DNICast

Direct Normal Irradiance Nowcasting methods for optimized operation of concentrating solar technologies

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[Methods for the estimation of the Direct Normal Irradiation (DNI)]

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1. Abstract

This report describes the combined nowcasting data sets that are created based on the nowcasts of different methods from the DNICast project. The data sets are prepared for their validation and their application in CST (Concentrating Solar Technology) models.

First a short summary of the combination method and the input data sets is presented. Then the two implemented combination methods are described in more detail including the output data format and their availability for the project consortium.

Keywords: Nowcasting, DNI, combination, uncertainty

2 Overview of the combination methods and the input data sets

In WP 3.4 of DNICast a combination of several nowcasts which have been developed in earlier work packages of the project was generated. The combination was performed for four, 3-months length forecast periods and two selected stations.

Two combination approaches are shown. The first approach makes use of the uncertainty of each input nowcasting data set. To calculate the optimal combination of the different provided nowcasts, the method of (Meyer et al., 2008) is applied to derive a combined product, considering the individual uncertainties of the nowcast products. For each set of refresh time and forecast time of the combined nowcast data set, the available different data sets are included in the combination.

The second combination method uses a time-dependent multi-regressive model. It is inspired in the forecasting optimization of precipitation (Turlapaty et al., 2012). For the merging purpose, an adaptive linear merging model is presented. In this scheme, the explanatory variables are those DNI values predicted in previous forecast events. Thus, each DNICast nowcasting output provides a number of variables depending on the forecasted horizon, the refresh time and the time step.

2.1 Characteristics of nowcasting inputs for the combination

Several nowcast from different methods are available:

1. DNI nowcasting method with all sky images.
2. Satellite based cloud and DNI nowcasting methods.
3. Numerical Weather Prediction (NWP) based nowcasting methods.

In Table 1, the main characteristics of the possible nowcast inputs for the combination are summarized.

Table 1: Main characteristics of the available DNICast nowcast inputs for the combination

Data source	Partner	Refresh interval (min)	Time res. (min)	Horizon (min)	Horizon (hour)
SKY IMAGES	ARMINES	1	5	30	0.5
SATELLITE	DLR-DFD	15	1	480	8
SATELLITE	DLR-IPA	15	5	360	6
SATELLITE	Meteotest	15	5	240	4

SATELLITE	SMHI	180	15	540	9
NWPM	SMHI	180	15	540	9

At each specific location the availability of nowcasts suppliers and supplied periods can vary. Thus, the availability of nowcasts suppliers and periods available at Plataforma Solar de Almería (PSA) are shown in Table 2. “(x)“ means that the entire month is not available.

Table 2: Available nowcast periods and suppliers at PSA

Data source	Partner	2010 JAN	2010 FEB	2010 MAR	2013 MAR	2013 APR	2013 MAY	2014 JUN	2014 JUL	2014 AUG	2015 SEP	2015 OCT	2015 NOV
SKY IMAGES	ARMINES							(x)	(x)	(x)	(x)	(x)	(x)
SATELLITE	DLR-DFD	X	X	X	X	X	X	X	X	X	X	X	X
SATELLITE	DLR-IPA	X	X	X	X	X	X	X	X	X	X	X	X
SATELLITE	Meteotest	X	X	X	X	X	X	X	X	X	X	X	X
SATELLITE	SMHI					X							
NWPM	SMHI	X	X	X	X	X	X	X	X	X	X	X	X

2.2 Testing sites and time periods

The combination approaches have been tested for two different sites. Figure 1 shows a map including the testing locations: Plataforma Solar de Almería (PSA) placed at the southeast of Spain and Ghardaia (GHA) placed in the north-center of Algeria.

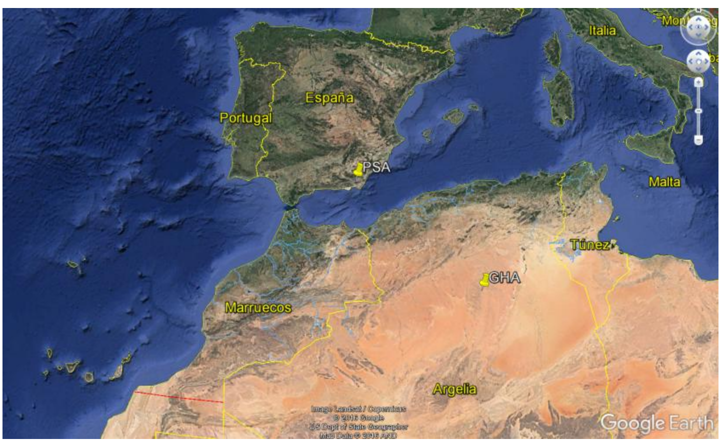

Figure 1: Plataforma Solar de Almería (PSA) and Ghardaia (GHA) location.

Each site has different nowcast availability. For instance, in Table 3, available nowcasts periods for the two selected locations from SATELLITE DLR-DFD are shown.

Table 3: Available periods at the selected locations from SATELITE DLR-DFD

Station	Lat. (°N)	Lon. (°E)	Altitude (m)	Full Name	Time period
PSA	37.0909	-2.3581	500	DLR_PSA	2010-Jan, Feb, Mar
					2013-Mar, Apr, May
					2014-Jun, Jul, Aug
					2015-Sep, Oct, Nov
GHA	32.386	3.78	463	Enermena_Ghardaia	2013-Mar, Apr, May
					2014-Jun, Jul, Aug

3 Combined nowcast provided by DLR-IFS

3.1 Methodology

To calculate the optimal combination of the different provided nowcasts, the method of Meyer et al. (2008) is applied.

In a first step, nowcasted DNI in Wm^{-2} is extracted for each available data set.

For each set of refresh time and forecast time for the combined nowcast data set, it is verified if a nowcasted DNI from the different data sets is available.

The combined DNI is calculated from all available nowcasted DNI_i from the data set *i* for each set of refresh time and forecast time:

$$DNI_{combined} = \left(\frac{1}{\sum_{i=1}^{n} \frac{1}{\Delta i}}\right) \cdot \left(\sum_{i=1}^{n} \frac{DNI_i}{\Delta i}\right)$$

Where $DNI_{combined}$ is the resulting combined DNI and DNI_i is the nowcasted DNI of the data set *i*, both given in Wm^{-2} for one time stamp. Δi is the absolute error for each data set *I* and this time stamp. Δi is provided by WP3.1-3.3 and WP4 as a function of the forecast horizon and the meteorological conditions.

The estimated absolute uncertainty of combined DNI $\Delta_{DNIcombined}$ is calculated with:

$$\Delta_{DNI_{combined}} = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial DNI_{combined}}{\partial DNI_i} \cdot \Delta i \right)^2}$$

given in Wm^{-2}.

If no absolute uncertainty is given for one set of refresh time and forecast time and one data set, a default uncertainty is estimated dependent on the data set.

If the absolute uncertainty of Meteotest (clim post-processed) is available, the absolute uncertainty of the persistence nowcast is estimated to be the same.

Table 4: Combined data sets by DLR-IFS

Work package	Project partner	Method	Data sets
3.2	DLR-IPA	Satellite based	DLR-IPA Satellite based
3.2	Meteotest	Satellite based	clim post-processed
			climdirect post-processed
			maccdirect post-processed
3.2	DLR-DFD	Satellite based	DLR-DFD Satellite based
3.3	SMHI	NWP based	- 15-min accumulated single grid point - 15-min accumulated average of 5x5 grid points around the station
-	DLR-ISF	Persistence	Persistence

3.2 Provided data set by DLR-IFS

The combined nowcast for DNI is provided for PSA and Ghardaia (four and two validation periods respectively, see Table 3).

The data set of the combined DNI and its uncertainty are delivered for the nowcasting parameters displayed in Table 5.

Table 5: Main characteristics of the combined nowcast by DLR-IFS

Refresh interval	15 min
Temporal resolution	15 min
Horizon	24 hours (maximal horizon of data set included in data set is 6 hours → 6 hours to 24 hours so far set to NaNs)

The final dataset has been uploaded in the ftp-site of DNICast dnicast@ftp.oie-lab.net at the following folder /data/Outputs/Forecasts/3.4_DLR_IFS_Combination_forecast.

3.3 Data format

The naming convention of the data files is the following:

Comb_NC_refr<refresh_time>min_res<temporal_resolution>min_hor<horizon>min_<location>_<yyyy>_<months_code>_<start_yyyymmddHHMM>_<end_yyyymmddHHMM>.dat

with the following abbreviations:

<refresh_time>: refresh time in minutes
<temporal_resolution>: temporal resolution in minutes
<horizon>: horizon in minutes
<location>: location code (PSA or GHA)
<months_code>: months code, e.g. 'JFM' for January, February, March
<start_yyyymmddHHMM>: start time stamp
<end_yyyymmddHHMM>: end time stamp

These files have the following ASCII format following the MESOR guidelines:

```
#MESOR v1.1 11.2007
#Converted to MESOR format by MeteoDataConverter.m - conversion date: 20-Mar-2017
#type nowcast
#unitName yyyy-mm-dd HH:MM, yyyy-mm-dd, HH:MM, W/m^2,
#IPR.providerName Deutsches Zentrum für Luft- und Raumfahrt (DLR)
#location.latitude[°E]: 37.091
#location.longitude[°N]: -2.358
#location.altitude[m]: 500
#timezone UTC+0
#comment Meteotest Sat (clim, climdirect, maccdirect), DFD Sat and SMHI NWP (1 and 2) combination
#comment infinite or missing combined nowcasts/uncertainties are marked with -999
#channel model_date yyyy-mm-dd
#channel model_time HH:MM
#channel horizon_date "yyyy-mm-dd"
#channel horizon_time "HH:MM"
#channel DNI "W/m^2"
```

#channel uncertainty "W/m^2"
#channel nr combined nowcasts " "
#begindata

2010-01-01 00:00	2010-01-01 00:00	0	0	1
2010-01-01 00:00	2010-01-01 00:15	0	0	3
2010-01-01 00:00	2010-01-01 00:30	0	0	3
2010-01-01 00:00	2010-01-01 00:45	0	0	3

…
%enddata

4 Combined nowcast provided by

4.1 Methodology

CIEMAT's combination uses a time-dependent multi-regressive model. It is inspired in the forecasting optimization of precipitation (Turlapaty et al., 2012). For the merging purpose, an adaptive linear merging model is presented. In our scheme, the explanatory variables are those DNI values predicted in previous forecast events. Thus, each DNICast nowcasting output provides a number of variables depending on the forecasted horizon, the refresh time and the time step. The combined model result N is calculated with the following equation using the total number of input variables:

$$N = \sum_i n_i$$

$$n_i = \sum_i FO_i \cdot d_i$$

$$d_i = \frac{Hm_i}{Rm_i}$$

Table 6 shows the definition of the used symbols and details to evaluate the number of inputs variables from each supplier (n_i).

Table 6: Nowcast input variables at CIEMAT methodology

Method	Partner	Refresh interval (min)	Horizon (min)	Data by time	Forecasted outputs	Inputs for comb.
		$\boldsymbol{Rm_i}$	$\boldsymbol{Hm_i}$	$\boldsymbol{d_i}$	$\boldsymbol{FO_i}$	$\boldsymbol{n_i}$
CAMARAS	ARMINES	1	30	30	1	30
SATELLITE	DLR-DFD	15	480	32	1	32
SATELLITE	DLR-IPA	15	360	24	1	24

SATELLITE	Meteotest	15	240	16	3	48
SATELLITE	SMHI	180	540	3	2	6
NWPM	SMHI	180	540	3	2	6

In order to determine the significant variables among the total inputs for the combination, a stepwise methodology is applied. Stepwise regression is a systematic method for adding and removing terms from a multilinear model based on their statistical significance in a regression.

Some tests have been done training general models for long periods such as the three months available by each year and it has been detected that the significant variables change when the training period changes. This is justified because stepwise models are locally optimal, but may not be globally optimal. Then, better results are obtained when using dynamic fitting. In addition, dynamic fitting aims to include new inputs when an additional supplier is available. For the dynamic fitting a moving window of two days has been established and then this is the time needed for an impact of the input changes in the model.

In addition to the combination, a post process treatment is needed. Physical limits are applied to the combined output. Due to the time-dependent multi-regressive model methodology increases the forecasted DNI variability, the treatment attempts to adjust this variability.

4.2 Provided data sets

The combined nowcast for DNI is provided for PSA and Ghardaia.

The data set of the combined DNI and the RMSE obtained in the training phase of the applied model are delivered for the nowcasting parameters displayed in Table 7.

Table 7: Main characteristics of the combined nowcast by CIEMAT

Refresh time	15 min
Temporal resolution	1 min
Horizon	4 hours (minimal horizon of data set included in the model)

The final dataset has been uploaded in the ftp-site of DNICast dnicast@ftp.oie-lab.net at the following folder /data/Outputs/Forecasts/3.4_CIEMAT_Combination_forecast.

4.3 Data format

The naming convention of the data files is the following:

CIEMAT_<model_version>_<location>_<YYYY>_<DDD>_<refresh_time>.TXT

With the following elements:
<model_version>: model version starting from ‘NC01’
<location>: location code (i.e. ‘PSA’)
<YYYY>: four digits year
<DDD>: three digits Julian day
<refresh_time>: refresh time in format ‘hhmm’

These files have the following ASCII format following the MESOR guidelines:

```
#MESOR V2017 IEC Draft
#Converted to MESOR format by Write_MESOR_from_DATOS_DNICast.m
#type nowcast
#unitName yyyy-mm-dd, HH:MM, W/m^2,
#IPR.providerName C
#location.latitude[°E]: 37.091
#location.longitude[°N]: -2.358
#location.altitude[m]: 500
#timezone UTC+0
#comment number of input models: 3
#channel horizon_date "yyyy-mm-dd"
#channel horizon_time "HH:MM"
#channel DNI "W/m^2"
#channel RMSE "W/m^2"
#channel nr nowcasts inputs from model 1 " "
#channel nr nowcasts inputs from model 2 " "
#channel nr nowcasts inputs from model 3 " "
#begindata
2010-01-01 00:00    0    0    12    3    14
2010-01-01 00:01    0    0    12    3    14
2010-01-01 00:02    0    0    12    3    14
2010-01-01 00:03    0    0    12    3    14
…
%enddata
```

5 References

Meyer, R., Geuder, N., Lorenz, E., Hammer, A., Ossietzky, C. Von, Oldenburg, U., Beyer, H.G., 2008. Combining solar irradiance measurements and various satellite-derived products to a site-specific best estimate, in: SolarPaces Conference. pp. 1–8.

Turlapaty, A.C., Younan, N.H., Anantharaj, V.G., 2012. A linear merging methodology for high-resolution precipitation products using spatiotemporal regression. International Journal of Remote Sensing 33, 7844–7867. doi:10.1080/01431161.2012.703345