Use of direct radiation forecasts to improve the reliability of solar thermal energy

Jose L. Casado-Rubio, Cristina Robles-Gonzalez, Maria-Aranzazu Revuelta, Isabel Martínez
Area de Aplicaciones, AEMET

Using ECMWF's Forecasts, 8th June 2018

Outline

- PreFlexMS project
- Red Electrica project
- Some additional remarks

PreFlexMS project

PreFlexMS
PREDICTABLE&FLEXIBLE SOLAR POWER WITH MOLTEN SALT ENERGY STORAGE

Predictable and **Flex**ible **M**olten **S**alts Solar Power Plant project (www.preflexms.eu) is a Horizon 2020 demonstration project which aims to improve the dispatchability of Concentrating Solar Power (CSP) plants.

PreFlexMS is a consortium of 13 partners from 8 European countries. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654984. Swiss partners are funded by the State Secretariat for Education, Research and Innovation of the Swiss Confederation.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

FR ALSTOM Power Systems

CH ALSTOM (Switzerland) Ltd.

IT Politecnico di Milano. Dept. of Electronics, Information and Bioengineering
ESE Engineering. Services for Energy S.r.l.
STF Salvatore Trifone e Figli S.p.A.

PL AGH University of Science and Technology. Dept.of Applied Computer Science
EC Systems Sp. z o.o.

DE DLR German Aerospace Center. Remote Sensing Data Center
DLR German Aerospace Center. Institute of Solar Research
University of Stuttgart Dept. of Life Cycle Engineering (GaBi)

SK GeoModel Solar s.r.o.

PT University of Evora. Renewable Energies Chair

ES AEMET State Agency for Meteorology
CENER National Renewable Energy Centre

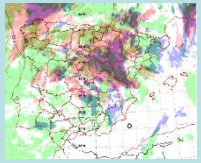
Direct Normal Irradiance (DNI) is the key parameter to predict the output from a Concentrated Solar Power (CSP) plant.

CSP plants with molten salts storage can adapt their output to the demand, storing energy during the day and dispatching it during the night.

One of the objectives of the project is to take into account DNI meteorological forecasts in the operation of CSP plants to get predictable solar power outputs, which can be modulated according to both meteorological conditions and economical constraints to optimize output and profit.

This would help to avoid the intermittency problem, omnipresent in many renewable sources of energy.

Meteorological models
(AEMET)



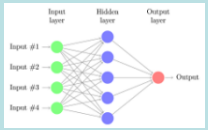
ECMWF High Res
3-hourly

ECMWF EPS
3-hourly, 50 members

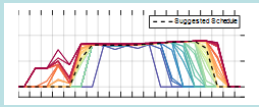
HARMONIE - AROME
every 15 min

gSREPS
3-hourly, 20 members

Machine learning (post-processing)
(CENER)



Dispatch Optimizer
(DLR)

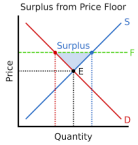


Optimal dispatch trajectory

Past observations

CSP Plant variables

Market price

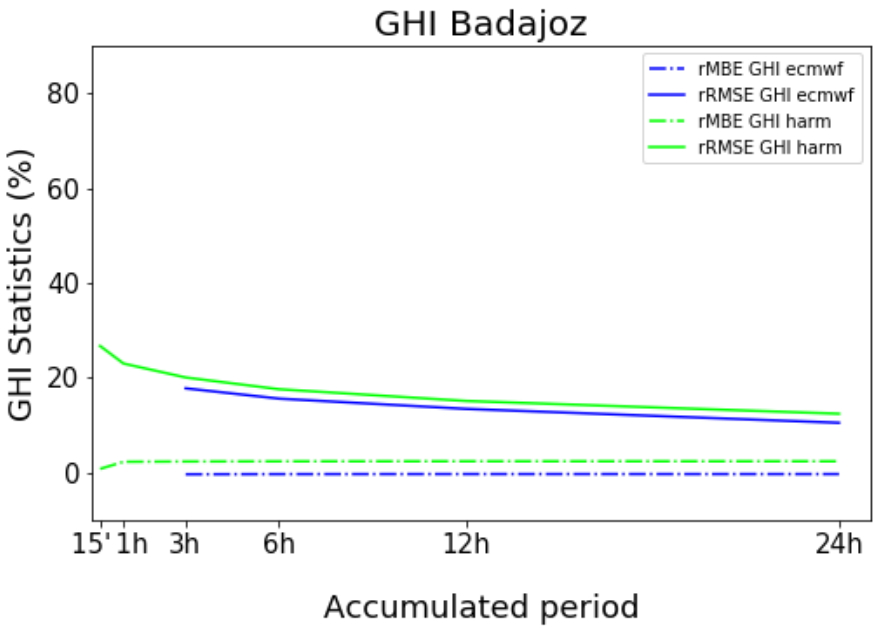


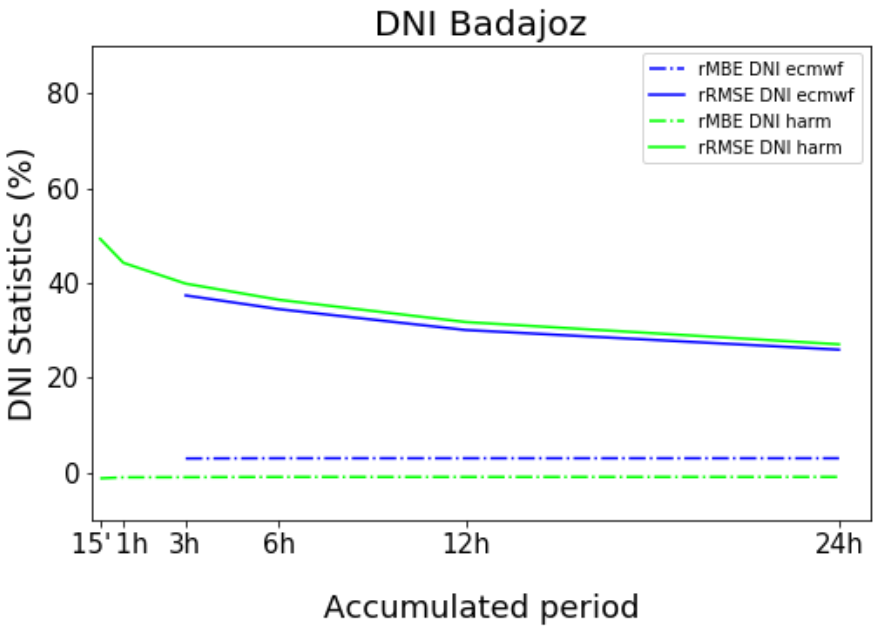
The prototype for the project is being built in Evora (Portugal), but a near station in Badajoz, part of AEMET radiation network, has been chosen to verify DNI forecasts.

Other stations of our network have been used too to get a more complete comparison.

The period verified spans three years: from March 2015 to February 2018 (Mar 2017 – Feb 2018 for 15-min Harmonie-Arome data)

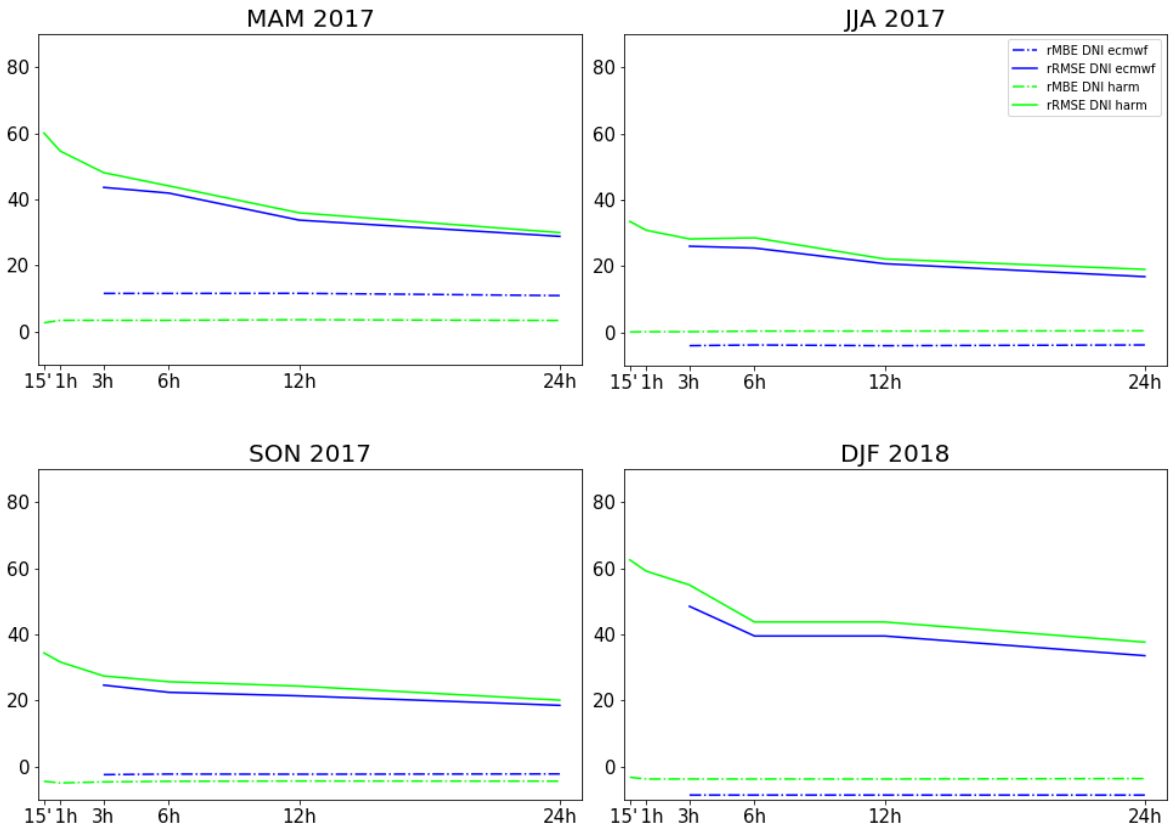
Errors for different accumulating periods:





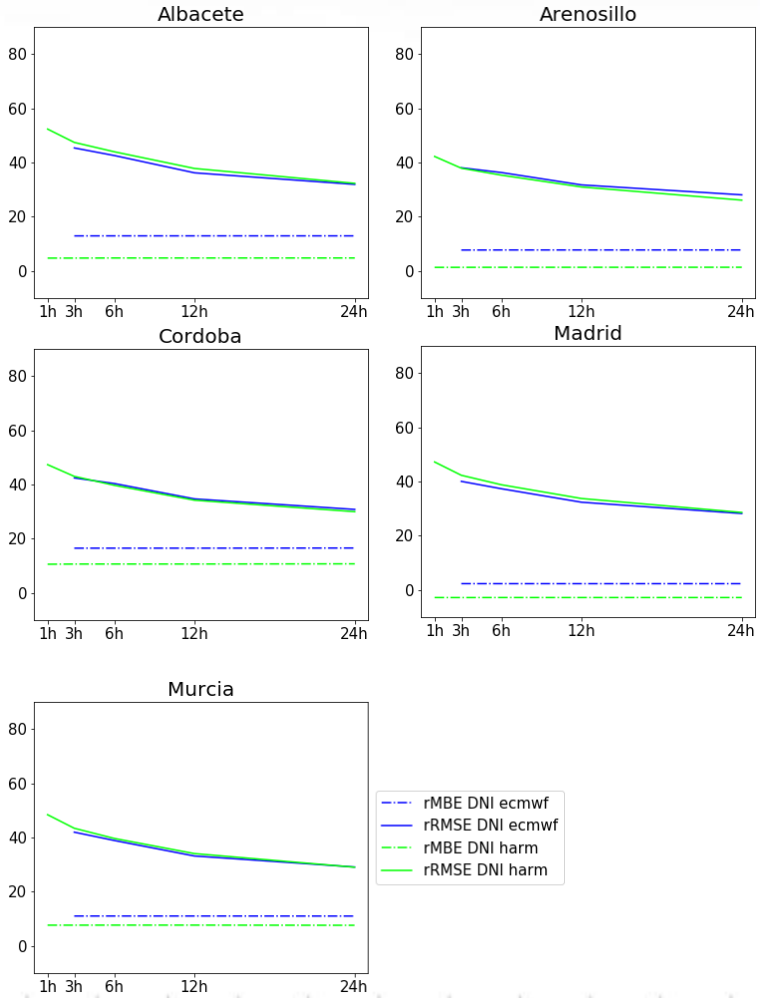
(1 day ahead predictions for the 0Z run are shown)

DNI error for each season of the year:



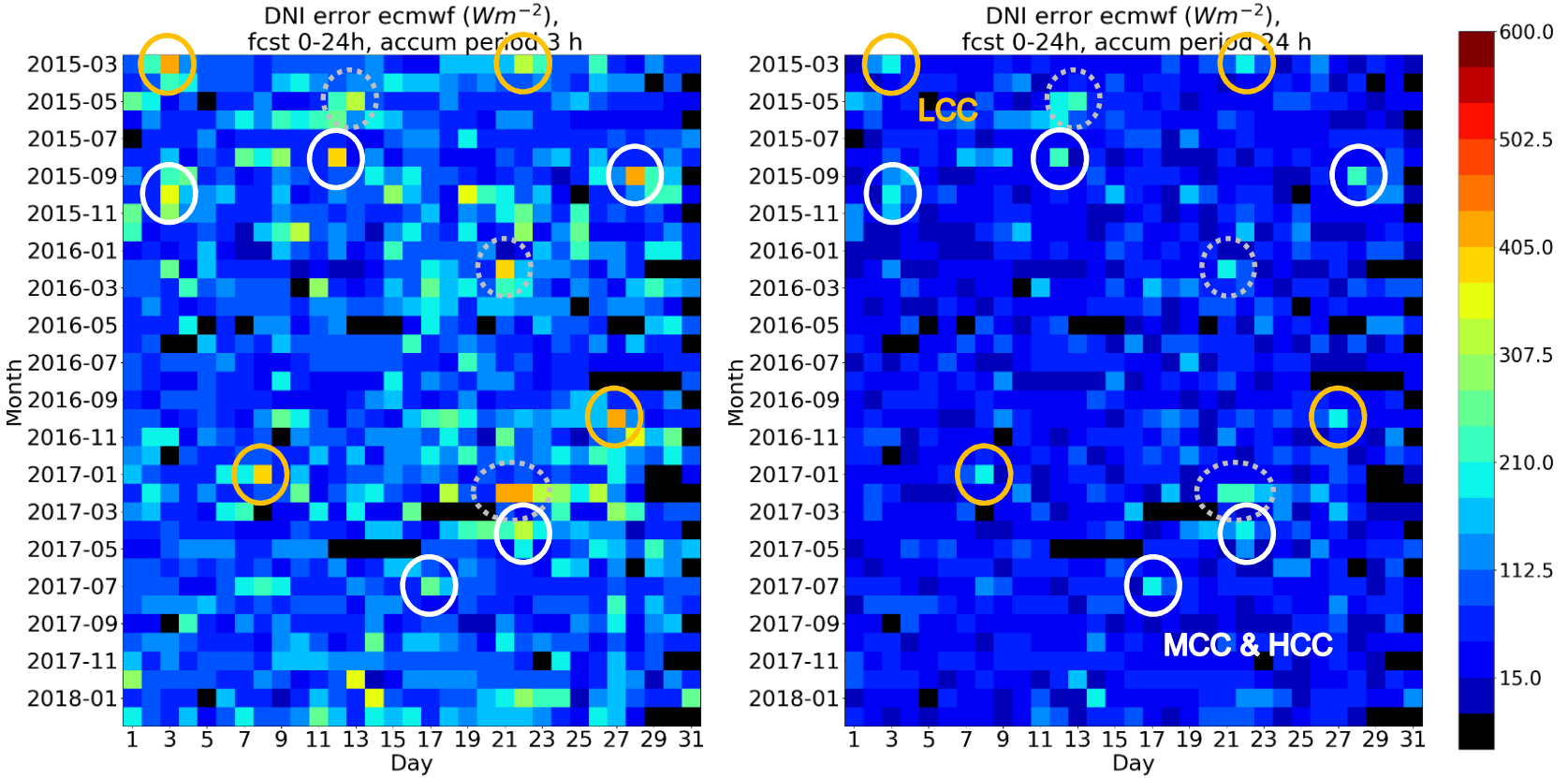
Notice the sharp increase in the error in winter for 3-hour and shorter accumulation periods.

DNI error for different locations:

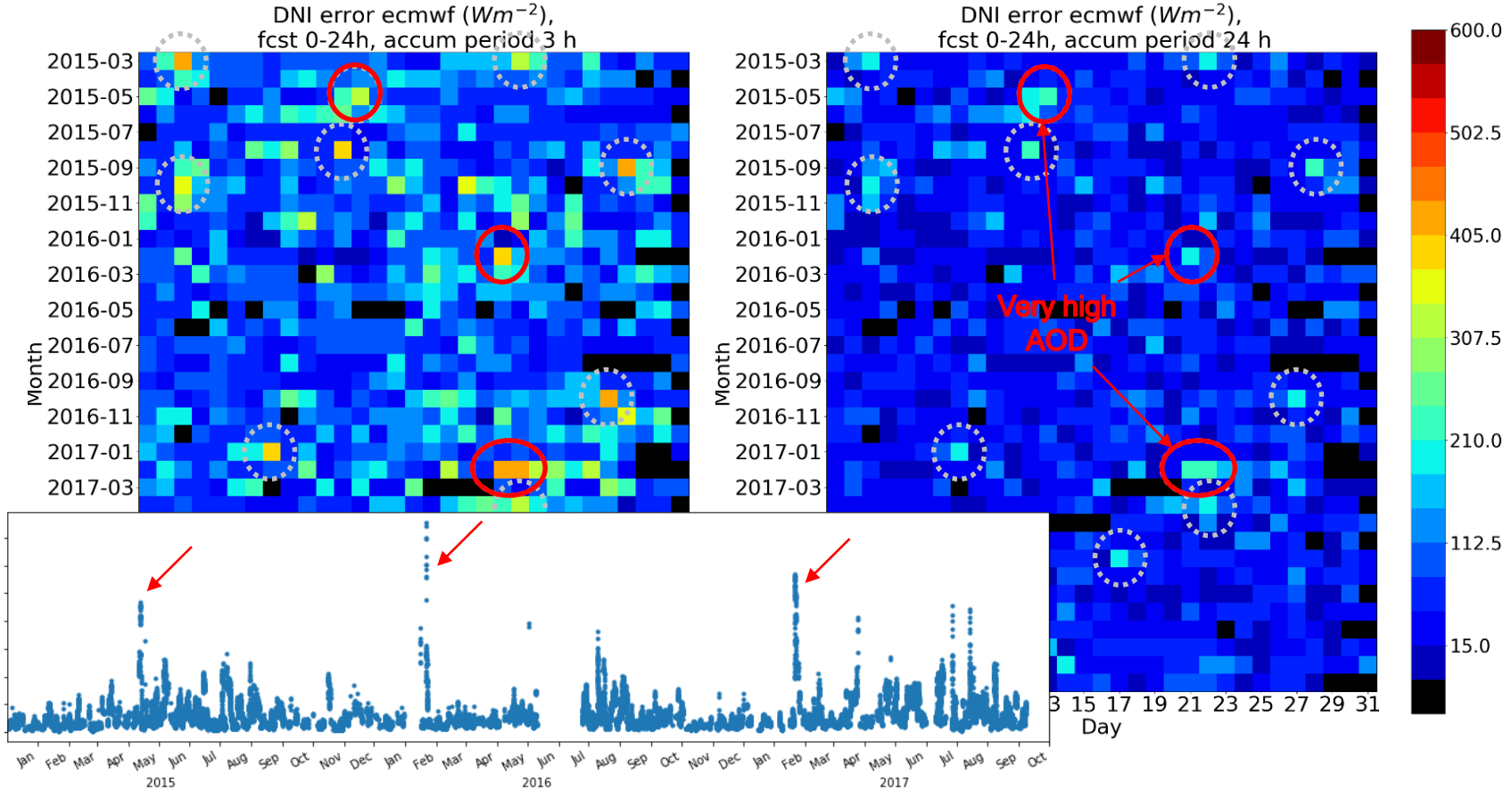


Harmonie-Arome and ECMWF model show a similar performance in other stations.

Sources of error:



Sources of error:



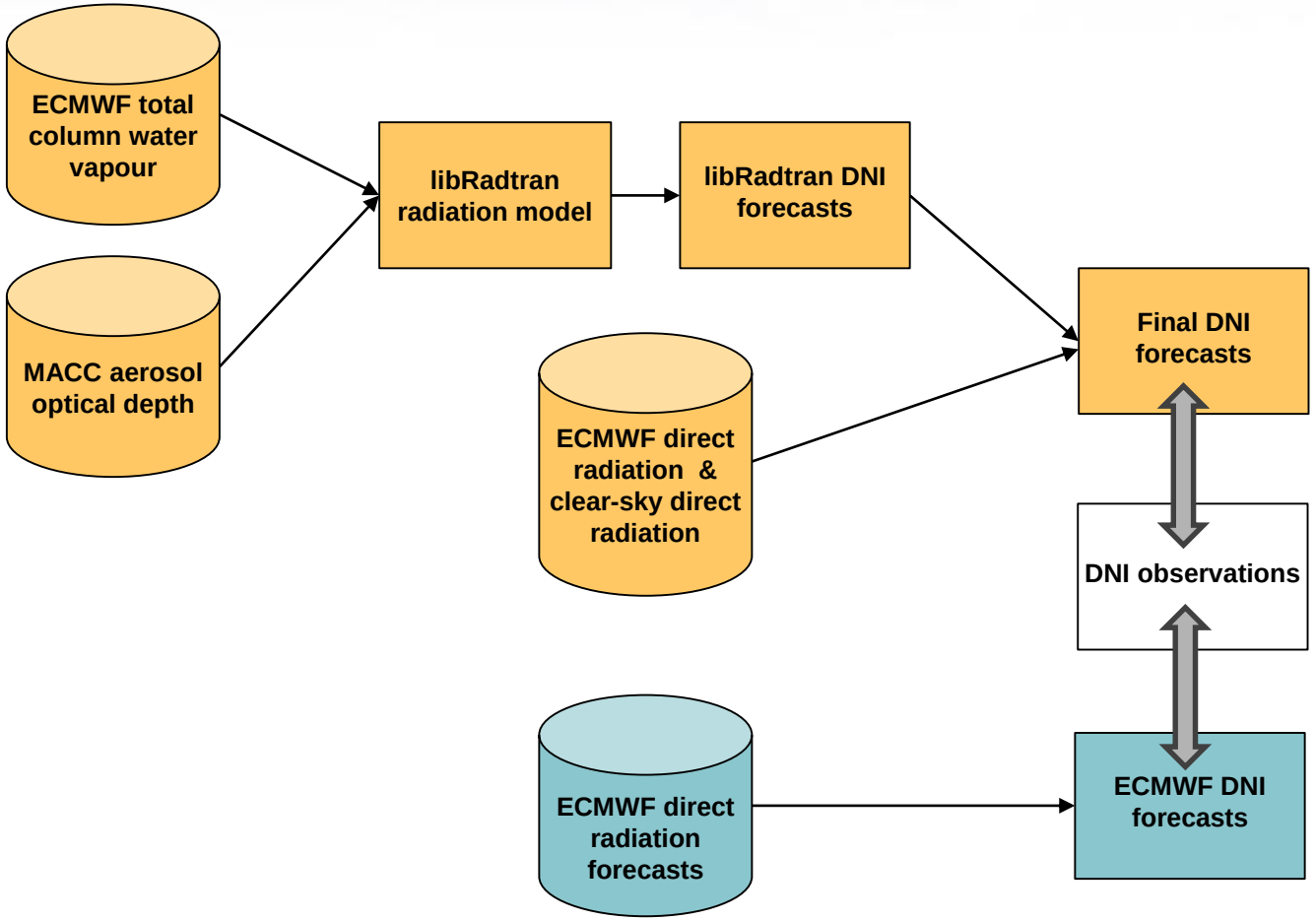
Red Electrica project

ECMWF direct radiation predictions have been compared with the direct radiation calculated by the libRadtran radiation model using as inputs the total column water vapour forecasted by ECMWF and the aerosol optical depth (AOD) forecasted by MACC (now CAMS).

This method, proposed first by Breitkreutz (2009), allows us to estimate the influence of aerosols in DNI forecasts for clear days, and in particular the effect of different aerosols species.

For cloudy days, ECMWF total sky direct solar radiation (fdir) and clear-sky direct solar radiation (cdir) have been used to estimate the effect of clouds:

$$DNI = DNI_{lrt}\frac{fdir}{cdir}$$


ECMWF total column water vapour
MACC aerosol optical depth
libRadtran radiation model
libRadtran DNI forecasts
ECMWF direct radiation & clear-sky direct radiation
Final DNI forecasts
DNI observations
ECMWF direct radiation forecasts
ECMWF DNI forecasts

Relative RMSE for clear sky situations

Clear sky situations have been selected according to the filters used by AERONET.

Site	Year	rRMSE (ECMWF)	rRMSE (lRt + MACC)
Badajoz	2013	9.8%	8.1%
Madrid	2013	12.9%	11.2%
Murcia	2013	10.6%	9.6%
Badajoz	2014	8.6%	6.8%
Madrid	2014	9.3%	9.1%
Murcia	2014	11.0%	9.4%

(Casado-Rubio et al., 2017)

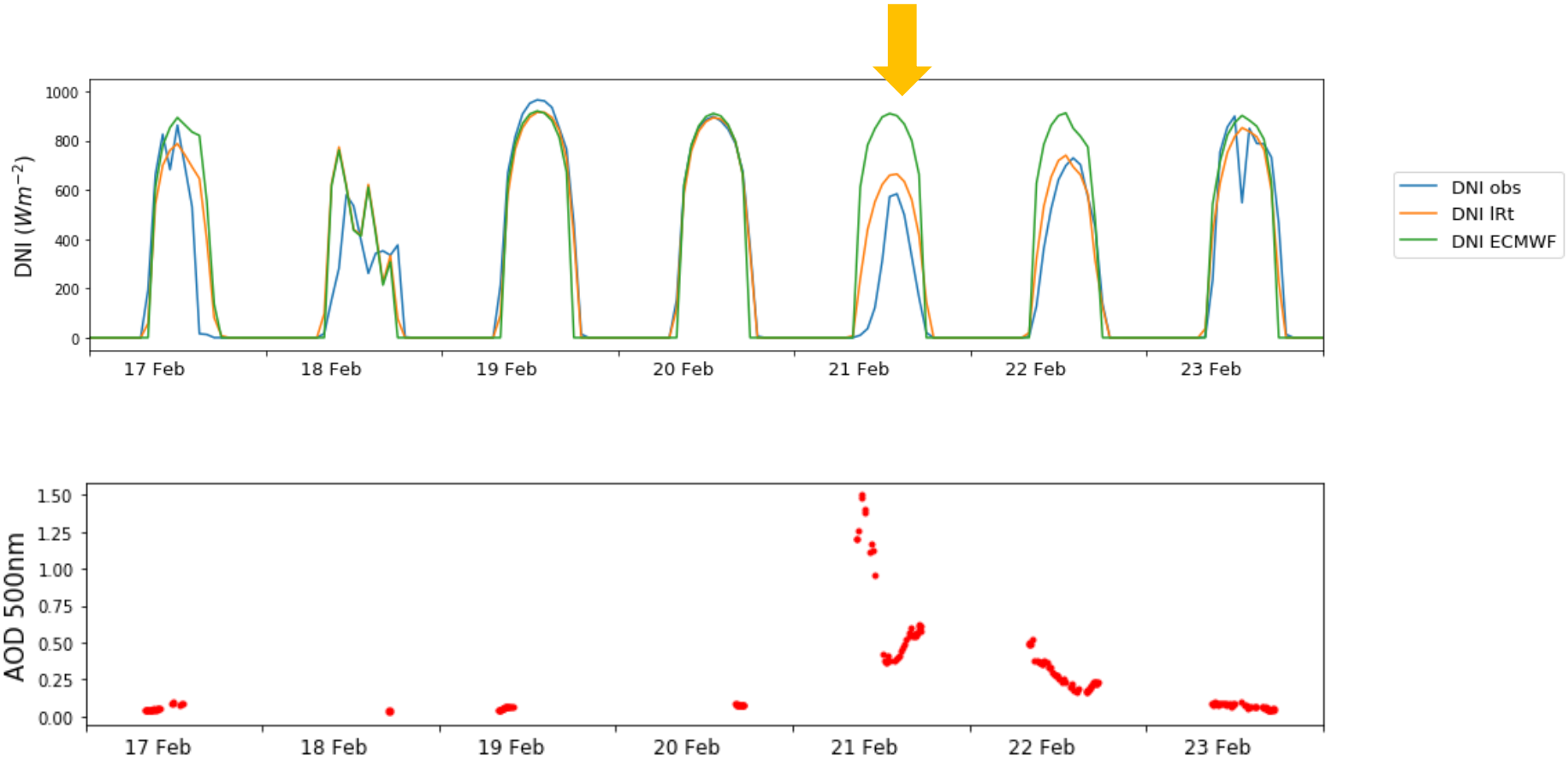
Relative RMSE in high aerosol content events

High aerosol content events are those where the measured AOD at 500 nm is higher than the 85th percentile.

Site	Year	rRMSE (ECMWF)	rRMSE (lRt + MACC)
Badajoz	2013	21.2%	13.7%
Madrid	2013	18.9%	13.3%
Murcia	2013	24.0%	17.5%
Badajoz	2014	19.5%	14.5%
Madrid	2014	19.0%	15.0%
Murcia	2014	23.6%	17.4%

(Casado-Rubio et al., 2017)

Case study: Badajoz, 21st Feb 2016



Summary

- ECMWF forecasts of direct radiation can be used in real time to increase the efficiency and profitability of CSP plants.

- Harmonie-Arome and the ECMWF model get similar scores for DNI in southern Spain.

- Although clouds are the main source of error, aerosols have a big impact in some specific days.

- CAMS (MACC before) is a valuable tool which can be used in an indirect way to include prognostic aerosols when forecasting direct radiation. A simple method which combines ECMWF direct radiation forecasts and CAMS aerosol forecasts has been developed to improve DNI predictions in specific locations.

Some remarks about our interaction with users

- Projects are usually carried out by different teams, located in several places (different buildings, cities or even countries). Communicating with users can be quite hard.
- Meteorologists and users have a different mindset/worldview. It can be quite difficult to understand each other.
- Meetings are useful, but are not held very often. A lot of time is usually wasted agreeing to very basic concepts.
- Using common tools can help to overcome these hurdles: it allows to build bridges and establish a common language.
- User-friendly, plug-and-play, easy tools are often more suitable, even if they are not very powerful: users can quickly learn to work with them, and a very deep knowledge of the subject is not needed.

Thank you for your attention!

Bibliography

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- Casado-Rubio, J.L., M.A. Revuelta, M. Postigo, I. Martínez-Marco, and C. Yagüe, 2017: A Postprocessing Methodology for Direct Normal Irradiance Forecasting Using Cloud Information and Aerosol Load Forecasts. J. Appl. Meteor. Climatol., 56, 1595–1608, doi:10.1175/JAMC-D-16-0297.1