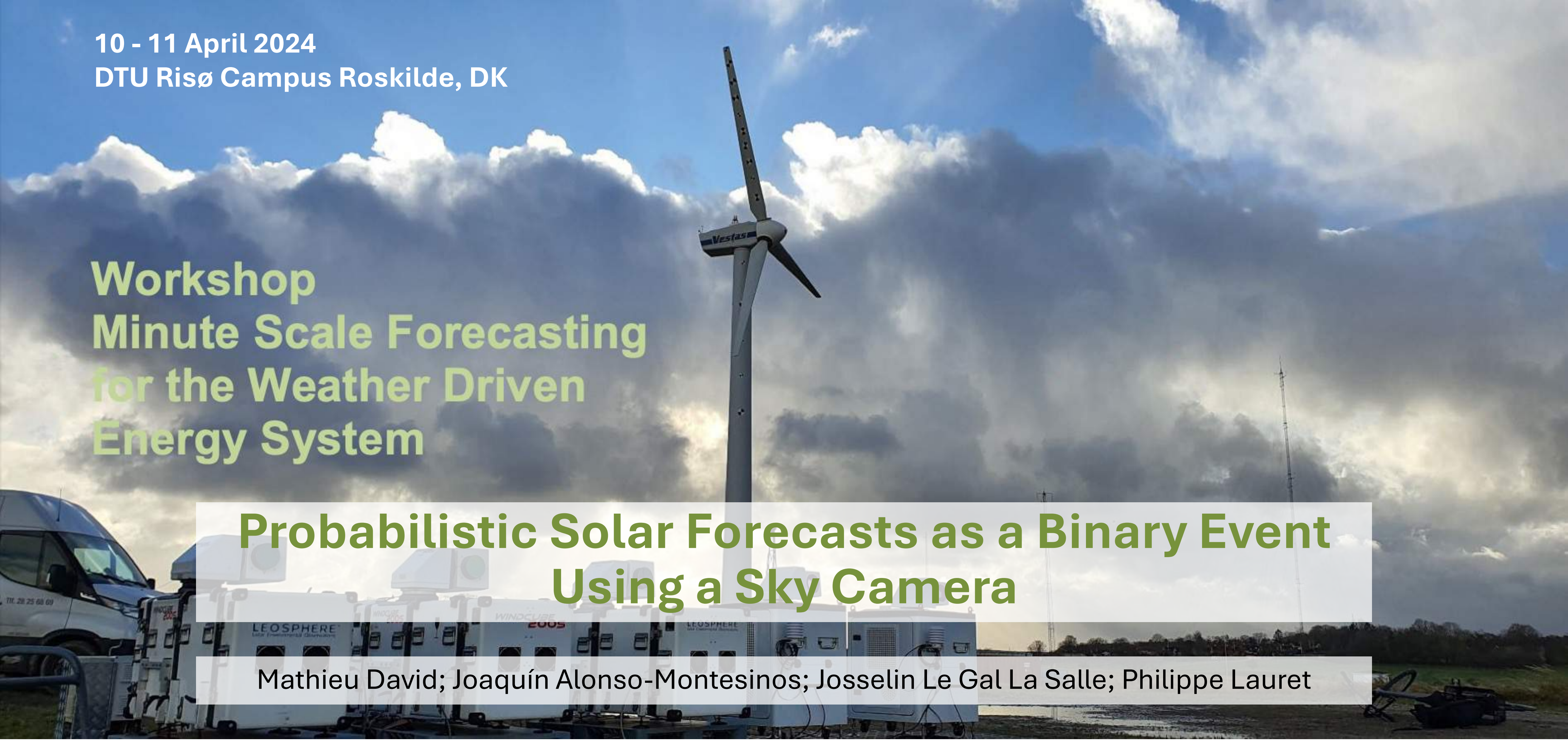
10 - 11 April 2024
DTU Risø Campus Roskilde, DK

Workshop
Minute Scale Forecasting for the Weather Driven Energy System



Probabilistic Solar Forecasts as a Binary Event Using a Sky Camera

Mathieu David; Joaquín Alonso-Montesinos; Josselin Le Gal La Salle; Philippe Lauret

International Energy Agency
Photovoltaic Power Systems Programme

TwInSolar

Funded by the European Union

Context and problem

Work inspired by concentrated solar plant (CSP) operation

Production depends on Direct Normal Irradiance (DNI) resource.

Main objectives for a CSP the operator:

- Maintain a stable power output
- Maximize the energy generation
- Optimal operation of the system

GEMASOLAR power plant, Spain

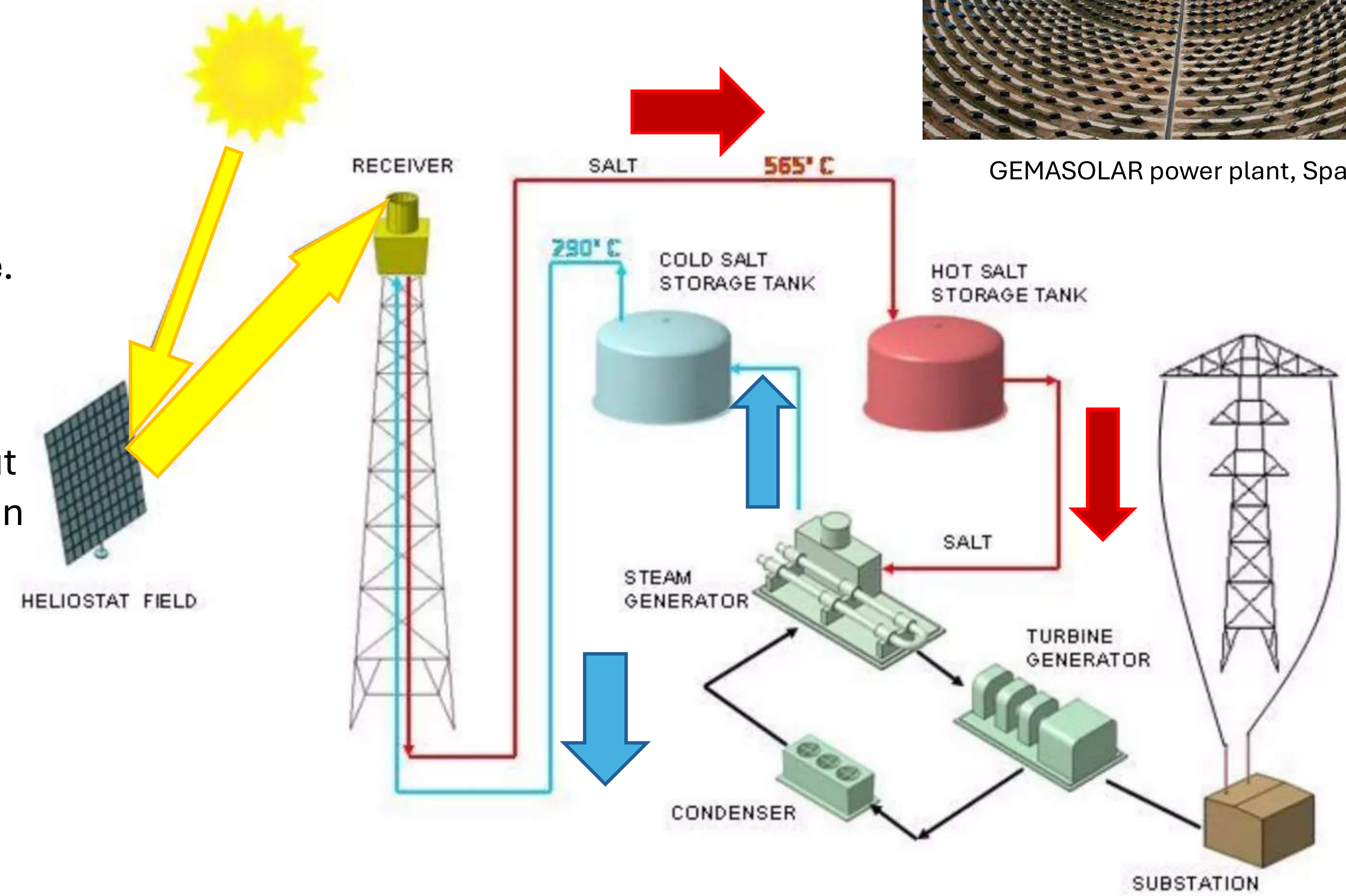


Illustration from: Burgaleta J.I. (2013). GEMASOLAR: A thermal solar power plant with 15h of thermal storage system. Workshop on application of solar forecasting, June 2013, Madrid

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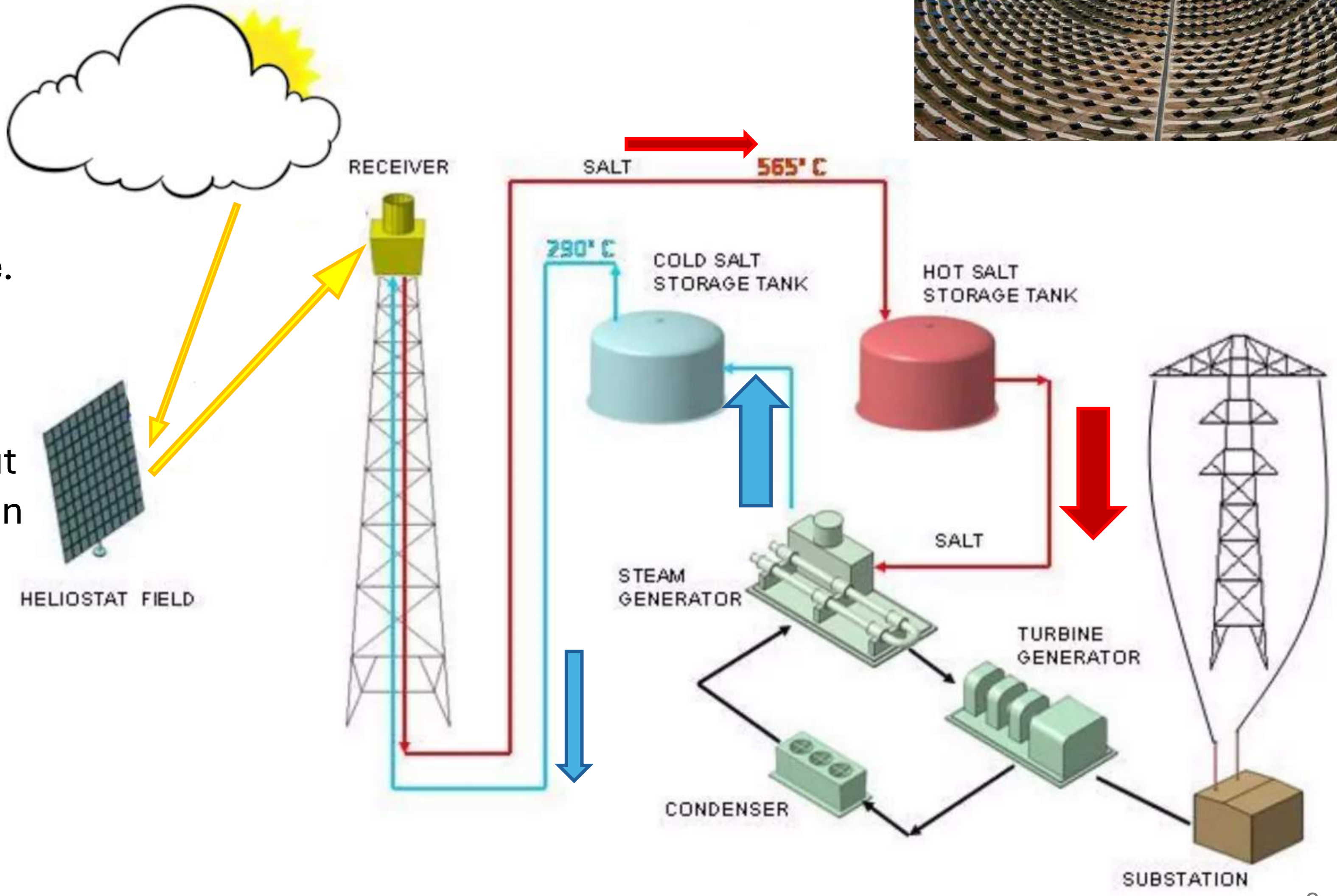

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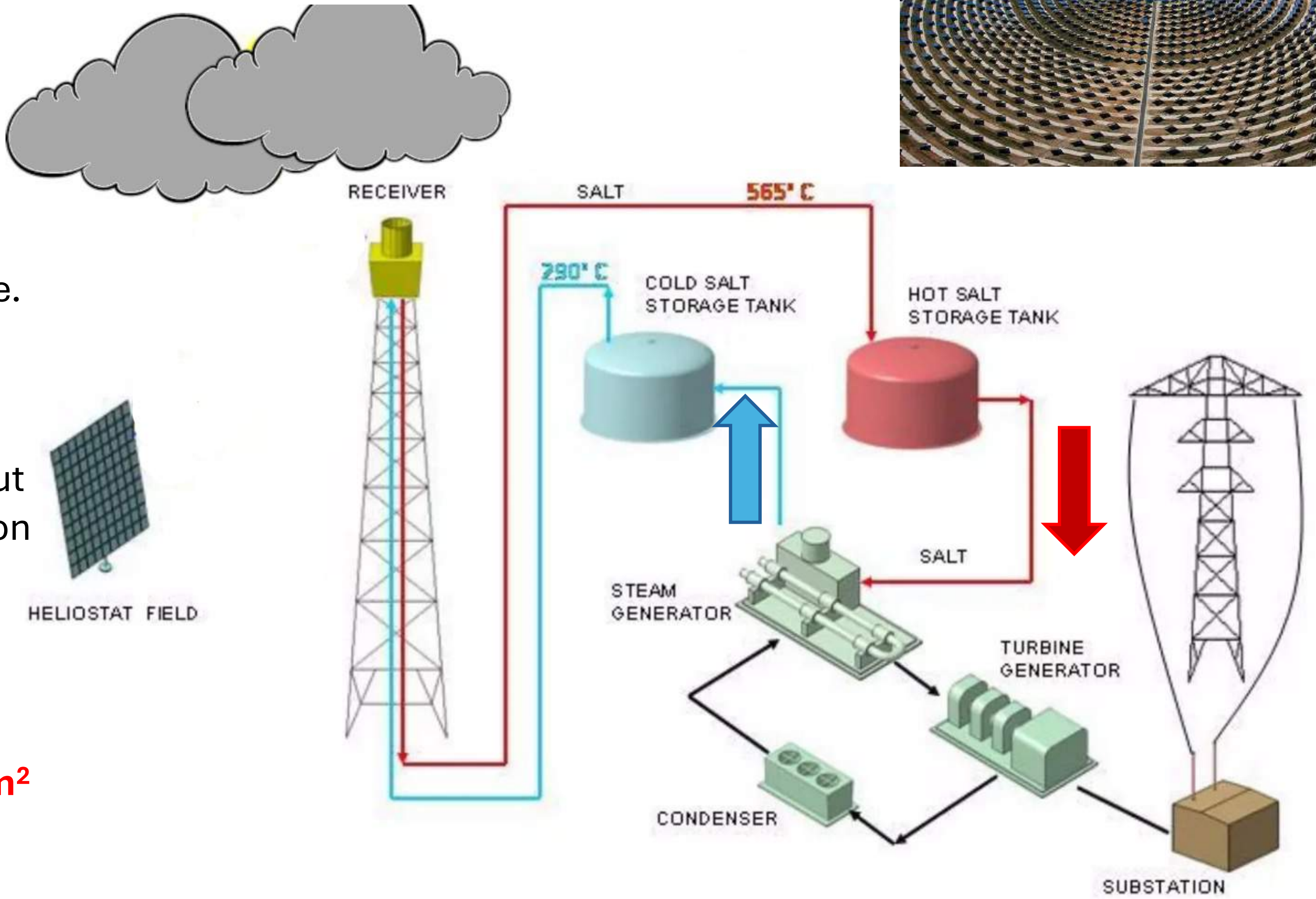


Critical DNI threshold: 400 W/m²

Illustration from: Burgaleta J.I. (2013). GEMASOLAR: A thermal solar power plant with 15h of thermal storage system. Workshop on application of solar forecasting, June 2013, Madrid

Intra-hour solar forecasting techniques

Goals

- Anticipate jumps in DNI (below or above 400 W/m²)
- Optimize real time plant operation

Most suitable techniques at intra-hour scale:

- Time series (statistical)
- All sky imagers (ASI)
- Satellites

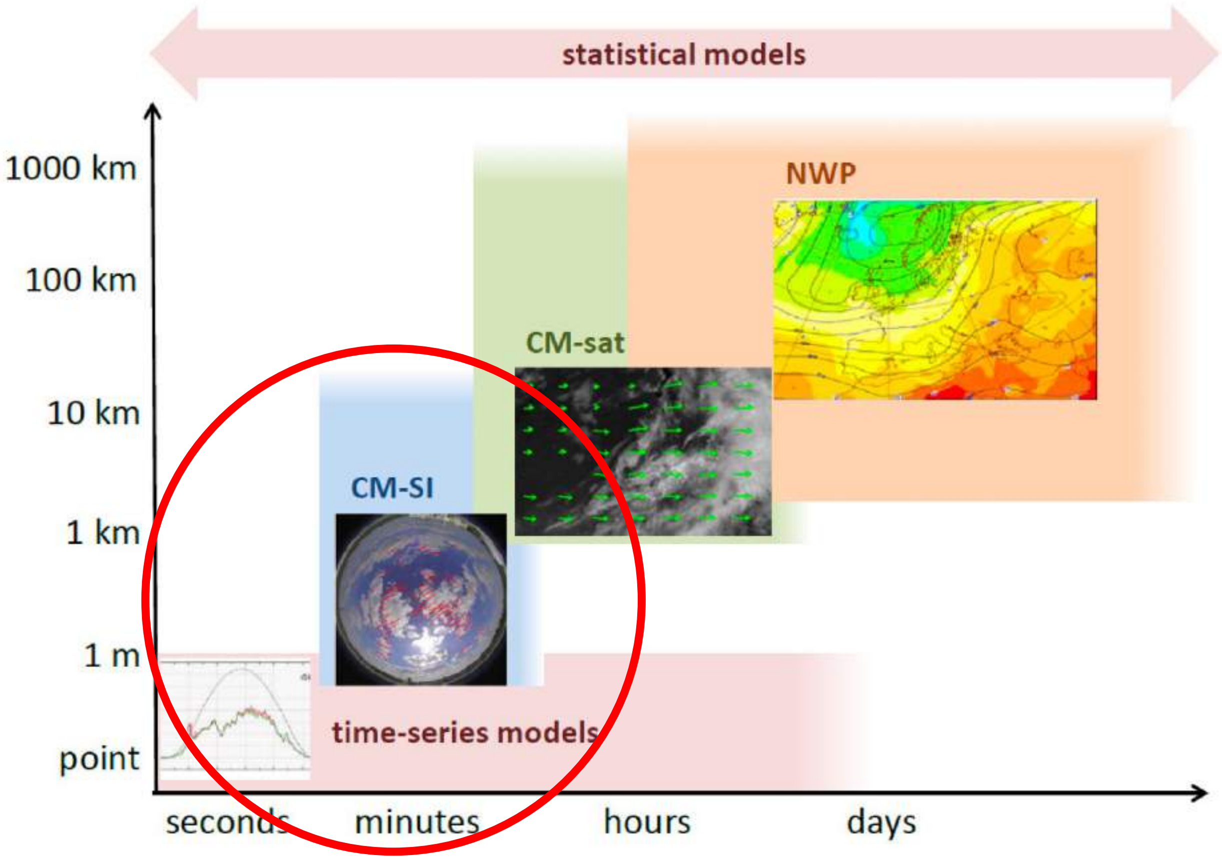
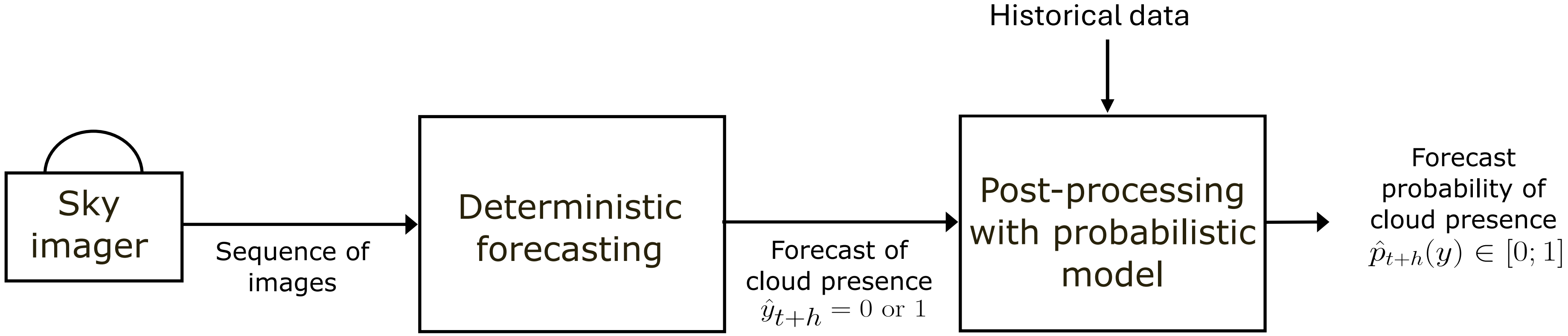


Illustration of different forecasting methods for various spatial and temporal scales

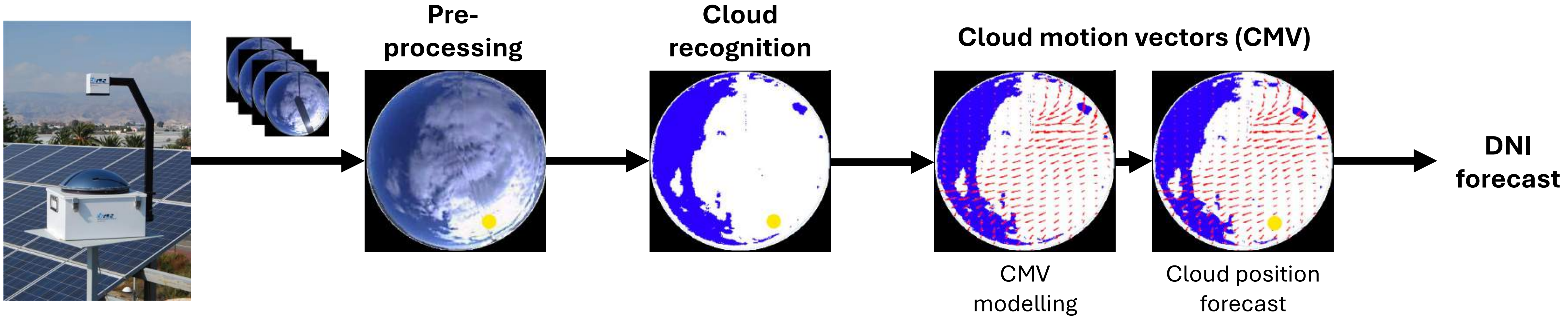
Sengupta, M., Habte, A., Wilbert, S., Gueymard, C., & Remund, J. (2021). *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications : Third Edition*. https://doi.org/10.2172/1778700

Forecasting approach

- Horizon: from 1 minute to 30 minutes ahead
- Resolution: 1-min and a single point (1 solar sensor)
- Binary: focus on the moment when the DNI jumps above or below 400 W/m^2
- Probabilistic: evaluate the probability associated to the event
- Approach: combination of time series of DNI and sky images with wo-step model:
    1. Deterministic binary forecast based on ASI
    2. Postprocessing with DNI time series to obtain a probabilistic forecast



ASI deterministic forecast



Binary forecast $\hat{y}_{t+h}$

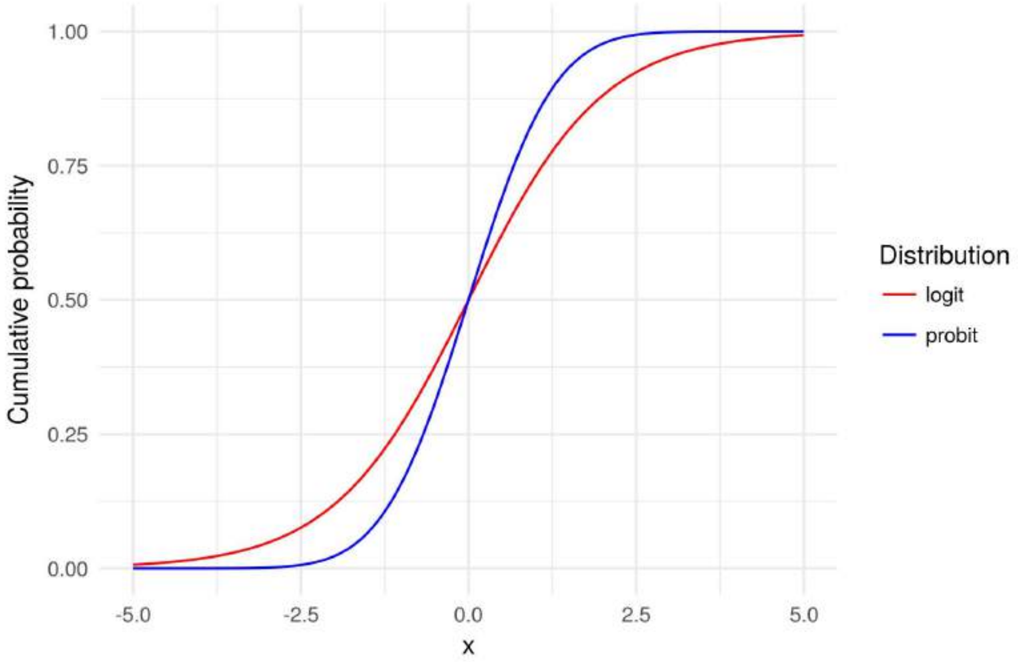
- Presence of clouds on the sun path that attenuate DNI below 400W/m^2 $\rightarrow$ $\hat{y}_{t+h} = 0$
- No cloud on the sun path $\rightarrow$ $\hat{y}_{t+h} = 1$

With t the current time and h the horizon

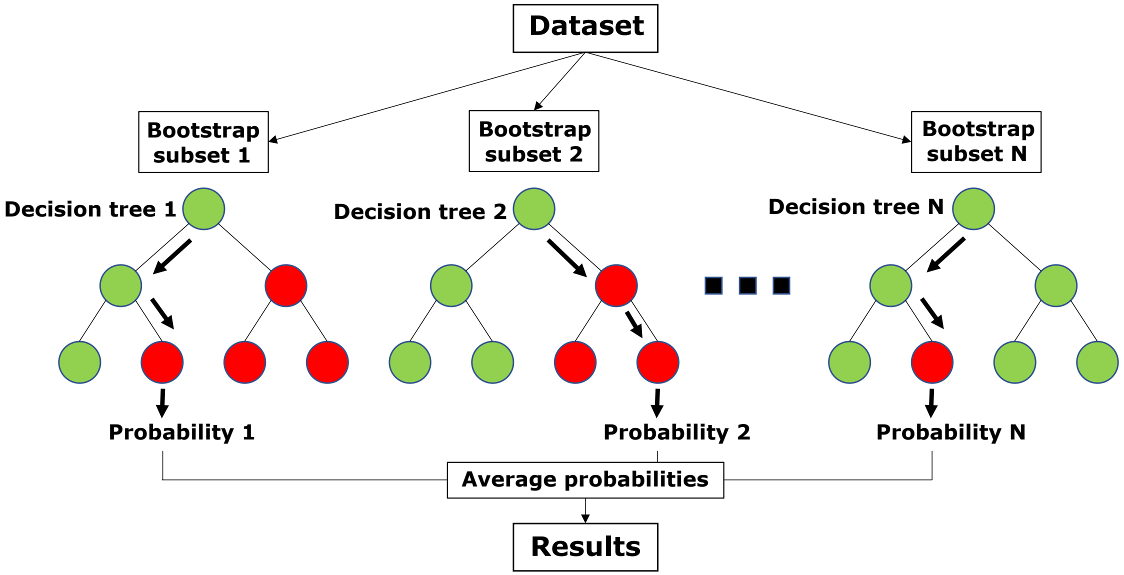
Postprocessing with probabilistic models

Test of 2 types of discrete choice models:

Parametric: logit and probit



Non-parametric: Random Forest (RF)



Postprocessing with probabilistic models

Implementation of the discrete choice models

Same inputs for a fair comparison

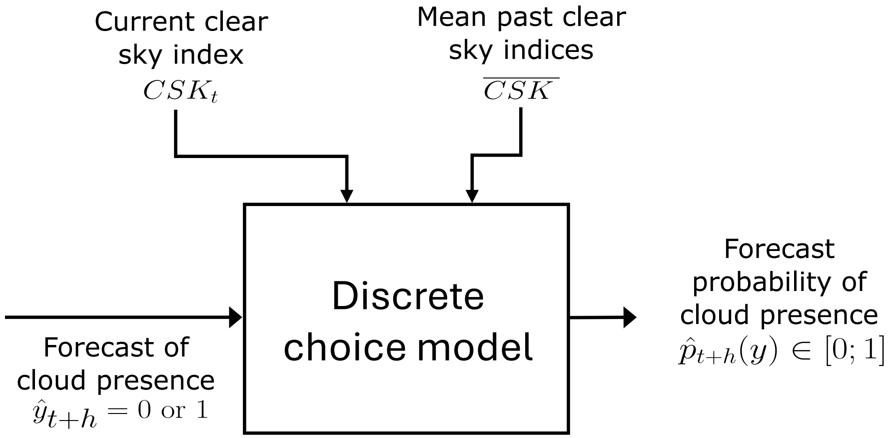
Tested inputs:

- ASI deterministic forecast
- Past GHI and DNI
- Past clear sky indices
- Past average and variability of clear sky index
- Solar zenith angle at horizon $t + h$

Best combination of inputs:

- ASI deterministic forecast ($\hat{y}_{t+h}$)
- Current clear sky index (CSK_t)
- Average clear sky index over the past 5 minutes ($\overline{CSK}$)

1 model per horizon



Case study and data

CIESOL testing facility in Almeria, Spain (36.8° N, 2.4° W, sea level)

Sky imager: TSI-880, image 352 x 288 color pixels (JPEG)

Solar irradiance measurements:

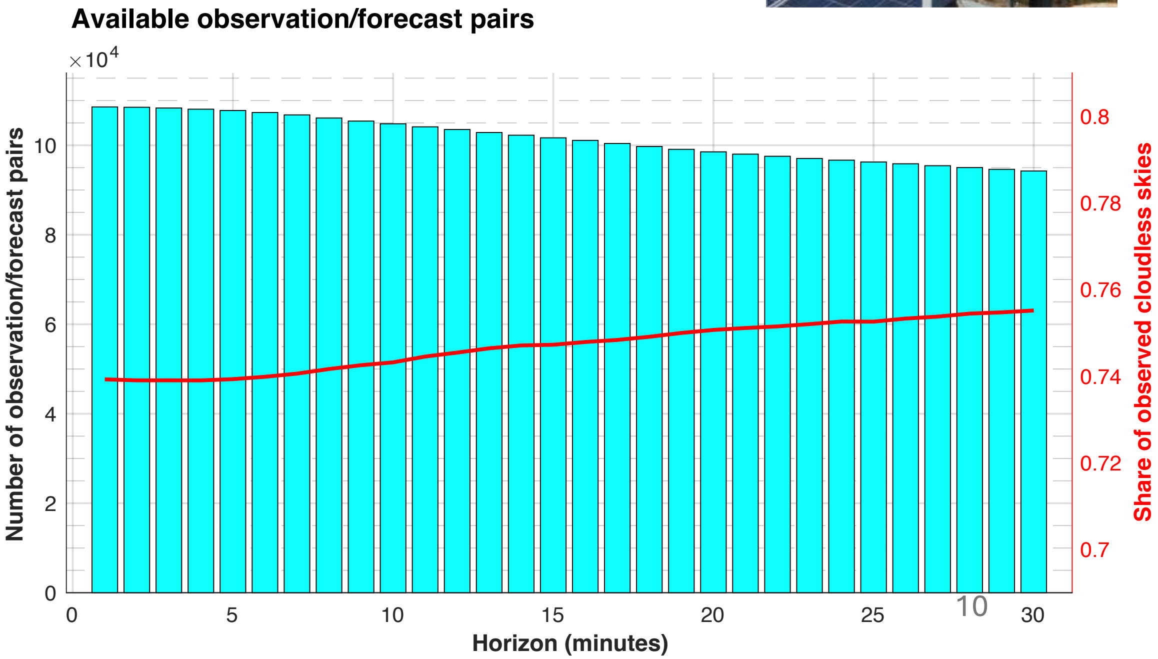
- GHI CMP 11 Kipp & Zonen
- DNI CHP 1 Kipp & Zonen
- Two axis solar tracker

2 years of 1 minute data: training set 2010, test set 2011

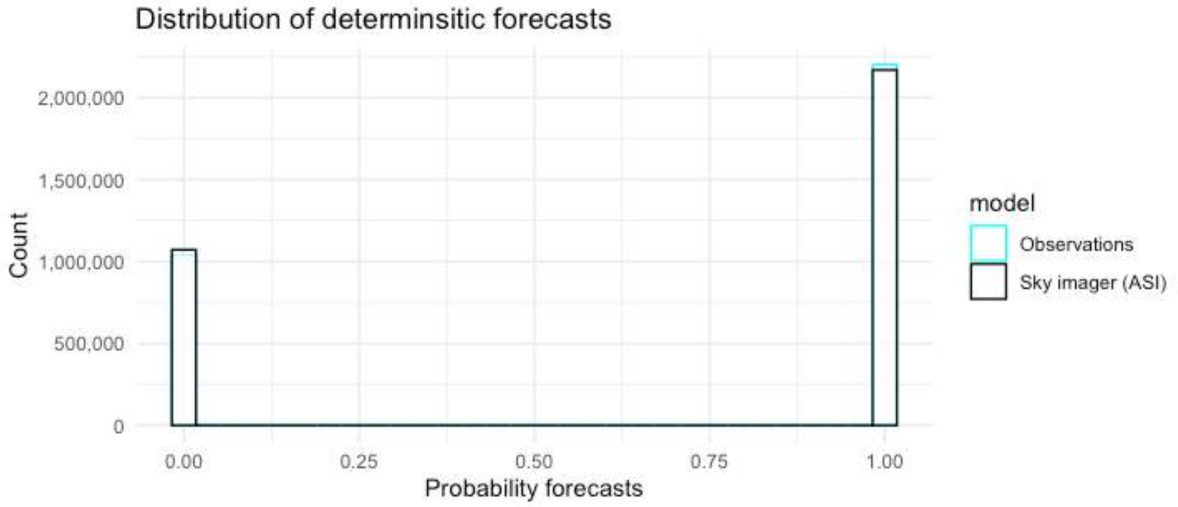
Filtering: solar zenith angle $\theta_z < 85°$

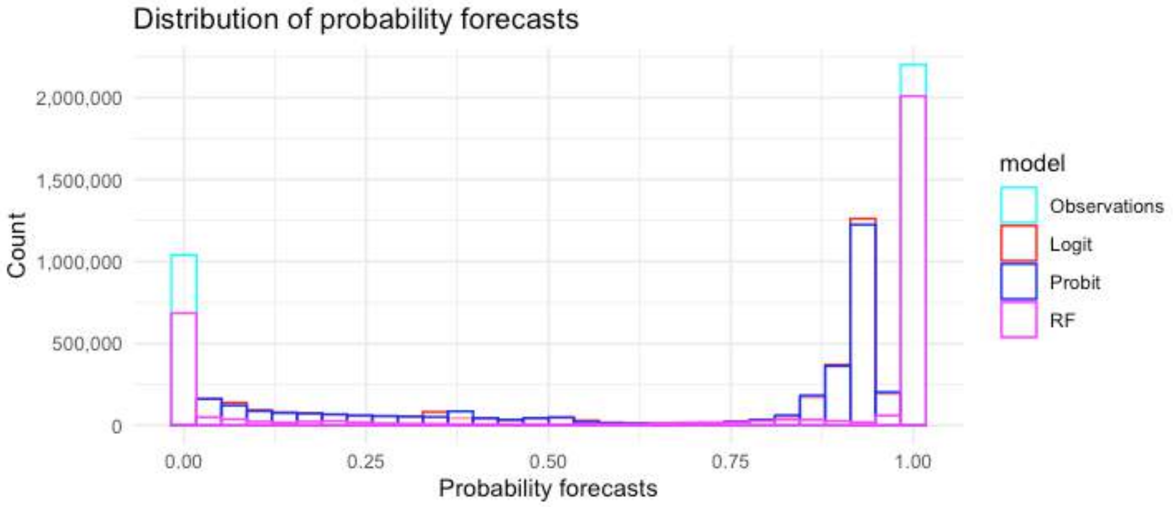
Available observation/forecast pairs:

- Decreases with time horizon
- Specific to ASI forecast
- Limited view angle
- Forecast horizon decreases for high cloud speed or low cloud base height
- Ratio of clear sky condition increase with horizon



Results





Deterministic forecasts:

- Probability = 0 or 1
- Apparent good agreement between observations and forecasts distributions

Probabilistic forecasts:

- Probability ranges from 0 to 1
- Logit and Probit unable to issue probability values of 0 or 1

Results: deterministic forecast

Error metric

$$Accuracy = \frac{Number\ of\ good\ forecasts}{Total\ number\ of\ forecasts} = \frac{hits + correct\ negatives}{Total\ number\ of\ forecasts}$$

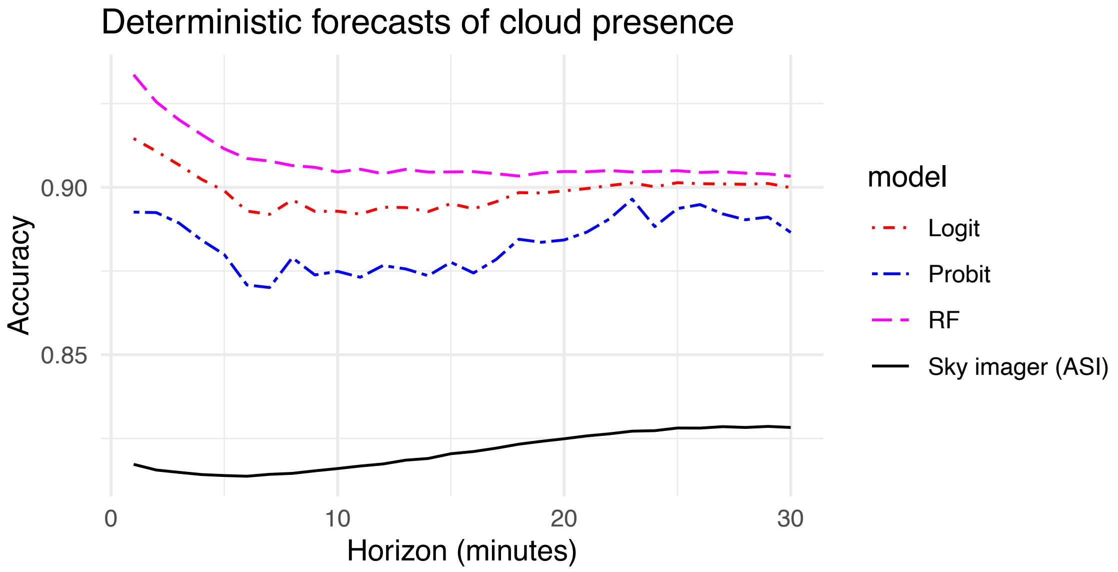
Perfect forecast: $Accuracy = 1$

		Observation	
		yes	no
Forecast	yes	hits	false alarms
	no	misses	correct negatives

Comparison before and after the postprocessing step

Assumption: perfectly calibrated probabilistic forecast

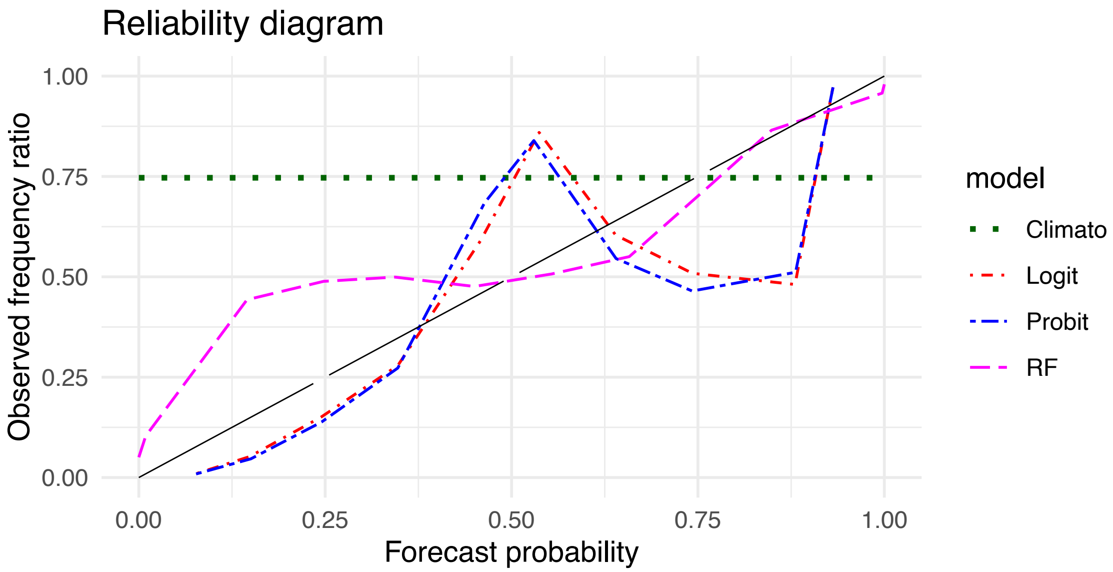
- Probability $\hat{p}_{t+h} \geq 0.5$ → event (no cloud)
- Probability $\hat{p}_{t+h} < 0.5$ → no event (cloud)



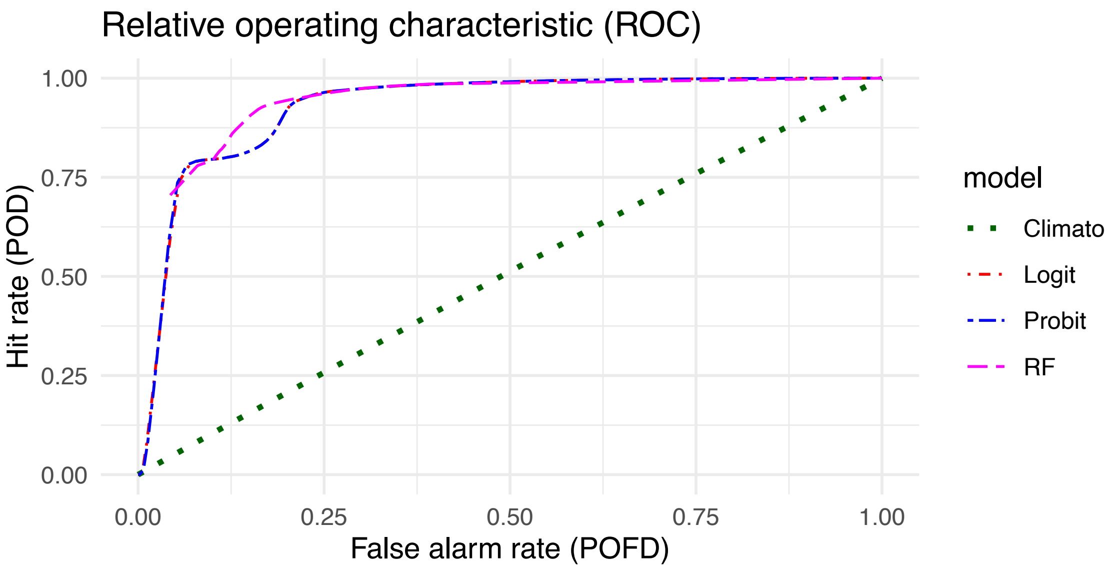
Results: probabilistic forecast

Quality of probabilistic forecast has two main attributes:

Reliability or calibration
(statistical consistency)



Resolution
(case-dependent forecasts)



The non-parametric model (RF) clearly outperforms the parametric approach (logit and probit).

Results: probabilistic forecast

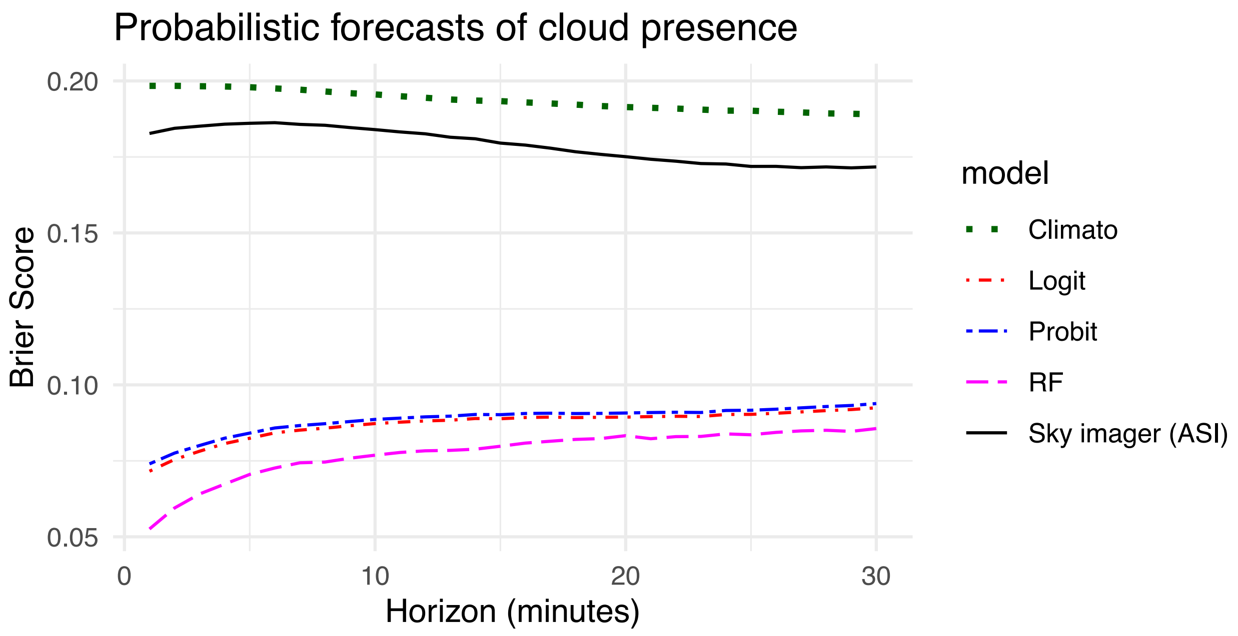
Overall quality evaluated with the Brier Score (BS)

$$BS = \frac{1}{N}\sum_{i=1}^{N}(\widehat{p_i} - obs_i)^2$$

Perfect forecast: $BS = 0$ (negatively oriented)

Strong improvement over the initial ASI forecast

Non-parametric model (RF) has the best quality



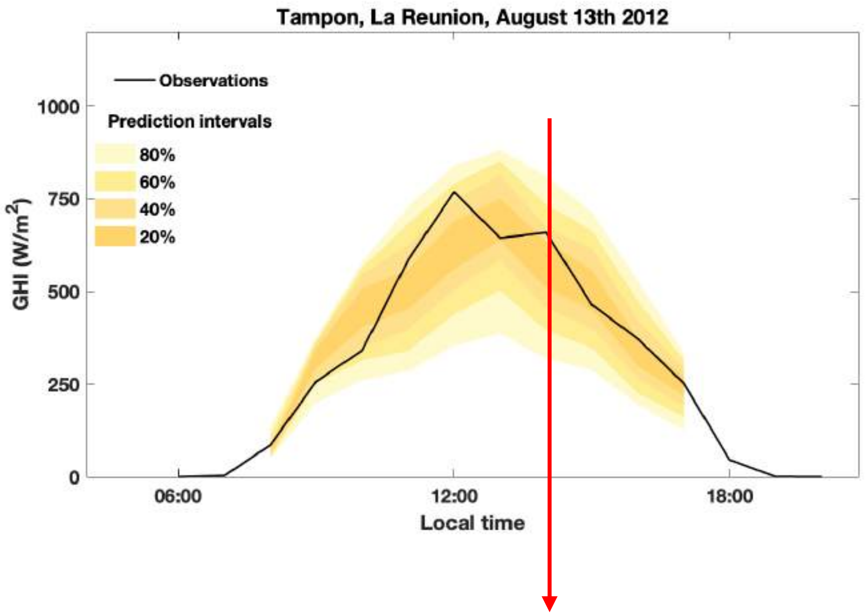
Discussion

Why did we not derive the probability of the event from classical probability forecast?

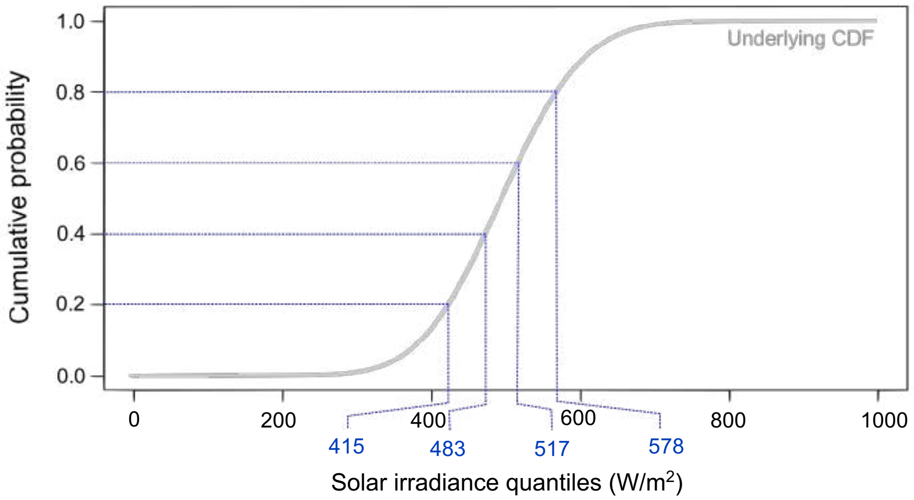
Usual approach:

- Forecast of a continuous variable
- Quantiles derived from probability levels
- High computation cost to have high quantile resolution (e.g. < 1 W/m^2)
- Low precision on the probability of being below or above a fixed threshold

This work proposes an inverse approach which consists of deriving the probability from a defined quantile.



Probabislistic forecast at 2PM



Conclusion and perspectives

- Methodology to generate minute scale probabilistic forecasts as a binary event
- First attempt in the field of solar forecast
- Strong forecast quality improvement compared to ASI deterministic forecast
- Non-parametric approach (RF) outperforms parametric models (logit and probit)
- Binary forecast required for various decision-making problems in the field of energy
- Extension of the binary approach
- Possibility to change how probability forecasts are generated based on quantile values rather than probability levels

More details: *David, M., Alonso-Montesinos, J., Le Gal La Salle, J., & Lauret, P. (2023). Probabilistic Solar Forecasts as a Binary Event Using a Sky Camera. Energies, 16(20), 7125*
https://doi.org/10.3390/en16207125

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Thank you for your attention

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