Analyzing the optimal orientation of single-and dual-axis tracking PV systems

Y. Blom, O. Chatzilampos, M. R. Vogt, O. Isabella, R. Santbergen

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PVPMC, Mendrisio

PVMD
Delft University of Technology

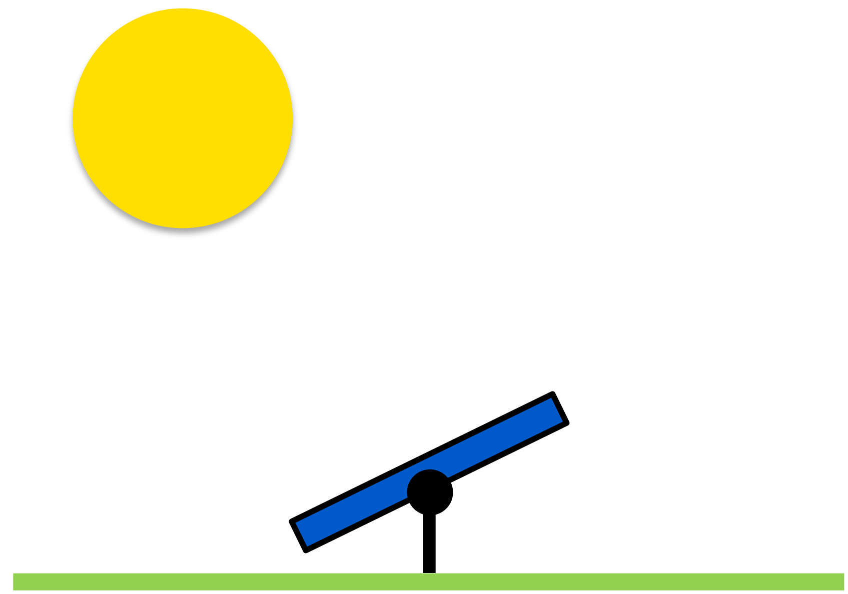
TU Delft

Motivation

- Incoming irradiance should be maximized

- Solar tracking can help

- Which orientation is optimal?



Motivation

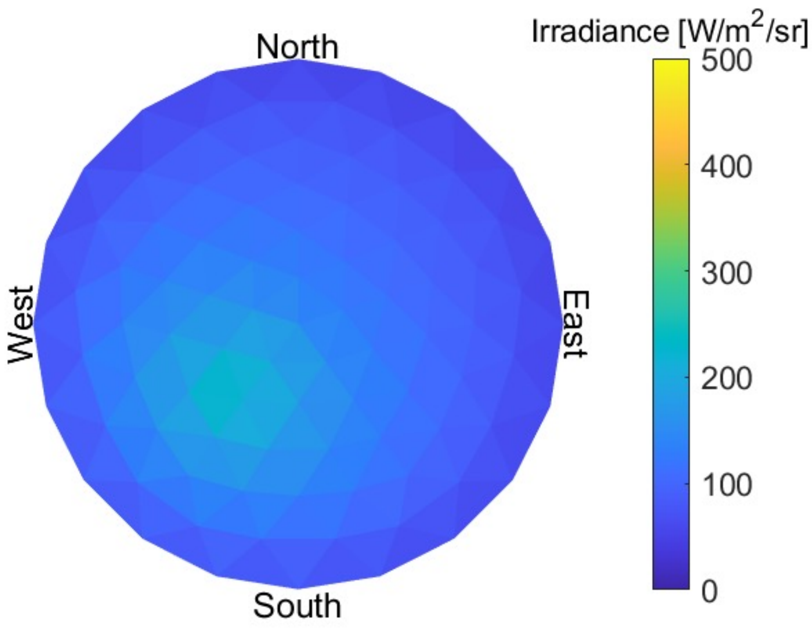
- **Different methods described in literature**
  - Astronomical tracking[1]/ true tracking[2]
  - Diffuse radiation method[3]
  - Analytic equations[4,5]

- **Based on assumption of diffuse irradiance is isotropic/azimuth independent**
  - In absence of direct irradiance, flat orientation is preferred

[1] R. Singh, et al., *Renewable and Sustainable Energy Reviews.* **82**, 3263-3278 (2018)
[2] Sandia National Laboratories, *pvlib: Single-axis tracking*, (accessed on 29-10-2023)
[3] J. Antonanzas, et al., *Solar Energy*, **163**, 122-130 (2018)
[4] K. R. McIntosh, et al., *IEEE Journal of Photovoltaics,* **12** (1), 397-405 (2022)
[5] C. D. Rodriquez-Gallegos, et al., *IEEE Journal of Photovoltaics*, **10** (5), 1474-1480 (2020)

Motivation

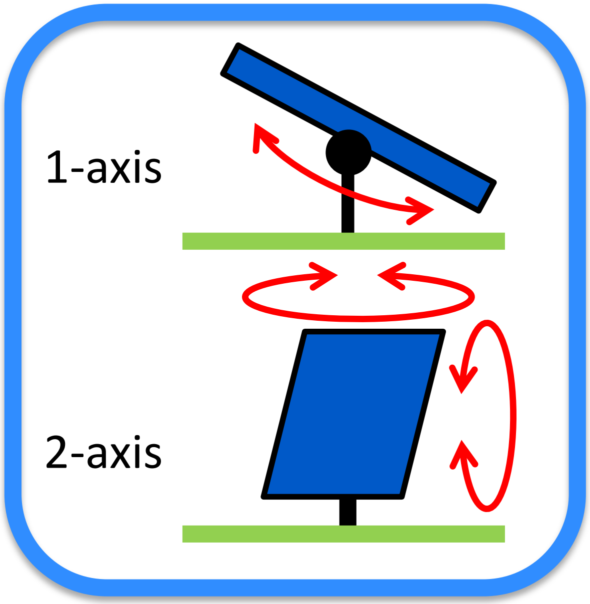
- **Diffuse irradiance should be treated anisotropic[1]**
- **Perez model[2]**
- **Irradiance map**
  - Delft, July 7th, 15:00
  - DHI = 400 W/m^2
  - ~~DNI = 600 W/m^2~~



[1] D. H. W. Li, G. H. W. Cheung, *Applied Energy,* **81** (2), 170-186 (2005)
[2] R. Perez, et al., *Solar Energy*, **50** (3), 235-245 (1993)

Objectives

Modeling

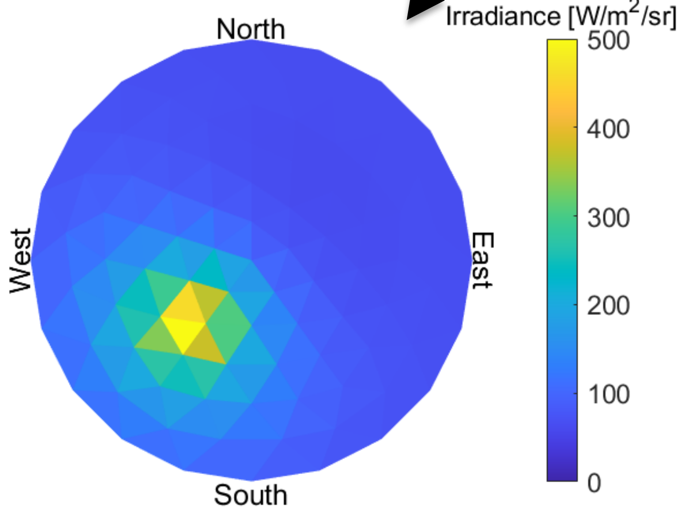


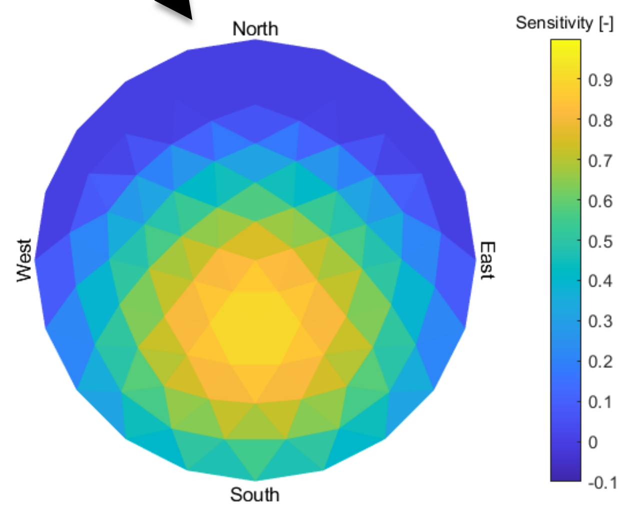
Optimal position

Simple equation

Modeling framework

- **PVMD Toolbox[1]**
- **Rec Irraddiance = Irradiance map x Sensitivity map[2]**

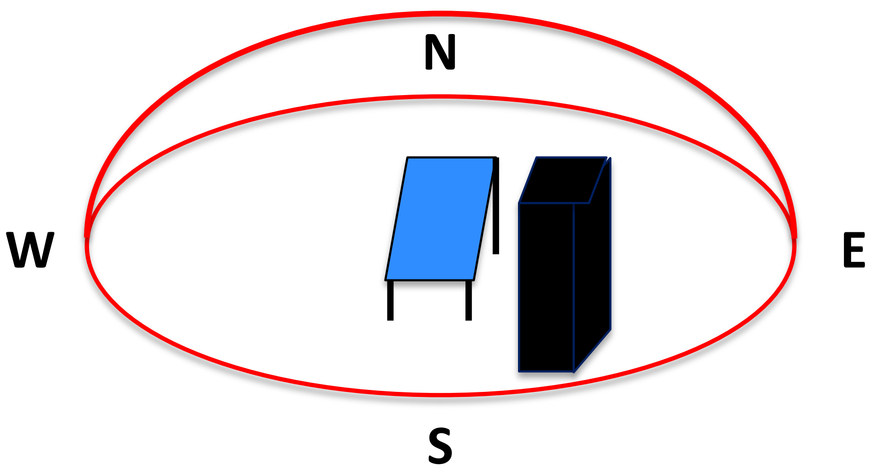


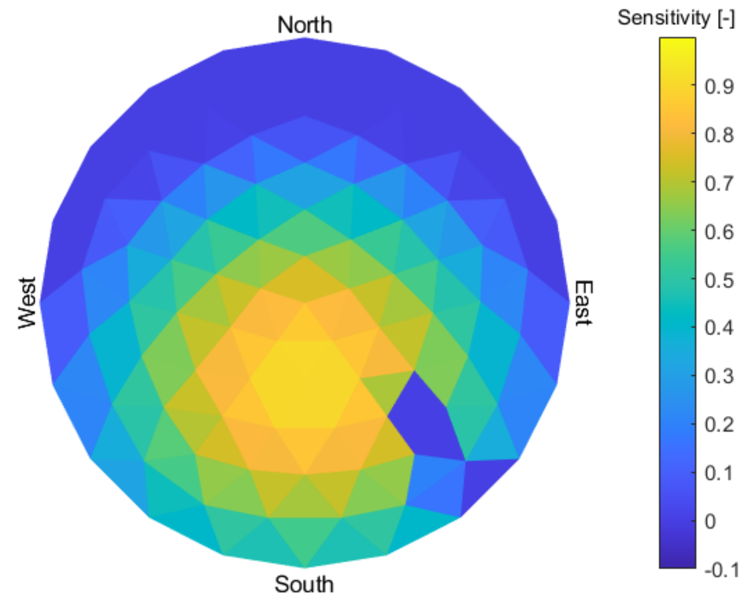


[1] M. R. Vogt, et al., *Sol. Energy Mater*, **247**, 111944 (2022)
[2] R. Santbergen, et al., *Solar Energy*, **150**, 49-54 (2017)

Sensitivity map

$$Sens = \frac{Irr_{abs}}{Irr_{vert}}$$





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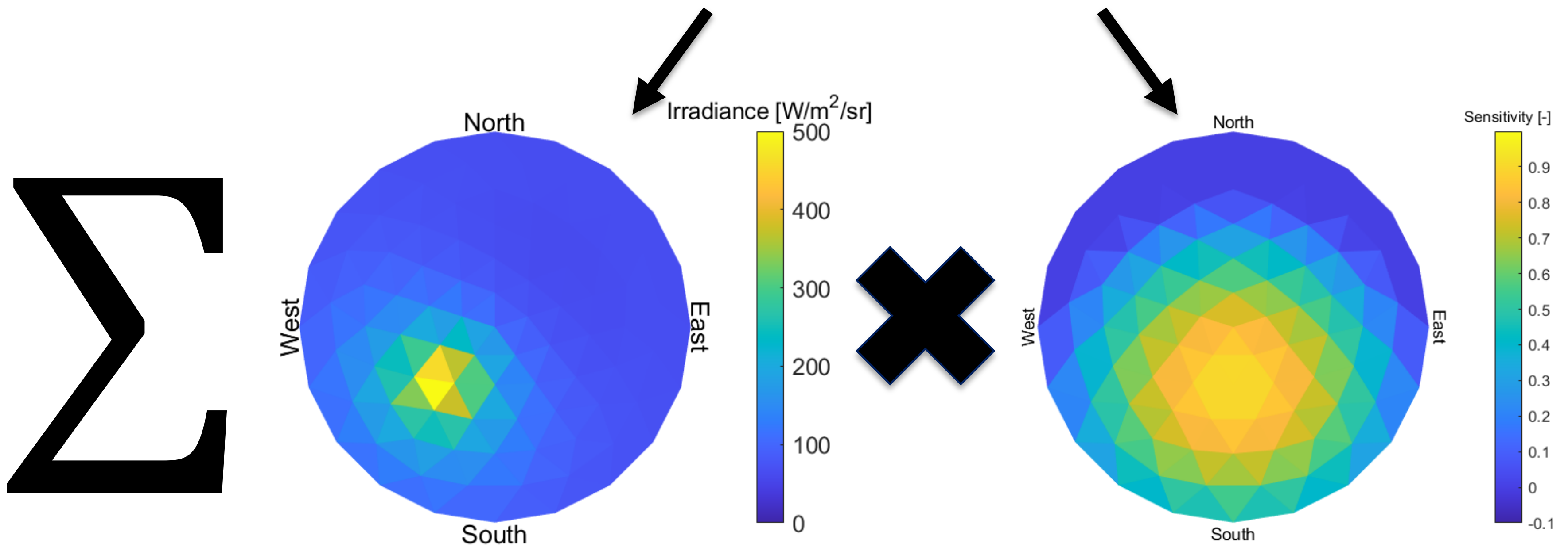

[1] M. R. Vogt, et al., *Sol. Energy Mater*, **247**, 111944 (2022)
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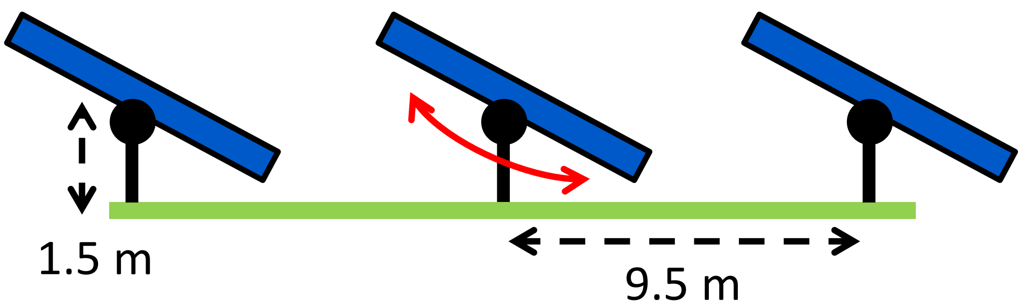
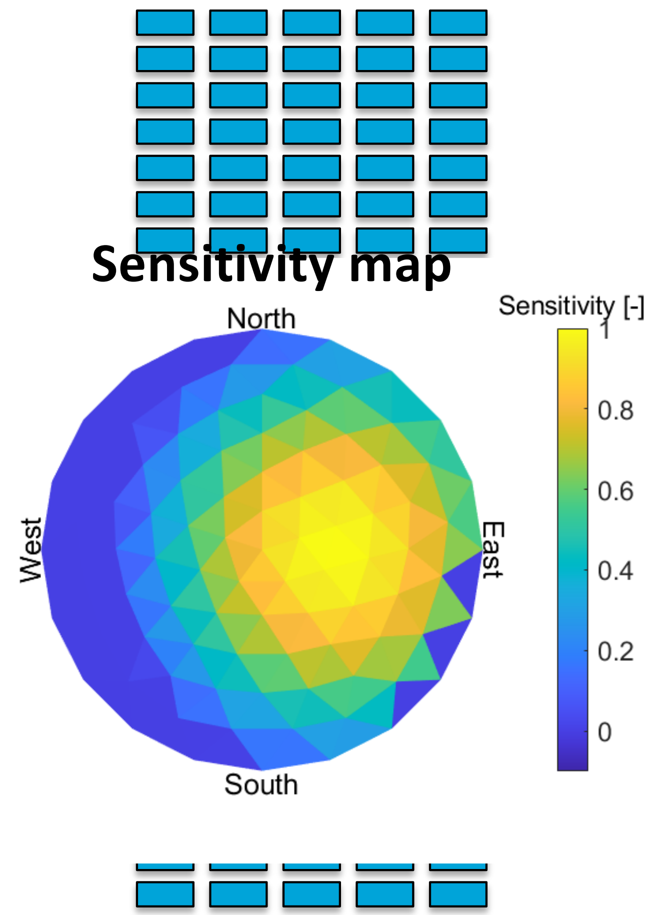
Sensitivity map 1-axis configuration

- **Assumptions**
  - Field of 5 by 25 modules
  - Backward raytracing[1] (two generations)
  - Albedo = 20% (Lambertian)





[1] A. Calcabrini, et al., *Progress in Photovoltaics,* **31**, 134 (2023)

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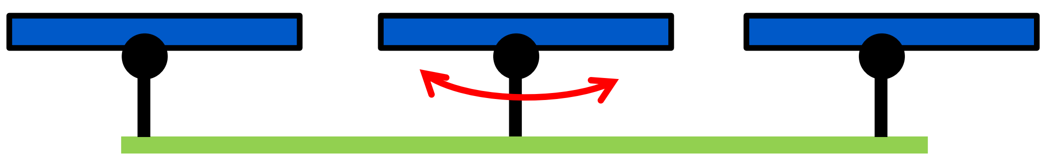

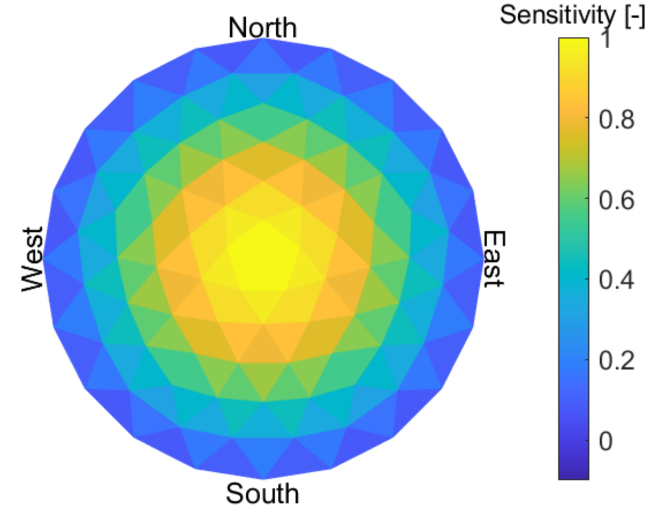

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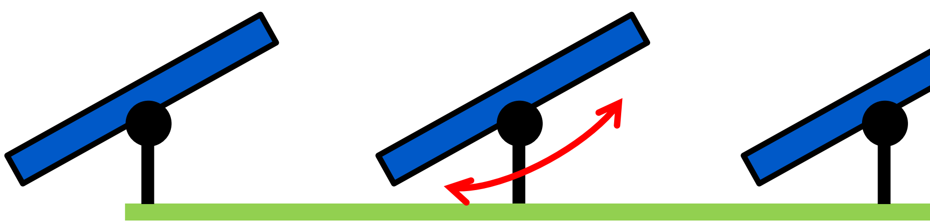
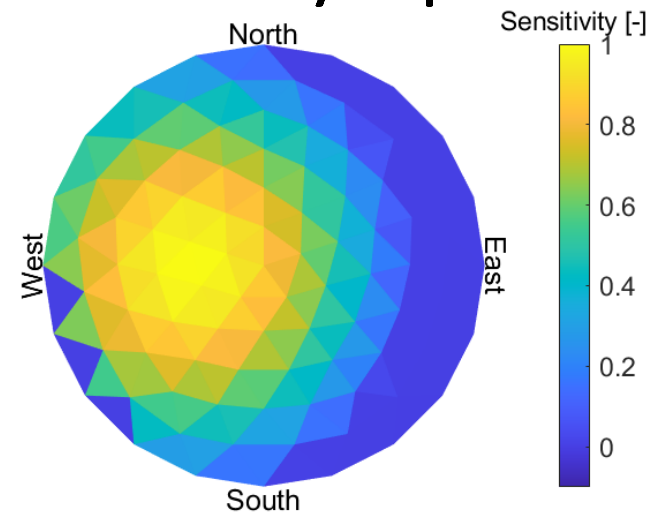


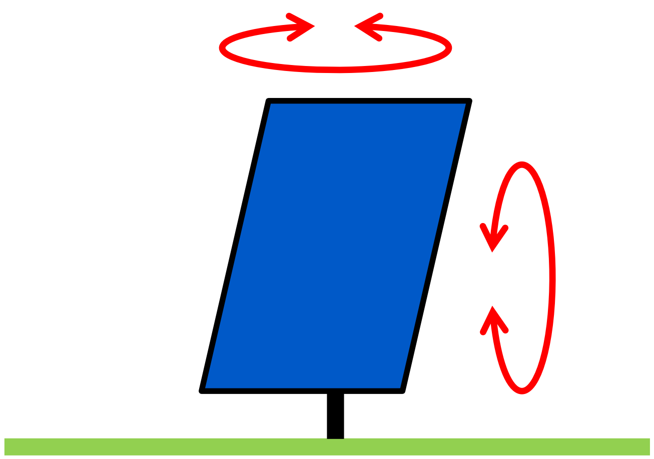
Sensitivity map



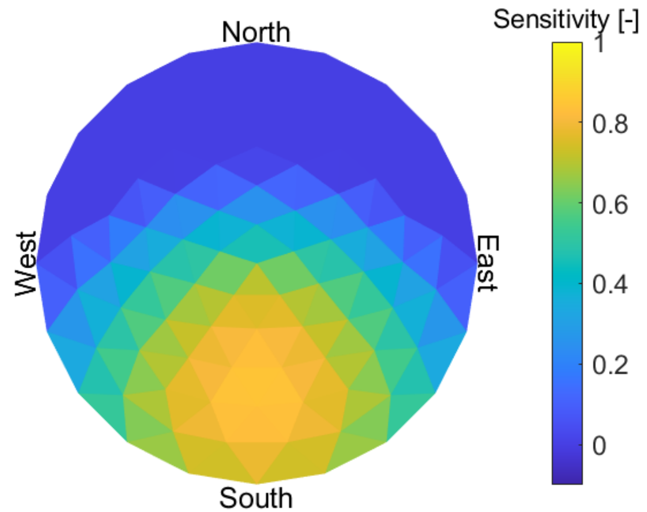
[1] A. Calcabrini, et al., *Progress in Photovoltaics*, **31**, 134 (2023)

Sensitivity map 2-axis configuration

- **Assumptions**
  - Stand-alone module
  - View factor approach
  - Albedo = 20% (specular)



Sensitivity map



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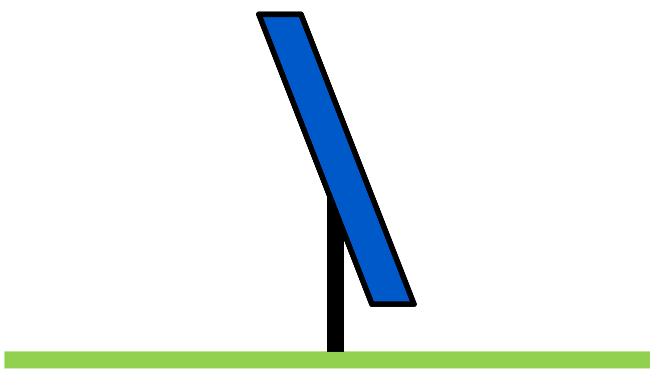

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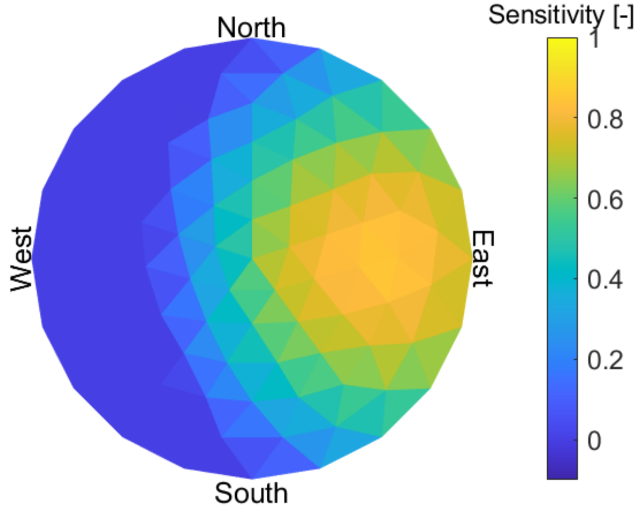

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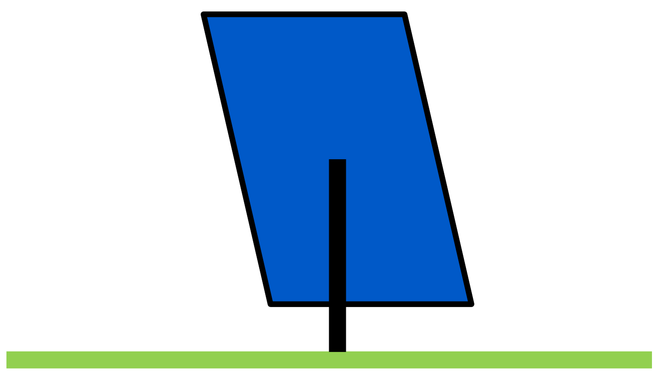

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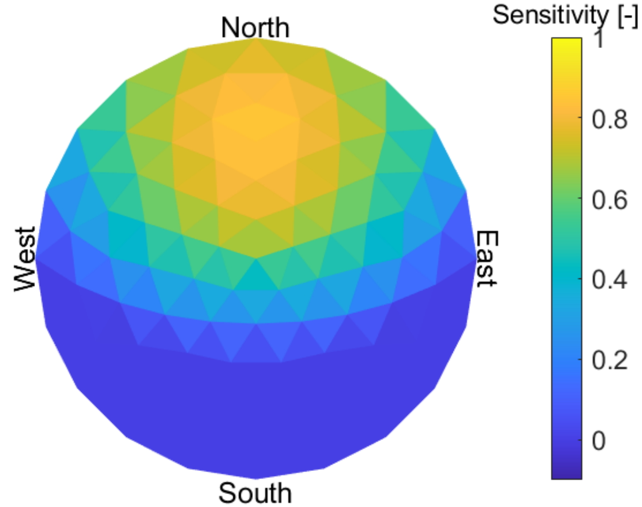

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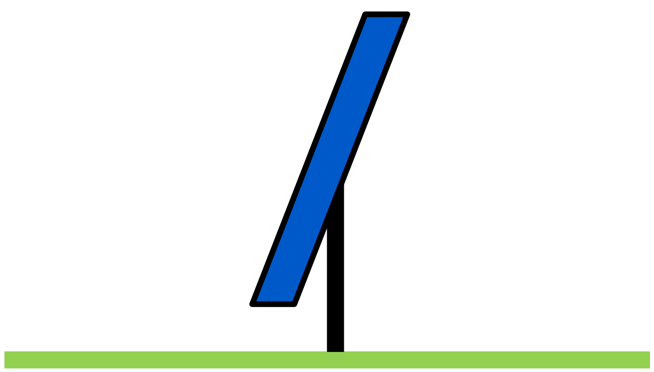

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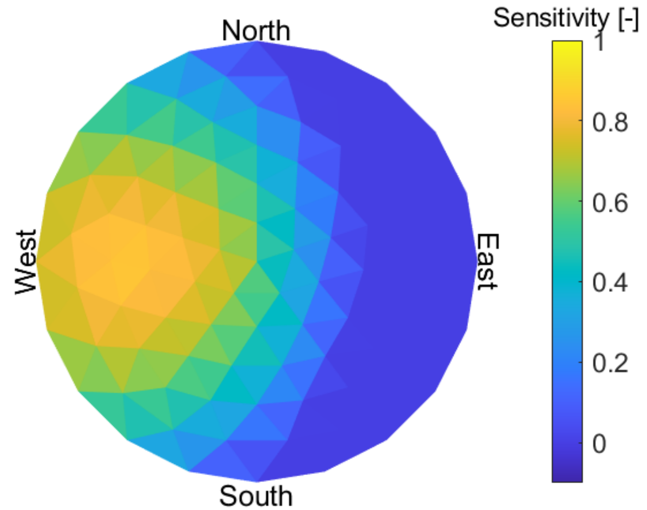
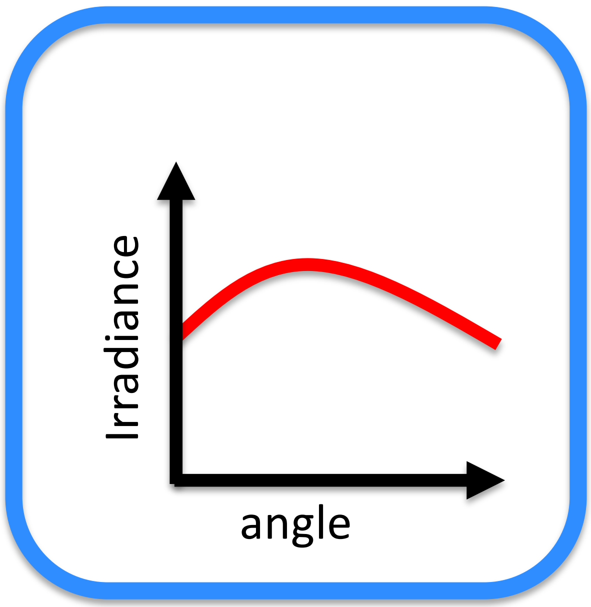


Objectives

Modeling

Optimal position



Simple equation

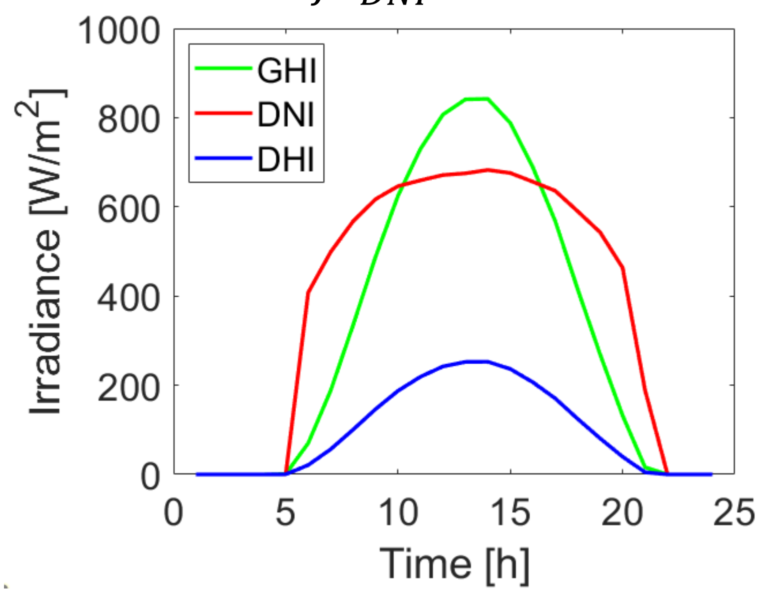
Optimal position

- **Input parameters**
  - Position sun: Delft, July 7th
  - Irradiance
- **Varying parameters**
  - Maximum value GHI ($GHI_{\max}$)
  - Fraction of direct component (fr_{DNI})

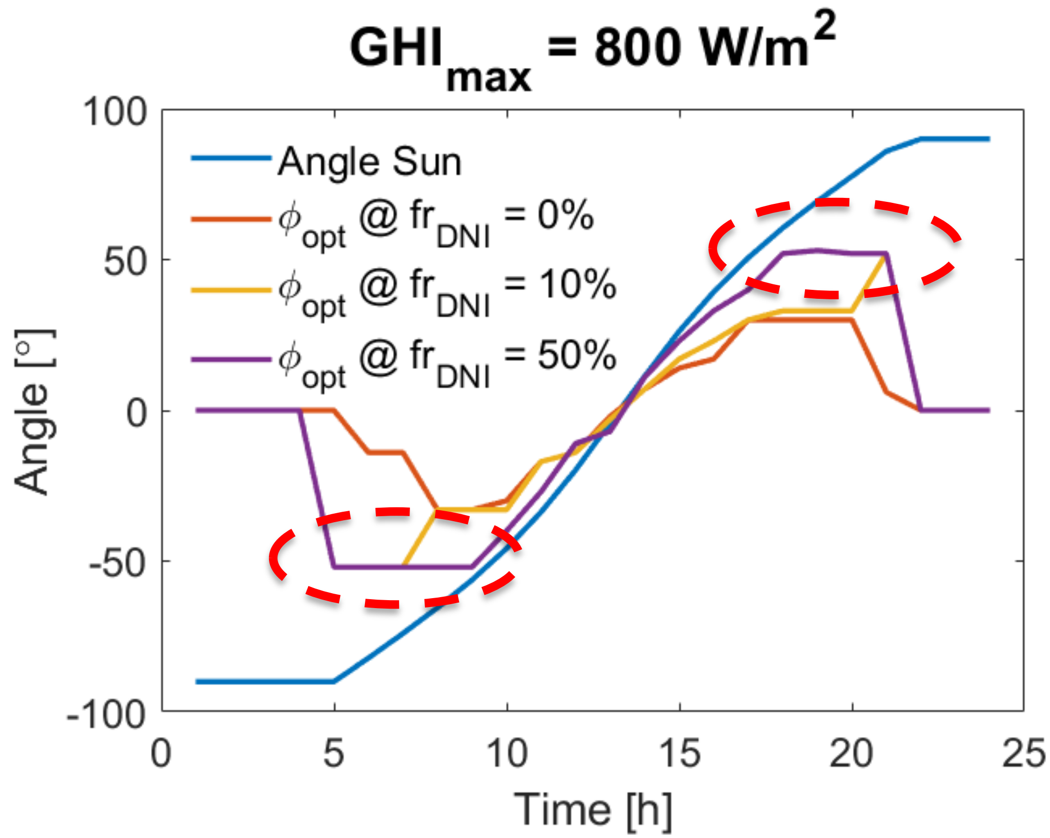
$$GHI = DHI + DNI \cdot \sin(\alpha_s)$$

$$fr_{DNI} = \frac{DNI \cdot \sin(\alpha_s)}{GHI}$$

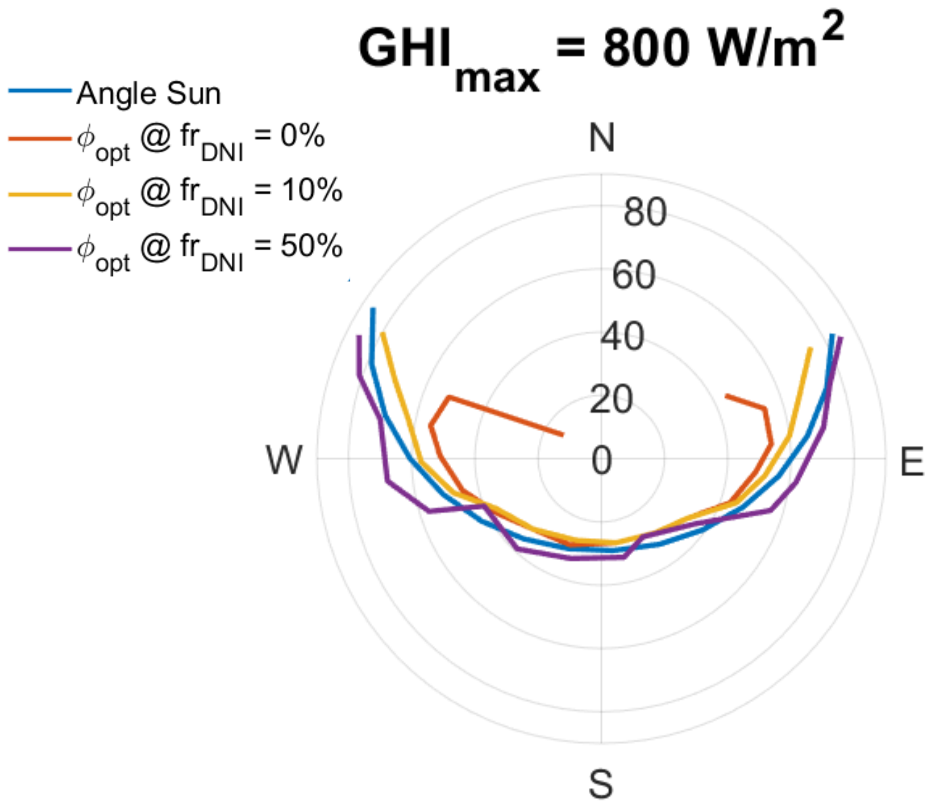
$fr_{DNI} = 70\%$



Optimal position 1-axis



Optimal position 2-axis



Objectives

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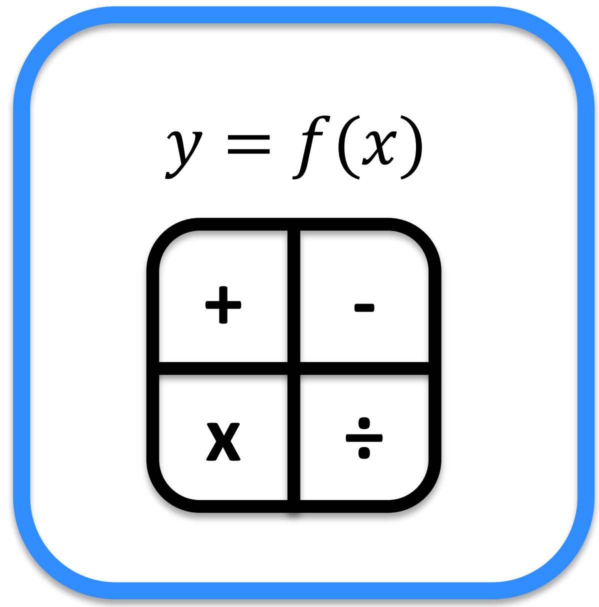
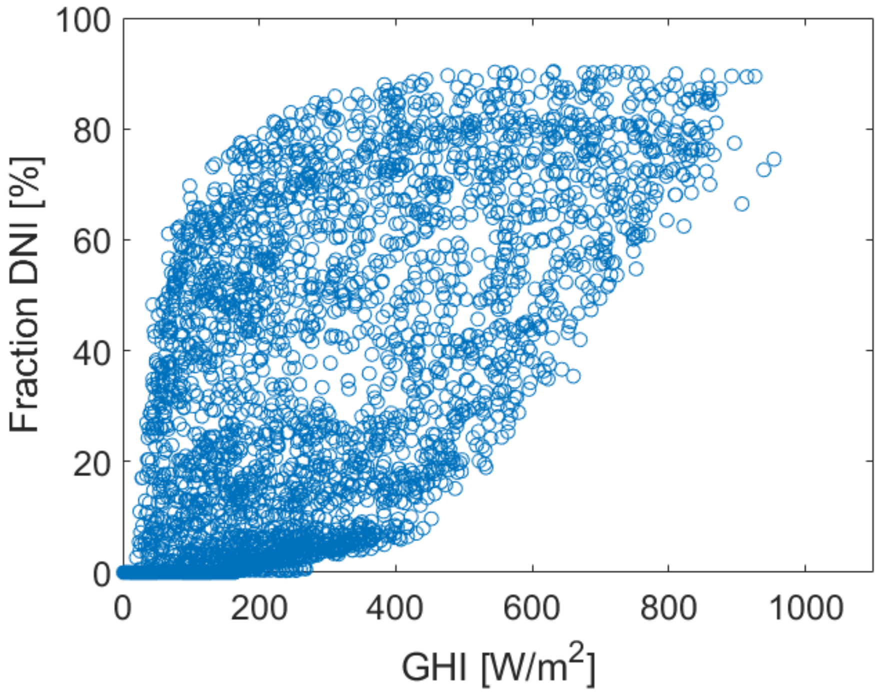
Simple equation



Simple equation

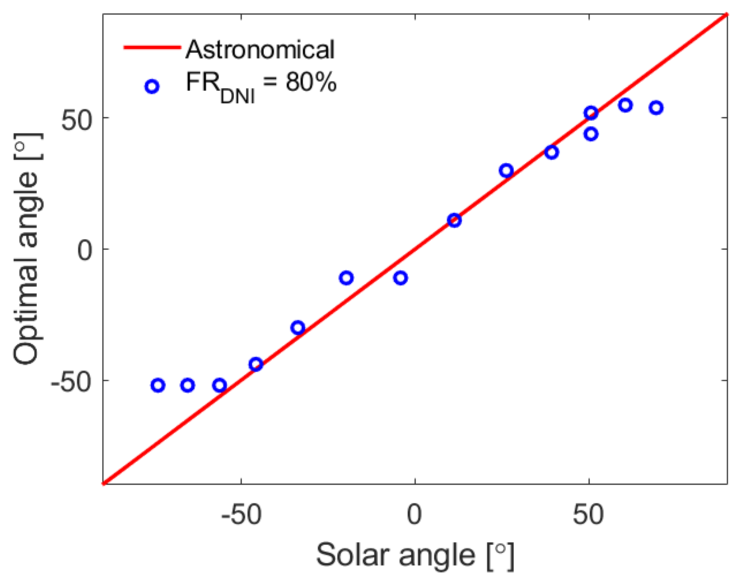
- **Simple equation to avoid complex modeling**
- **Realistic input conditions**
- **RMSE of $\phi_{eq} - \phi_{sim}$**

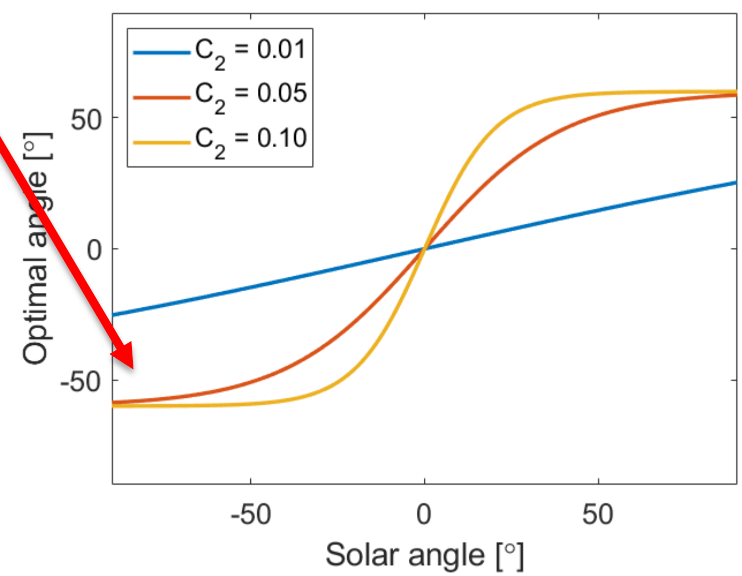
Delft, TMY



Simple equations 1-axis

- **Goal:** $\phi_{eq} = f(\phi_{sun}, GHI, fr_{DNI})$ $\boxed{C_2 = c_{2,1} + c_{2,2} \cdot fr_{DNI}}$
- **Propose:** $\phi_{eq} = C_1\left(\frac{2}{1+e^{-C_2\phi_{sun}}} - 1\right)$





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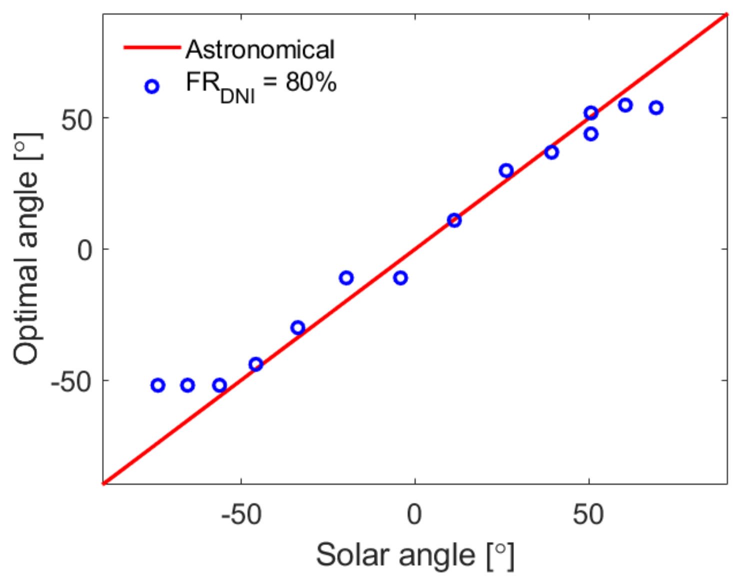


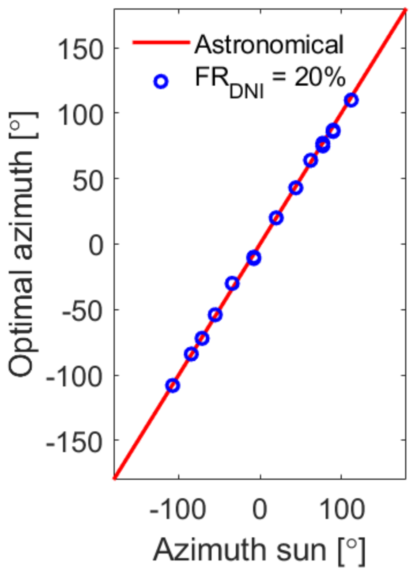
$C_1[\,^\circ]$	55
$c_{2,1}[(\,^\circ)^{-1}]$	0.012
$c_{2,2}[(\,^\circ)^{-1}]$	0.026
$RMSE^*_{astro}[\,^\circ]$	$4.7 \cdot 10^{-3}$
$RMSE^*_{eq}[\,^\circ]$	$1.9 \cdot 10^{-3}$

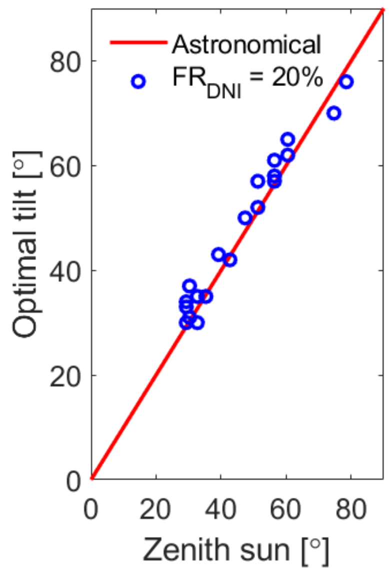
*weighted with GHI

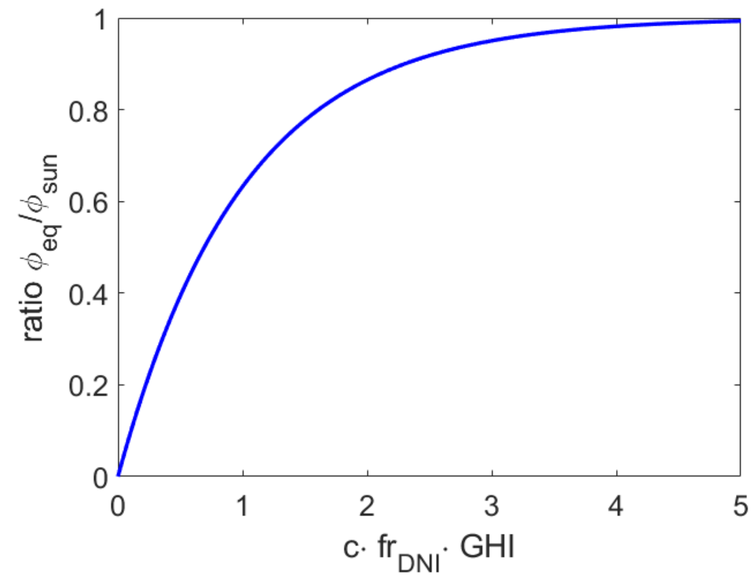
Simple equations 2-axis

- **Goal:** $Az_{eq} = f(Az_{sun}, GHI, fr_{DNI})$ $\phi_{eq} = f(\phi_{sun}, GHI, fr_{DNI})$

- **Propose:** $Az_{eq} = Az_{sun}$ $\phi_{eq} = \left(1 - e^{-c \cdot fr_{DNI} \cdot GHI}\right)\phi_{sun}$







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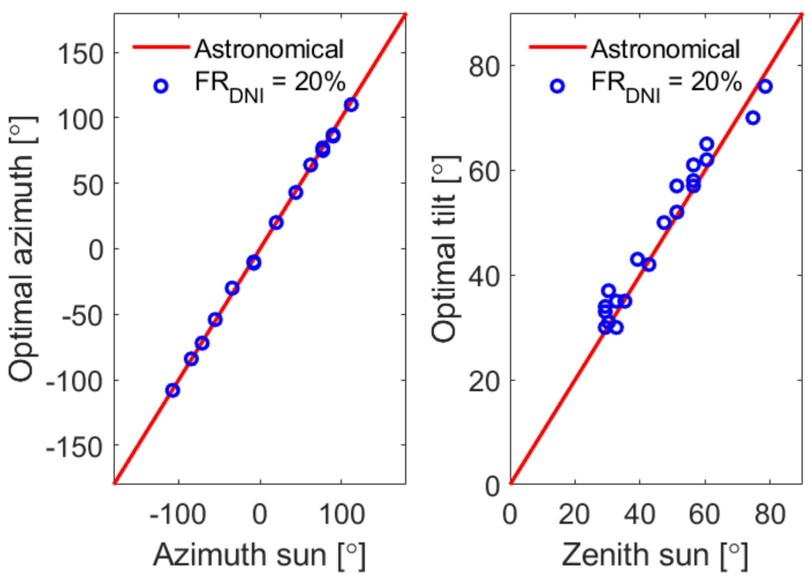
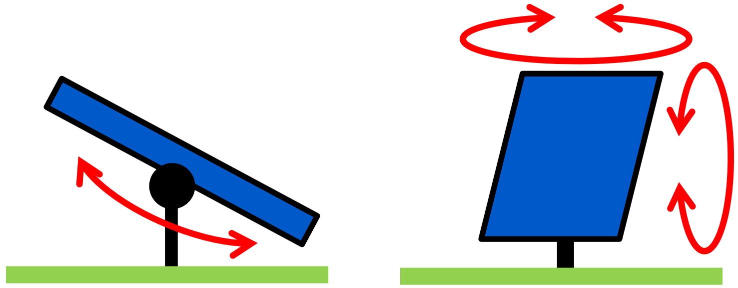


$c\ [(W/m^2)^{-1}]$	0.075
$\text{RMSE*}_{astro}[\ ^\circ]$	$4.5 \cdot 10^{-3}$
$\text{RMSE*}_{new}[\ ^\circ]$	$4.0 \cdot 10^{-3}$

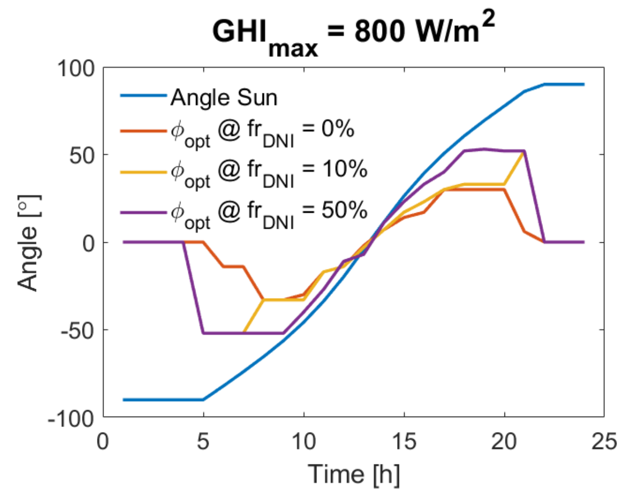
*weighted with GHI

Conclusion

- Modeling framework 1-axis and 2-axis



- Optimal position for different weather conditions
- Equations to predict optimal orientation



1 axis
$\phi_{eq} = C_1 \left(\frac{2}{1 + e^{-C_2 \cdot \phi_{sun}}} - 1 \right)$

2 axis
$Az_{eq} = Az_{sun}$ $\phi_{eq} = \left(1 - e^{-c \cdot fr \cdot Irr}\right) \cdot \phi_{sun}$

Thank you for your attention!

TU Delft Institutes

Urban Energy

e-Refinery

AgTech

TU Delft Climate Action Programme

Contacts

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PVMD funding

HyET Solar Flexible light weight solar modules

HORIZON 2020

Horizon Europe

HORIZON 2020

HyET Solar Flexible light weight solar modules

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Different climates