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Final report: contribution of Meteotest

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Zusammenfassung

Die Universität Genf und Meteotest haben die Schweiz im IEA SHC Task 46 in der Periode von 2011 bis 2016 vertreten. Das Ziel des Tasks war es, der Solarindustrie, dem Stromsektor, den Behörden und der Organisationen aus dem Bereich der erneuerbaren Energien das Verständnis für qualitativ hochstehende ("bankable") Datensätze zu erhöhen.

Vorhersagen der Globalstrahlung werden immer wichtiger und häufiger genutzt – sei es für grosse PV-Anlagen, Stromnetzbetreiber oder für Gebäudesteuerungen. Eine wichtige Komponente des Tasks war es zu zeigen, wie genau die Solarstrahlung für die nächsten 3-5 Tage vorhergesagt werden kann. Ein Vergleich ("benchmark") von verschiedenen Vorhersage-Methoden für Deutschland, Österreich, Dänemark und die Schweiz wurde dazu im 2016 veröffentlicht und ist in diesem Bericht kurz beschrieben.

Ein weiteres wichtiges Arbeitsgebiet des Tasks war das Verständnis und die Beschreibung von kurzzeitigen Schwankungen und Rampen der Solarenergie im Minutenbereich, welche durch Wolkenzug verursacht werden. Diese Schwankungen werden von Netzbetreibern häufig gefürchtet. Ein Bericht - erarbeitet in Zusammenarbeit mit dem IEA PVPS Task 14 - zeigt, dass die Elektrizitätsunternehmungen keine Angst vor diesen Schwankungen haben müssen, da sich diese stark ausmitteln, je grösser das Gebiet und länger die untersuchte Zeitperiode ist.

Ein drittes zentrales Thema betraf die Methoden zur Berechnung von langjährigen Mittelwerten basierend auf kurzfristigen Messungen. Dabei werden kurzfristige und präzise Messungen an langfristige aber ungenauere Messungen (z.B. basierend auf Satelliten) angepasst. Solche Methoden werden heute immer öfter angewendet, um die Unsicherheit bei der Planung für sehr grossen PV-Anlagen zu senken.

Abstract

The University of Geneva and Meteotest represented Switzerland in the IEA SHC Task 46 in the period from 2011 to 2016. The goal of this task was to increase the understanding of the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions forthe “bankability” data sets provided by public and private sectors.

Solar forecasts are getting more and more important and are often used nowadays – by operators of big PV installations, electrical distribution and transmission systems or building automation systems. A major component of the task was to provide information on how accurately solar resources can be forecasted in the near future (sub-hourly, 1-6 hours, and 1-3 days) so that utilities can plan for the operation of large-scale solar systems operating within their systems. A benchmark with different forecasting methods for Germany, Austria and Switzerland has been published in 2016 and is described shortly in this final report.

Another major component of the task was understanding short-term resource variability associated with cloud passages that cause power “ramps” (in the range of minutes), an important concern of utility operators with large penetrations of solar technologies in their system. A report – written in the framework of IEA PVPS 14 – has been published in 2015. The main message of this report is that utilities shouldn't panic about intermittency, as this is smoothed out strongly in space and time.

A third topic Meteotest was involved in, was dealing with site-adaption techniques: this paper shows which techniques are available for correlating local short term measurements with long term data sources to get results with lower uncertainties, which are needed to get bankable data.

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Abkürzungen

Abbreviation	Description
BKW	Bernische Kraftwerke
CMV	Cloud Motion Vectors
CSP	Concentrated Solar Power
DWD	German Weather Service / Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
IEA	International Energy Agency
IFS	Integrated Forecast System
MCP	Measure Correlate Predict
MSG	Meteosat Second Generation
NWP	Numerical Weather Prediction
PVPS	Photovoltaic Power Systems
RMSE	Root Mean Square Error
RSI	Rotating Shadowband Irradiometer
SHC	Solar Heating and Cooling
TCP	Technology Collaboration Programs
WMO	World Meteorological Organization

Background

Solar resource Tasks have a long tradition in the IEA Technology Collaboration Programs (TCP). The first Task dealing with resource aspects was IEA Solar Heating and Cooling (SHC) Task 4, which started in 1977. The most recent Task, IEA SHC Task 46 “Solar resource assessment and forecasting” started in July 2011 and will be completed in December 2016. It is the successor of the Task 36 (2005-2010).

IEA SHC Task 46 was supporting the three Technology Cooperation Programs IEA SHC, PVPS and SolarPACES. It has maintained collaboration with IEA PVPS Task 14 (through Jan Remund, Meteotest) and is represented as Task 5 in the IEA SolarPACES (by Richard Meyer, Suntrace).

University of Geneva (Pierre Ineichen) and Meteotest (Jan Remund) have been representing Switzerland in Task 46. This report shows the main results of the work by and with cooperation of Meteotest. The work of Pierre Ineichen has been already published in a Final Report (Ineichen, 2015).

Goals

The goal of IEA Task 46 "Solar Resource Assessment and Forecasting" was to provide the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions with the means to understand the “bankability” of data sets provided by public and private sectors. A major component of the task is to provide this sector with information on how accurately solar resources can be forecasted in the near future (sub-hourly, 1-6 hours, and 1-3 days) so that utilities can plan for the operation of large-scale solar systems operating within their systems. Another major component of the task is understanding short-term (1-minute or less) resource variability associated with cloud passages that cause power “ramps”, an important concern of utility operators with large penetrations of solar technologies in their system.

Based on the outcomes of precedent Task 36, the objectives of IEA SHC Task 46 were to:

- Evaluate solar resource variability that impacts large penetrations of solar technologies
- Develop standardized and integrating procedures for data bankability
- Improve procedures for short-term solar resource forecasting
- Advance solar resource modelling procedures based on physical principles to provide improved evaluation of large-scale solar systems using both thermal as well as PV technologies

Achieving these objectives reduces the cost of planning and deploying solar energy systems, improves efficiency of solar energy systems through more accurate and complete solar resource information, and increases the value of the solar energy produced by solar technologies.

IEA SHC Task 46 focused on

1. the development, validation, and access to solar resource information derived from surface-based observations, satellite-based platforms, and numerical weather prediction (NWP) models
2. solar resource variability and forecasting issues pertinent to grid-tied or large-scale penetrations of solar technologies into a national energy system

3. data bankability issues, especially those related to solar resource measurement practices and merging of measured and modeled data sets
4. exploring means by which to improve the modeling of the solar resource using satellite-based platforms or other weather observations

As with Task 36 the audience for the results of the Task included the technical laboratories, research institutions and universities involved in developing solar resource data products. More importantly, data users, such as energy planners, solar project developers, architects, engineers, energy consultants, product manufacturers, and building and system owners and managers, and utility organizations, were the ultimate beneficiaries of the research, and were informed through targeted reports, presentations, workshops and journal articles. Key results of this task were posted to the IEA SHC Task 46 Publications web site.

Work plan

1.1. Subtask A: Solar Resource Applications for High Penetrations of Solar Technologies

This Subtask developed the necessary data sets to allow system planners and utility operators to understand short-term resource variability characteristics, in particular up and down ramp rates, to better manage large penetrations of solar technologies in the grid system. Although this work is primarily focused toward PV systems, which react almost instantaneously to cloud passages over individual panels, the information is also useful for solar thermal and CSP systems where intermittency due to variable solar resources can impact their ability to meet load demands. Subtask A consisted of three main activities:

– Activity A1: Short-Term Variability
– Activity A2: Integration of solar with other RE
– Activity A3: Spatial and Temporal Balancing Studies of the Solar and Wind Energy Resource

1.2. Subtask B: Standardization and Integration Procedures for Data Bankability

This task addressed data quality and bankability issues related to both measurement practices and use of modeled data. Subtask activities were:

– Activity B1: Measurement best practices
– Activity B2: Gap-Filling, QC, Flagging, Data Formatting
– Activity B3: Integration of data sources
– Activity B4: Evaluation of Meteorological Products
– Activity B5: Data Uncertainties over Various Temporal and Spatial Resolutions

1.3. Subtask C: Solar Irradiance Forecasting

Solar irradiance forecasting provides the basis for energy management and operations strategies for many solar energy applications. Depending on the application and its corresponding time scales different forecasting approaches are appropriate. In this subtask forecasting methods covering timescale from several minutes up to seven days ahead were developed, tested and compared in benchmarking studies. The use of solar irradiance forecasting approaches in different fields was investigated, including PV and CSP power forecasting for plant operators and utility companies as also irradiance forecasting for heating and cooling of buildings or districts. Subtask activities were:

– Activity C1: Short-term forecasting (up to 7 days ahead)

– Activity C2: Integration of solar forecasts into operations

1.4. Subtask D: Advanced Resource Modeling

Although most of the work in the previous Task 36 involved the testing and evaluation of existing solar resource methodologies, some specific additional methodologies have been identified that could be developed within a new task. These methodologies are driven by specific information requests from energy developers and planners. They can include new data sets required for the control and heating and cooling in buildings, solar resource forecasting for CSP plant operations, and the impact of climate change on solar resources, both from an historical perspective as well as estimates of future impacts. Subtask activities were:

– Activity D1: Improvements to existing solar radiation retrieval methods

– Activity D2: Development of global solar resource data sets for integrated assessment of global and regional RE scenarios modelling, with a special focus on CSP and solar heating technologies

– Activity D3: Long term analysis and forecasting of solar resource trends and variability

Results

In this chapter we pick some of the main results of the five-year international project. It is organized by subtasks and chronologically. Mostly – but not only – projects are shown, in which also Meteotest has been involved.

The results of IEA SHC Task 46 up to 2013 have been published in the "Best Practices Handbook for the Collection and Use of Solar", published by the National Renewable Energy Laboratory (NREL) (Sengupta et al., 2015). An update of this handbook including the results of the Task until 2016 is planned for 2017.

2.1. Subtask A

In cooperation with the IEA PVPS Task 14 we published a report about temporal and spatial variability and smoothing effects (Remund et al., 2015[1]). It showed the validity of the variability models developed by SUNY/Albany (Hoff and Perez, 2011) at six test regions worldwide based on ground measurements (Figure 1).

The equations given can be used to determine the spatial and temporal smoothing effects and therefore also the fleet variability of PV installations, which is needed for grid modelling with high penetration of PV.

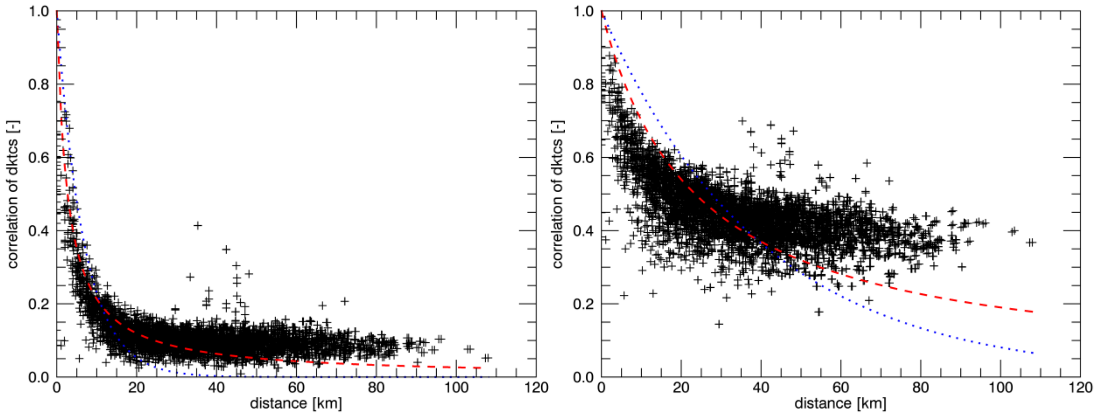

Figure 1: Correlation coefficients of relative ramp rates (“dktcs”) vs. distance for production data of 90 PV installations in the Canton of Berne (Source: Energiepool Switzerland / “KEV” installations). Left: 15 minute resolution, right: 1 hour resolution. Dashed and pointed lines: theoretical values based on Hoff and Perez (an exponential and a hyperbolical model).

Within this report also adequate spatial and temporal resolutions have been calculated. The temporal and spatial variability are mainly linked to the cloud size and speed. As cloud sizes and speed lay within some typical ranges, the variability and smoothing show also typical values. Using one second data, two stations are very low correlated (correlation factor < 0.2) already at a distance of 100 m.

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[1] http://iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=2733

Using one minute data this limit is typically in the range of 1-3 km and using one hour data this limit is typically reached with a distance of 150 km. Table 1 shows the ranges of the adequate distances.

Temporal resolution	Adequate distance ranges [km]
1 second	10 – 100 m
15 seconds	40 – 400 m
1 minute	600 m – 7 km
5 minutes	3 – 33 km
15 minutes	9 – 100 km
1 hour	36 – 400 km
3 hours	100 – 1200 km

Table 1: Adequate time and spatial resolutions depending on solar variability

2.2. Subtask B

2.2.1. Intercomparison of rotating shadowband radiometers

MeteoSwiss has been performing intercomparisons of three different rotating shadowband radiometers (RSI) and various Delta-T SPN1 in Payerne, Switzerland, in the framework of the COST Action ES1002 WIRE. The investigated RSIs are the RSR2 (Irradiance), the RSP (Solar Millennium/Reichert GmbH) and the Twin RSI (Services) (Figure 1).

Final results were condensed in the best practices report (Wilbert et al., 2015). The comparison campaign represented an important step towards the qualification of the performance of RSIs and the Delta-T SPN1. The data from the collocated MeteoSwiss Baseline Surface Radiation Network (BSRN) station were used as reference for the intercomparison.

A new measurand for resource assessment that was investigated in subtask B1 is the sunshape and the circumsolar radiation. The replication of a newly developed measurement system was presented in (CNRS/DLR, 2012).

Figure 2: Test instruments during the measurement campaign in Payerne (Photo: MeteoSwiss).

2.2.2. Site-adaptation techniques

A team around Jesus Polo (Ciemat, Spain) including Meteotest wrote a report and a peer reviewed paper about the "Integration of ground measurements to model-derived data (Polo et al., 2016).

At any site, the bankability of a projected solar power plant largely depends on the accuracy and general quality of the solar radiation data generated during the solar resource assessment phase. The term “site-adaptation” has recently started to be used in the framework of solar energy projects to refer to the improvement that can be achieved in satellite-derived solar irradiance when short-term local ground measurements are used to correct systematic errors and bias in the original dataset.

Our contribution presents a review of different possible techniques that can correct long-term satellite-derived solar radiation data through the use of short-term on-site ground measurements. The possible approaches that are reported may be applied in different ways, depending on the origin and characteristics of the uncertainties in the modelled data.

As an example of a site-adaptation technique a simple measure-correlate-predict (MCP) method based on satellite and re-analysis data was described and validated by Meteotest. This method is based on the assumption that the ratio between short to long term averages is constant for different data sources. Table 2 shows the relative RMSE of this technique used for different re-analysis datasets and satellite based irradiation data.

Re-analysis data are based on numerical weather prediction models, which are run for historic periods including all available ground and satellite measurements. Re-analysis data are widely used for wind energy site-adaptations and are freely available. However for irradiance re-analysis data show very high bias and large RMSE values, which prohibits the direct usage for resource assessments.

Dataset	Provider	Original RMSE [%]	MCP RMSE [%]
Re-analysis MERRA	NASA	16.3	3.3
Re-analysis ERA-Interim	ECMWF	11.2	3.4
Satellite (Helioclim)	Transvalor	3.8	3.0

Table 2: Relative root mean square error (RMSE) of the estimation of the long term averages

The simple MCP method lowers the RMSE significantly. Together with a one year measurement at the ground – which needs to be of high quality – the RMSE can be reduced to 3 – 3.4%, which is clearly lower than using one year measurements or satellite data alone (3.8% in Table 2).

2.3. Subtask C

2.3.1. Forecast with sky cameras

The analysis and forecast with sky cameras (Figure 2, also called cloud cameras or total sky imagers) is a popular topic, in which many scientific groups are currently involved. With two cameras the cloud position and height can be detected and forecasted for the next 10 – 15 minutes.

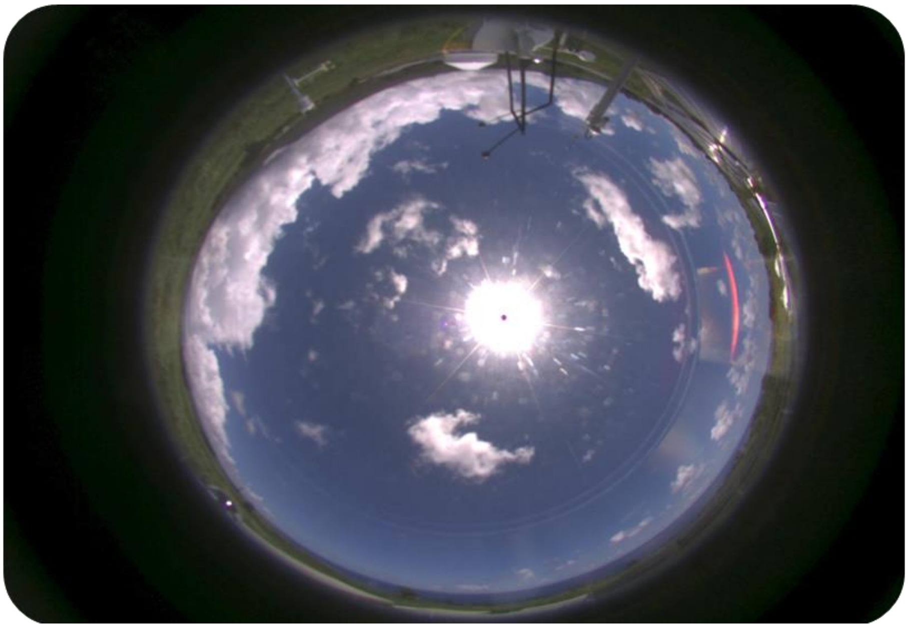

Figure 2: Picture from cloud camera (La Réunion, Source: EDF / Mines Paristech).

The University of California at San Diego (UCSD) are among the pioneers and are continuously working on improving cloud detection from ground based sky imagers as a basis for very short term forecasting with high resolution. The UCSD prototype produces high-quality sky imagery with a high dynamic range, allowing for more accurate cloud fields and more reliable thin cloud detection. No shadow band is necessary, leading to 10% more imagery available and interpolation errors eliminated. The state-of-the-art sky imager forecasting device with algorithms for 15 minute ramp forecasting has a high temporal and spatial resolution, a reasonable coverage of approx. 15 km^2 and is applicable for short time-horizon up to 20 minutes (Yang, 2014).

Mines ParisTech - in cooperation with EDF R&D- has been working on 3D reconstruction of cloud motion and corresponding shadow on the grounds from stereoscopic and optical flow analysis of hemispherical images from 2 fish-eye cameras. The stereoscopic analysis with correlation-based cloud matching to assess parallax and therefore 3D position is combined with a Kalman filter to detect cloud heights. First results are encouraging and the value of the application of a Kalman filter has been shown.

Also the University of Oldenburg developed forecasts of solar radiation and PV power using a sky imager. The measurements devices at the University of Oldenburg include the sky imager, a spectrometer, PV modules, and global horizontal and tilted, diffuse and direct measurements. Results have been published by Schmidt (2016). Generally sky imager based forecasts are better than persistence for few minutes only. Skill scores are often negative (that means for many situation persistence is better). However especially in broken cloud situations forecasts based on sky imagers show clear advantages.

2.3.2. Nowcasting with a combination of satellite cloud position and wind vectors from weather models

This group of forecast has a forecast horizon of 15 minutes to 6 hours, which is called nowcasting according World Meteorological Organization (WMO). Prediction models for solar power have usually a forecast horizon of 12 to 72 hours (for example COSMO-EU model of German Weather Service). However for this time scales the spatiotemporal evolution of the cloud is difficult to predict and is uncertain with increasingly longer time scales. A shortened forecast horizon (1 - 6 hours) leads to a significant improvement in prediction accuracy (Dierer et al., 2010).

The University of Oldenburg has been working on evaluation and further development of their cloud motion vector (CMV) forecasting algorithm based on Meteosat satellite images (Kühnert, 2015). Images from Meteosat Second Generation (MSG) satellites provide valuable information for forecasting clouds and solar irradiance several hours ahead by using cloud motion vectors (CMV). An approach to derive irradiance information from MSG images and of predicting the cloud situation by applying CMV is described and an evaluation of the irradiance forecast for single sites and regional averages on basis of a one year data set is presented. The CMV forecast shows a superior performance in comparison to forecasts with numerical weather prediction (NWP) models up to 5 hours ahead.

In the reporting period, the research on satellite based irradiance forecasting at the Uniersity of Oldenburg has been extended to the use of wind fields from NWP model forecasts as an alternative to satellite derived CMVs to advect clouds, as proposed also by Meteotest (see below).

At the University of Oldenburg, wind fields from the IFS model operated at the ECMWF were used for this purpose and a first study for May 2012 was performed. A particular focus was on the analysis of the forecast accuracy in dependence on the NWP model level of the applied wind fields that ideally should match the actual cloud heights. Figure 3 shows a very similar performance of forecasts based on cloud advection with NWP wind fields and satellite derived CMVs for the investigated period.

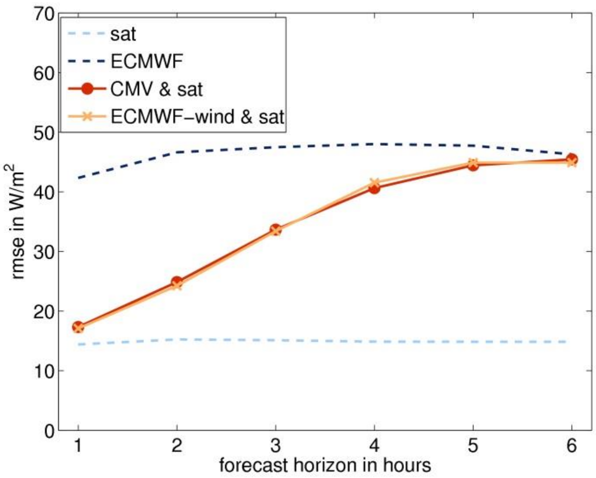

Figure 3: RMSE in dependence on forecast horizon for forecasts based on cloud advection with NWP wind fields (orange) and satellite derived CMVs (red). For comparison the RMSE of ECMWF based forecast as well as satellite derived irradiance is given. Database: average irradiance for 290 stations in Germany, May 2012.

The conclusion of this work is, that the method using cloud vectors from NWP wind fields shows the same quality, but with much less computer resources and is therefore interesting for the operational service.

2.3.3. Nowcasting based on satellite images

During partly overcast conditions, high and low radiation levels can alternate within a very short time. In a project carried out by Meteotest, such short-term fluctuations were predicted with the following approach:

The shortest-term forecast model was based on a combination of satellite images and numerical weather model WRF to determine the motion of the clouds, as well as the clear sky radiation model for calculating the radiation on the surface. From the satellite images (MSG, 3 km resolution) the current cloud cover index was determined.

With the help of the wind field from the numerical weather model WRF trajectories in the clouds for a determined length of 6 hours with a time resolution of 15 minutes were calculated. The global radiation was forecasted with help of the clear sky model and the calculated future position of the clouds.

The forecast was recalculated every 15 minute (the frequency of the satellite images) for 6 hours. With the multi-channel retrieval system of MeteoSwiss (includes visible and long-wave channels) also clouds during the night could be determined what allows forecasting the radiation also during early morning hours.

The forecast data were compared with ground measurements from 12 stations of the SwissMetNet network and with data from 3 test sites. The project was supported by the BKW FMB AG and was going on until spring 2014.

Meteotest continued the research on the combination of cloud and radiation fields from satellite images with wind fields from the NWP model WRF. This shortest term solar forecasting algorithm for 0.5 - 6 hours ahead which is updated every 15 minutes (Figure 4) has been evaluated for more than 20 sites in Switzerland, including low lands, alpine and high-alpine stations.

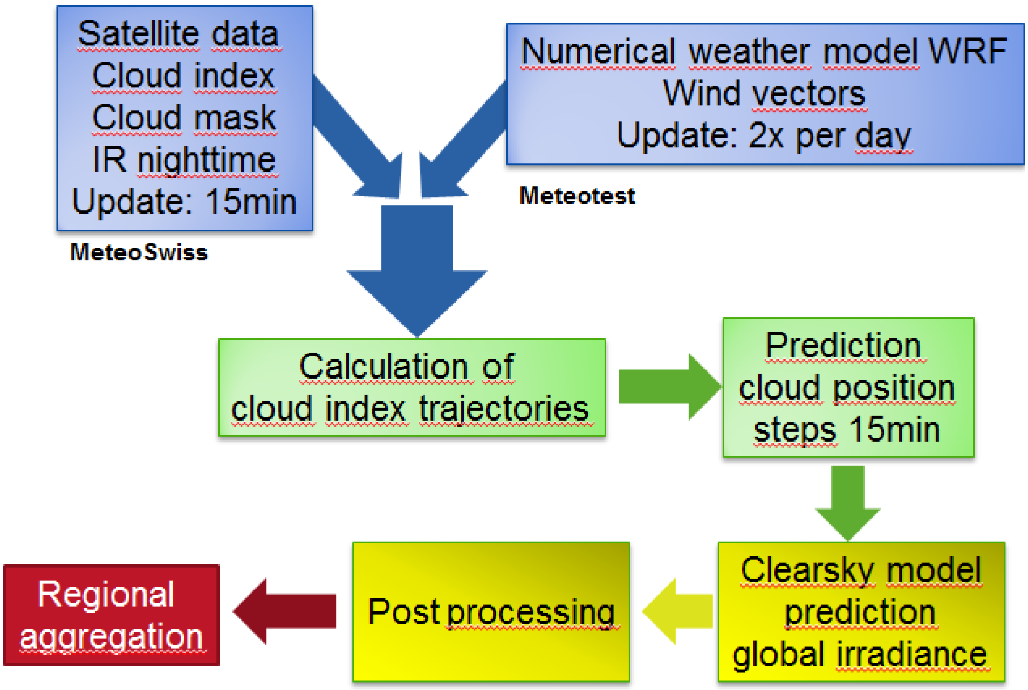

Figure 4: The shortest term forecast model of Meteotest.

The RMSE ranges between 75 – 200 W/m^2 (20 - 60%), depending on season, station and forecast horizon (Figure 5). The uncertainty is low in flatland and much higher in the Alps. The improvement of this approach over NWP WRF direct models output for 3 – 6 hours is about 40%. A particular focus during the reporting period has been on the investigation of Kalman filters to improve the forecasts. In has been found, that this post-processing approach is useful to correct for clear sky days, but not for cloudyd days.

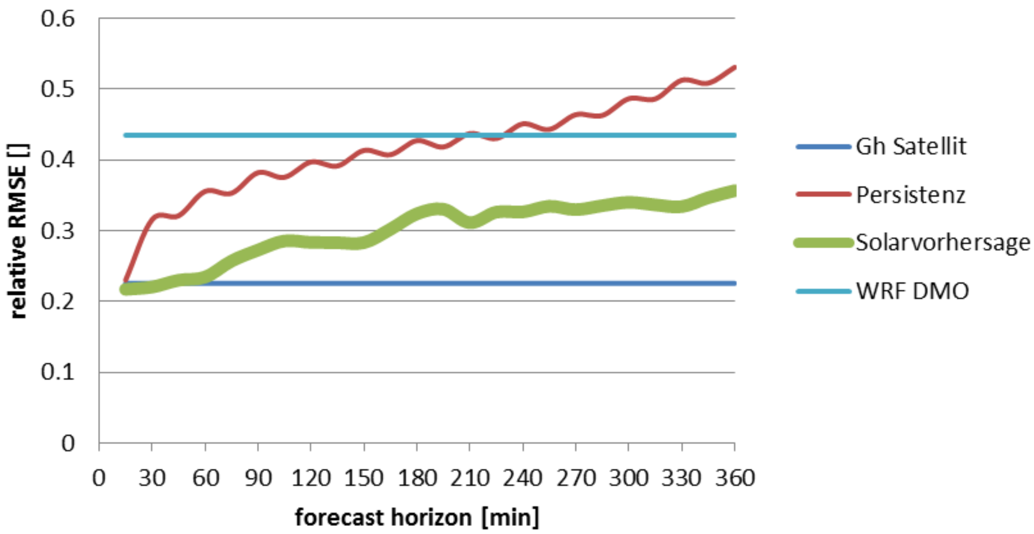

Figure 5: Relative RMSE in dependence on forecast horizon for forecasts based on cloud advection with NWP wind fields ("Solarvorhersage"). For comparison the RMSE of WRF based forecast ("WRF DMO") as well as satellite derived irradiance ("Gh Satellit") and persistence ("Persistenz") is given.
Database: irradiance of a **single** station (Bern-Zollikofen) in Switzerland, July – September 2012.

Results have been presented at PV-Symposium in Bad Staffelstein and PVSEC conferences (Müller and Remund, 2014a & 2014b).

The results of Meteotest are in accordance with those found by Univ. of Oldenburg:

- the altitude of the wind vectors is not sensible; the altitude of 2.5 – 3.5 km shows the best results
- the forecast errors for the first hour are up to 50% lower than for NWP models
- the results of the method are better or equal than those from NWP up to 4 (summer) – 6 hours (winter) ahead

The model has been further developed for forecasts of Direct Normal Irradiance (DNI) in sunny climates in the EU FP7 project DNICast (Müller and Remund, 2016).

2.3.4. Multi-Model forecasts

University of Oldenburg has been investigating an approach based on linear regression to combine forecasts based on cloud motion vectors from satellite images and forecast data of two Numerical Weather Prediction (NWP) models (Lorenz et al., 2012). The used NWP model data are operational forecasts of the integrated forecast system (IFS) run by the European Centre for Medium-Range Weather Forecasts (ECMWF) and the COSMO-EU model, operated by the German Weather Service DWD. There is a strong potential for improving the forecast performance by combining different models. The combined forecasts outperform the single model forecasts for all forecast horizons investigated. For regional day-ahead predictions an improvement of 10% compared to the ECWMF based forecasts is found, when combining the two NWP model forecasts. For intra-day predictions with additional integration of satellite based CMV forecasts, the benefit is even much larger (Figure 6)

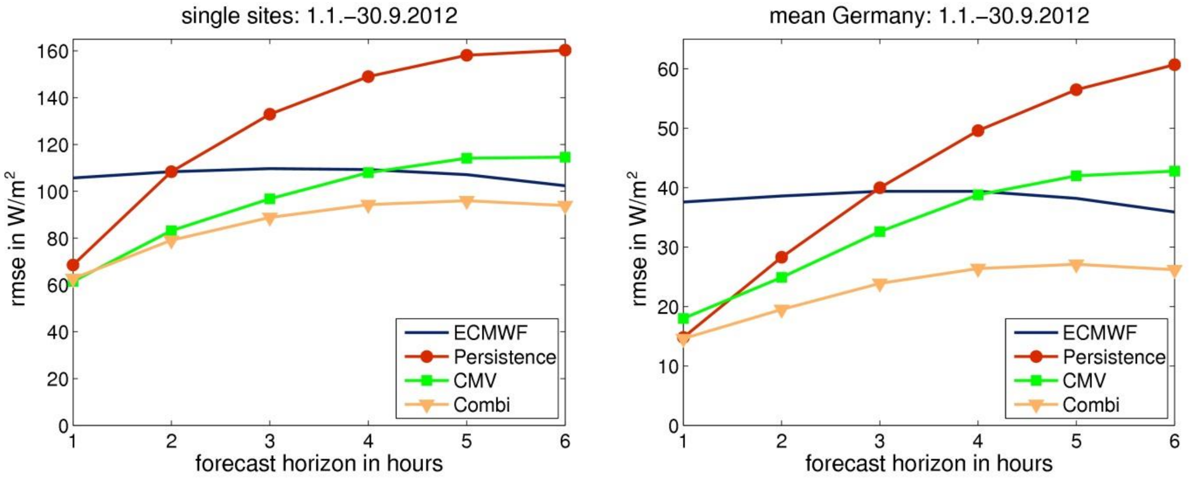

Figure 6: RMSE of ECMWF based, CMV and combined forecasts in comparison to persistence in dependence on the forecast horizon. For the ECMWF based forecast, the 12:00 UTC run of the previous day is evaluated independent of the forecast horizon and variations of the RMSE with the forecast horizon are due to the horizon dependent data sets Left: single sites, right: German mean.

2.3.5. Benchmark of NWP (day ahead) forecasts

A team of the University Oldenburg, Danish Meteorological Institute, Bluesky Wetteranalysen and Meteotest made and published a comparison of irradiance forecasts based on numerical weather prediction models (Lorenz et. al, 2015 and 2016).

Solar global horizontal irradiance forecasts based on numerical weather predictions for a variety of different models have been benchmarked. These included direct model output of several numerical weather prediction models, a rapid update cycle model assimilating satellite derived cloud products as well as radar data, the multi model ensemble prediction system GLAMEPS, and two systems based on statistical post-processing or – in meteorological terms - model output statistics (MOS).

In order to allow for a transparent and comparable analysis of the different methods a joint, consistent framework of evaluation has been set up. As a basis for the comparisons we have compiled a common data set of hourly measured solar irradiance values for Denmark, Germany, and Switzerland. Local and regional forecasts were analysed with respect to different properties. In particular we showed that spatial and temporal averaging effects have a strong impact on the RMSE when comparing solar irradiance forecasts of NWP models with different output resolutions.

Furthermore we investigated a new approach to evaluate the model's ability to represent and forecast solar irradiance and cloud variability. The benefit of high resolution mesoscale models in this respect was demonstrated.

Figure 7 shows the relative root mean square error (RMSE, relative to average irradiance) for 18 German locations. In the first hours the "$MT_{GFS\text{-}MOS}$" model performed best. This model (provided by Meteotest) included a statistic post processing and was updated each hour based on measurements of the meteorological networks. In the period between 12 and 36 hours the multi model (UOL_{Combi}) showed the lowest uncertainties. In our study this was a combination of $\mathrm{ECMWF}_{\mathrm{IFS,HR}}$ and $\mathrm{DWD}_{\mathrm{COSMOEU}}$ models of German Weather Service (DWD) provided by the University of Oldenburg. Bluesky's model ($\mathrm{Blue}_{\mathrm{GFS}}$) and ECMWF show similar uncertainties. Locally higher resolved models like $\mathrm{DW}_{\mathrm{COSMOEU}}$ or $\mathrm{DMI}_{\mathrm{HIRLAM,SKA}}$ showed higher uncertainties. For the averaged irradiation of all location the order was the same – but the deviations between the models and the level of the forecast errors were smaller.

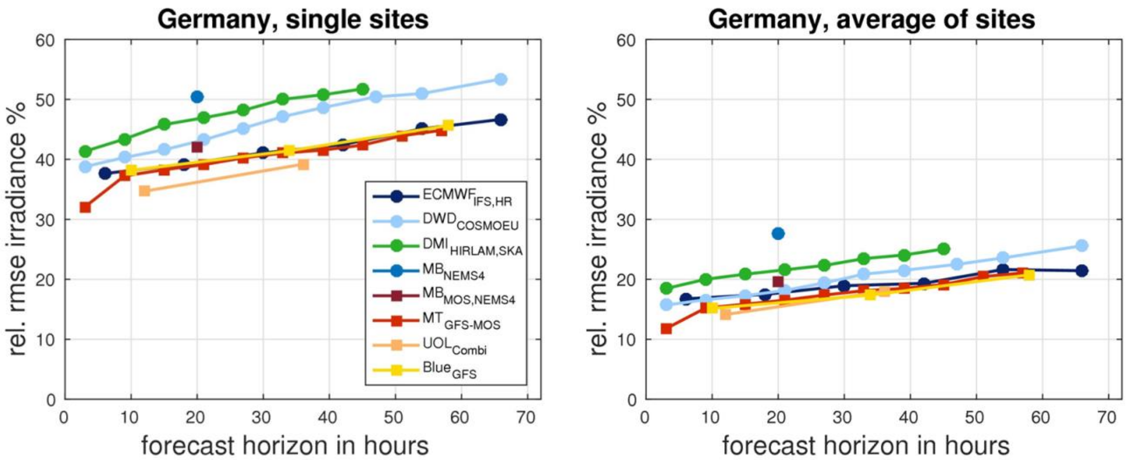

Figure 7: Relative root mean square errors of different forecast models for each 18 German locations (left) and for the averaged irradiation of all sites.

However the RMSE did not show the whole picture. Local and temporal smoothed models showed lower RMSE values as the risk of double penalties is lowered – this is the case when the peak in irradiations are forecasted with a small temporal deviation. Therefore we introduced another measure showing the ability of the forecasts to include variability.

This new measure was the correlation of the measured and forecasted root of the sum of the ramps during certain periods (typically half a day). Using this measure the order of the models is inversed: locally higher resolved regional models show a much higher correlation than global, smoothed or post-processed models (Figure 8).

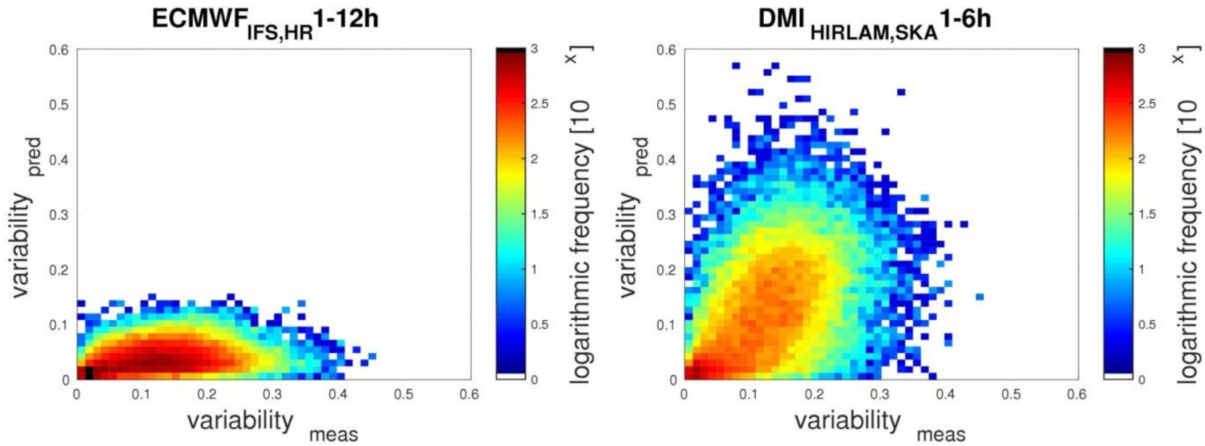

Figure 8: Heat map (showing density distribution) of measured and forecasted variability. Left: Global $ECMWF_{IFS,HR}$ model, right: regional $DMI_{HIRLAM,SKA}$ model.

2.4. Subtask D

In Subtask D, approaches to improve satellite-derived solar resource models have been investigated, especially by taking into consideration 3-dimensional cloud information and improved aerosol data. A key publication developed by a number of Task 46 participations titled “Direct Normal Irradiance Related Definitions and Applications: The Circumsolar Issue” has been published shortly in Solar Energy Journal (Blanc et al., 2014), addressing the importance of understanding the role of circumsolar radiation in the immediate vicinity of the solar disk in accurately representing DNI measurements for concentrating solar power applications.

Due to financial limitations - especially concerning the partner NASA, which should have leaded this Subtask - not all intended work could be made.

Conclusions & impacts

The Task enabled the close interaction of the main research stakeholders in the field of solar resources. The work of the last six years have been presented in many conferences and published as conference proceedings, workshops, webinars, IEA reports and peer reviewed papers.

Among the most important work, a new Best Practices Handbook for the Collection and Use of Solar data, a more detailed circumsolar radiation definition and an international benchmark of forecasts have been published.

This kind of work would have been impossible to achieve without a given framework of a IEA TCP.

The participation in IEA SHC Task 46 enabled Meteotest to keep on track with the ongoing state of the art of the solar resources. The knowledge has been included in diverse updates of the software Meteonorm (www.meteonorm.com), which is one of the standard products built in PV and solar thermal simulation tools (e.g. PVSyst and Polysun).

Due to the Task Meteotest could develop their shortest term forecast method based on satellite images. The participation in the Task helped to induce additional national scientific projects like "Kürzestfrist Einspeisevorhersagen für Solarstrom im Kanton Bern" (by BKW Ökofonds) or the EU FP7 DNICast (http://www.dnicast-project.net/), where similar topics have been handled.

Outlook

As a matter of fact the scientific work concerning solar resources is not finished with the end of IEA SHC Task 46. A new solar resource Task is therefore proposed for IEA PVPS.

The new Task will be moved to the IEA PVPS TCP due to the fact that the main target audience is coming nowadays from PV and due to the withdrawal of the USA from the IEA SHC.

The successful and efficient collaboration of experts from numerous countries during the last years as well as the positive responses received from various stakeholders clearly defined the need for a continuation of the cooperation within an IEA TCP.

This need is further highlighted by four key facts:

- Meteorological and climatological information is getting more and more important as penetration of PV increases and size of PV installations grows
- Needs of stakeholders are growing especially concerning uncertainty levels, which have to be lowered
- More and more universities and private companies are involved in this topic and a growing number of partners want to be part of the Task
- Solar resource and forecasting knowledge is progressing continually albeit slowly. The continuation of a solar resource Task enables the spreading of this knowledge to the user communities.

As the penetration of PV increases, improved accuracy and finer spatial and temporal resolution of solar data sets are needed to optimize the performance of these technologies in the energy system of a particular region or country.

International collaboration and consensus on developing and managing these data sets will expedite the high penetration of solar technologies, and improve markets for these technologies. Large scale PV plants now need accurate resource and forecast data due to high investment costs.

Therefore Task participants will focus on the following two scientific issues:

1. High frequency variability and solar forecasts for managing grids with high penetration of PV and local storage
2. High quality solar resource assessments and forecasts for solar installations notably in the multi MW class

High frequency variability and high quality needs are also important issues for the planning and the operation of Concentrating Solar Thermal facilities and CPV, which will be a focus of the Task as well.

In addition, the development of bankable data sets for system sizing and performance evaluation are important to Solar Heating and Cooling technologies, and will be a focus of this task.

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