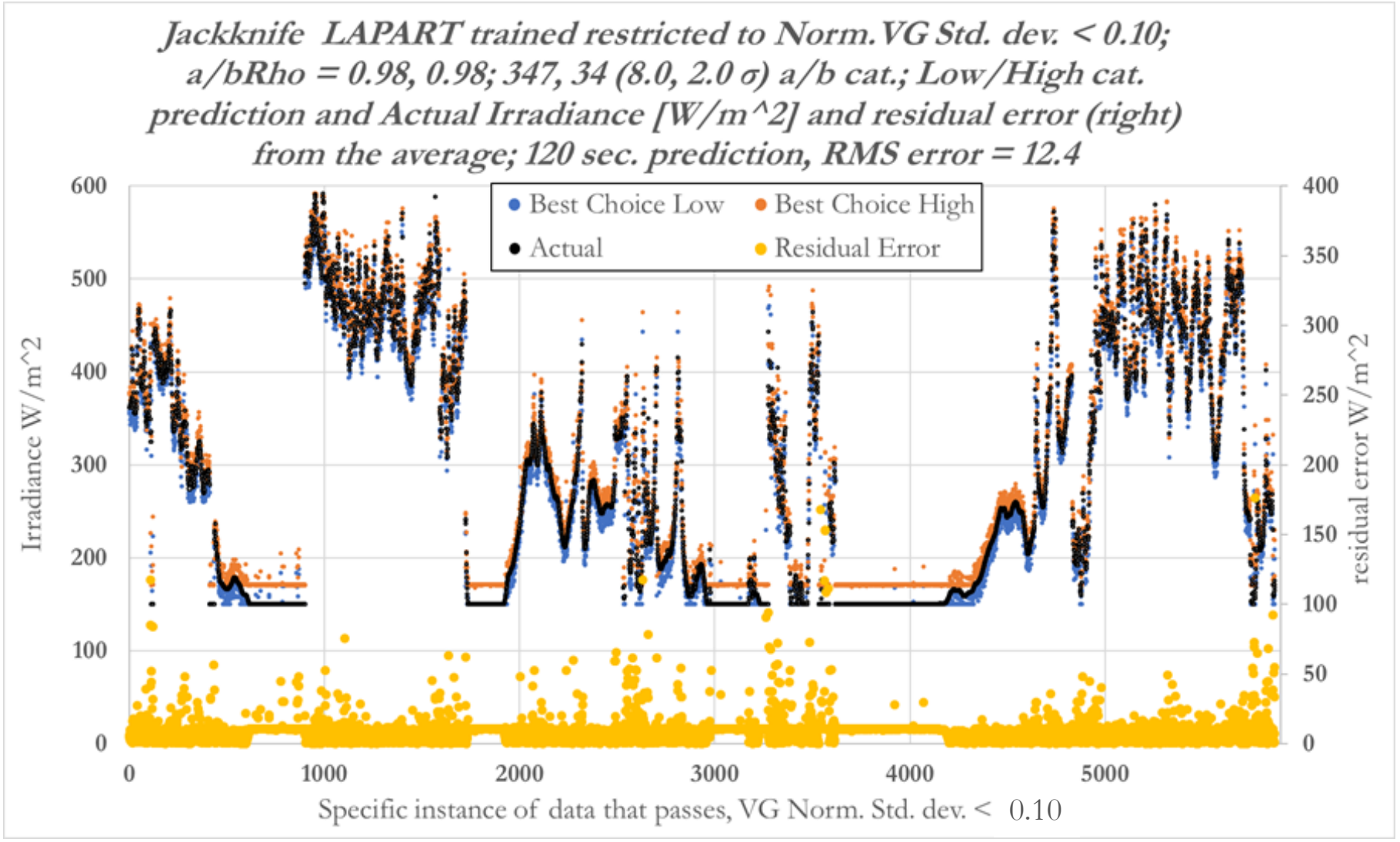
Reducing Variability in the Inputs



Conclusions

- Two minute predictions are possible using LAPART and IR images.
- It was shown that LAPART can learn and obtain predictions with an expected average error of less than the size of the B-side category is possible.
- Irradiance predictions possible instead of just occluded/sunny.
- Stitching algorithm was formulated for multiple sensors.
- Deployed a weatherproof model as fielded proof of concept in our STTR.
- Quantified the errors in the system.
- Two patents were issued.
- New Sensors will have better resolution.
- Actively marketing for more research.
- Actively marketing for buyers.
- Looking for more fielded trial opportunities.

Special Thanks to:
Prof. Andrea Mammoli
Co-Inventor/Advisor

Special Thanks to:
Prof. Thomas Caudell
Co-Inventor/Advisor

Thank You

THE UNIVERSITY OF NEW MEXICO

STC.UNM
SUPPORTING TECHNOLOGY TRANSFER AND CATALYZING ECONOMIC DEVELOPMENT AT THE UNIVERSITY OF NEW MEXICO

Dr. Anthony Menicucci, PhD
University of New Mexico, Research Professor
Department of Mechanical Engineering
amen@unm.edu
20210115