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IEA SHC TASK 36: SOLAR RESOURCE KNOWLEDGE MANAGEMENT

GLOBAL RADIATION SHORT TERM FORECAST AND TRENDS / AEROSOL CLIMATOLOGY

Annual Report 2009

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Project- / Contract Number	101498 / 151784
Duration of the Project (from – to)	July 2005 – June 2010
Date	14.12.2009

ABSTRACT

In the framework of IEA Solar Heating and Cooling (SHC) task 36 Meteotest investigates the possibilities and quality of global radiation forecast, the trend of recent global radiation data and distribution of atmospheric aerosols.

In the fourth year the validation of the global radiation forecast of Meteotest's operational WRF model was going on. An extended benchmarking project was done for Central Europe and Southern Spain. A strong dependence of the forecast accuracy on the climatic conditions is found. For Central European stations the relative rmse ranges from 40% to 60%, for Spanish stations relative rmse values are in the range of 20% to 35%. At the current stage of research, irradiance forecasts based on global model numerical weather prediction models in combination with post- processing show best results (ECMWF-OL). All proposed methods perform significantly better than persistence

The work of building an updated aerosol climatology has been finished in 2009. In the applied method ground and satellite data (of NASA) of the last decade are merged and mixed in five steps. The results of the work were 12 monthly and one yearly map of aerosol optical depth and Linke turbidity (used e.g. in Meteonorm). The uncertainties for aerosol optical depth is 43% and for Linke turbidity 19%. The results are satisfying, in the same range as other recent publications.

A short analysis of recent global radiation trends was done by Meteotest based on 24 sites from the Global Energy Balance Archive (GEBA). For the period between 1950 and 2009 and the mean of all analysed 24 sites a negative and statistically significant trend of -1.41 W/m^2 per decade could be found. Regional trends were mostly not significant. However for the sub periods 1950-1985 most regions showed a significant negative trend and for 1985-2009 most regions showed a significant positive trend, what's consistent to the theory of global dimming and brightening.

Introduction

In the framework of IEA Solar Heating and Cooling (SHC) task 36 "Solar Resource Knowledge Management" [1] Meteotest investigates mainly the possibilities and quality of global radiation forecast. The task 36 is divided into 3 main subtasks:

a) Standard qualification for solar resource products (includes benchmarking of different radiation estimation models based on satellite measurements).

b) Common structure for archiving and accessing solar resource products (includes prototype of online tool for accessing data).

c) Improved techniques for solar resource characterization and forecast; improve satellite retrieval methods for solar radiation products; conduct climatological analysis of solar resources.

The aim in the radiation forecast subtask is to define the quality of the existing models and to enhance the quality. Main partners in this subtask are listed in Table 1.

Additionally this year work has been done within part c). on estimation of trends of recent global radiation data and on a new aerosol climatology.

Work done and results

RADIATION FORECAST

Models and data

In 2009 a benchmark of 8 forecast models (Tab. 1) was made for 24 sites in Europe (Figure 1) [2].

Table 1: Overview on forecasting approaches.

Team & abbreviation	**Approach**	**NWP model with spatial and temporal resolution**
University of Oldenburg, Germany, ECMWF-OL	Statistical post processing in combination with a clear sky model	ECMWF [3] - 0.25°x 0.25° - 3 hours
Bluesky, Austria a) SYNOP b) BLUE	a)"human" cloud cover forecast (by meteorologists) b) BLUE FORECAST: statistic forecast tool	for b) GFS - 1° x 1° and 0,5°x 0.5° - 3 hours and 6 hours
Meteocontrol, Germany MM-MOS	MOS (Model Output Statistics) by Meteomedia GmbH	ECMWF 0.25°x 0.25° 3 hours
Meteotest, Switzerland, WRF-MT	Direct model output of GHI, averaging of 10x10 model pixels	WRF/GFS [4] 5km x 5km 1 hour
Cener, Spain CENER	Post processing based on learning machines models	Skiron/GFS [5] 0.1°x 0.1° 1 hour
Ciemat, Spain CIEMAT	bias correction	AEMET-HIRLAM 0.2°x 0.2° 1 hour
University of Jaen, Spain WRF-UJAEN	Direct model output GHI	WRF/GFS 3km x 3km 1 hour

The period of comparison is July 2007 – June 2008. The forecasts of the first three days were checked.

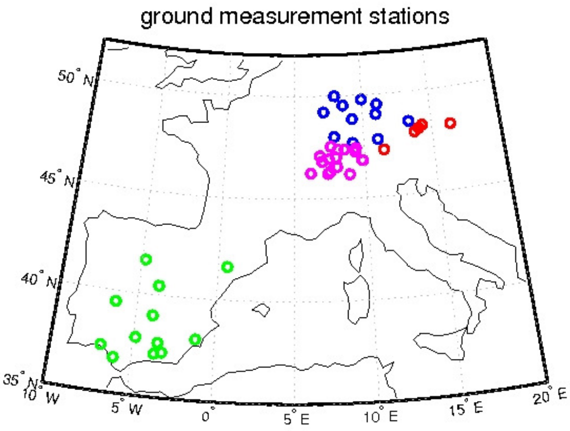

Figure 1: Locations of ground measurement stations. Green: Spanish stations, blue: German stations, pink: Swiss stations, red: Austrian stations

Results

The overall results can be found in Lorenz et al. [1]. Here only the results for Switzerland are given as example. For Switzerland global radiation forecasts of the University of Oldenburg, Meteocontrol, Meteotest and BLUESKY were available for benchmarking. Table 2 and Figure 2 give an overview on the evaluation results for the first forecasting day.

The relative root mean squared error (rmse) for the first forecast day varies between 39 % and 45% with best performance of the unbiased Oldenburg approach and the slightly biased BLUESKY approach. For Switzerland, the relative rmse for the MM-MOS and WRF-MT forecasts is very similar for all forecast horizons. With respect to the mean absolute error (mae), the WRF forecasts show a slightly better performance than the MM-MOS. The persistence forecast show a considerably higher relative rmse and mae than all NWP based forecasts. The persistence forecast and the Meteocontrol approach show a negative bias of about 7%.

Table 2: rmse, mae, and bias for the four forecasting approaches and persistence, first forecast day, complete Swiss data set.

approach	*rmse* in W/m^2	*mae* in W/m^2	*bias* in W/m^2
ECWMF-OL	107 (39.6%)	70 (25.8%)	-1 (-0.3%)
BLUESKY	109 (40.5%)	73 (27.0%)	-9 (-3.3%)
MM-MOS	122 (45.0%)	85 (31.5%)	-18 (-6.6%)
WRF-MT	119 (44.2%)	76 (28.0%)	4 (1.3%)
persistence	158 (58.4%)	104 (38.7%)	-17 (-6.3%)

The rmse values differ more than 15% in dependence on the station. Best performance by all approaches is achieved for the sunny stations, like for example Sion. Alpine and pre-alpine mountain top stations and regions like Napf or Jungfraujoch show the highest uncertainties.

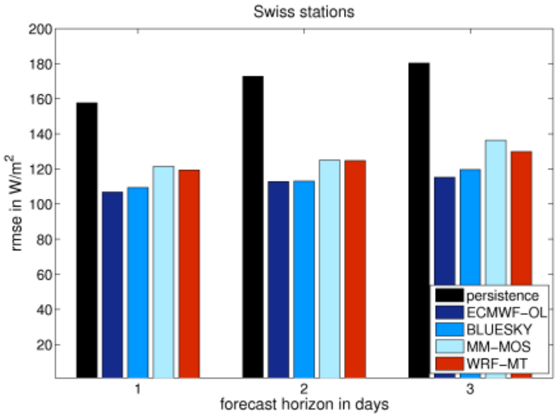

Figure 2: Relative *rmse* for the four forecasting approaches and persistence in dependence on the forecast horizon.

Overall, it can be concluded that for Switzerland the approaches of University of Oldenburg and Blue Sky achieve slightly higher accuracy than those of Meteocontrol and Meteotest. The Meteotest approach produces the most realistic distribution of irradiance values. Due to variations in topography and climate all forecasting approaches show a strong dependency of the forecast accuracy on the station.

Results for Central Europe and Southern Spain

A strong dependence of the forecast accuracy on the climatic conditions is found. For Central European stations the relative rmse ranges from 40% to 60%, for Spanish stations relative rmse values are in the range of 20% to 35%. At the current stage of research, irradiance forecasts based on global model numerical weather prediction models in combination with post- processing show best results (ECMWF-OL). All proposed methods perform significantly better than persistence. There is ongoing development of the methods to predict irradiance by the IEA SHC Task 36 members. Accordingly, evaluation and comparison of the forecasts will be continued and extended to recent ground measurement data.

AEROSOL CLIMATOLOGY

The work of building a new aerosol climatology, begun in 2006, has been finished in 2009. The method hasn't been altered much since the first version, but the input data has been updated significantly. Three global ground and satellite data sources have been used (Table 3).

Table 3: Aerosol datasets used in the work.

Source	Type	Resolution	Time period
MODIS	Satellite (Terra, NASA)[1] Level 3 data	1 °	2001 – 2008
MISR	Satellite (NASA) [2]	1 °	1999 – 2006
Aeronet	Ground measurements (NASA) [3]	207 sites	1993 – 2008 (variable for each site)

[1]: http://MODIS.gsfc.nasa.gov/
[2]: http://eosweb.larc.nasa.gov/PRODOCS/MISR/level3/overview.html
[3]: http://aeronet.gsfc.nasa.gov/

In the applied method ground and satellite data are merged and mixed in five steps. The two satellite sources have first been merged to ground measurements and then mixed to get a result for the whole globe. In a further step the data has been merged to the ground truth.

1. Preparation of satellite and ground data
2. Linear correction of satellite data to ground data
3. Mixing of the two satellite sources
4. Calculation of Linke turbidity
5. General and specific correction to ground sites.

Results

The results of the work were 12 monthly and one yearly map of aerosol optical depth and Linke turbidity. As an example the yearly mean of aerosol optical depth is shown in Figure 3.

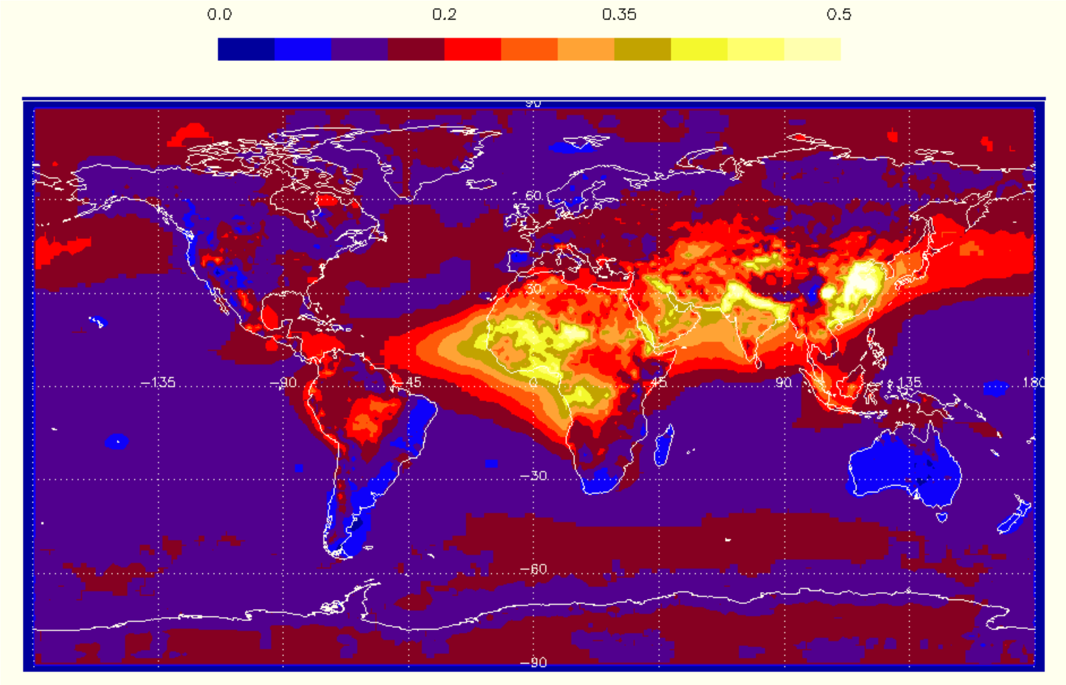

Figure 3: Yearly mean of aerosol optical depth at 550 nm 2001-2008.

Linke turbidity and aerosol optical depth has been tested at 14 Aeronet sites, which haven't been used for mapping. The validation results are given in Table 4. The uncertainties for aerosol optical depth are approximately 0.1 (43%) and for Linke turbidity 0.7 (19%). For sites with Aerosol loads lower than 0.5 the uncertainty is significantly lower (0.06 / 35%). The results are satisfying, in the same range as other recent work (Gueymard [6] or Kinne [7]) and improved compared to the pre-existing climatology of Remund et al. [8].

Table 4: Aerosol datasets used in this work.

Type	mbe [ ]	rmse [ ]	rmse relative [%]
Aerosol opt. depth (all)	0.001	0.0995	42.7%
Aerosol opt. depth < 0.5	0.023	0.0646	35.2%
Linke turbidity	0.19	0.66	17.5%

GLOBAL RADIATION TRENDS

During the last years the discussion about trends of recent global radiation did leave the scientific circles (keywords "global dimming and brightening" [9 – 12]). Especially engineers in the field of solar energy were getting aware, that climatological values of global radiation are not constant.

The short analysis done by Meteotest is focused on time series of duration of at least 40 years for stations included in the Global Energy Balance Archive (GEBA; IACETH, http://proto-geba.ethz.ch). The work lies in-between the broad analysis for worldwide datasets and those for some few sites with very long measurements. For the duration of at least 40 years 24 sites could be used. Additionally the work is focusing on some practical aspects which are linked to the use of solar databases like PVGIS (http://re.jrc.ec.europa.eu/pvgis/) or Meteonorm (www.meteonorm.com).

The distribution of the analyzed sites is concentrated very much to regions of central Europe, India and Japan and all sites are from the northern hemisphere. Due to this the no conclusions for the whole globe can be drawn.

The following three questions have been looked at:

1. Trend of the time series of monthly data:
   Are there general trends visible or trends in sub periods?
   This question was tested with the total dataset between 1950 and 2009 and two periods between 1950 – 1985 and 1985 – 2009.
2. Trend of 10 and 20 years means:
   How much are means of time periods of the past different compared current periods?
3. Dependence of the variability depending on the length of a measured period:
   How much is the standard deviation of a mean of a measurement depending on the duration? Is this value site dependent?

All time series have been corrected for the seasonal effects. The sites have been grouped in 10 regional groups.

Results

For the whole period between 1950 and 2009 and the mean of all sites a significant negative trend of -1.4 W/m^2 decades could be found. For most groups no significant trend is visible. Nevertheless for Germany and Austria (Hamburg, Trier, Braunschweig, Würzburg and Salzburg) a slight positive trend can be seen and for Switzerland, Asia, India and Canada a negative trend. The large negative trend for Switzerland (Davos, Weissfluhjoch and Locarno-Monti) was mainly induced by the station Weissfluhjoch, but also without this site the trend is significant and negative (-1.0 W/m^2).

For the two sub periods 1950 – 1985 and 1985 – 2009 for most groups of stations a significant trend could be found (Table 5)

Table 5: Result of linear trend analysis for the periods 1950-1985 and 1985-2009

		1950-1985		1985 - 2009	
Nr	Group	Trend [W/m^2 10 y]	P	Trend [W/m^2 10 y]	P
1	all	-4.70	0.000	1.82	0.019
2	Europe*	-1.88	0.009	4.13	0.000
3	Northern Europe	-0.22	0.801	2.94	0.006
4	Germany / Austria	-1.16	0.206	4.64	0.001
5	Switzerland	-7.69	0.000	3.07	0.003
6	United Kingdom	-1.27	0.097	1.52	0.134
7	Asia	-5.59	0.000	1.43	0.177
8	Japan	-6.43	0.000	5.25	0.000
9	India	-6.48	0.000	-5.44	0.001
10	Canada	-0.188	0.001	-0.02	0.909

* without Weissfluhjoch

For the period 1950-1985 only negative trends were found. For all regions beside Northern Europe, UK and Germany/Austria the trends are significant. The overall trend is -4.7 W/m^2 per decade. Strongest trends are found in Switzerland, Japan and India.

For the period 1985-2009 (including data for most sites up to 2005) all regions but India and Canada showed a positive trend. The overall trend comes to 1.8 W/m^2 per decade.

This evaluation is consistent to the theory of global dimming and global brightening. Only for the UK where the trends are very small and for India and Beijing, where the trends are negative for all periods, the theory can't be backed statistically. As the changes in aerosol concentration, based mainly on industrial processes, are one of the main reasons for brightening and dimming, this findings are not astonishing. In India and China industry still has a strong growth, whereas in Europe and Japan industry has lowered the output of aerosols after 1985.

The negative trend after the year 2000 seen in Hinkelman et al. [10] could be found in Edmonton only.

Comparison of different time periods

Additionally the moving 10 and 20 year means have been compared to the values with an end time of 2005 (1986 – 2005 and 1996 – 2005). This shows how much climatologies of various time periods are different compared to most current ones.

Figure 4 shows the comparison of all sites. Periods with end time of 1990 and later show for many sites a consistent growth. Before 1990 the situation is much more diverse. The growth since 1990 (period 1981-1990) comes to approximately 5%.

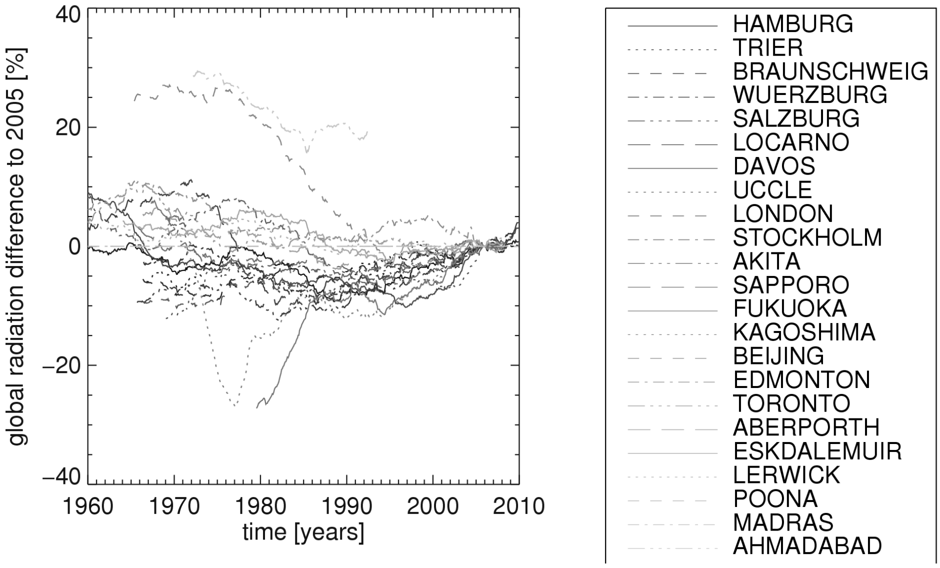

Figure 4: Variation of decadal means in % compared to 1996-2005. Time shows the end point of the 10 years period.

Looking at 20 year means, the differences are much smoother. The growth compared to 1971-1990 is in the range of 3-4%. The situation before end time of 1990 is much more diverse than the situation afterwards. The trends of 2-decade means in Asian are quite different. Beijing shows a strong negative growth. Japanese sites show a strong negative trend in the eighties and a strong positive trend afterwards.

Dependence of variation with duration of measurements

Figure 5 shows the dependence of the standard deviation of the mean of a time series on the time period of the measurements for all sites.

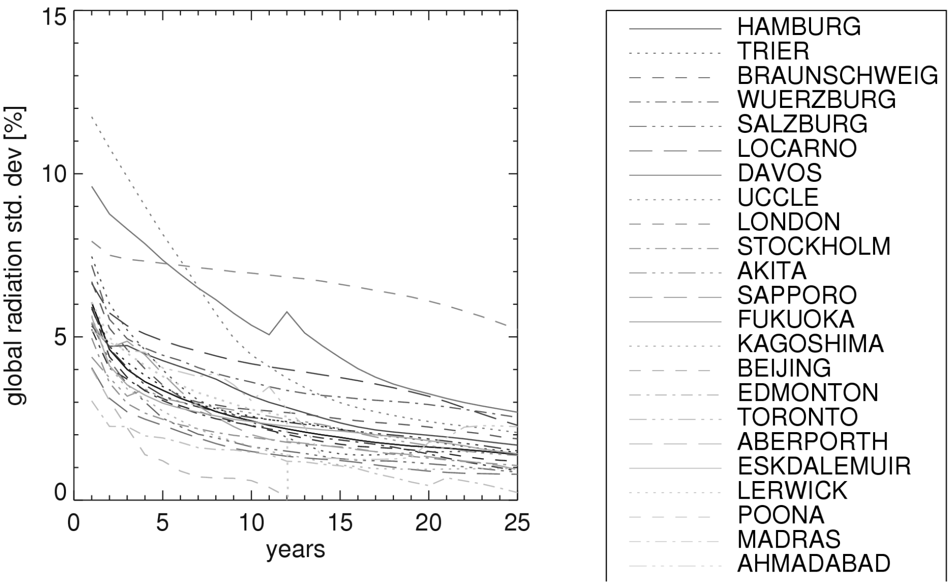

Figure 5: Variation of measurements depending on duration of measurement.

Projekt XY, Erstautor, Institution

The variation is quite different from site to site. Most sites have a standard deviation of 6% for a 12 month means which goes down to 2-3% at 10 years and 2% at 20 years. The biggest lowering happens mostly in the first 5 years. German and Austrian sites all have a similar level of variations, which start at 6% for 1 year and are at 2.5% for 10 years and 1.5-2% at 20 years.

National / international cooperation

The work was done in the framework of IEA Solar Heating and Cooling task 36. From Switzerland there is also University of Geneva part of the task team.

Outlook

The task will be finished next year. The team is preparing the final documents and will held a workshop in March 2010 to define work plans of planned future tasks.

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