POLITECNICO
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Photovoltaic power generation nowcasting: cloud type classification forecast through satellite data and imagery

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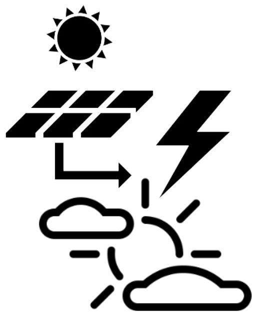
Introduction

FRAMEWORK

Grid connected PV systems (and RES) are expected to **grow in number**



PROBLEM

Sudden variations **in weather conditions** may cause significant variations in RES power production. In PV systems this is mainly due to **moving clouds** which are affecting **solar radiation**.

In **national electrical grids sudden power inflows raise issues** of **stability** and **reliability.** These fluctuations on **small scale**, i.e. in **microgrids**, affect **dispatchability.**

ACTUAL SOLUTION

Usually, two technologies are adopted to mitigate this issue:

- **Battery energy storage system** (**ESS**), which should be properly sized and coordinated “a priori”
- Backup generators (usually carbon based) are included

GAP → **An accurate short-term solar radiation forecast is needed!**

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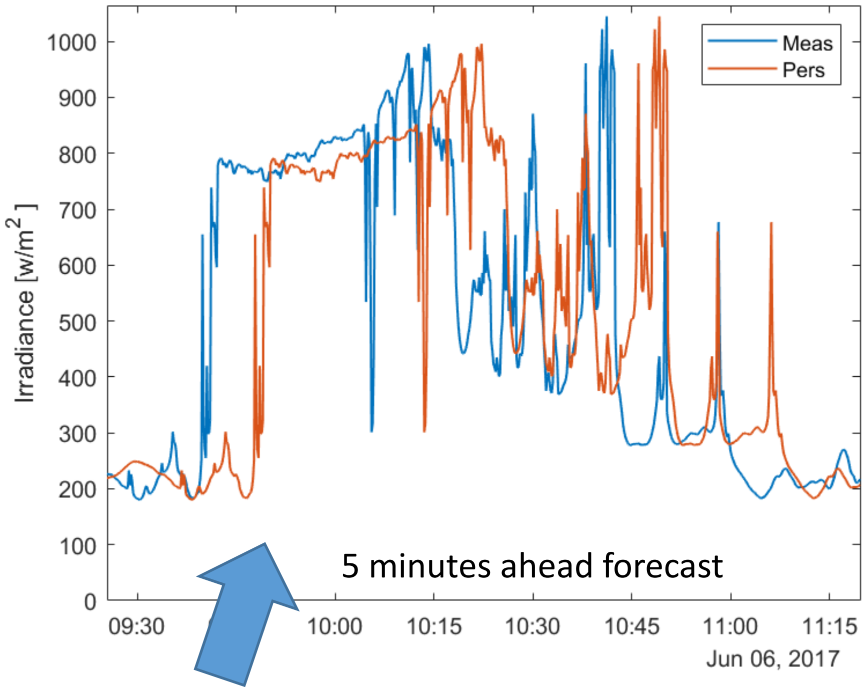
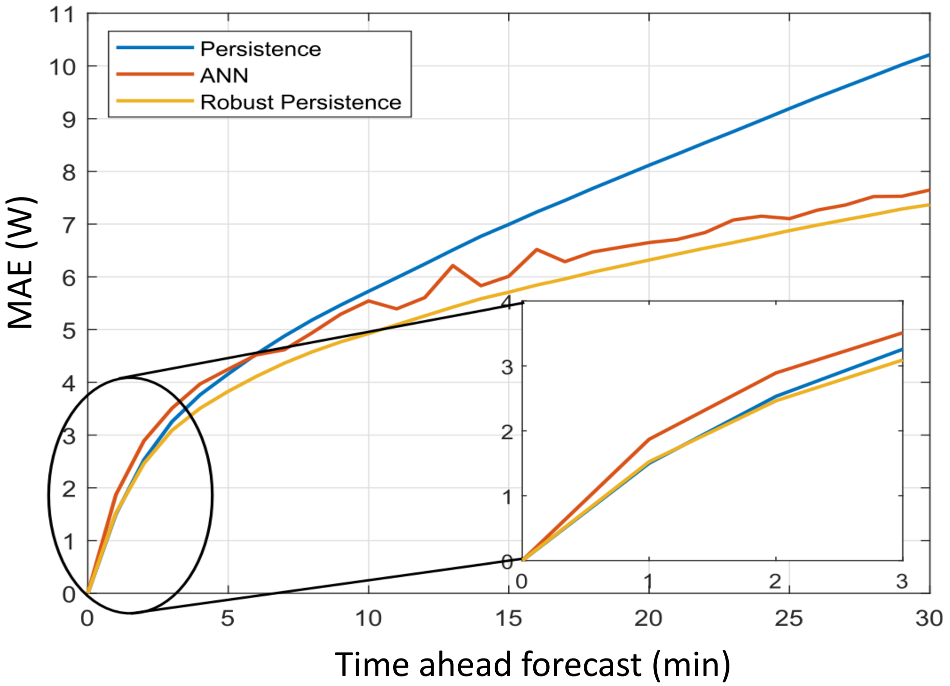
Nowcasting: Persistence vs ANN

Persistence and ANN are typical methods for day-ahead and intraday forecasting of solar radiation.



Persistence fails in predicting **sudden ramps and drops** of solar irradiadiance



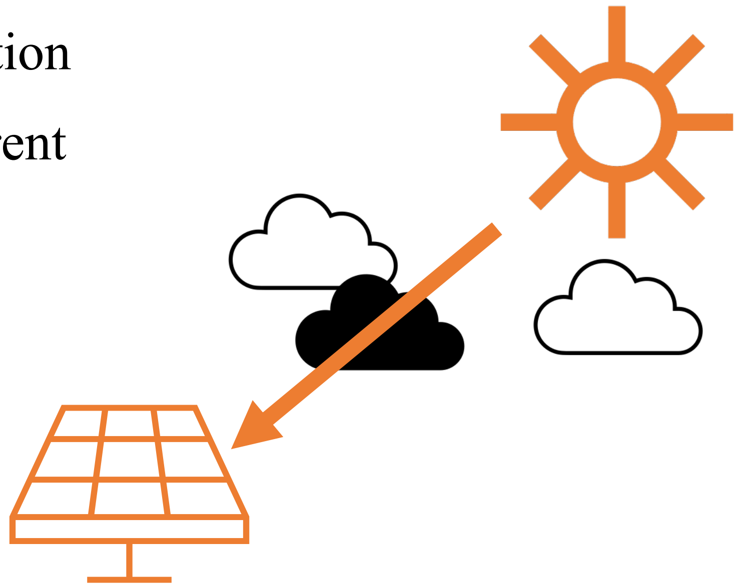
After 5 minutes ahead forecast **robust persistence** shows good accuracy

S. Leva, A. Nespoli, S. Pretto, M. Mussetta and E. Ogliari, "PV Plant Power Nowcasting: A Real Case Comparative Study With an Open Access Dataset," in IEEE Access, vol. 8, pp. 194428-194440, 2020

Proposed Solution

TARGET: to set a simplified methodology for 15 minutes ahead forecast (nowcasting) of the sudden variations (peaks and drops) of solar irradiance on a given location through satellite images.

1. Dynamic Cloud model development: cloud-to-Sun solar irradiance interaction
2. Cloud type classification forecast through satellite data and imagery: different training layout comparison and reduced satellite data classification
3. Most effective Machine Learning techniques (ANN and Random Forest) for Nowcasting setting up: sizing and performance assessment



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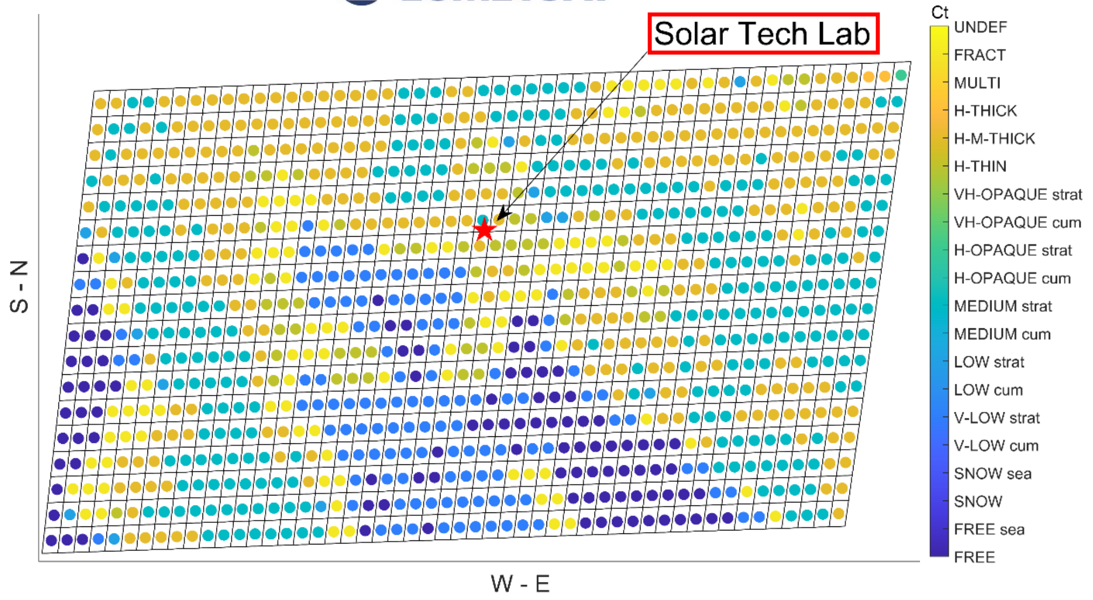
Case study: SolarTech Lab, Milan

- **SATELLITE DATA (15 min.)**

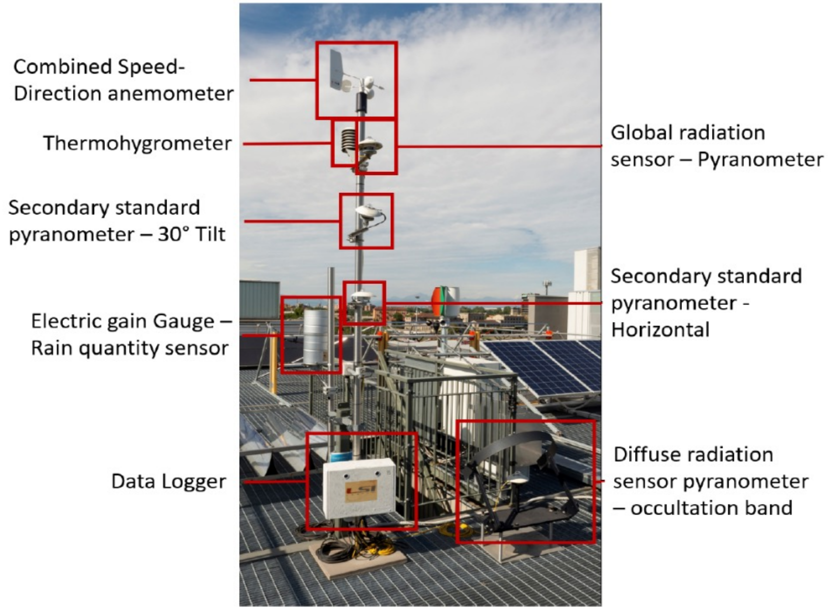
EUMETSAT



- Size: 18x51 pixel (1 pixel =3x5 km)
- Cloud type (19 classes) & Cloud top altitude
- Latitude and longitude
- 385 images available (~10 days)

RSE Ricerca Sistema Energetico

- **WEATHER STATION MEASUREMENTS (10 sec.)**



- Global Horizontal Irradiance (GHI) [W/m^2]
- Wind speed [m/s] and direction [°]
- Rain [mm]

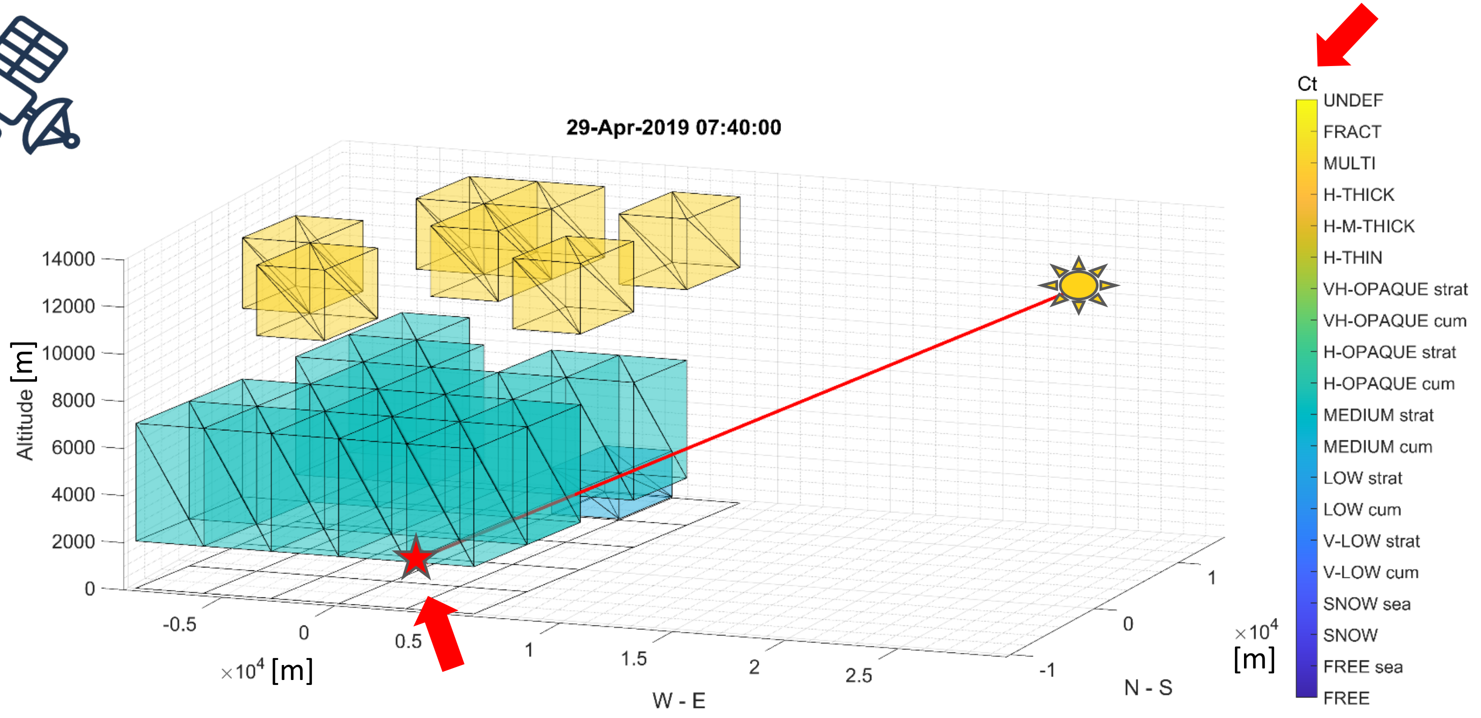
Solar Tech LAB

Dynamic Cloud model 1/2

The aim of this model is to identify the cloud position (pixel) that could mitigate the beam component of solar radiation on a given location

Available information:

- Latitude and longitude of each pixel
- Cloud type
- Cloud top altitude measure
- Cloud bottom altitude (from literature)
- Solar altitude and azimuth angles
- Clear Sky GHI_{CS}



★ : Solar Tech Lab

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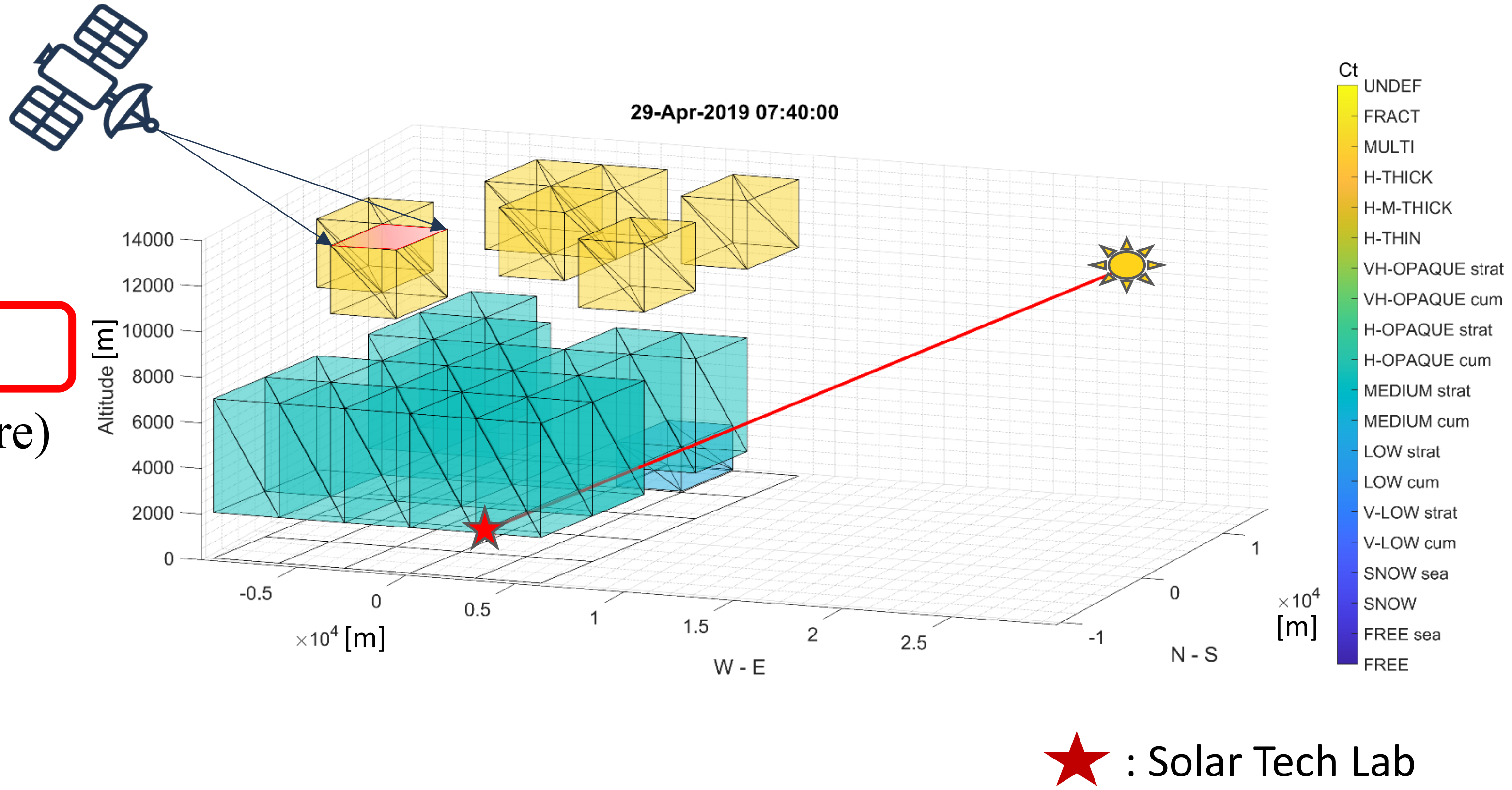

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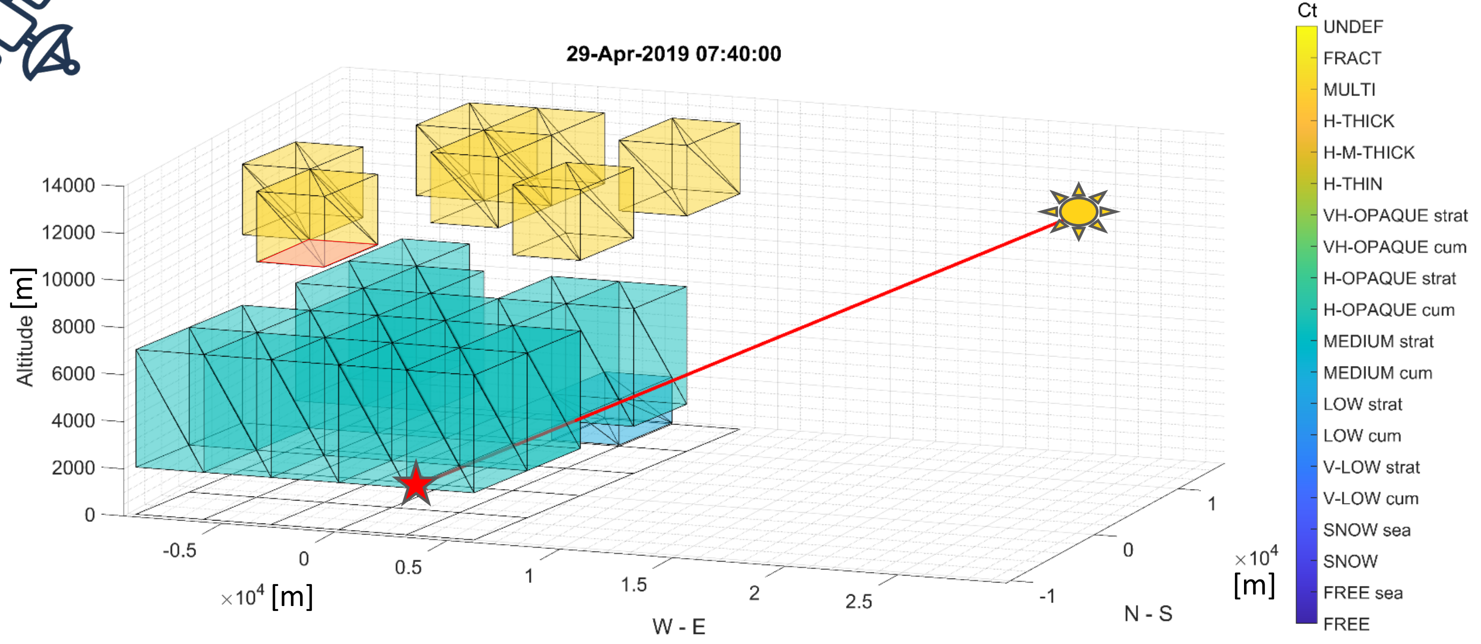

★ : Solar Tech Lab

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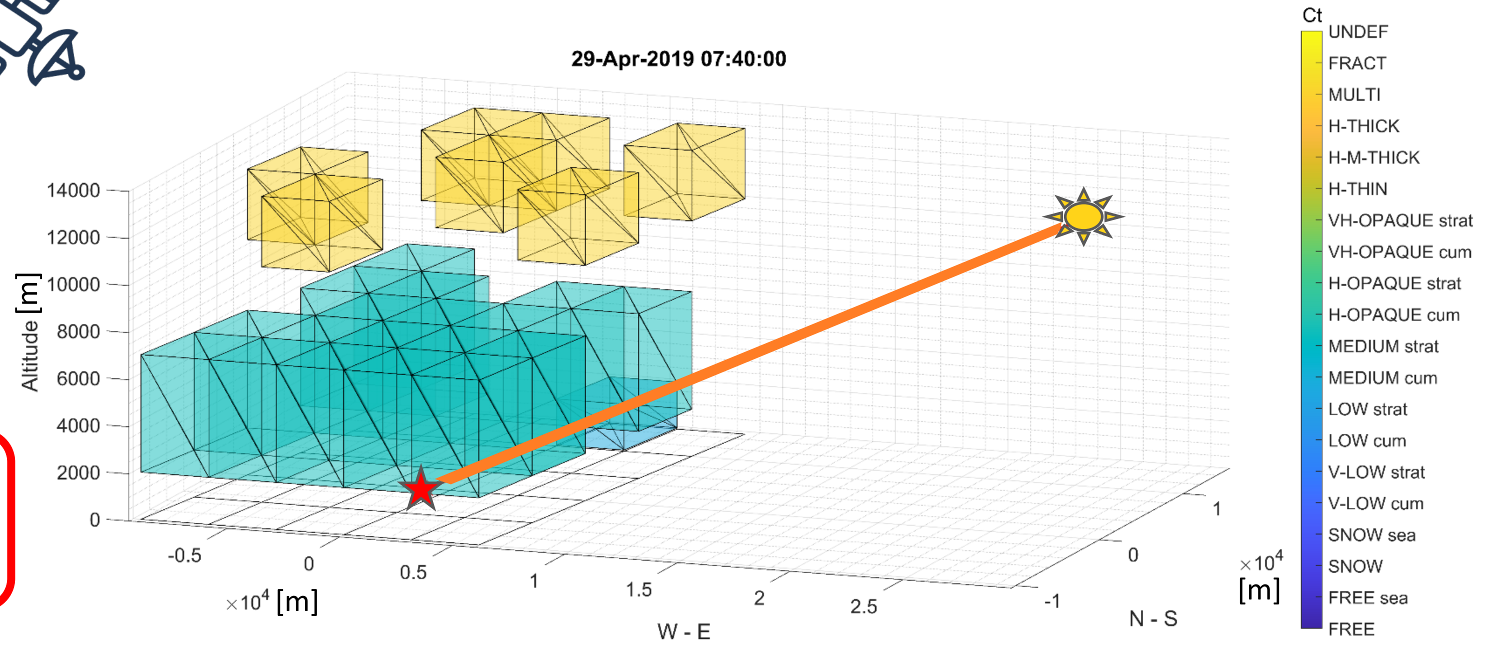

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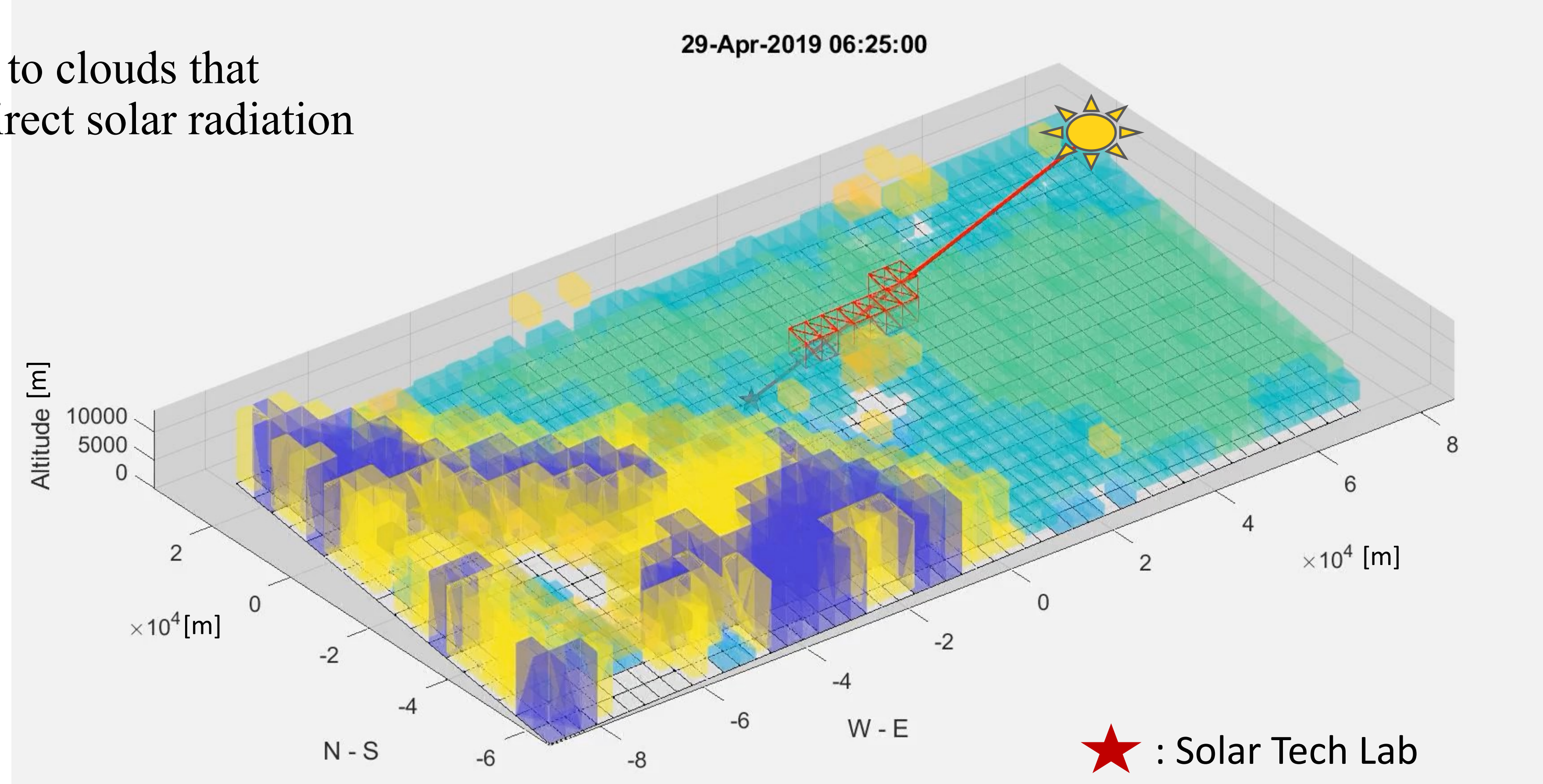
Complete model

red pixels refer to clouds that interfere with direct solar radiation



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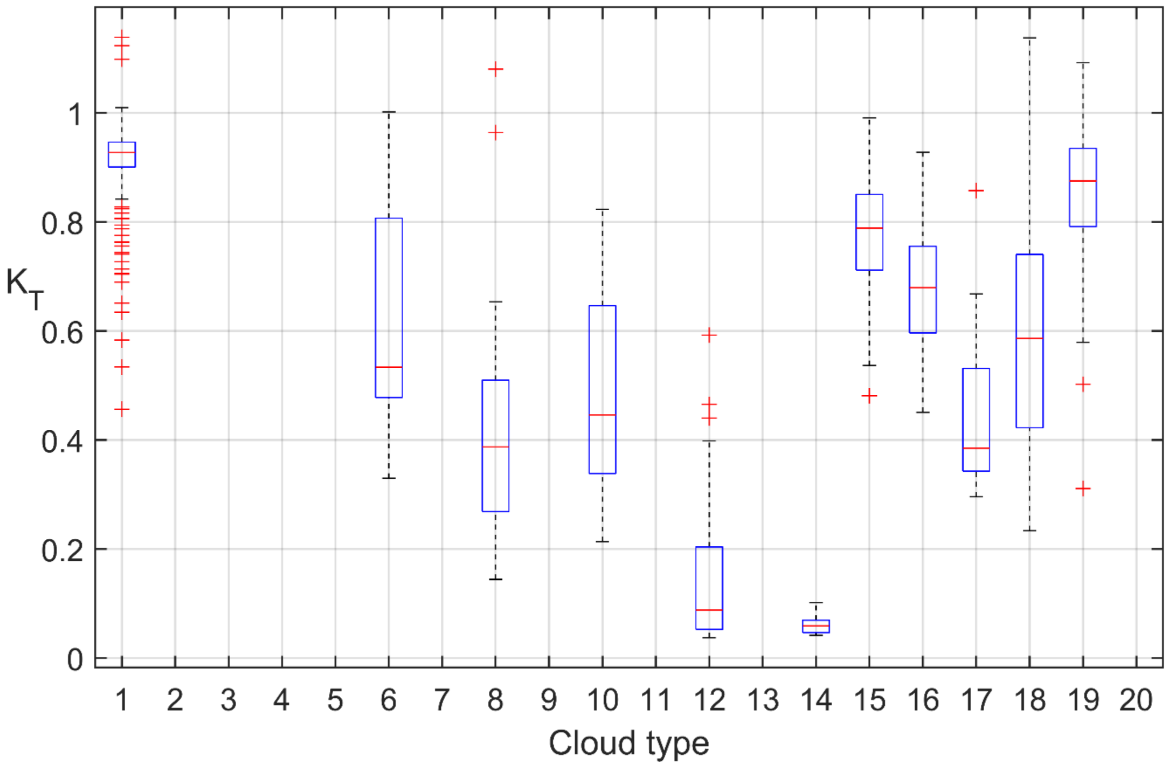
Cloud type classification 1/2

red pixels from the Cloud model ⟶ Clearness index ($K_T = \frac{GHI_{measured}}{GHI_{clear\ sky\ model}}$)



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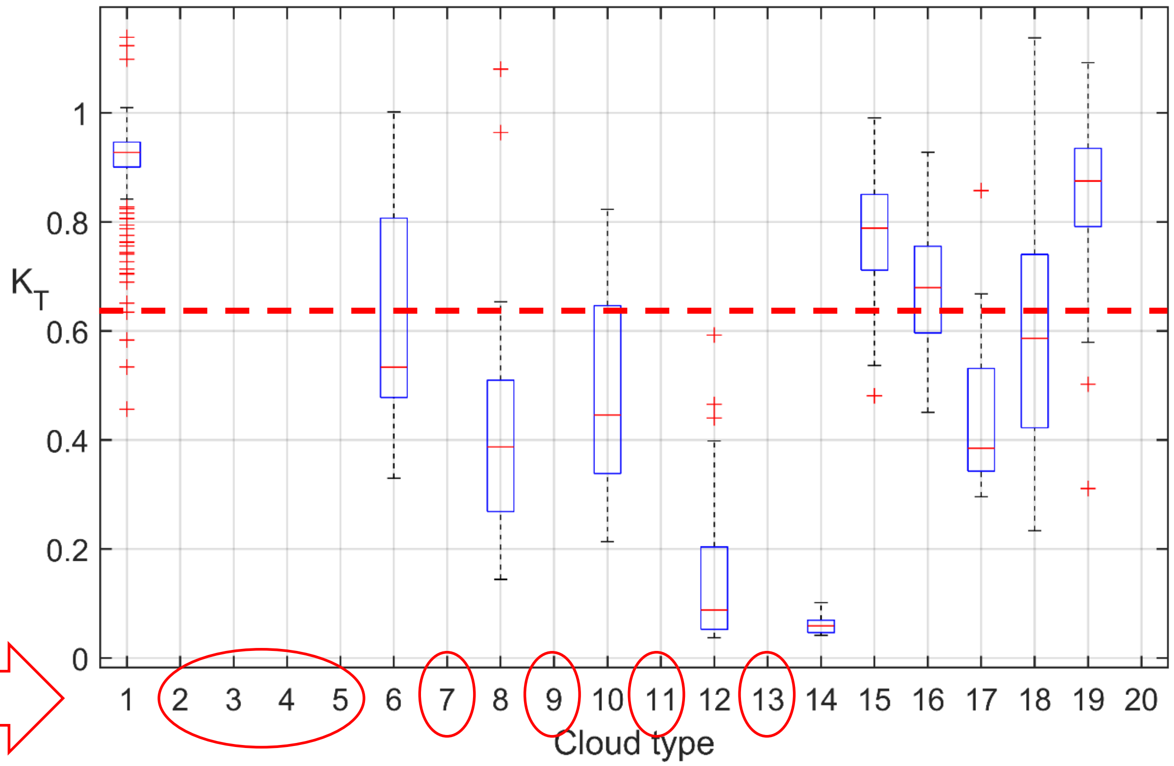
Cloud type classification 1/2

red pixels from the Cloud model ⟶ Clearness index ($K_T = \frac{GHI_{measured}}{GHI_{clear\ sky\ model}}$)

Different Cloud types with overlapping K_T



Some classes with few samples

Missing Cloud types

A reduced satellite data classification is needed!

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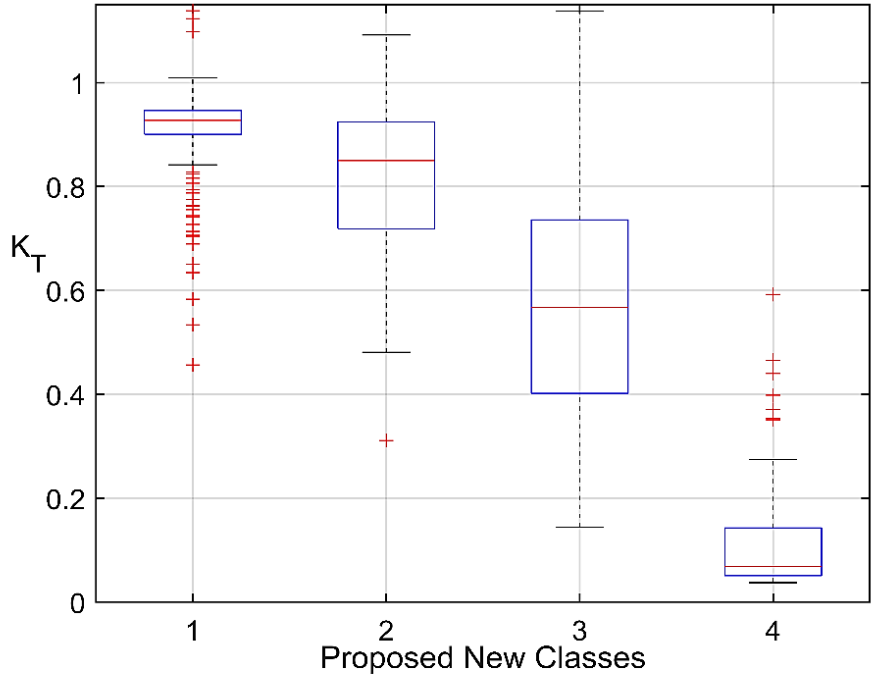
Cloud type classification 2/2

- 4 New Classes proposed by merging different Cloud Classes from the previous 19

Original classes Conf. 1	Aggregated classes Conf. 2	Hot encode Conf. 3
1	1	[1, 0, 0, 0]
15, 19	2	[0, 1, 0, 0]
6, 8, 10, 16, 17, 18	3	[0, 0, 1, 0]
12, 14	4	[0, 0, 0, 1]

Reduced Cloud Classes with mainly non overlapping K_T



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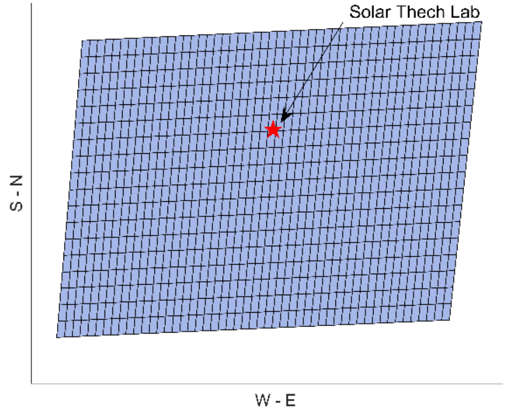
Input dataset selection

5 proposed input scenarios:

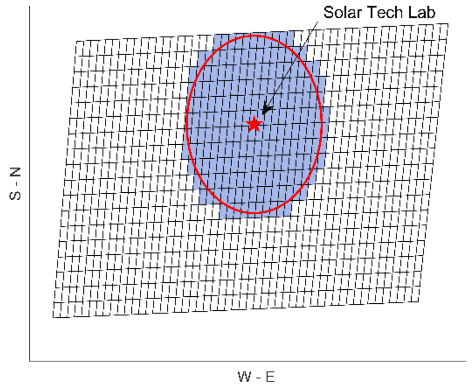
Exploited pixel

Full available dataset

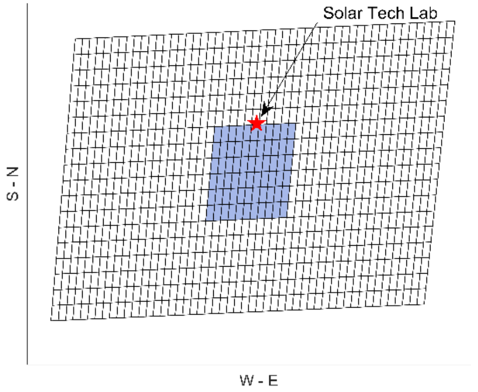


Full Frame

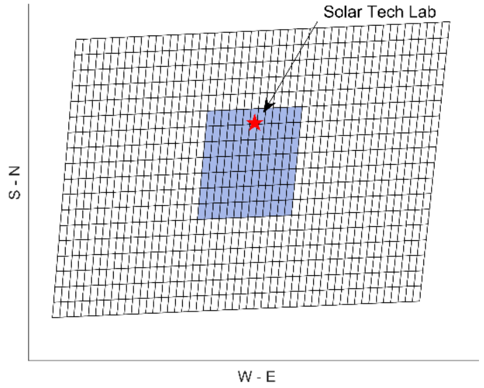
4 Reduced datasets



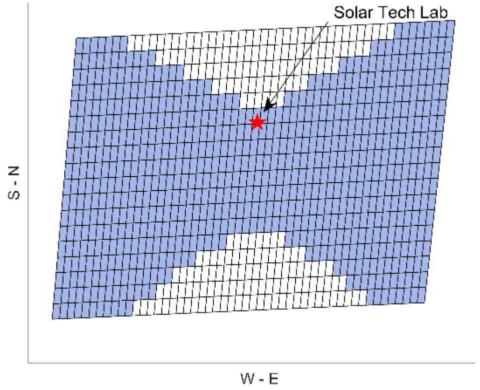
Circle, radius 30 Km



Area 11x6



Area 13x7



Butterfly

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Input dataset selection

Input

Satellite data provided in three different configurations for each previous scenario (3 conf. x 5 scenarios = 15)

- Conf. 1 = Original classification (1-19)
- Conf. 2 = Reduced classification (1- 4)
- Conf. 3 = Reduced classification (1- 4) in One-Hot-Encode

Common data
Solar altitude angle
Solar azimuth angle
Wind speed
Wind direction
Rain
Clearness Index

Target

Clearness Index (K_T) Membership Class

Label	Interval
C1	$0 \leq K_T < 0.20$
C2	$0.20 \leq K_T < 0.45$
C3	$0.45 \leq K_T < 0.75$
C4	$K_T \geq 0.75$

K_T Classes from bibliography

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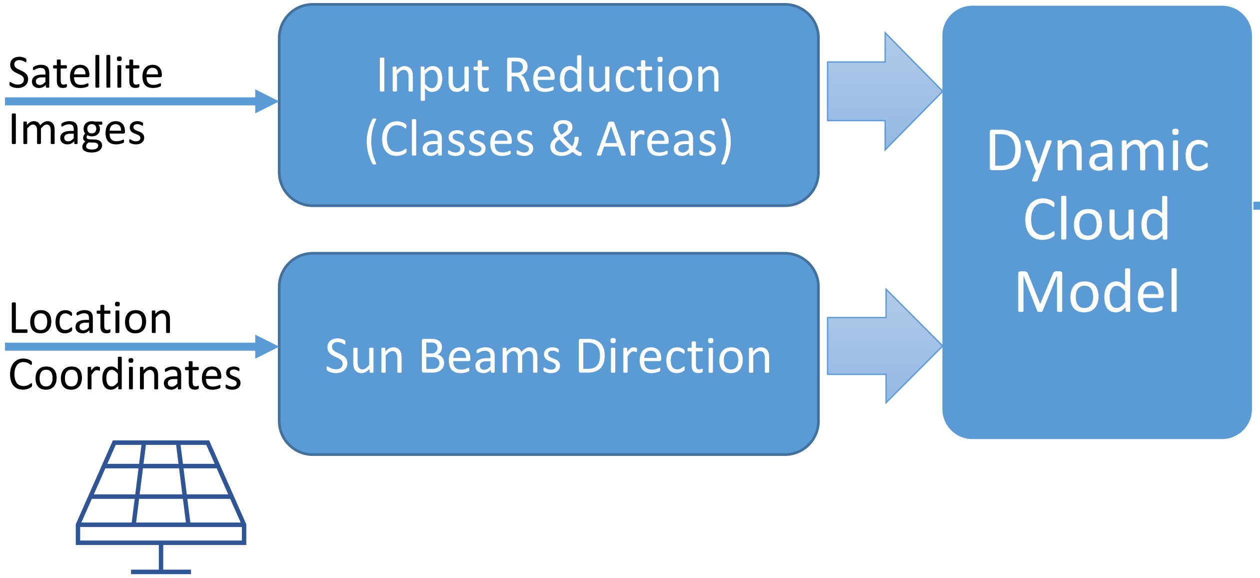
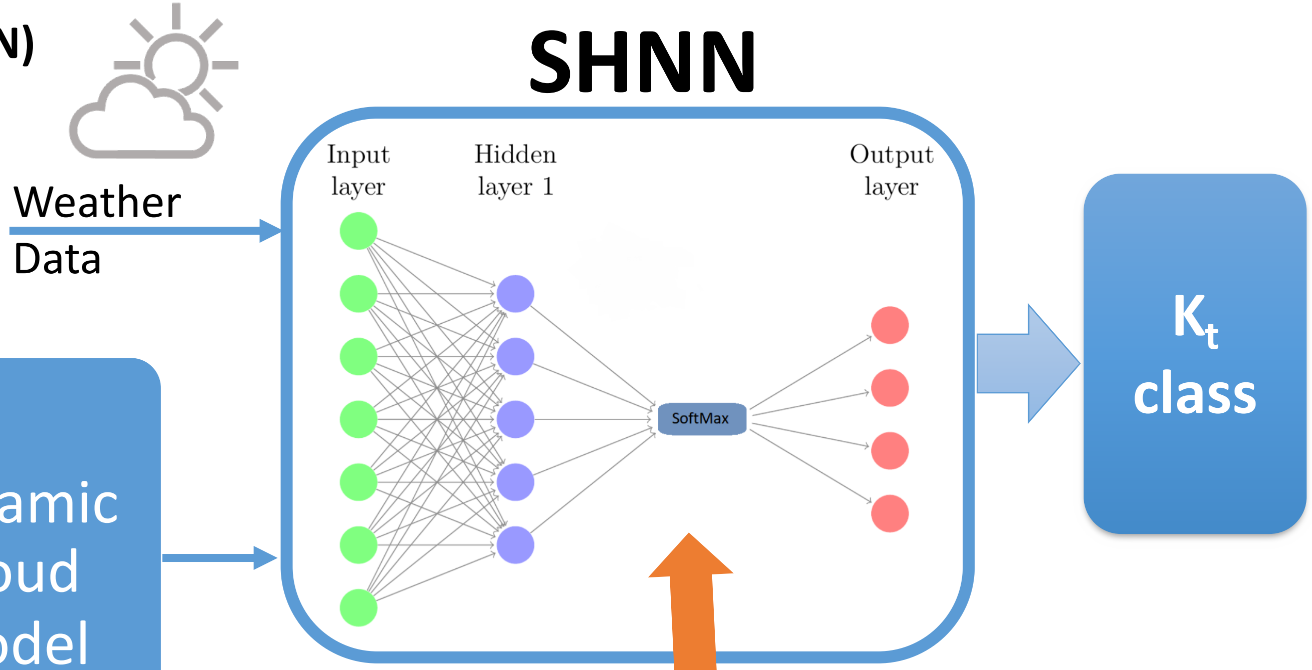
ANN Layout

Single Hidden Layer FeedForward Neural Network (SHNN)

- *Scaled Conjugate Gradient* as training algorithm
- *Cross-entropy* as performance function
- *Ensemble forecast (average of 10 results)*
- *70% training – 15% validation*





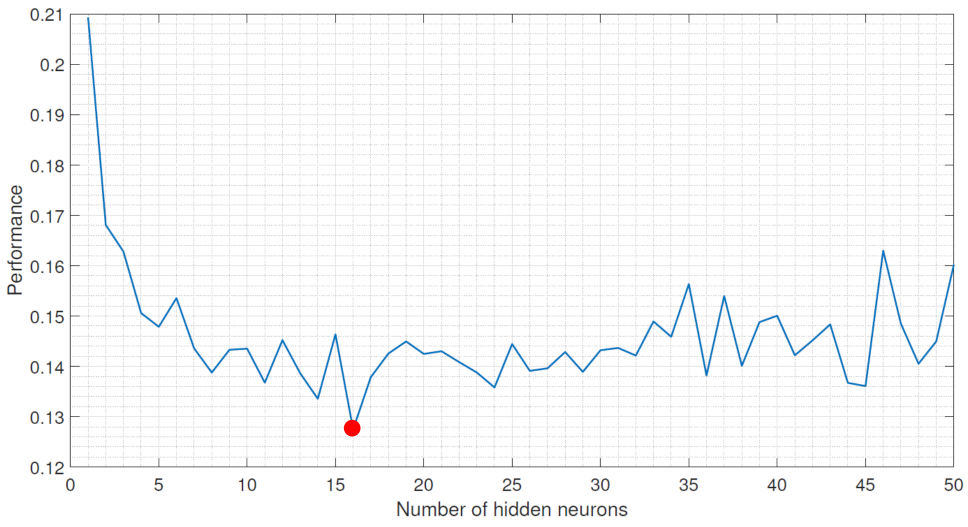
The output unit activation function is the softmax function:

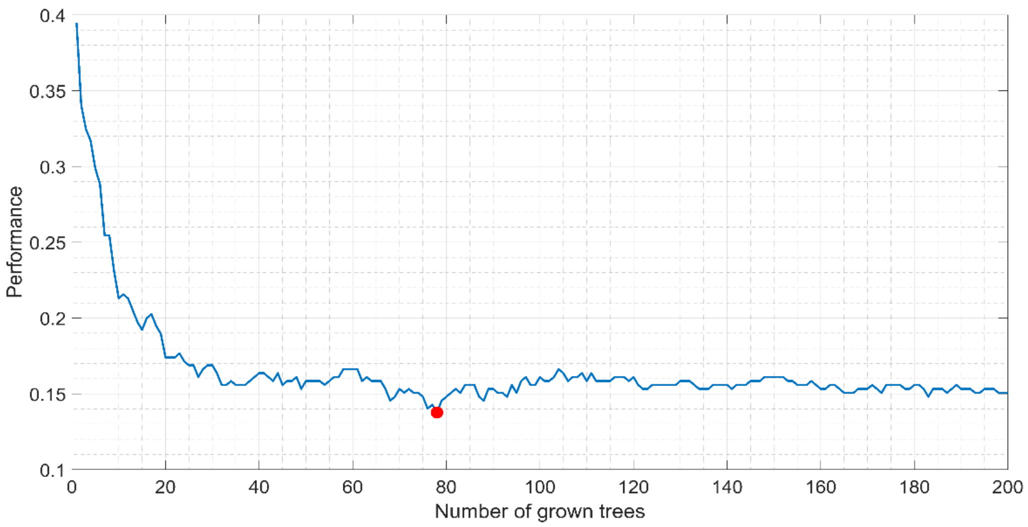
$$y_r(x) = \frac{\exp(a_r(x))}{\sum_{j=1}^{k} \exp(a_j(x))},$$

where $0 \le y_r \le 1$ and $\sum_{j=1}^{k} y_j = 1$.

Sizing and Performance evaluation

Sizing: Identification of the optimal number of Hidden neurons or trees with Out Of Bag (OOB) algorithm





Performance: Identification of the classification performance of each Machine Learning model with OOB algorithm

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Results

Single Hidden layer FFNN	Conf. 1	Conf. 2	Conf. 3
Circumference 30	68.1%	75.8%	73.2%
Area 11x6	72.5%	77.9%	74.0%
Area 13x7	72.5%	76.6%	74.3%
Butterfly	69.6%	79.7%	80.3%
Full Frame	72.5%	79.0%	79.0%

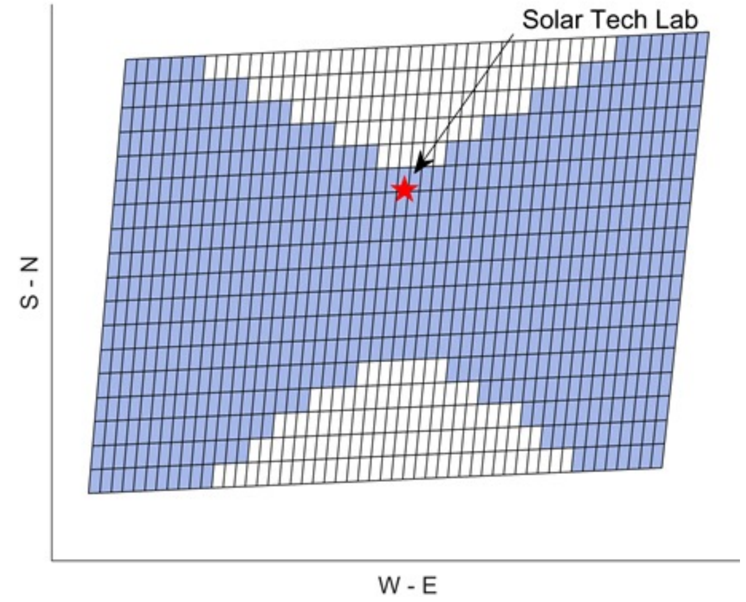
- Increased Classification Accuracy with reduced dataset
- Less accurate than Random Forest

Random Forest	Conf. 1	Conf. 2	Conf. 3
Circumference 30	83.1%	81.6%	81.0%
Area 11x6	82.9%	82.3%	82.3%
Area 13x7	84.2%	83.1%	81.0%
Butterfly	81.6%	82.6%	83.1%
Full Frame	81.8%	81.8%	81.6%

- Best Classification Accuracy
- Globally Robust (always >81%)

Best Results

Single Hidden layer FFNN



Reduced classification (1- 4)
One-Hot-Encode

Output Class \ Target Class	1	2	3	4	
1	**36** 9.4%	**3** 0.8%	**0** 0.0%	**0** 0.0%	92.3% 7.7%
2	**4** 1.0%	**23** 6.0%	**4** 1.0%	**4** 1.0%	65.7% 34.3%
3	**2** 0.5%	**10** 2.6%	**68** 17.7%	**21** 5.5%	67.3% 32.7%
4	**0** 0.0%	**6** 1.6%	**22** 5.7%	**182** 47.3%	86.7% 13.3%
	85.7% 14.3%	54.8% 45.2%	72.3% 27.7%	87.9% 12.1%	**80.3% 19.7%**

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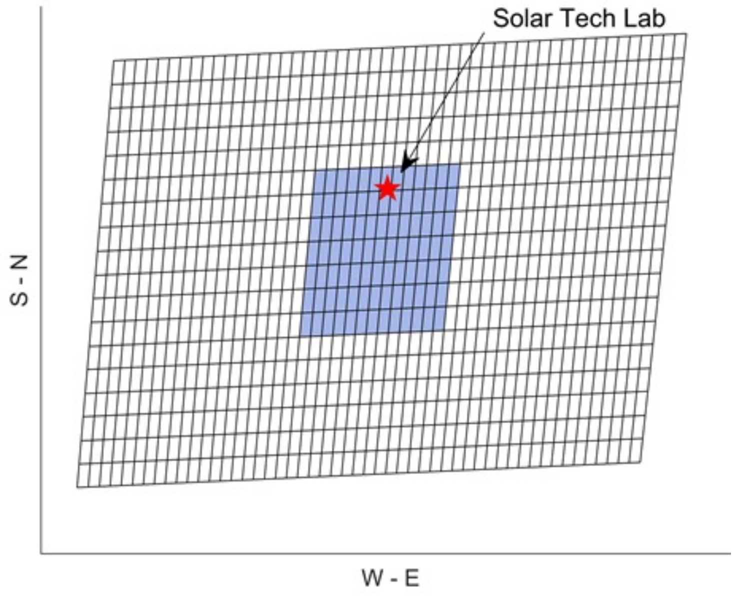
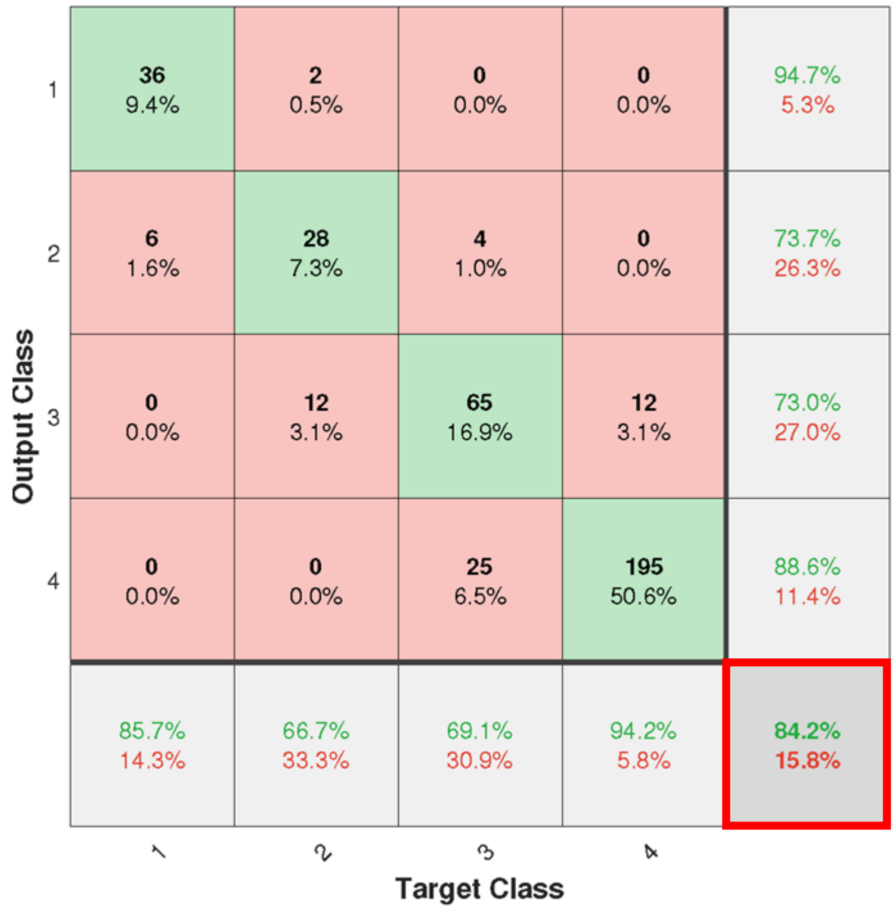
Best Results

Random Forest



Original classification (1-19)



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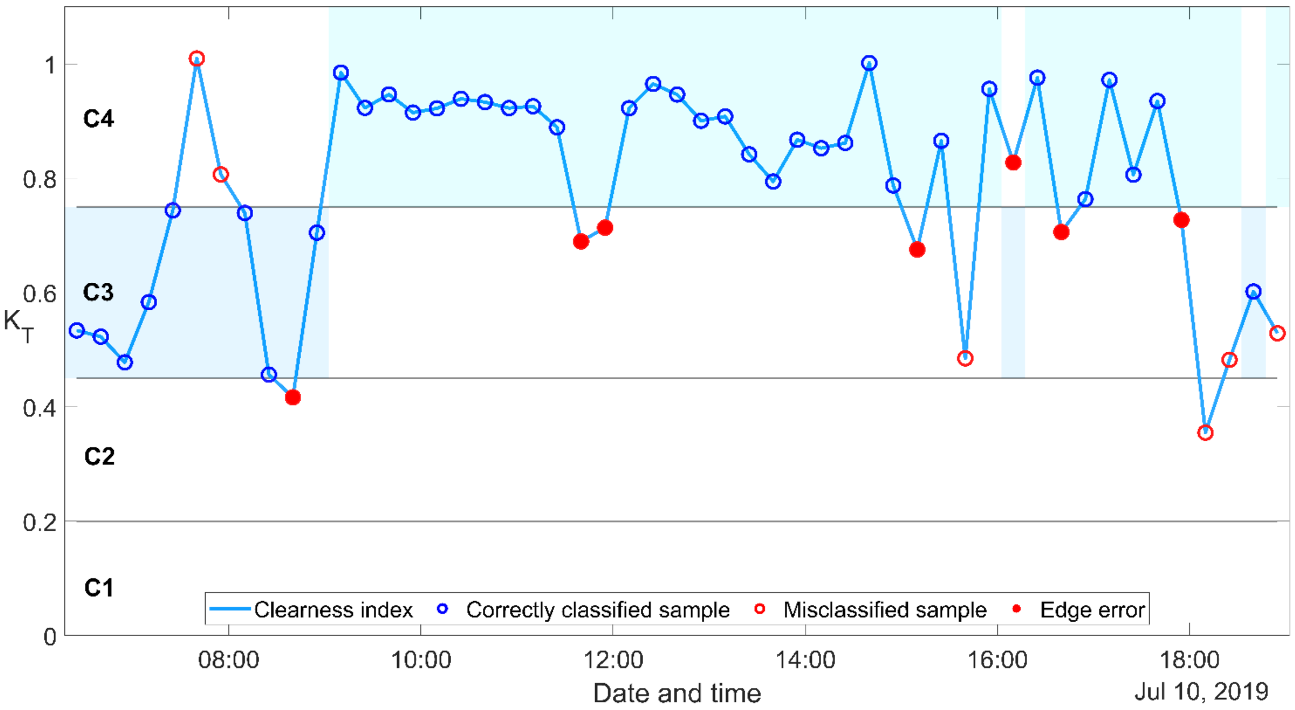
Future improvements

Most common errors are due to rigid classification



Mitigation strategies

I. Fuzzy logic classification

II. Confidence interval

III. From Classes to continuous values

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Conclusions

Simplified methodology for the 15 minutes ahead forecasting (nowcasting) of the solar irradiance on a given location through satellite images

Dynamic Cloud model development

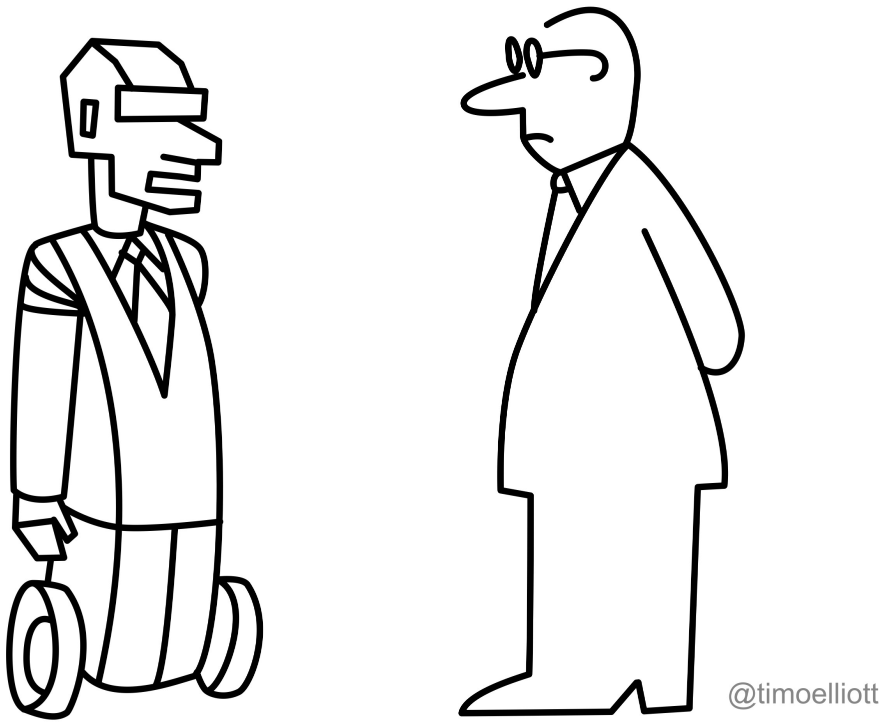
- Cloud model able to identify the Cloud typology interacting with the direct sun beams
- Reduced Cloud type classification (from 19 to 4), based on Clearness Index, improved the neural network performance up to 10%

Solar irradiance nowcasting through Machine Learning Techniques

- Random forest results are more accurate than Artificial Neural Networks
- Reduced dataset scenarios (Area 13x7 & Butterfly) always provided the best training accuracy (> 2%)
- Satellite data and imagery, combined with weather measurements, improved the prediction of the solar radiation 15 minutes ahead on a specific geographic target up to 84.2% using Random Forests (Area 13x7)

Nespoli, A., Niccolai, A., Ogliari, E., Perego, G., Collino, E., & Ronzio, D. (2022). Machine Learning techniques for solar irradiation nowcasting: Cloud type classification forecast through satellite data and imagery. *Applied Energy*, *305*, 117834.

THE END



"The good news is I have discovered inefficiencies.
The bad news is that you're one of them."

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