UNIVERSIDADE DE ÉVORA

CÁTEDRA ENERGIAS RENOVÁVEIS

ICT Instituto de Ciências da Terra

Short-term Forecasting for Direct Normal Irradiance with Numerical Weather Prediction Models in Alentejo

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IPMA Workshop

A previsão numérica do tempo em Portugal: estado da arte e novos desafios, IPMA, November 26-27th 2018, Lisbon.

Overview

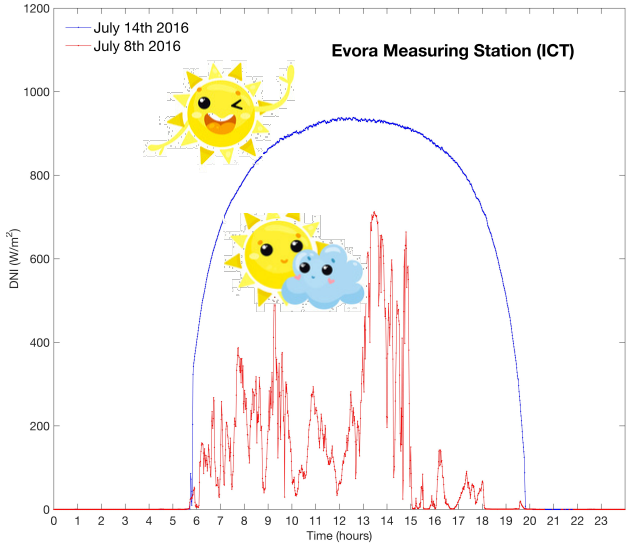
- **Forecasts** of direct normal irradiance (**DNI**) are essential for an optimized operation strategy of concentrating solar power (**CSP**) systems, particularly during partly cloudy days, allowing **to reduce the uncertainty of solar plant outputs due to solar irradiance intermittency**.

- Current state-of-the-art Numerical Weather Prediction (NWP) models:

  - The **first DNI forecasts** (ECMWF) are dated **around 2014**.

  - Still require **further validation over DNI forecasts**, mainly due to **cloud representation** during overcast periods.

- Objectives: Use of the Integrated Forecasting System (IFS), the global NWP model from the European Centre for Medium-Range Weather Forecasts (ECMWF), **to assess short-term forecasts of DNI in southern Portugal and integrate these in the operation of CSP systems**.

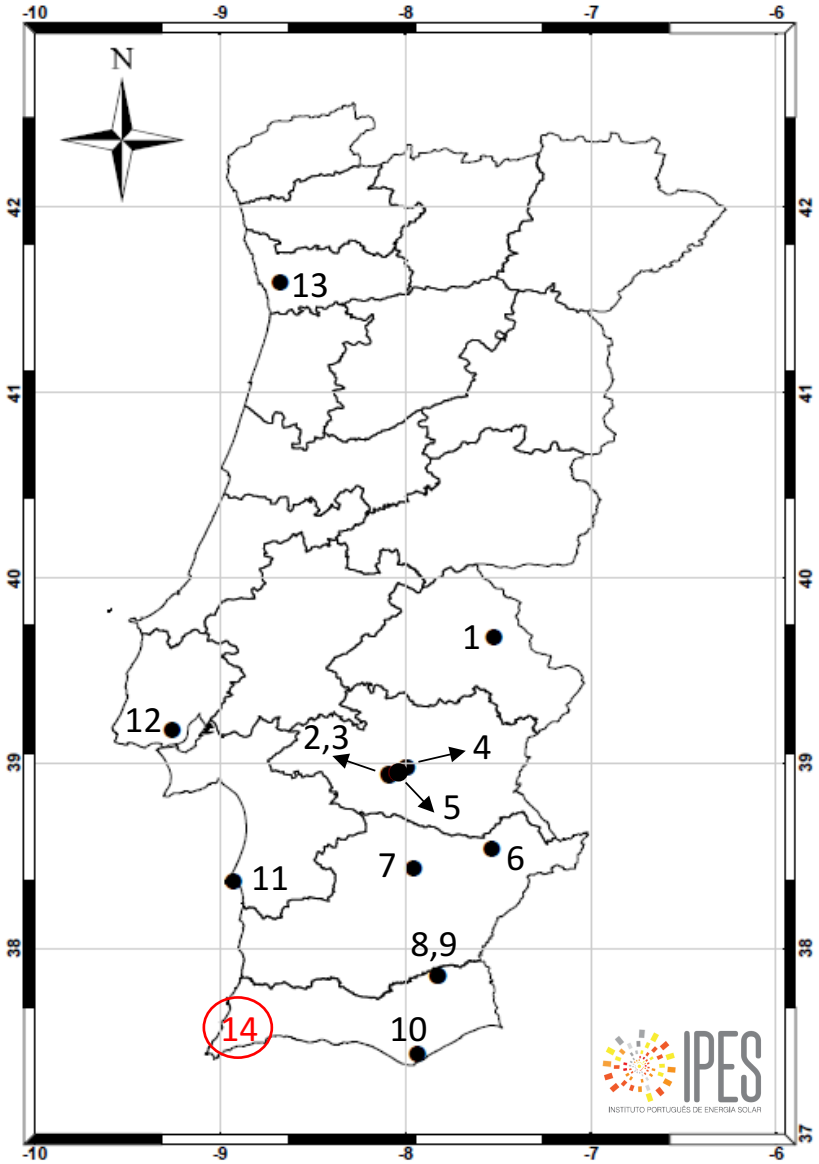


Solar Assessment

- For Portugal, **available commercial data** is provided by companies (e.g. SOLARGIS and Meteonorm).
- These companies do not have ground-measuring data to validate their model estimations in Portugal.
- There is an expected range of bias outside validation sites of about ±8% to ±12%.
- As part of the **DNI-A project** (reference ALT20-03-0145-FEDER-000011), a DNI network has been growing since **2014** with the objective to map the DNI availability (kWh/m^2) in Portugal.

1. Portalegre – AREANATEJO
2. PECS – University of Évora
3. EMSP – University of Évora
4. Évora – University of Évora
5. Alcamizes – EDP Innovation
6. Moura – Lógica
7. Beja – University of Évora
8. Martim Longo – CapWatt
9. Martim Longo – Enercoutim
10. **Olhão – IPMA**
11. Sines – University of Évora
12. Lisboa – LNEG
13. Porto – INEGI
14. Sagres (to be installed soon)

DNI Network

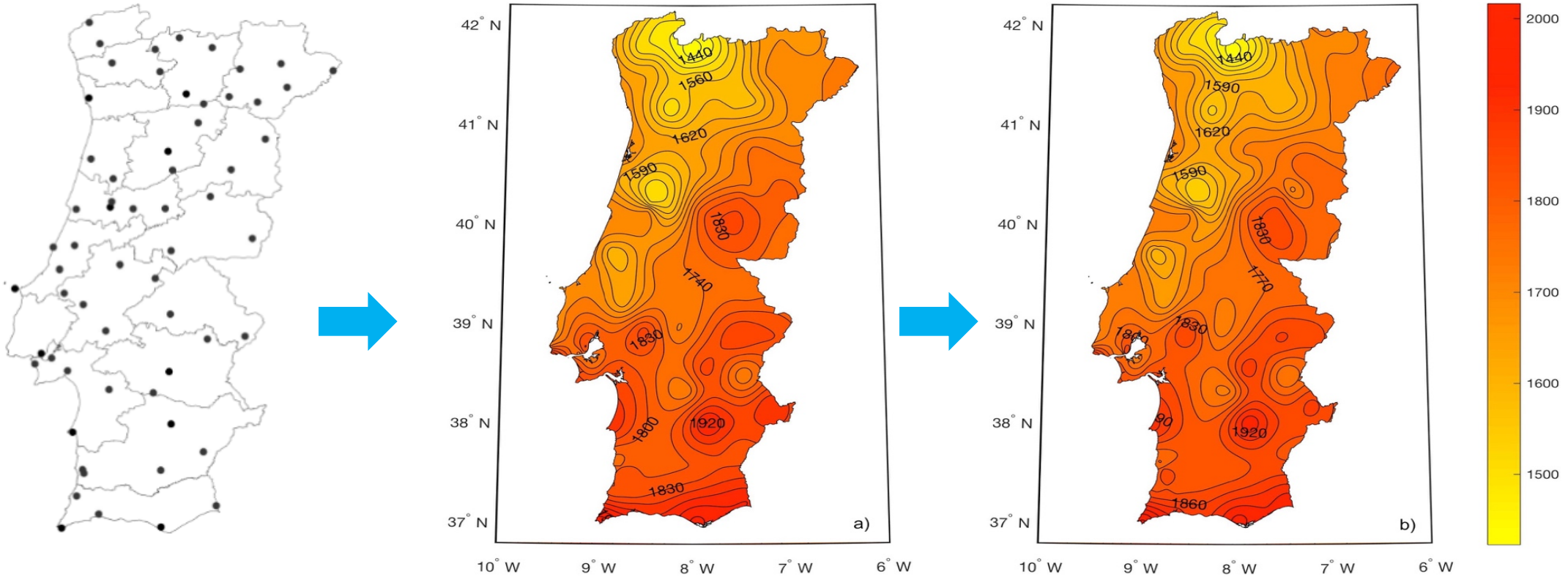


Network of operational ground-measuring stations for Direct Normal Irradiance (DNI) in continental Portugal since 2014. Cortesy of Afonso Cavaco (IPES), afonso.cavaco@ipes.pt

Solar Assessment

H.G. Silva, P. Canhoto, E. Abreu, Francis M. Lopes, A. Cavaco, J. Neto, M. Collares-Pereira. "Solar Irradiation Gap-Filling with Estimator Matrices (SIGMA) Validated for Portugal (Southern Europe)". (in preparation)

- The mapping of Global Horizontal Irradiance (GHI) has already been performed with IPMA's network of 89 GHI ground-measuring stations.



Annual GHI availabilities (kWh/m^2/year) in Portugal from 2001 to 2017, estimated by: (a) simple linear interpolation of the missing data; (b) processing method: Solar Irradiation Gap filling with estimator Matrices (SIGMA).

DNI Short-term Forecasts

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Short-term forecasts of GHI and DNI for solar energy systems operation: assessment of the ECMWF integrated forecasting system in southern Portugal

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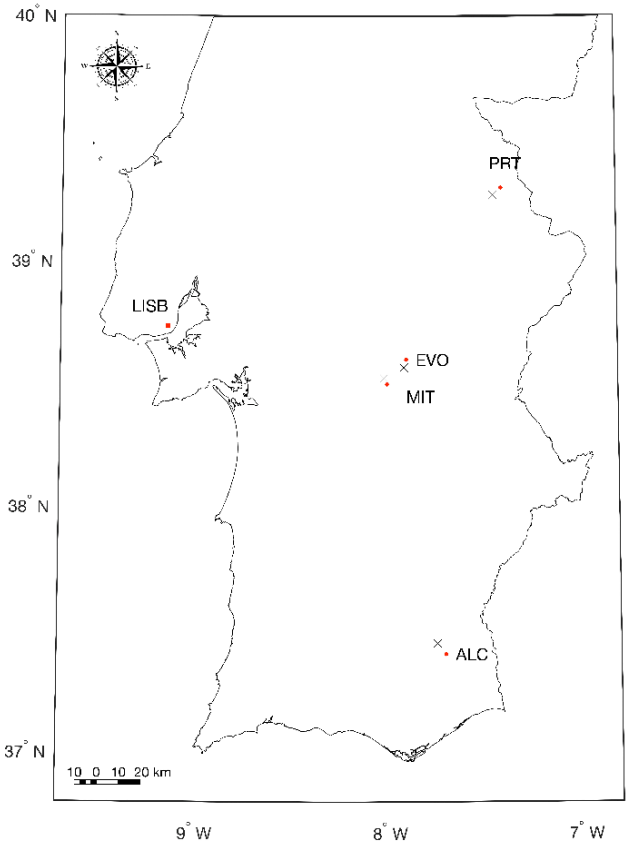
[d] Portuguese Solar Energy Institute, IIFA, Palácio do Vimioso, Largo Marquês de Marialva, Apart. 94, 7002-554 Évora, Portugal



Stations used for measurements (black crosses) and model (red dots).

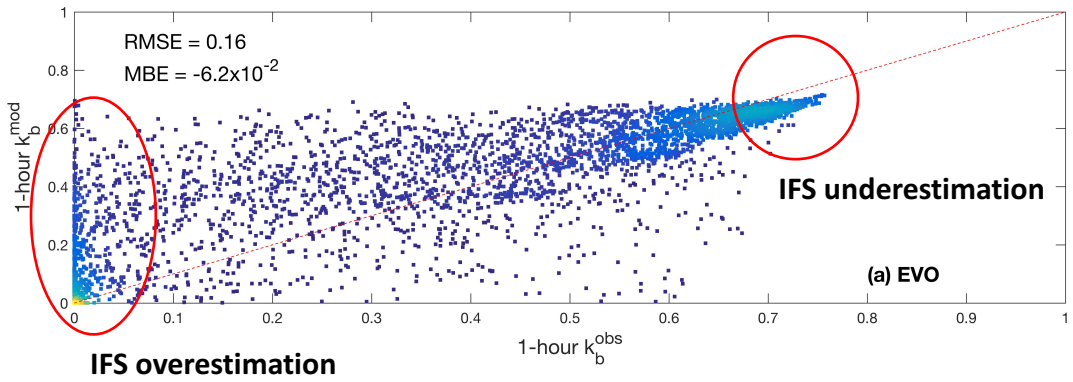
- Ground-observations at Mitra (MIT), Évora (EVO), Portalegre (PRT) and Alcoutim (ALC).
- In-situ hourly averages for **1 year** (starting in April 1st 2016) of **DNI and GHI** were used for analysis.
- The Integrated Forecasting System (IFS), the global model from ECMWF setup:
  - **McRad (cycle 41R2) radiative scheme;**
  - Spatial resolution of 0.1º (~ 11km in latitude);
  - Output is hourly accumulated values (i.e., time step values integrated in an hourly basis);

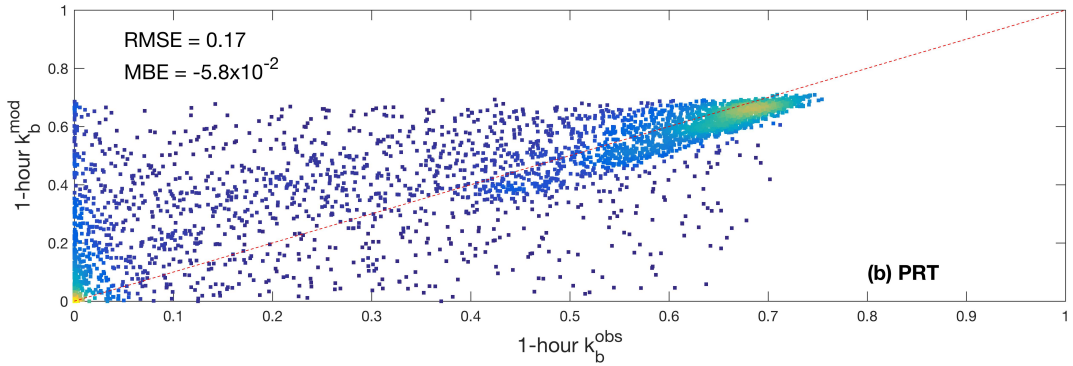
DNI Short-term Forecasts

$$E_b = \sum_1^{24} DNI$$

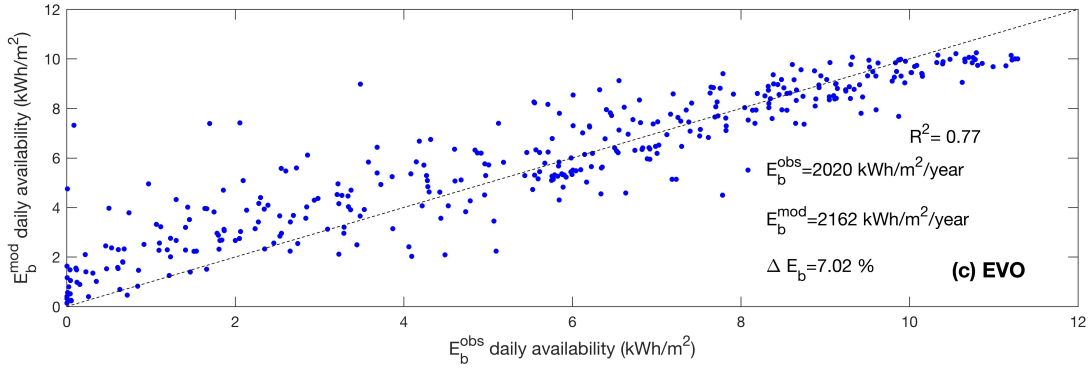
$$k_b = DNI_{obs}/DNI_{TOA}$$

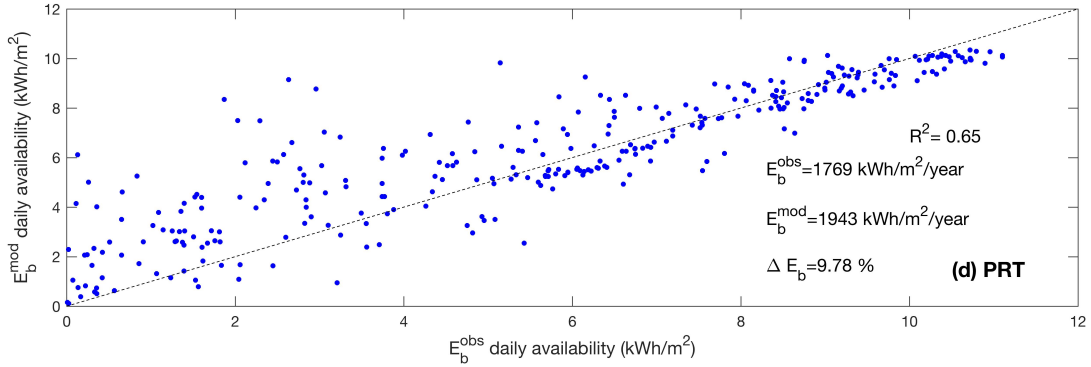
$$\Delta E_b = \left(\sum E_b^{mod} / \sum E_b^{obs} - 1\right) \times 100\%$$





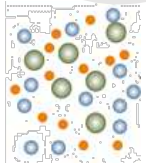
Hourly clearness indices for DNI (k_b) in two ground-measuring stations (EVO, PRT) during one year (April 1st 2016 to March 31st 2017).





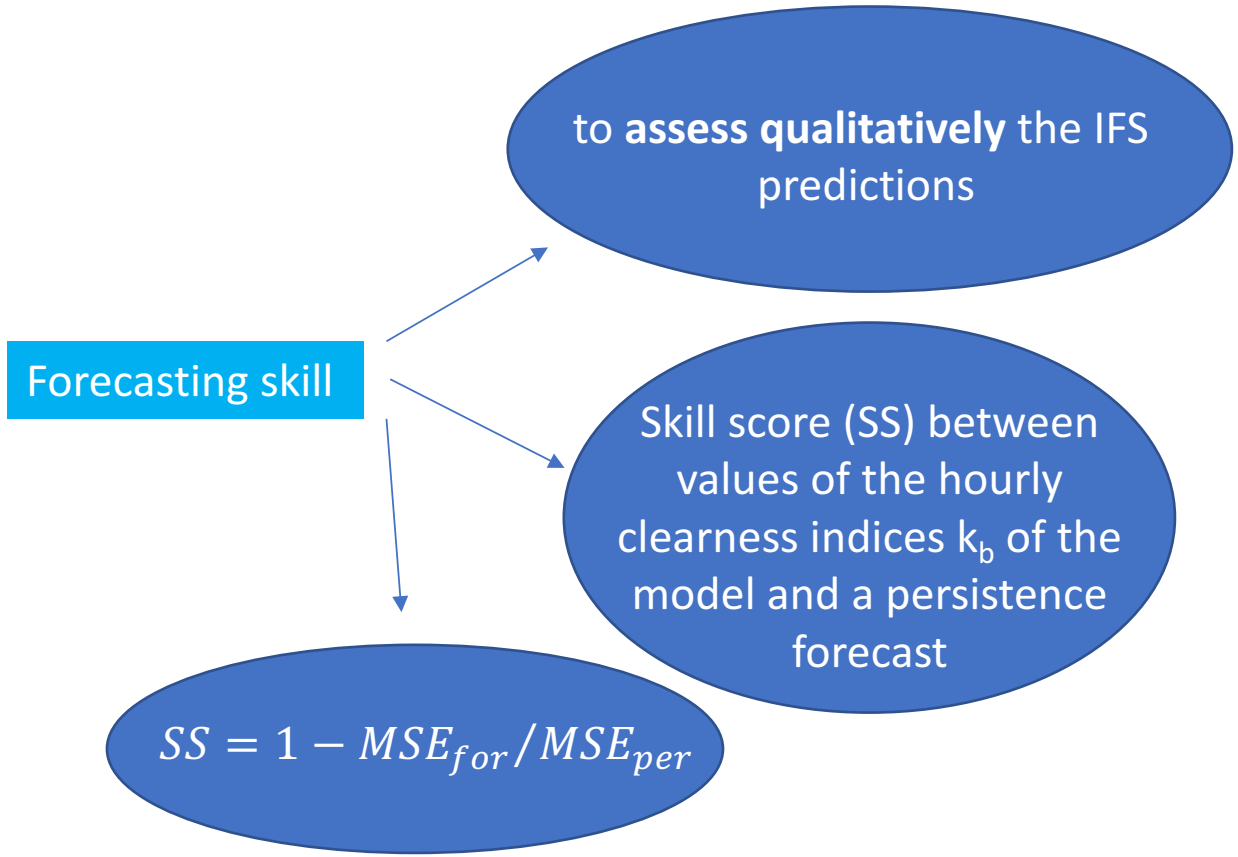
Daily availabilities (kWh/m^2) for DNI (E_b) in two ground-measuring stations (EVO, PRT) during one year (April 1st 2016 to March 31st 2017).

Model overestimation → **Cloud representation** (e.g. Altostratus)

Model underestimation → 

Mean monthly aerosol climatology (Tegen et al., 1997)

DNI Short-term Forecasts



IFS vs. Measurements

k_b	EVO	MIT	PRT	ALC
r	0.81	0.79	0.76	0.79
RMSE	0.15	0.15	0.17	0.16
MBE	-2.8×10^{-02}	-0.03	-0.04	-0.05
MAE	0.10	0.11	0.11	0.11

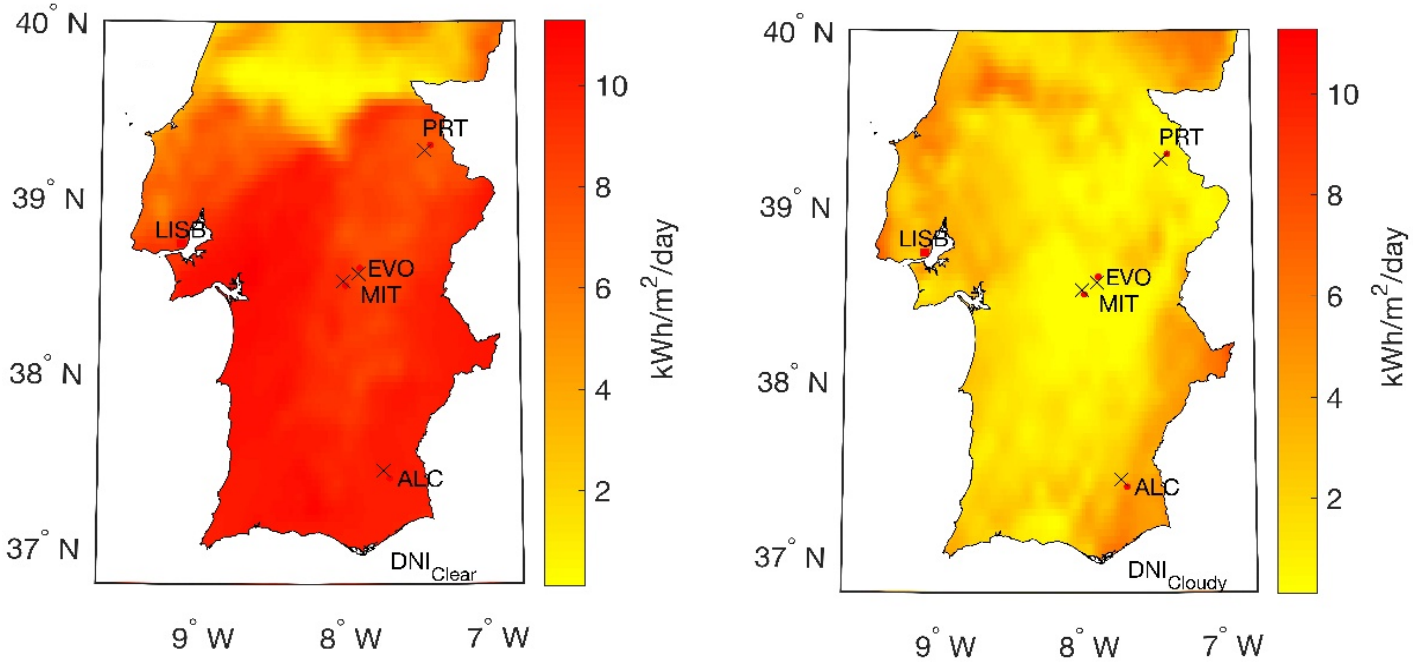
Persistence vs. Measurements

k_b	EVO	MIT	PRT	ALC
r	0.52	0.50	0.46	0.54
RMSE	0.24	0.24	0.26	0.24
MBE	-2.4×10^{-04}	-1.8×10^{-04}	4.0×10^{-03}	3.1×10^{-04}
MAE	0.17	0.17	0.17	0.16

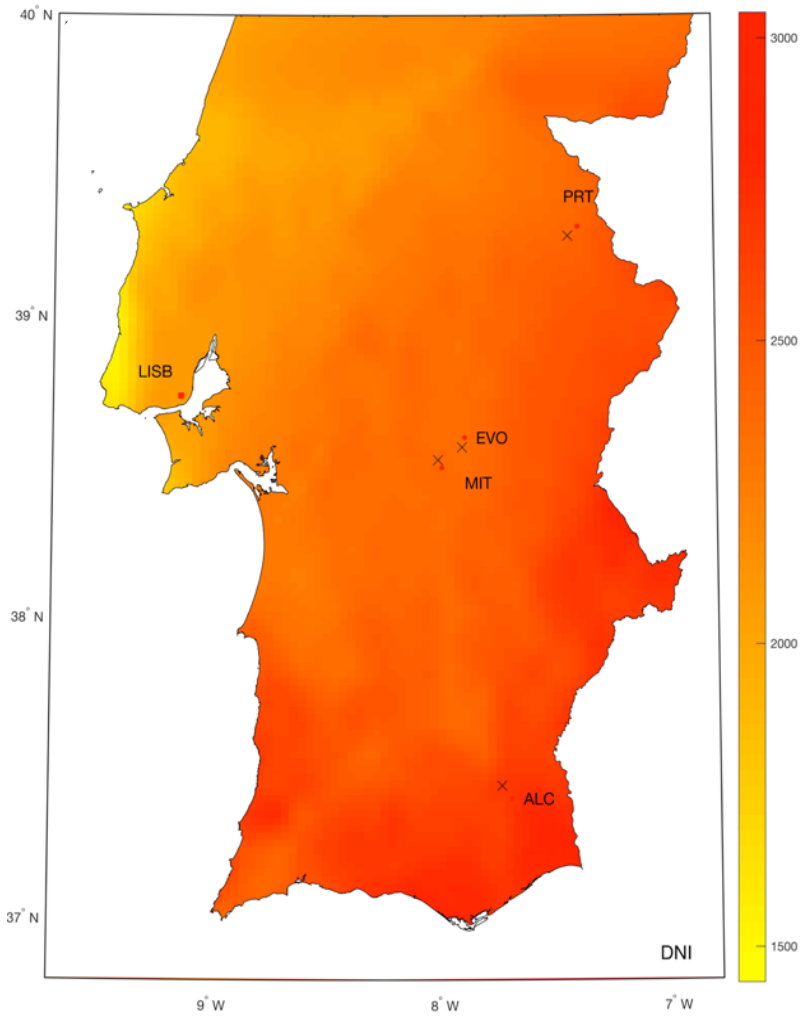
IFS vs. Persistence

k_b	EVO	MIT	PRT	ALC
SS	0.6094	0.6094	0.5725	0.5556

DNI Short-term Forecasts



Spatial distribution of predicted daily irradiation availability (kWh/m^2/day) for two test cases: **one clear sky day (July 12th 2016)** on top and **one cloudy day (May 8th 2016)** on bottom.



Spatial distribution of **predicted annual DNI availability** (kWh/m^2/year) in southern Portugal for 365 days.

New Radiative Scheme (ecRad, CY43R3)

- **Operational since July 2017**;
- General improvement towards the code.
- Aerosol climatology: **Tegen** (Tegen et al., 1997) → **CAMS** (prognostic aerosol scheme initiated by a aerosol data assimilation system)
- Reduction in noise in cloudy skies (Hogan and Bozzo, 2018);

Évora station

	McRad	ecRad
SS_{hourly}	0.59	0.66
SS_{daily}	0.69	0.77

Skill score (SS) calculated with k_b values (hourly and daily data) for the **McRad (July 1st 2016 to June 30th 2017)** and **ecRad (July 1st 2017 to June 30th 2018)**.

Statistical hourly analysis (McRad vs. ecRad):

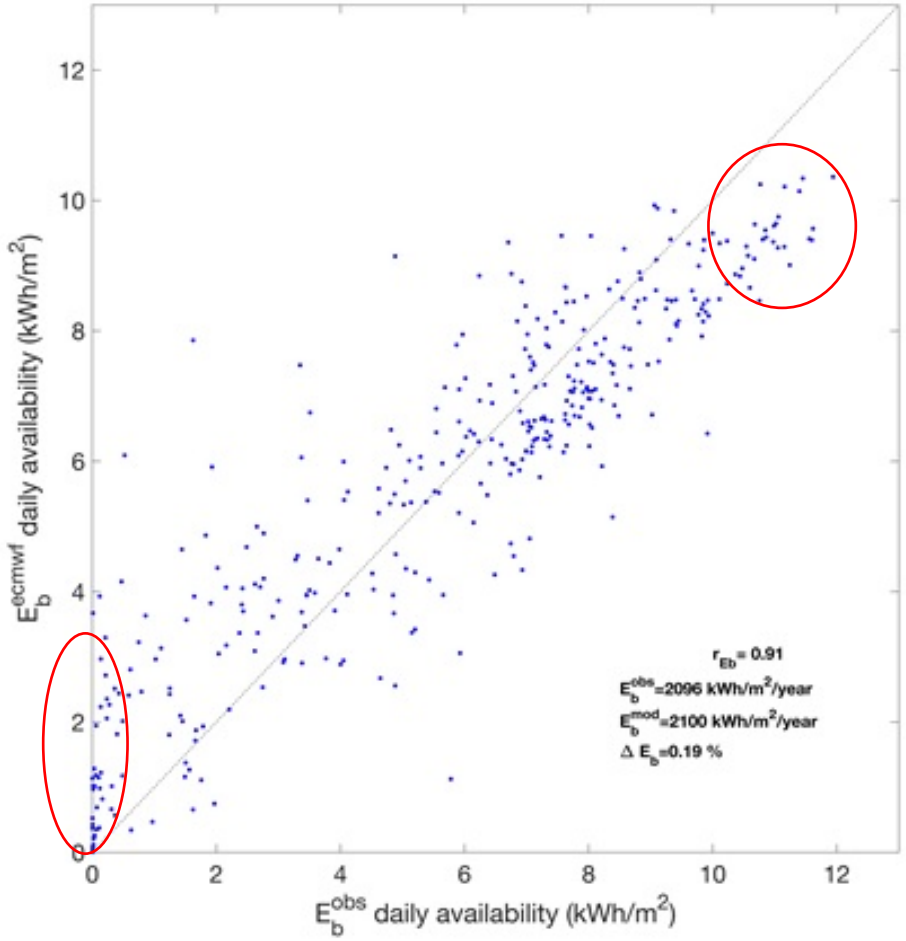
Évora station

	McRad		ecRad	
	Observation	IFS	Observation	IFS
Mean (W/m^2)	463.61 (+10.6%)	512.76	444.24 (+1.2%)	444.76
Median (W/m^2)	501.74	563.31	452.32	457.80
Std. dev (W/m^2)	351.71	310.67	361.87	310.72

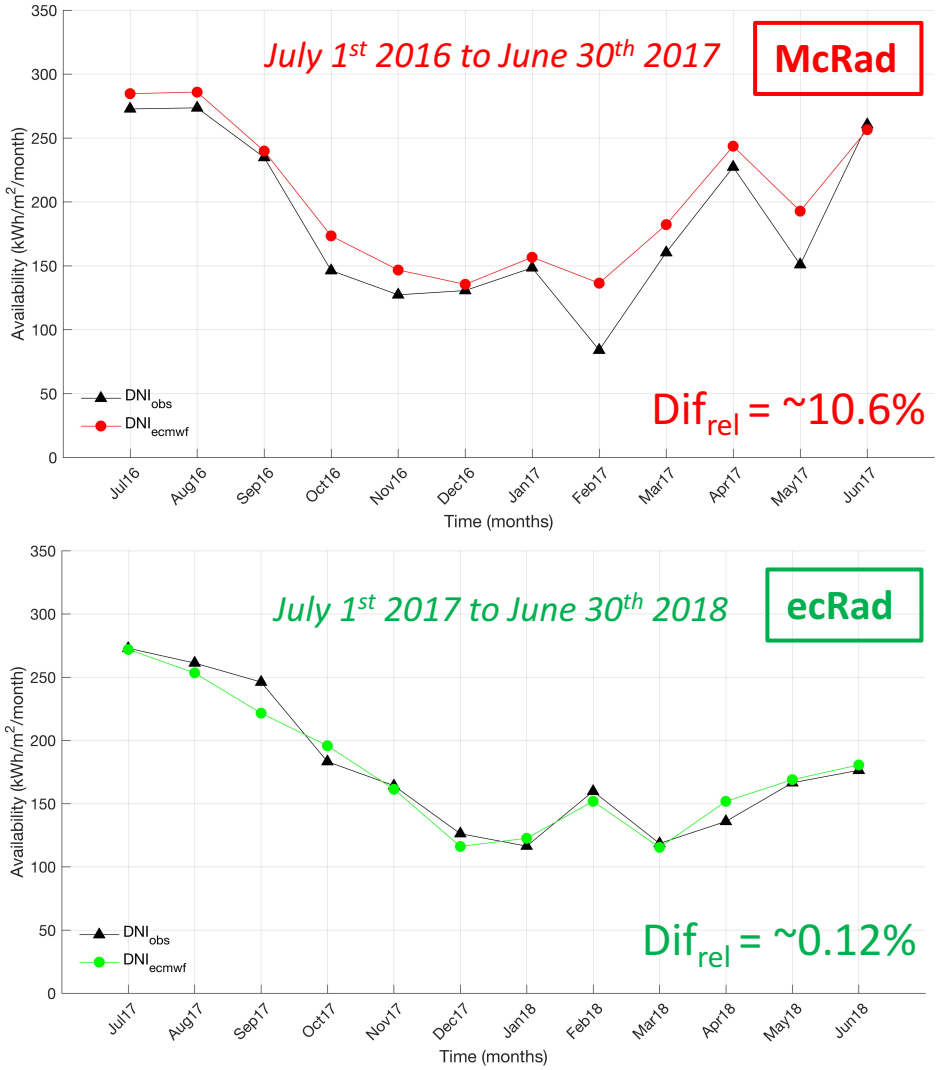
ecRad **predicted annual mean values closer** to measured values than McRad.

ecRad Radiative Scheme

- Although ecRad performs better than the previous McRad, there is still over and underestimation of the model towards measurements



Daily availabilities (kWh/m^2) for DNI (E_b) in EVO during July 1st 2017 to June 30th 2018 (ecRad radiative scheme).



Monthly availability (kWhm^2/month) for DNI in EVO during July 1st 2016 to June 30th 2017 (McRad) and July 1st 2017 to June 30th 2018 (ecRad). Relative differences obtained through the sum of DNI hourly values.

On going and future work

- IFS short-term **forecasts** are **used in a simulated CSP system through the System Advisor Model (SAM)** software developed by the U.S. Department of Energy and National Renewable Energy Laboratory (NREL).

- Preliminary analysis with the **used parameters**: **DNI** (McRad) and **Meteorological data** from the IFS and measurements was performed (SolarPACES 2018).

- Output of the predicted **annual electricity injection** to the grid E_G (MWh) from a linear parabolic-trough power plant.

- Relative difference of ~12.16% between the E_G based on forecasted and measured data.

- <u>Current work:</u>

    - McRad is replaced by the ecRad in SAM analysis.

    - Include a higher number of input parameters from real power plants in SAM software.

Predictive Value of Short-term Forecasts of DNI for Solar Energy Systems Operation

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Abstract. Solar power forecasting plays a critical role in power-system management, scheduling, and dispatch operations. Accurate forecasts of direct normal irradiance (DNI) are essential for an optimized operation strategy of concentrating solar thermal (CST) systems, particularly under clear-sky conditions during partly cloudy days. In this work, short-term forecasts from the radiative scheme *McRad* (Cycle 41R2) included in the Integrated Forecasting System (IFS), the global numerical weather prediction model of the European Centre for Medium-Range Weather Forecasts (ECMWF), together with in-situ ground-based measurements, are used in a simulated linear parabolic-trough power system through the System Advisor Model (SAM). Results are part of a preliminary analysis concerning the value of DNI predictions from the IFS for the improvement of the operationalization of a CST system with similar configurations as the Andasol 3 CST power plant. For a 365-day period, the present results show high correlations between predictions of energy to grid based on measurements and IFS forecasts mainly for daily values (~0.94), while the lower correlations obtained for hourly values (~0.89) are due to cloud representation of the IFS during overcast periods, leading to small deviations with respect to those from measurements. Moreover, as means to measure the forecasting skill of the IFS, daily and hourly skill scores based on local measurements and a persistence model are obtained (0.66 and 0.53, respectively), demonstrating that the IFS has a good overall performance. These aspects show the value that forecasted DNI has in the operation management of CST power systems, and, consequently, in the electricity market.

SolarPACES 2018
Solar Power & Chemical Energy Systems
Oct 2–5, 2018 | Casablanca, Morocco

ECMWF → NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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COMPETE 2020

ALENTEJO 2020

PORTUGAL 2020

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Francis M. Lopes, Ricardo Conceição, Hugo G. Silva, Thomas Fasquelle, Rui Salgado, Paulo Canhoto, Manuel Collares-Pereira. "ECMWF Forecasts of DNI for Optimized Operation Strategies for Linear Parabolic-trough and Central Receiver Systems". (in preparation)

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Francis M. Lopes, Ricardo Conceição, Hugo G. Silva, Rui Salgado, Paulo Canhoto, Manuel Collares-Pereira. "Predictive Value of Short-term Forecasts of DNI for Solar Energy Systems Operation". SolarPACES 2018 Proceedings. (submitted for review)

Francis M. Lopes, Hugo G. Silva, Rui Salgado, Afonso Cavaco, Paulo Canhoto, Manuel Collares-Pereira. "Short-term Forecasts of GHI and DNI for Solar Energy Systems Operation: assessment of the ECMWF Integrated Forecasting System in Southern Portugal". Journal of Solar Energy, August 2018, 170, 14-30. doi: 10.1016/j.solener.2018.05.039

Thank you.