NOWCASTING SOLAR RADIATION USING CLOUD SATELLITE AND HIGH RESOLUTION NUMERICAL MODEL OUTPUTS

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1.- INTRODUCTION

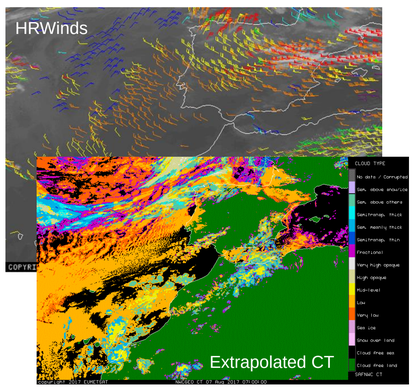
AEMET (the Spanish Meteorological Agency) is currently developing a project for the Spanish transmission system operator, Red Eléctrica de España, to improve hourly Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) forecasts in Spanish solar power plants. There is a need of using nowcasting models to forecast the availability of solar radiation in order to low electricity generating costs. The nowcasting tool developed by AEMET provides every 15 min the hourly solar radiation accumulated fluxes for the coming 4 hours. The meteorological data used are: satellite cloud type observations and forecasts calculated using Meteosat Second Generation (MSG) information and surface radiation forecasts from the high resolution numerical weather prediction (NWP) model HARMONIE/AROME (Hirlam Aladin Regional/Meso-scale Operational NWP model), Both type of data are combined using different weights depending on the forecast time horizon. The accuracy of the tool has been analyzed comparing the GHI and DNI forecasts with the ground solar radiation measurements from nine stations from AEMET network. The verification results in terms of RMSE are similar to those found in the bibliography, with the advantage that the satellite component of the tool does not require the use of a model to convert satellite imagery to average insolation on the ground.

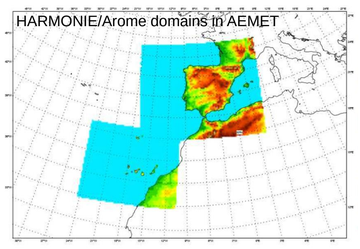
2.- METHODOLOGY AND DATA

- **Satellite-EXIM module**: the tool uses the Cloud Type (CT) information generated every 15 min by the EUMETSAT SAFNWC/MSG (www.nwcsaf.org) software package. The cloud categories have been reclassified so that the higher CT value corresponds to the higher amount of light blocked by the cloud. For each category it has been obtained the best fit between the AEMET solar radiation observations from seven peninsular AEMET stations and the solar zenith angle. The best results have been obtained using linear models for GHI and cubic ones for DNI (exponential, gaussian, logarithmic and quadratic models have also been tried to fit the observed data). Once we can convert CT into instantaneous solar irradiance we calculate the hourly accumulation using a trapezoidal integration of the satellite derived irradiances within the previous hour. The EXIM (Extrapolated Imagery) product uses the HRW (High Resolutions Winds) of the SAFNWC software package to cinematically extrapolate the CT observed up to four hours. The satellite information is averaged from 5 X 5 pixels windows centered at the pixel station ((the MSG pixel resolution is 3km at the subsatellite point). The training dataset includes 2007-2014 satellite and observation data.

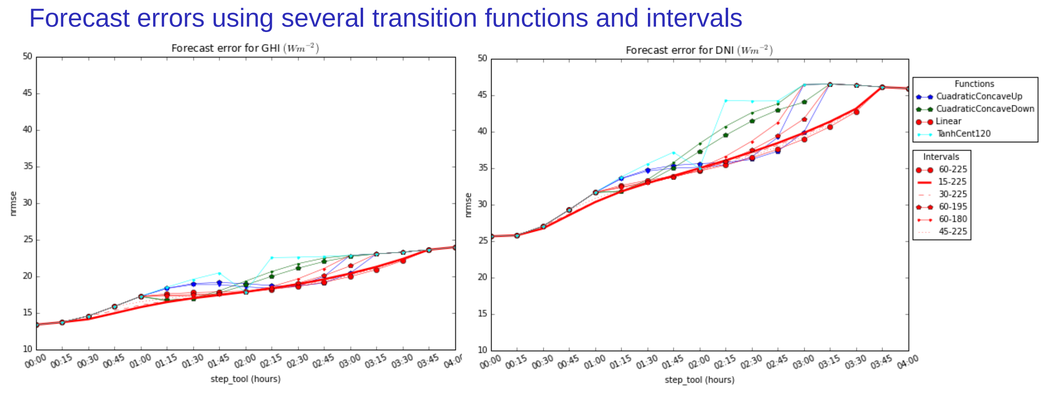
- **NWP-HARMONIE module**: the tool extracts the forecasts of hourly GHI and DHI (Direct Horizontal Irradiance) at surface level from the HARMONIE/AROME run in AEMET in two domains (including the Iberian Peninsula and Canary Islands). The model is run by AEMET every three hours with a 2.5 km horizontal resolution and forecast horizons from +00h to +48h having output every 15 min The forecasted DHI by the model has been converted into DNI afterwards dividing by the cosine of the zenithal angle. The model information is obtained from a linear interpolation of the four nearest to the station grid points.

- The **nowcasting tool** provides every 15 min the hourly solar radiation accumulated fluxes for the coming 4 hours. The forecasts from satellite and NWP modules are combined depending on different forecast time horizons. The transition function chosen to provide the weights of each module forecasts along the predicted time range is a linear function witch takes a zero value for the HARMONIE forecast at a time horizon of 15 min and one for 225 min The sum of model and satellite weights is equal to one being the satellite contribution dominant for the first two forecasted hours and the numerical model one the for last two hours.

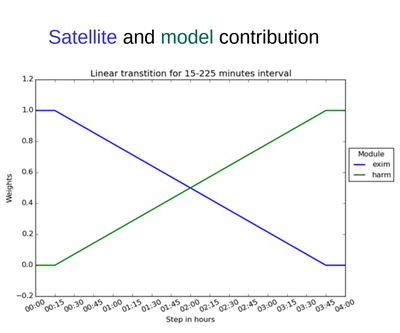




Forecast errors using several transition functions and intervals



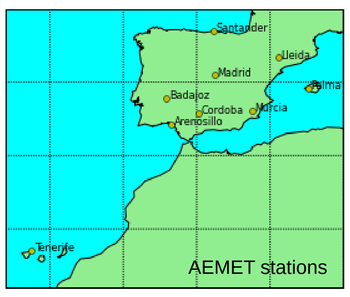
Satellite and model contribution



Transition functions:

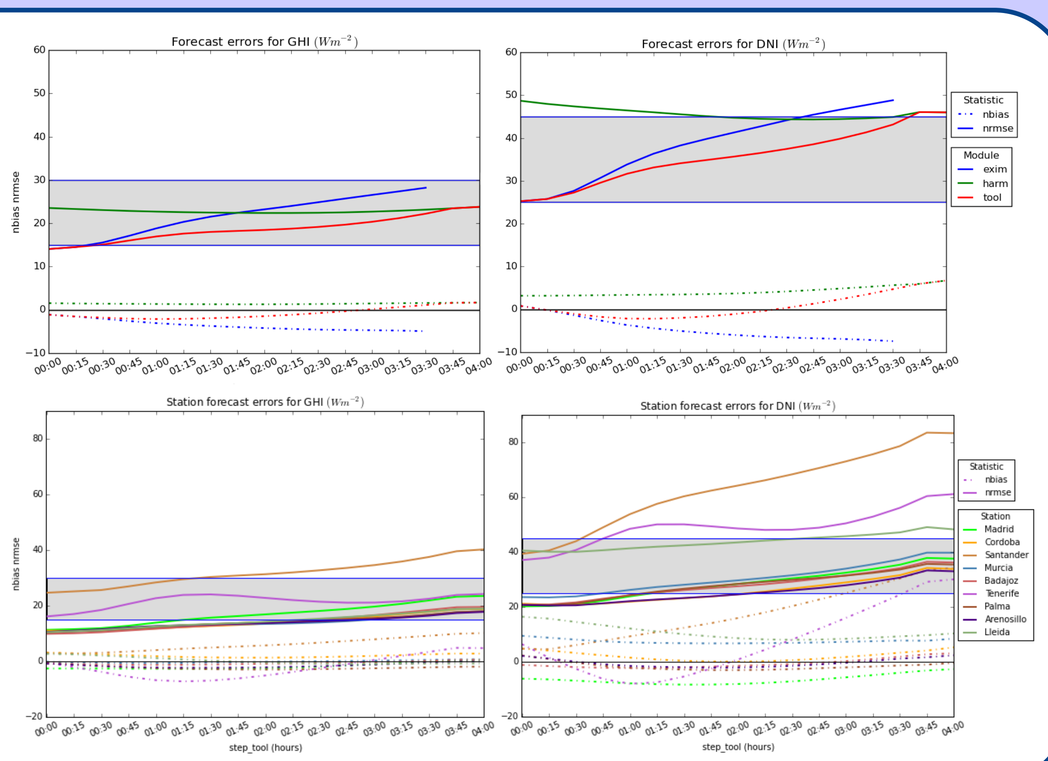
- Several types of transition functions have been tested to assigne the optimun contribution of satellite and model forecasts along the predicted range: Linear, Quadratic (Concave Up and Down) and Hyperbolic Tangent. Each function has been applied along diferent time horizons.
- The normalized root mean square error (nRMSE) obtained comparing the forecasted radiation with the measurements from Dec 2016 to Jun 2017 corresponding to seven peninsular AEMET stations has been used to choose the best transition function.
- The Linear function along 15-225 min interval (red solid line) provided the minimum forecast error.

3.- VALIDATION RESULTS



- The tool validation studies has been performed comparing the hourly GHI and DNI forecasted by the tool with the measurements from nine AEMET ground-based stations, the seven peninsular used in the calibration plus two insular from Balearic and Canarian islands.
- The validation dataset include forecasts and observations from the period Dec 2016-June 2017.

- The top plots show the hourly, normalized by the observation, nRMSE and nBIAS for the satellite and NWP modules as well as for the tool. These global results represent the forecast error for all the stations. The results of the tool forecast for each station separately are shown in the bottom plots.
- Globally, the satellite forecast has a negative increasing nBIAS and the NWP forecast present positive values, more stable for GHI. The tool compensate both behaviors resulting always in lower nRMSE errors.
- In cloudy regions and middle latitudes the hourly nRMSE using satellite information are expected in the range of 15%-30% for GHI and 25%-45% for DNI. These ranges are shown in grey in the graphics. The global validation of GHI is included within these thresholds for all time horizons and only are exceeded for the DNI an the end of the forecasted period. Most of the stations remain in the expected rage of validation errors.
- The hourly nRMSE using mesoscale atmospheric modeling for 24-hour lead time forecasts are usually in the range of 10%-50% for GHI and 30%-100% for DNI, depending on sky conditions. Global and individual validation tool errors are always into or lower than these thresholds.



4.- CONCLUSIONS AND FUTURE WORK

- The nowcasting tool developed by AEMET presents better scores than satellite and NWP modules separately, being the GHI (nRMSE around 14-24%) better forecasted than the DNI (nRMSE around 25-46%).
- The nRMSE values are similar to those found in the bibliography with the advantage that the satellite component of the tool does not require the use of a model to convert satellite visible imagery into the expected ground solar irradiance.
- Validation results depend on the ground station. Most of them present similar behavior but some (Santander, Tenerife, Lleida) differs from the average. A calibration based on a single station ground observations could improve the results.
- Validation studies will be perfomed based on single or grouped cloud categories.
- In the next step probabilistic forecasting approach will be introduced using ensembles from different numerical models and applying some type of perturbations to satellite forecasts .

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