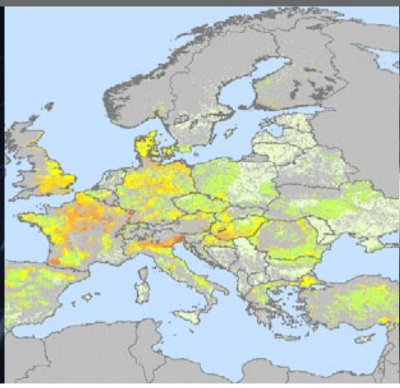
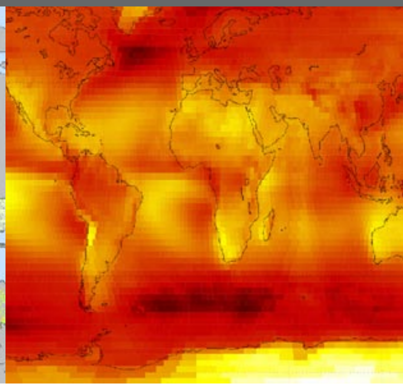
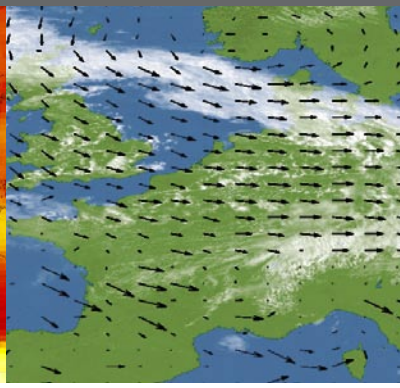
Virtual Institute of Energy Meteorology







REMOTE SENSING AND ATMOSPHERIC PHYSICS FOR AN EFFICIENT USE OF RENEWABLE ENERGIES

Status Report
2004 - 2007

vIEM

Cover illustrations:

Left: Solar and wind power supply of the 'Energielabor' at Oldenburg University.

Center left: Net primary production of vegetation in Europe. Results from the BETHY (Biosphere Energy Transfer Hydrology) Model at DLR-DFD.

Center: Cloud index image with motion vectorfield based on Meteosat-7 data (Oldenburg Universtity).

Center right: Global map of long-term averaged direct normal irradiance based on 21 years
of ISCCP data (DLR-IPA).

Status Report 2004 - 2007

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vIEM - Virtual Institute of Energy Meteorology

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Content

1 ENERGY METEOROLOGY

Research in Support of an Intelligent Use of Energy

The specific characteristics of renewable energy production makes meteorological information a product of increasingly important value for the energy industry. Assessing the available ressources, providing near-real time information of wind and solar energy production, and forecasting the expected power in various time scales are subject of extended efforts in research and development. The virtual Institute of Energy Meteorology (vIEM)adresses these new challenges.

The recently published 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has undoubtly increased the pressure on the global community to introduce renewable energies as one key element in a global strategy on climate protection.

This will boost a so far secondary influence on energy supply which has been already revealed by the rapid development of renewable energies in the recent years: Weather and climate more and more affect large parts of the energy production due to the fluctuating nature of the new "fuels" wind and solar energy. Climate change also may define a further need for future adaptation measures within the conventional energy sector. The availability of appropriate meteorological information thus will play a key role in the development of tomorrow's energy systems.

The recently formed virtual Institute of Energy Meteorology (vIEM) has been established as an instrument to address these upcoming needs. vIEM has been set up with basic support from the Helmholtz-Gemeinschaft Deutscher Forschungszentren (Helmholtz Association of German Research Centres) and shall foster scientific collaboration between Helmholtz institutes and universities. The participating DLR institutes and Oldenburg University agreed to join their scientific efforts in this challenging research field.

The subtitle of the corresponding Helmholtz activity „Energy Meteorology – Remote Sensing and Atmospheric Physics for an Efficient Use of Renewable Energies" defines the current research area of vIEM and reflects the manifold needs for increasing the scientific efforts in view of one of the global challenges of the next decades: Providing the fast growing global economy with clean, sustainable and climate-compatible energy.
No doubt, renewable energies will contribute in very high amounts to this energy future – only the time horizon for their introduction seems uncertain. But a global energy system based largely on renewables will be different from what we are familiar with. The supply side of this coin shows the strong dependency on the fluctuating nature of these new 'fuels', e. g., solar irradiance and wind energy. Instead of taking from large stocks of energy carriers as oil, coal and natural gas, the use of renewable energies strongly depends on the availability of these energy fluxes in both, appropriate temporal and spatial scales.

It is evident, that a precise knowledge of the resource base of renewable energies is essential, both from a global perspective and on a local scale for, e.g., the planning of new power plants. Solar and wind power forecasts of very high quality in a variety of temporal and spatial scales are necessary to efficiently integrate renewables into the electricity supply. Energy needs of the built environment more and more will be dependent on weather and climate, considering its role for decentralized energy supply is even in its early days. Intelligent control of the complete energy sector needs detailed information – not only, but largely on weather related issues. Also, the complex interactions between energy use and climate reveals many questions which urgently need answers – to be delivered by the new discipline Energy Meteorology.

vIEM's current activities on Energy Meteorology focus on three areas: basic and applied research, application and service development including consultancy, and education.

The research activities up to now have been method development to provide the solar energy community with satellite-derived solar irradiance data, initial research for solar irradiance forecasting, resource information for the grid integration of large shares of solar and wind power, and aspects of the long-term variability of renewable power production. Transferring research output into business applications has been subject of the European projects PVSAT-2 and ENVISOLAR. Industrial partnership is an important emphasis of vIEM's activities. Finally, vIEM's educational activities have concentrated on the organization of workshops dedicated to PhD level education, first steps towards new instruments as e-learning have been done.

As a virtual institute, new options for positioning itself in the scientific landscape are given and in this respect vIEM has already set several marks. The book 'Solar Energy Resource Management for Electricity Generation from Local Level to Global Scale' resulting from a workshop in Ispra includes major contributions by vIEM members. The novel scientific concept of a virtual institute has been supported by the new research project WISENT (Knowledge Network Energy Meteorology) funded by the German ministry of research and technology BMBF. WISENT is a collaboration of vIEM with a research partner from computer science and an industrial partner and shall provide the corresponding IT environment for this new form of distributed scientific work. vIEM also contributed to the creation of the new Task 36 'Solar Resource Knowledge Management ' in the Solar Heating and Cooling Programme of the International Energy Agency. Finally, a first workshop entirely dedicated to the subject Energy Meteorology has been organized in 2006 assisted by the national Forschungsverbund Sonnenenergie (FVS).

Looking into energy's future, it seems obvious that its supply will be derived in large parts from a network of local sources: solar, wind, biomass and even hydrogen-based generation. Integrating them into an efficient and reliable energy system will be the big challenge. As the most perfect information about the available fuels is an absolute 'must' for this development, the future role of Energy Meteorology will be even more prominent than it is today. vIEM is prepared to carry a large part of it. This Status Report provides insights in the new research area Energy Meteorology and the spectrum of scientific activities of the institute. The specific competences of vIEM's member institutions cover a large part of this spectrum.

The German Aerospace Center (DLR) is one of the most well-known scientific sites regarding the theme Energy & Atmosphere. Its German Remote Sensing Data Center (DFD) maintains relevant data archives, participates in the development of new energy-specific methods and contributes largely to market development activities in this sector. The Institute of Atmospheric Physics (PA) covers all aspects of modelling the solar radiative transfer in the atmosphere and the influence of clouds on available solar energy. Subject of the vIEM-related activities of the Institute of Technical Thermodynamics (TT) are technical aspects of the grid integration of renewable energies and concentrated solar thermal power production.

Oldenburg University's Institute of Physics has long experience in renewable energy research. Its Energy Meteorology Unit is the first university research unit entirely dedicated to the subject of Energy Meteorology. General focus of the work are meteorological aspects of the integration of both wind and solar energy technologies into the energy supply systems.

The Helmholtz Gemeinschaft made it possible to establish this promising way of scientific collaboration in a new scientific area of research. The partners of the virtual Institue of Energy Meteorology intend to expand this work into a sustainable activity supporting the transfer of today's energy system into one which uses energy in an intelligent manner and is compatible with a human and environmental friendly global development.

2 SCIENTIFIC PRIORITIES

OVERVIEW OF CURRENT RESEARCH TOPICS

2.1 Grid Integration of Large Shares of Solar and Wind Power

Due to the limitation of fossil resources and their impact on climate change, the future energy system will depend on large shares of renewable energy sources. This poses a major challenge on the development of future energy systems, as renewable resources have very different characteristics to the currently used conventional resources. DLR TT analyses the balancing of the different renewable resources.

2.2 Improved Estimation of the Solar Resource

Accurate information about the availability of the solar resource is a key requirement for the successful implementation of solar energy systems. The advantage of satellite-based estimates lies in their inherent broad-area coverage. Together, Oldenburg University, DLR DFD and DLR PA give strong emphasis to achieve the best possible accuracy, comparable to ground measurements.

2.3 Forecasting of Solar Radiation

Power generation from renewable solar energy systems is highly variable due to its dependence on meteorological conditions. An efficient use of these fluctuating energy sources requires reliable forecast information for management and operation strategies. Oldenburg University and DLR-DFD investigate different approaches to forecast radiation for time scales from the sub-hourly range up to three days ahead.

2.4 Long-term Variability of Renewable Power Production

Solar energy applications require knowledge of either the global irradiance or the direct normal irradiance. DLR-ISIS is the first global long-term data set, which includes both components over a period of 21 years. For the use of wind energy, the characteristics of wind power resources must be well known and understood. The knowledge about extreme values of wind force in the North Sea region becomes important in view of the industrial use of the area. DLR IPA looks at the solar side and Oldenburg University at the wind.

2.1 Grid Integration of Large Shares of Solar and Wind Power

Due to the limitation of fossil resources and their impact on climate change, the future energy system will depend on large shares of renewable energy sources. This poses a major challenge on the development of future energy systems, as renewable resources have other characteristics than the currently used conventional resources.

CARSTEN HOYER-KLICK, YVONNE SCHOLZ, JULIA GEHRUNG, CHRISTOPH SCHILLINGS (DLR TT), KLAUS WISSKIRCHEN (DLR DFD)

Patterns of renewable electricity flows

The availability of many renewable resources is determined by weather conditions. Solar energy has a diurnal cycle due to the sun-earth geometry and during the day it is influenced by the presence of clouds and aerosols. Wind energy depends on the movement of weather systems. Biomass and hydro energy depend e.g. on the available radiation, rain rates, soil type and humidity, but the weather influence for these sources has a longer time scale. Weather varies strongly with time and distance. Especially with solar and wind energy, a future energy system has to cope with a constantly changing distribution of the power sources. The changing patterns will also reduce the overall intermittency of fluctuating renewable resources as shown in Fig. 1 for five distributed wind turbines in Germany. The power output of each single turbine changes between 0 and 100 percent, the power sum only between eight and 75 percent. Also the relative changes are slower than originatingfrom single turbines.

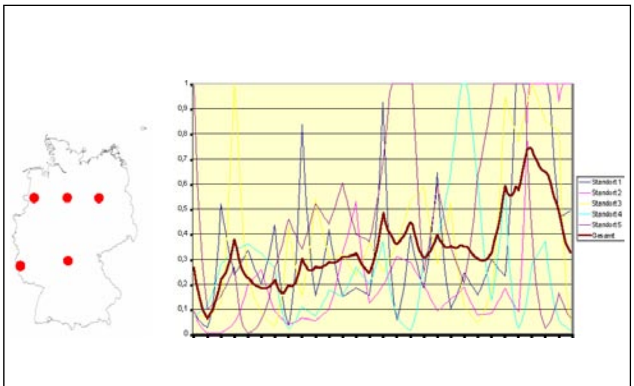

Fig. 1: Relative power production of five wind turbines and power sum for ten days in autumn.

A mix of technologies also has balancing effects: sunny areas can feed their power into cloudy areas and the wind often blows the strongest in "bad weather" conditions with rain and clouds, when there is little solar energy locally available. To make use of the balancing effects, an enhanced electricity network is necessary, which can transport the balancing flows. The knowledge about patterns of the different renewable resources is therefore very important in the development of our future energy system.

Aims and targets

It is one of the aims of vIEM to analyse the balancing of the different renewable resources. The target is to develop a model which can quantify the balancing flows in an electricity grid on an hourly basis. This corresponds to the tertiary control of the electricity grid or the level of power dispatch. More detailed electro technical modeling requires data in much higher temporal resolution. A model based on hourly energy balances supports the analysis of an optimal mix of different renewable energy technologies and their spatial distribution. The mix of renewable energies will also influence the remaining non-renewable power production. As renewable energies gain higher shares in the energy systems, there will be an increasing number of situations where they can serve the total energy demand and therefore reduce the demand for conventional "base load" power. Future conventional systems will need to be much more controllable as current medium or peak load plants with much less full load hours.

Storage of electricity

The pattern of renewable electricity generation will also influence the need for storage: How much storage is needed, how often is storage used, what are typical storage times (minutes, hour, days, weeks), where may be good locations to optimize power flows?

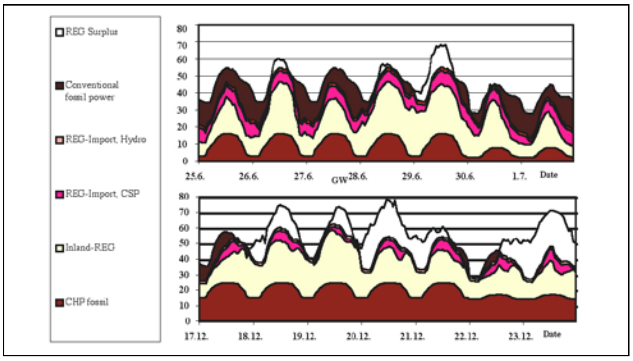

Fig. 2: Hourly electricity balance of Germany of one network node for a year 2050 scenario. A summer week (top) and a winter week (bottom) are shown.

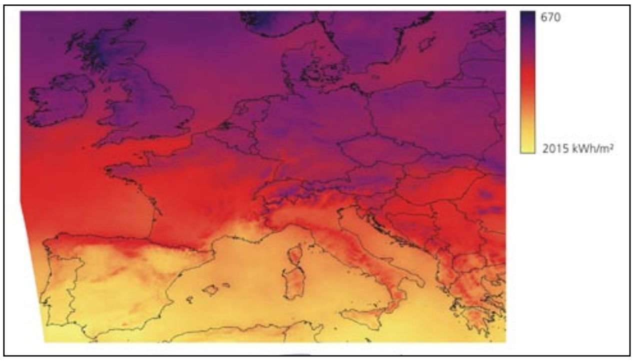

Fig. 3: Annual sum of global irradiance in 2004 in kWh/m².

This work builds upon two previous activities. Brischke (2005) modeled the German electrical system in four nodes (north, west, south and east) on an hourly basis (Fig. 2).

Reise (2004a, b) modeled the balancing flows for Germany on a regular grid corresponding to the Meteosat satellite pixels. The typical amount of energy transport over several scales of distance was modeled assuming an ideal transport grid with infinite capacity. The next step will be to consider a more realistic network topology in order to account for limited transmission capacities or to obtain information about beneficial transmission capacity extensions.

Resources

The first activities concentrated on the analysis of resources and created an inventory of renewable resource. Solar resource data is taken from the DLR data base SOLEMI (Solar Energy Mining) which was expanded to produce direct normal and global irradiance. Fig. 3 shows an annual sum of global irradiance in Europe in 2004. The data is available for every grid cell (with a spatial resolution of 10 km) in an hourly time step. Wind resources are taken from the new model LME, operated by the German Weather Service DWD.

Biomass resources are based on statistical data (EUROSTAT and FAOSTAT), land cover data and net primary production describing the carbon uptake in vegetation which is analysed at DLR-DFD based on satellite measurements and soil-vegetation-atmosphere-transfer modelling (Gehrung, 2006; Wißkirchen, 2004). Two different approaches have been applied. In the first case, the statistical data has been disaggregated equally with the land use data. This has been done e.g. for forest wood. In a second approach a weighted disaggregation has been done on the base of the net primary production. Although not leading to an improvement of wood forest resource maps, this approach was found to be essential for the disaggregation of surplus straw resources (Fig. 4)

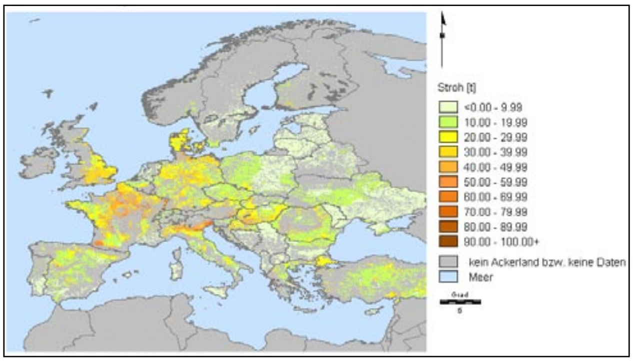

Fig. 4: Surplus straw for energy. This map is based on statistical data of available surplus straw and a weighted disaggregation based on net primary production (Gehrung, 2006).

Potentials of renewable energy production

The geographical distribution of renewable energy production is not only influenced by the resources. Some technologies have restrictions in suitable land areas. Concentrating solar power plants need large even areas of solid grounds. PV is often integrated into roof tops. For example, the density of installed PV can be estimated based on land cover data to derive a fraction of used area. Fig. 5 shows a map of potential PV production based on land cover data and a solar resource map for one specific hour. Further inputs are estimations on PV system sizes and distributions of system orientations.

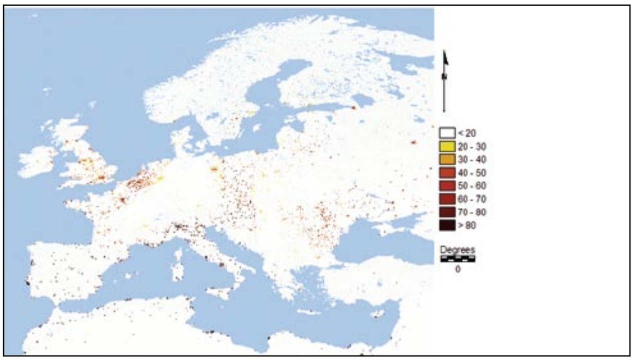

Fig. 5: Potential of power production at 1 October, 2005, 12:00 – 13:00, in MW/km² (Scholz et al, 2006)

Hourly potential maps as in Fig. 5 for each renewable energy technology can be used as input to model power flows in the electricity grid. They provide information about the maximum power generation in a certain hour with the maximum installed power generation capacity corresponding to chosen ecological, social and other conditions. They do not provide information about the actual amount of power generation facilities installed which might be considerably smaller than the maximum installable capacity. Capacities to be installed in the future are determined in several scenarios based on annual energy balances without considering temporal fluctuations. The following questions can not be answered with this approach: Is fossil energy backup or storage required? If yes: how much of it and where should it be installed? Must the transmission grid be extended? If yes: how much transmission capacity is required and where?

In order to find out about generation capacities to be installed in different regions, an optimisation model is being developed in the ongoing PhD thesis of Y. Scholz. In the model, hourly power generation potentials and hourly electricity demand in all European and in some countries of the MENA-region (Middle East and North Africa) are considered as well as transmission lines between neighbour countries. The model finds the least-cost energy mix and cross-region transport capacities for the whole region. This information about the most cost-efficient energy mix and transport capacities can be used for new scenarios of the development of the energy supply system.

In combination with the power generation potential in each hour, data can also be provided for more detailed network studies. Therefore, the power production can be aggregated to the nearest network node and used as power production value at this node (Fig. 6). Each grid cell of the analysis raster is associated with a node of the electricity network. All the cells associated with one node are balanced in the node.

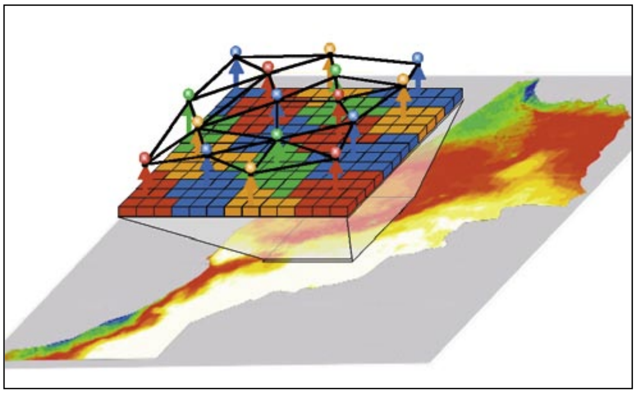

Fig. 6: Model for the aggregation to network nodes. The coloured grid points correspond to the node in the same colour.

Future Research

As this is current work, the next steps will be the development and implementation of a model which can describe the energy flows on an hourly basis. This can be used to evaluate the impact of different scenarios of renewable energy development and different spatial distributions on the necessary energy transport in the electricity grid.

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2.2 Improved Estimation of the Solar Resource

Accurate information about availability of the solar resource is a key requirement for a successful implementation of solar energy systems. The advantage of satellite-based estimates lies in their inherent broad-area coverage. Therefore, strong emphasis is given to achieve the best possible accuracy, comparable to that from ground measurements. In the following we discuss the latest developments in satellite-based solar radiation estimates.

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Surface solar irradiance is derived from satellite measurements by either physical or statistical methods. Physical methods calculate the radiative transfer of solar radiation through the atmosphere taking optical properties of atmospheric constituents from satellite measurements or from climatologies into account. Statistical methods use the shortwave reflection of the atmosphere from satellite images as a measure of cloudiness in empirical relations and, in combination with a clear sky model, derive the solar irradiance on the ground. The underlying assumption is that the reflection of clouds and of the atmosphere is linearily related to the transmission of solar radiation through the atmosphere. In both cases it is common pratice to separate between a clear and a cloudy atmosphere. Homogeneous clouds can easily be embedded into a model of an atmosphere composed of plane-parallel layers and thus treated with one-dimensional radiative transfer. This is different for inhomogeneous clouds which must be treated with three-dimensional radiative transfer calculations or by following their impact on radiative transfer with suitable parameterizations.

The partners of vIEM have their expertise in different areas: Both, Oldenburg University and Deutsches Zentrum für Luft- und Raumfahrt (DLR) employ a semi-empirical method, known as the cloud index method. Additionally, DLR specializes in radiative transport calculations and the retrieval of the necessary input data about atmospheric constituents. At present, the statistical method delivers the best estimates of surface solar irradiance in validation with ground measurements. The precision of the cloud index method results from a calibration procedure in which the brightness of each image pixel is calibrated individually, i.e. calibration constants are set specifically for each image pixel. By contrast, deterministic physical models strongly depend on the quality of the information on the state of the atmosphere. Effectively, the cloud index method records the state of the atmosphere in the calibration constants. Yet, a description in terms of physical parameters as for instance cloud optical depth, effective droplet radius, aerosol concentration, and water vapor level is preferable. It is expected that physical models will outperform statistical procedures once the quality of the atmospheric input data is sufficient. Our challenge is to optimize the quality of atmospheric data and to choose the most suitable model for exploitation of our data base.

Different know how is available at the vIEM partners and used as background for the current vIEM research work package: DLR-DFD and DLR-IPA developed the software package APOLLO for the retrieval of cloud physical properties. In addition, DLR-DFD is working on a near-real time estimation software of aerosol concentrations in the atmosphere called SYNAER. The work of DLR-IPA is concentrated on radiative transport calculations, particularly three-dimensional calculations. This software package is called MYSTIC.
Considering that a full Monte Carlo simulation of radiative transfer is very time consuming, Oldenburg University developed a parameterization of radiative transport (CloudS) for the purpose of operational solar irradiance estimates (Kuhlemann). For use in statistical methods, the software package SOLIS has been developed at Oldenburg University which combines the cloud index method with a sophisticated clear sky model. The goal is to replace climatological input parameters with near real-time estimates as provided by DLR-DFD. Besides the interest in a better description of the atmosphere, Oldenburg University was also investigating an improved estimation of surface parameters. One special case, namely the presence of snow on the ground, has to be given special attention in order to ensure that the estimated pixel brightness reflects the degree of cloudiness, not the degree of snow cover, which would result in an erroneous irradiance estimate. In Fig. 7 glo-

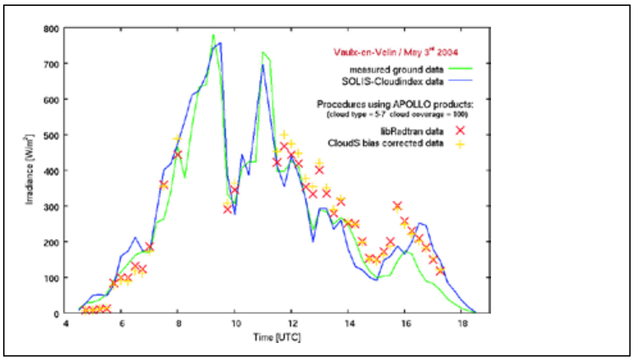

Fig. 7: Global irradiance measurements and satellite-based values derived from the Solis Cloud Index method, radiative transfer calculations performed with libRadtran on APOLLO retrieved Cloud optical depth and the radiative transfer parameterization CloudS.

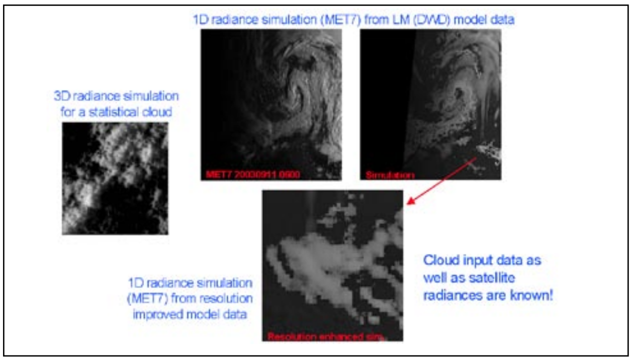

Fig. 8: One-dimensional radiative transfer calculations are performed on atmospheric conditions predicted by the Local Model (LM) of the German Weather service (DWD). This enables to get synthesized satellite images in different resolutions together with solar irradiance data at the ground. Since cloud input data as well as satellite radiances are known this gives the opportunity to evaluate new algorithms for remote sensing of cloud properties and solar surface irradiance.

bal irradiance measurements are compared to satellite-based values derived by different approaches.

Since improved resolution of satellite sensors needs to be accounted for with new algorithms for the remote sensing of cloud properties, DLR-IPA started to set up complete cloud datasets for algorithm evaluation. These sets are derived from one-dimensional radiative transfer calculations performed on liqiud water contents predicted by the Local Model of the German Weather Service (DWD). This enables to get synthesized satellite images (Fig. 8) in different resolutions together with solar irradiance data at the ground. Since cloud input data as well as satellite radiances are known, this gives the opportunity to evaluate new algorithms for remote sensing of surface irradiance.
A study was performed to analyse the impact on surface irradiance of inhomogeneous clouds. Cloud properties retrievals based on 1D radiative transfer calculations can be biased, as shown by Zinner et al. [2006] and Zinner and Mayer [2006] for stratocumulus clouds, due to unresolved sub-pixel cloud inhomogeneity (plane-parallel error). The use of the High Resolution Visible channel of SEVIRI enables to partially account for this inhomogeneity and to reduce the plane-parallel bias: For partly clouded pixels an underestimation of 10-20 percent in cloud optical thickness and a minor influence on cloud transmission with 2-5 percent has been detected.

In future the satellite-based estimation of solar resources will be further improved by a deeper insight of three-dimensional cloud effects. Parameterizations of these effects will be incorporated into the cloud index method. Weak spots of algorithms can be detected by the synthesized satellite images, which will help to enhance the quality of satellite derived irradiance data.

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Schemes for an Improved Estimation of the Solar Resource

1.

1. Physical models based on radiative transfer calculations

APOLLO → **libRadtran / CloudS**

STATUS:	work in progress
PRELIMINARY RESULT:	so far, physical models still do not match the accuracy achieved by cloud index methods

2.

2. Near-real time estimates of clear sky parameters as aerosol concentration and type together with total water vapor column (TWC)

SYNAER/MSG TWC → **SOLIS**

status:	work in progress
preliminary result:	MSG TWC was validated and is currently prepared for operational use, SYNAER is still in development, version 1.0 is operational

3.

3. Improved surface parameters: snow detection

Snow Detection → **Cloudindex-Method**

status:	essentially finished, some details remain
preliminary result:	a significant improvement has been achieved for irradiance estimates in the presence of snow: for Feb and March 2005 the negative bias reduced from –13.5% to –6%.

4.

4. Hybrid method between a statistical model and a physical model

APOLLO → **Cloudindex-Method**

status:	started
preliminary result:	first results indicate an improvement from a geometrical correction: The correct position of a cloud is determined by considering its height and the viewing geometry.

5.

5. Three-dimensional calculations for case studies

Cloud Properties → **Mystic**

status:	started
preliminary result:	3D effects have been demonstrated

2.3 Forecasting of Solar Radiation

Power generation from renewable solar and wind energy systems is highly variable due to its dependence on meteorological conditions. An efficient use of these fluctuating energy sources requires reliable forecast information for management and operation strategies. Examples are the management of electricity grids with high penetration rates from renewable sources, storage management and control of solar thermal power plants, and control systems in buildings. Oldenburg University and DLR-DFD investigate different approaches to forecast radiation for time scales from the sub-hourly range up to three days ahead.

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Due to the strong increase of renewable energies the significance of the prediction of meteorological quantities such as wind velocity and solar irradiance is rising. Today, wind power prediction systems are already available that improve the integration of wind energy into the electricity supply system. Also, the prediction of solar yields becomes more and more important for utilities with the increasing portion of solar energy sources. In Germany already more than 2 GWpeak of photovoltaic power are installed and annual growth rates of more than 20 percent are expected. The Spanish feed-in law already includes incentives for correct prediction of solar yields for the next day.

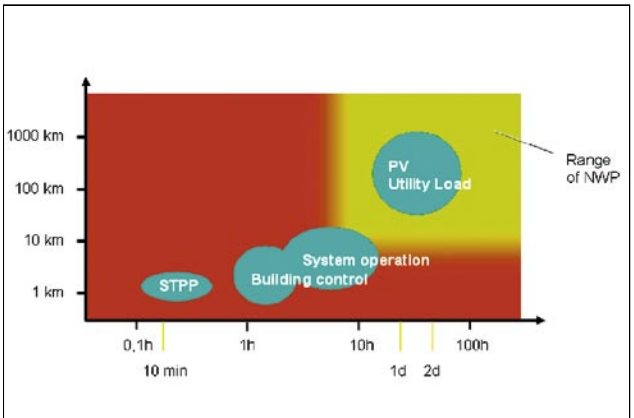

Fig. 9: Typical target applications for irradiance forecasting and their respective spatial and temporal scales. (STPP = Solar Thermal Power Plants, PV = Photovoltaics). The blue area depicts the range for which the use of Numerical Weather Prediction (NWP) models is appropriate.

The time scale and the corresponding spatial scale of the forecast are governed by the application and its time constants (Fig. 9). For example, integration of solar power into electricity grids will largely benefit from regional forecasts of distributed PV systems of one or more days ahead, while for the management and grid integration of solar thermal power plants site-specific forecasts from a few minutes onwards are required.

For forecast horizons of up to three days we analyse the potential of numerical meteorological models in forecasting solar irradiance and clouds. For very short term forecasting in a temporal range of a few minutes to a few hours we propose an approach based on satellite cloud motion vectors. In order to provide enhanced forecasts for clear sky situations we investigate the integration of aerosol forecasts using chemical transport models.

Forecast of clouds and solar radiation with numerical weather prediction models

Numerical weather prediction (NWP) models are expected to have the potential to satisfy the requirements in forecasting solar irradiance for up to several days. Global NWP models usually have a coarse resolution and do not allow for a detailed mapping of small-scale features. The global model run by the European Center for Medium range Weather Forecasts (ECMWF), provides forecasts with a temporal resolution of 3h hours and a spatial resolution of 25km x 25km, including forecasts of global irradiance, but without direct irradiance.

To obtain forecasts with the high temporal and spatial resolution required for solar energy applications we investigated the use of the regional climate model MM5 (Grell et al., 1994), developed at the Penn State University/National Center for Atmospheric Research (PSU/NCAR). A case study was performed with different configurations of MM5 to define an appropriate set-up. Furthermore, we analysed the use of different data sources, e.g. global model of the ECMWF or the German Weather Service (DWD) as initial and lateral boundary conditions.

As a second approach to achieve forecasts of site specific, hourly values we analysed different spatial and temporal interpolation techniques to refine ECMWF global model irradiance forecasts. An optimum adjustment of the temporal resolution was achieved by applying a clear sky model to consider the typical diurnal course of irradiance. For comparison, we evaluated irradiance forecasts of an operational MOS (Model Output Statistic) forecasting scheme based on ECMWF model output and satellite derived irradiance data (Bo-finger and Heilscher, 2004).

Fig. 10 shows a comparison of the different forecasting approaches. The refined ECMWF irradiation forecasts deliver results which are much better than the MM5 forecasts and are comparable to the MOS predictions. In case of clear sky situations the optimised ECMWF forecast is 5 to 10 percent better than the MOS system.

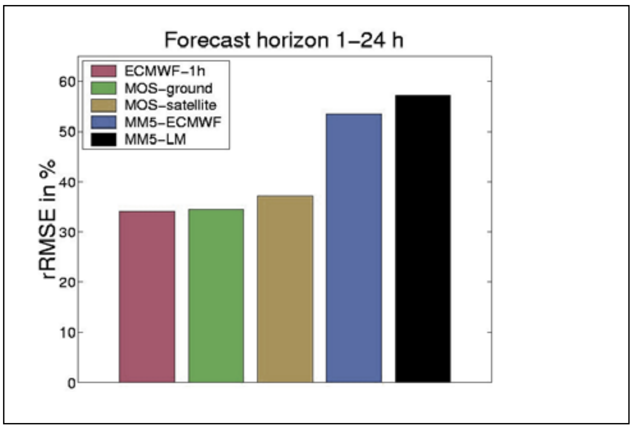

Fig. 10: Relative RMSE for different hourly forecasts of the global irradiation with a forecast horizon of one day. Evaluation with ground measurements of 8 DWD stations for 40 days in summer 2003.

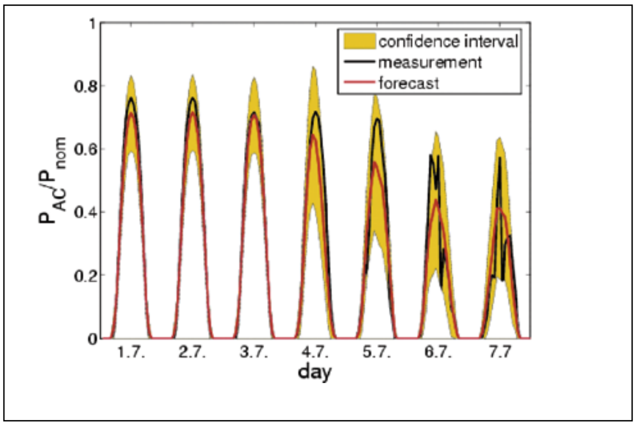

Figure 11: Forecast of power output normalized to the installed power P_{nom} with confidence intervals in comparison to measured power output for a PV system in southern Germany for 7 days in July 2006 (forecast horizon: one day).

The specification of the forecast accuracy is an important issue for an effective application of forecasts. Fig. 11 shows measured and forecasted PV system power output using refined ECWMF irradiance forecasts with confidence intervals. Weather specific confidence intervals were determined on the basis of a detailed error analysis. Further details on the analysis of NWP models for irradiance forecasting can be found in Girodo, 2006.

Short term forecasting based on satellite data

For forecast horizons of a few minutes to hours, it is important to incorporate information on the actual atmospheric state. Data of the European Meteosat satellites are a high quality source for irradiance and cloud information because of their excellent temporal and spatial resolution.

For short-term time scales, the temporal change of cloud structures is mainly caused by cloud motion. We developed an approach for forecasting based on the calculation of motion vector fields from satellite images (see also Lorenz et al., 2004, Engel, 2006). In a first step, cloud index images, according to the semi-empirical Heliosat method (Hammer et al., 2003), are calculated from the satellite data. Following, motion vector

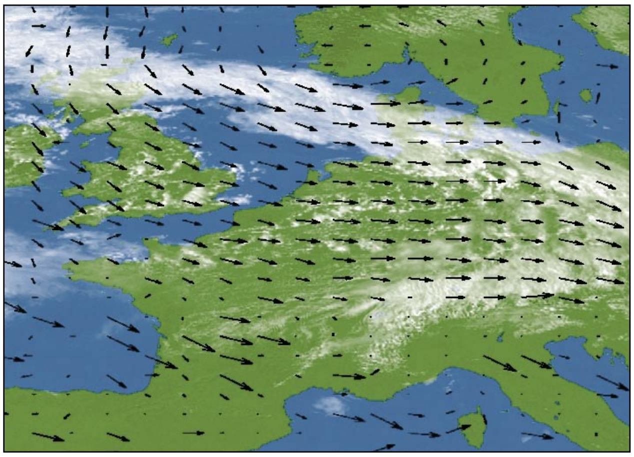

Fig. 12: Cloud index and motion vector field based on data of Meteosat-7 (8.5.2005, 14:00).

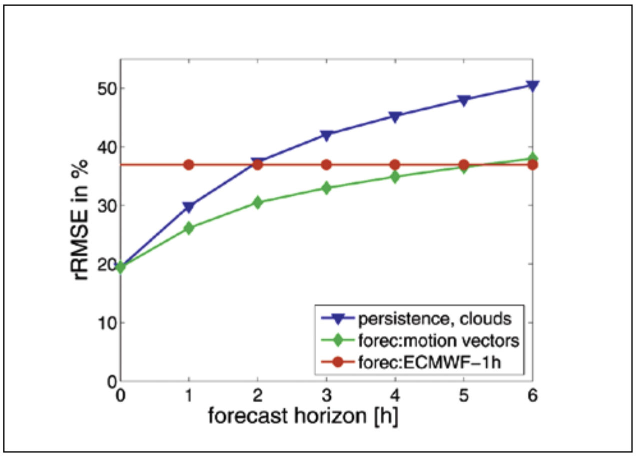

Fig 13: Relative RMSE of global irradiance forecast based on motion vectors depending on the forecast horizon in comparison to the rRMSE of forecasts based on persistence and the rRMSE of ECMWF based forecasts for the first forecast day.

fields are derived from consecutive cloud index images. An example for a vector field based on Meteosat-7 data is given in Fig. 12.

The future cloud situation is determined by applying the calculated vector field to the actual image. The cloud forecast is optimised by application of smoothing filters to eliminate randomly varying small-scale structures due to atmospheric turbulence and convection which are not predictable. Finally, solar surface irradiance is derived from the predicted cloud index images using the Heliosat method.

Fig. 13 displays the relative RMSE of this approach applied to Metoesat-8 data in dependence of the forecast horizon. The evaluation was performed for the period April 2004 – March 2005 with ground-measured values of 16 DWD stations. For comparison the rRMSE of forecasts based on persistence of the cloud situation and the rRMSE of ECMWF based forecasts for the first forecast day is given. The proposed approach based on motion vector fields leads to significantly better results than forecasts based on the assumption of cloud persistence. Furthermore, for forecast horizons in the range of a few hours, the approach based on satellite data leads to better results than the ECMWF based forecasts.

Improved Forecasting of Clear-Sky Irradiances Using Chemical Transport Models

Clear-sky situations are most relevant for solar power production. But clear sky solar irradiance, in particular direct clear sky irradiance, varies significantly depending on the actual composition of the atmosphere. Aerosols, water vapour and ozone have relevant effects on scattering and absorption also in the shortwave spectral region. While prediction of water vapour and ozone is already possible with 'classical' weather forecasting models and statistical methods, forecast of atmospheric aerosol content is still a matter of ongoing research. A first approach was realized in the chemistry transport model EURAD (European Dispersion and Deposition Model), which has been developed for purposes of air quality monitoring at the University of Cologne. This model predicts aerosols distinguishing between major aerosol components such as soot, organic particles and inorganic acids which allows spectral irradiance information. DLR-DFD is preparing a prototype for a surface solar irradiance forecast.

To evaluate the suitability of EURAD aerosol data as input data for solar irradiance forecasts, forecasted AOD (aerosol optical depth) of the EURAD system for the period of July to November 2003 was validated against ground based measure-

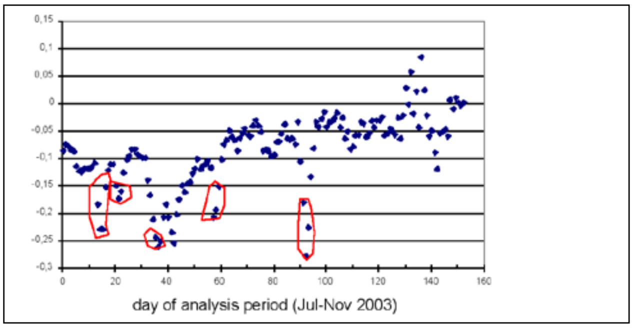

Fig. 14: Daily mean values of absolute differences in AOD550 (EURAD minus AERONET) – marks show days with Sahara dust storm events leading to high particle loads in Western and Central Mediterranean areas

ments from the AErosol RObotic NETwork (AERONET) (see also Breitkreuz et al., 2007). Results show that for the whole period and all stations the combined set of models slightly underestimates measured AOD. This general trend is altered by strong regional tendencies, leading to good agreements between model and measurements for Northern and Middle Europe, and to severe underestimations of AOD in the central Mediterranean region, especially in the summer.The latter is mainly due to Sahara dust storm which cannot be modelled correctly in the EURAD system yet. The mean forecast quality for single stations and as well for all stations can be severely altered by these dust storm events especially in the solar energy relevant Mediterannean region (Fig. 14). This means that the integration of dust storm information will significantly improve aerosol forecast based on chemical transport models. One possible approach is the assimilation of satellite based aerosol measurements into the model suite. This is being investigated at DLR-DFD in cooperation with the University of Cologne within the framework of the DFG project AERO-SAM (Boundary layer AEROsol characterization from Space by advanced data assimilation into a tropospheric chemistry transport Model).

To quantify the effects of changing aerosol loads for solar energy applications, spectrally resolved direct and diffuse irradiance forecasts were calculated from EURAD model output and ancillary atmospheric information from model and satellite data sources. The results were compared to routinely available ECMWF forecasts of global solar irradiance as well as ground and satellite based measurements. First examples for cloud free cases show that the irradiances forecasts reach improved accuracy levels compared to ECMWF global irradiance forecasts.

Future Research

Research on irradiance forecasts for energy specific applications is still at the beginning. Considerable effort is required to improve forecasts of direct and global irradiance. Possible approaches for improvement are an enhanced modelling of clouds and radiation in NWP models, integration of enhanced aerosol forecasts, the application of statistical post processing to NWP output, and the use of ensemble predictions. The conversion of irradiance forecasts to prediction of the power output of renewable energy systems is another task of energy meteorology. Finally, the development of optimised weather dependent operation strategies for solar energy systems in cooperation with the system operators is required.

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2.4 Long Term Variability of Renewable Power Production

2.4.1 Long-Term Variability of Global and Direct Solar Irradiance

Solar energy applications require knowledge of either the global irradiance (e.g. for photovoltaic power plants) or the direct normal irradiance (e.g. for concentrating solar power plants). DLR-ISIS is the first global long-term data set which includes both components. The unique temporal coverage of 21 years allows to derive stable long-term averages, to evaluate the variability of irradiance from year to year, and to study the effect of extreme atmospheric conditions on the irradiance at the surface, e.g. after a volcanic eruption. The analysis of the long-term variability of the direct normal irradiance contributed to the approval of several 50 MW solar thermal power plants in Southern Spain.

SINA LOHMANN, RICHARD MEYER, BERNHARD MAYER (DLR IPA)

DLR-ISIS (Irradiance at the Surface Derived from ISCCP Cloud Data) irradiances are derived with detailed radiative transfer calculations based on physical optical properties of the atmosphere. For that purpose we used the radiative transfer package libRadtran (Mayer and Kylling 2005). A fast yet accurate two-stream approximation was selected. Absorption by atmospheric gases was modeled with the accurate 32-band correlated-k method by Kato et al. (1999) which covers the complete solar spectrum from 250 nm to 4600 nm. Cloud microphysics was included using Mie-calculations for liquid water droplets and a parameterization for non-spherical particles for ice clouds. Further details on the procedure developed for DLR-ISIS can be found in Lohmann (2006a) and in Lohmann et al. (2006b). The input for the radiative transfer calculations, in particular the cloud information, was mainly taken from ISCCP (International Satellite Cloud Climatology Project). The ISCCP project currently covers the time span from July 1983 to June 2005, including data from several geostationary and polar orbiting satellites calibrated and homogenized to a consistent cloud product (Schiffer and Rossow 1983). ISCCP provides data in different spatial and time resolutions. We selected the ISCCP FD input data set (Zhang et al. 2004), which provides 3-hourly cloud observations on a 280 km x 280 km equal area grid and also includes global irradiance as a product. The grid was adopted for the DLR-ISIS data set. The complete cloud information was incorporated as consistently as possible in our calculations, considering the 15 cloud types provided by ISCCP, the respective optical thicknesses, droplet and particles sizes, and the corresponding water and ice cloud optical properties. Using the same assumptions for the calculation of global and direct irradiance as were used for the retrieval of the cloud optical properties in ISCCP guarantees the highest possible accuracy.

The aerosol was separated into tropospheric and stratospheric aerosol. The optical thickness of the tropospheric aerosol was taken from the NASA-GISS data set which was originally generated as input to climate model simulations. The data is based on observations of the optical properties for the most common aerosol types. The global distribution of aerosol types was modelled with the help of emission data and transport models for the dissemination of the aerosol particles. The results were combined in one data set of 12 climatological monthly averages for optical thickness on a 4° x 5° grid (Tegen et al. 1997). Stratospheric aerosol is mainly produced by major volcanic eruptions and therefore highly variable: Stratospheric aerosol content is very high directly and up to a few years after major volcanic eruptions and a low background level between eruptions is assumed. We used the data set by Sato et al. (1993) which was also created for NASA-GISS climate simulations and covers the time period from 1850 to 1997. It consists of monthly averages of optical thickness of the stratospheric aerosol in 7.5° latitude bands. For the period covered by the DLR-ISIS data set, it is based on satellite observations of the Stratospheric Aerosol Monitor (SAM II) and the Stratospheric Aerosol and Gas Experiment (SAGE I+II). Two major volcanic eruptions affect the results of the DLR-ISIS data set: The eruption of El Chichon (Mexico) in April 1982 and the eruption of Pinatubo (Philippines) in June 1991. After 1997, an exponential decrease until 2000 was assumed and no stratospheric aerosol has been included in the radiative transfer calculations after 2000.

Additional input parameters like total ozone and water vapour profiles are also taken from the ISCCP FD input data set, based on the Total Ozone Mapping Spectrometer (TOMS) and the TIROS Operational Vertical Sounder (TOVS). Together with the surface albedo and the mean elevation above sea level for each grid box included in the ISCCP data set, these are used to derive irradiances for the DLR-ISIS data set.

The global average of direct normal irradiance from the DLR-ISIS data is 145 W/m², for the global irradiance a value of 186 W/m² was derived. Direct radiation is more sensitive to clouds and aerosols. Therefore, typical cloud situations lead to very low average e.g. in the zone of westerly winds over the southern polar ocean, or to very high irradiance values e.g. in deserts or Antarctica. Therefore, the direct normal irradiance shows larger variability than global irradiance (Fig. 15a).
To study the impact of large volcanic eruptions, time series of the DLR-ISIS data set were calculated twice, with and without stratospheric aerosol. The time series of the average direct normal irradiance shows a strong decrease by up to 25 percent) after the eruption of Mt. Pinatubo while the global irradiance is reduced only by five percent (Fig. 15b).

The reason for the much lower sensitivity of the global irradiance is the fact that the larger part of the radiation which is removed from the direct beam by scattering reaches the surface as diffuse radiation. For the same reason, the comparison of the time series also shows a stronger year-to-year variability for direct radiation: On average, the annual mean of the direct normal irradiance of one year differs by seven percent from the values of the year before or after. For global irradiance, annual means differ only by three percent on average.

Direct normal irradiance shows a strong increase between 1986 and 2000. Part of this increase is caused by the recovery of the atmosphere after the eruptions of El Chichon and Pinatubo. However, even in the calculations without stratospheric aerosols a statistically significant increase of 0.4 percent per year was found. This increase is caused by a decrease in ISCCP cloud amount. This trend in ISCCP cloud amount is subject of ongoing discussion. Future studies will have to show whether this is an artefact of the satellite data processing for ISCCP or a real decrease of cloud amount.

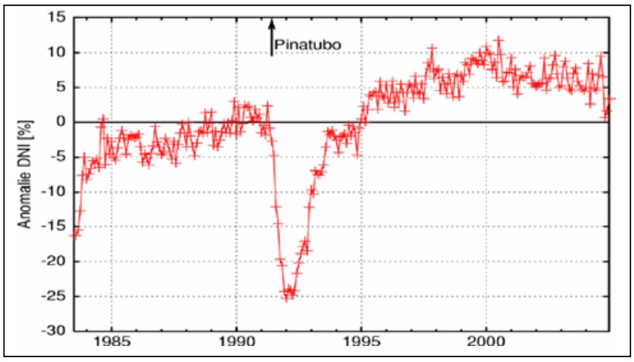

Fig. 15b: Anomaly of average direct normal irradiance after the Pinatubo eruption form DLR-ISIS data.

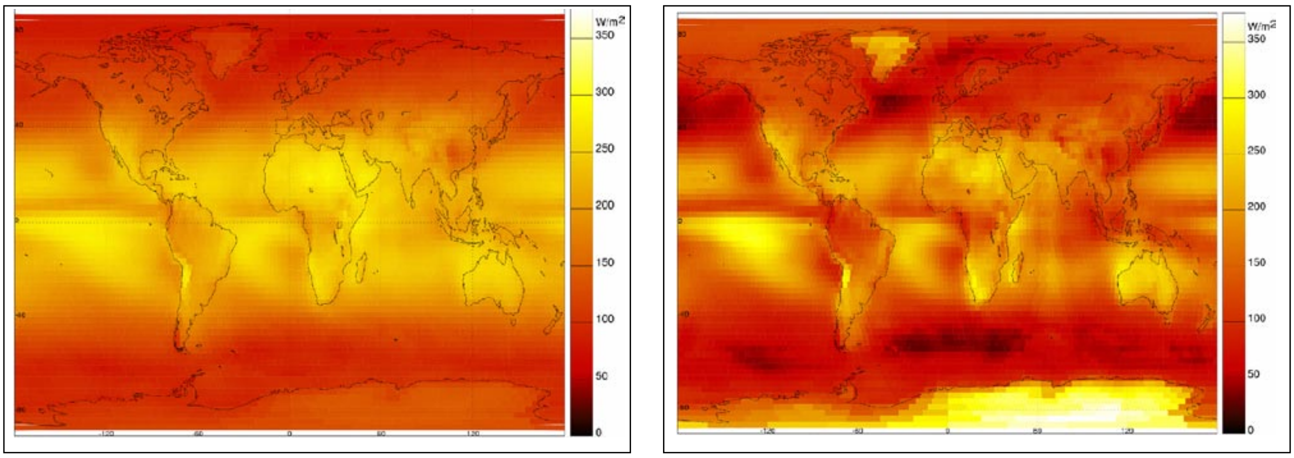

Fig. 15a: DLR-ISIS average irradiances, left: global irradiance, right: direct normal irradiance.

The validation of the monthly means of the DLR-ISIS data by comparison with surface observations showed good agreement. For a single grid box, direct normal irradiance was mostly underestimated during summer, but overestimated during winter (Lohmann et al. 2007). This effect is mostly caused by scaling effects due to the comparison of a 280 km x 280 km grid box average to measurements of a single station within this box. The systematic comparison of DLR-ISIS data with observations from 78 stations shows that the DLR-ISIS direct normal irradiance is on average three percent lower than the surface observations. Global irradiance from DLR-ISIS, on the other hand, was three percent higher than surface observations on average over 89 stations.

The DLR-ISIS data set is used to determine the average annual irradiance at sites for new concentrating solar power plants, to evaluate the variability of irradiance from year to year and study the effect of extreme atmospheric conditions on the irradiance at the surface e.g. after a volcanic eruption. The analysis of the long-term variability of the direct normal irradiance in the DLR-ISIS data set contributed to the approval of several new concentrating solar power plants in southern Spain. A dedicated webpage was built for the DLR-ISIS data set, http://www.pa.op.dlr.de/ISIS/, where a detailed description and some products are available.

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2.4 Long Term Variability of Renewable Power Production

2.4.2 Long-term Variability of the Wind Resource and Wind Conditions over the North Sea

For the planning of expensive wind farms, the characteristics of wind power resources must be well known and understood. Especially the deployment of offshore wind energy use needs detailed knowledge about the wind conditions over the sea. Common questions raised by investors and engineers are: What is the expected wind energy yield? Typical questions from engineers and operators are: What is the maximum wind speed exceeded once every fifty years? What is the frequency of strong and extreme winds and how long do storms last to ensure safe wind power integration into the power system? Did storms become more frequent in the past?

KAY SUSELJ, ABHA SOOD, VINCENT LAYEC, LÜDER VON BREMEN, DETLEV HEINEMANN (OLDENBURG UNIVERSITY)

Wind extremes over the North Sea

A study of extreme and strong winds has been performed using the ERA 40 re-analysis data from the European Centre of Medium-Range Weather Forecasts (ECMWF) (Layec, 2006). The distribution of 10m wind speeds can be described with the Weibull distribution:

$$f(u) = k/A\ (u/A)^{k-1} \exp(-(u/A)^k)$$

With A the scale parameter and k the shape parameter calculated from ERA-40 wind speeds. The long tail of the distribution is used to estimate a speed vmax that is exceeded once in a time period T (44 years return period) on a 6 hourly basis:

$$v_{max} = A(-\ln(1/T))^{1/k}$$

The return period is evaluated and plotted for the FINO-1 met masts in the German Bight (Fig. 16) and shows a strong dependency on wind direction. Easterly winds are generally about 5 m/s weaker than westerly winds. Their occurrence is also less frequent. The result should not be affected by land as the investigated grid point is far in the German Bight (~ 50 km). It can be suggested that foundation constructions take this into account to prevent over-design.

At cut-off wind speeds between 20 and 25 m/s sudden losses of rather large shares of offshore wind power endanger the operation of entire power systems. Although the quality of wind power forecasting has reached high standards, information on risks and frequency of power cut-offs is needed for the planning of large-scale offshore wind power integration, i.e. the power system has to be set up for high ramp rates and sufficient reserve capacities.

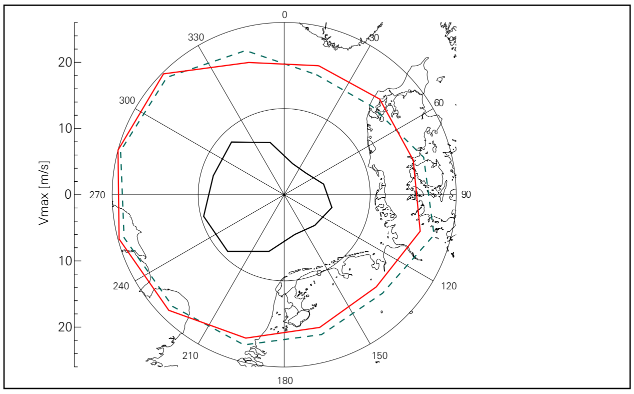

Fig. 16: Sectorwise vmax from ERA-40 data (red, solid curve) and estimated from Weibull distribution percentile (dashed), frequency in black at 55°N, 5°E (FINO-1).

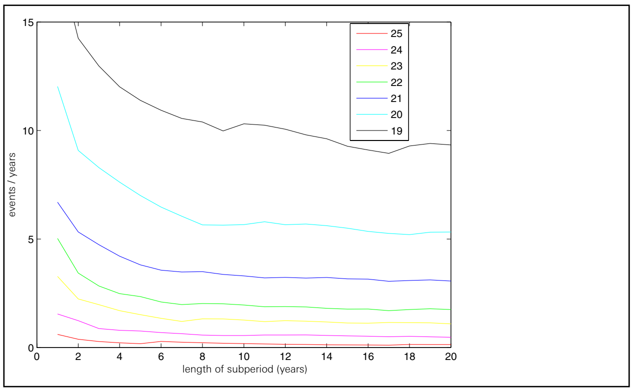

Fig. 17: 95 % storm frequency (events per year) at 55°N, 5°E (FINO-1) exceeding a certain wind speed threshold depends on length of time series.

Estimations from ERA-40 data show that the length of the investigated time period is very important to evaluate the statistical occurrence of events (cut-offs) per year (Fig. 17). Note, that given wind speed classes are for wind speeds at 10m height; real number of cut-offs might be higher due to stronger winds at hub height and higher speeds on a finer temporal and spatial scale. The scale of ERA-40 is 110x65km, only. The need for downscaling these data is expressed in the next paragraph.

Wind variability over the North Sea

The long term variability of the wind resource is analyzed using 55 years of NCEP/ NCAR (Kistler et al., 2001) reanalysis data. The wind speed anomaly from the annual cycle is used as a variability measure. This anomaly was related to the large scale circulation patterns, which were derived from the sea level pressure anomaly above the European North Atlantic region. We defined Scandinavian Iberian, Scandinavian Icelandic and Great Britain circulation indices and show that they have an important influence on the wind speed anomaly. As the circulation patterns can also be found in the results of climate models, this allows to look into the future behaviour of the wind variability.

The spatial domain of the wind speed covers the North Sea region [5°W-20°E, 50°N-60°N], while the sea level pressure data is taken on the larger European North Atlantic region [80°W-40°E, 30°N-70°N]. The anomalies from the annual are obtained as the difference from the instantaneous data and long time daily averages for both quantities.

For the wind speed anomaly the empirical orthogonal functions (EOF) (von Storch and Zwiers, 1999) were calculated to isolate its most important signals. The first three EOFs and the corresponding time series (principal components, PCs) were used. Together they explain 67 percent of the regional variance. In Fig. 18 the first EOF shows a coherent increase above the whole domain with maximum amplitudes above the North Sea. The second and the third EOF are oriented from north-west to south-east and from south-west to north-east, respectively.

The circulation patterns have been calculated as follows: The time averaged sea level pressure anomaly has been determined for days with a low, medium and high PC of the wind speed anomaly. Figs. 19–21 shows the results. The Scandinavian-Iberian (ScIb) index was derived as the sea level pressure anomaly difference between west of Scandinavia and west of Iberia. It is used as the predictor of the first PC of wind speed anomaly (Fig. 19). Similarly, the Scandinavian Iceland (ScIc) index was obtained above the Scandinavia and Iceland (Fig. 20) and employed as a predictor of the second PC, whereas the Great Britain (GB) index is used as a predictor for the third PC (Fig. 21).

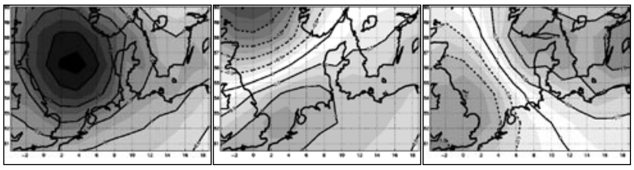

Fig. 18: The first three empirical orthogonal functions of wind speed anomaly.

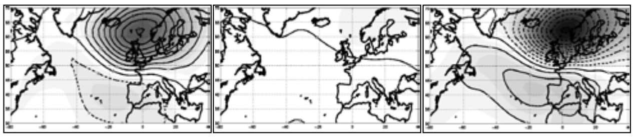

Fig. 19: The average sea level pressure anomaly for the days when the first principal component of the wind speed anomaly was low, medium and high.

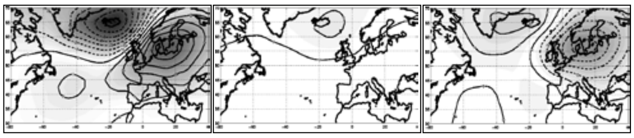

Fig. 20: Same as Figure 19, except for the second PC of wind speed anomaly.

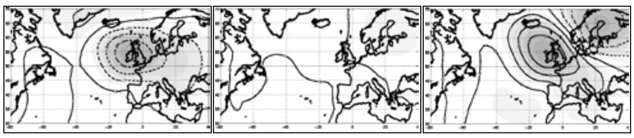

Fig. 21: Same as Figure 19, except for the third PC of wind speed anomaly.

The derived circulation patterns together with the EOFs were used to reconstruct the wind speed anomaly field. The correlation coefficient between reconstructed and original data is shown for the summer (Jun.-Sept.) and winter (Dec.-Mar.) months separately (Fig. 22). The wind speed anomaly can be better predicted in winter, with the correlation coefficient higher than 0.5 in more than half of the domain. In summer, correlation coefficient is the highest in the western part of the domain with the values up to 0.45.

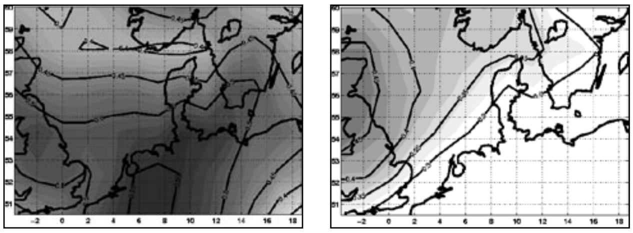

Fig. 22. Correlation coefficient between original wind speed anomaly and wind speed anomaly predicted from circulation indices for winter (left) and for summer (right).

Conclusions on Wind Variablity

The correlations between wind speed anomaly and sea level pressure anomaly confirms the strong relationship of these quantities, since often the sea level pressure is a main factor of the wind speed. The Scandinavian Iberian Index represents the meridional sea level pressure anomaly gradient above Europe and is among all circulation patterns the best correlated to the wind speed anomaly. This index shows some similarity with the well known North Atlantic Oscillation (NAO) (Hurrel, 1995). The derived Scandinavian Icelandic and Great Britain indicec importantly influence the second and third PC of wind speed anomaly.

Future Research

This work was a first step towards analyzing extreme winds and understanding the wind speed anomaly above the North Sea region. In the future, the long term reanalysis data shall be refined by dynamical downscaling. The downscaled data with their increased vertical resolution will help to study the vertical wind profile and shear as well as the extreme wind. Further, improvements in the downscaled wind speed close to the coastline are expected due to a better representation of the land-sea interface.

The results shown here are useful for statistical downscaling and interpreting the climate model results. As the circulation patterns can also be found in these results, this allows to look into the future behaviour of the wind variability and its extremes.

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3 AGENDA FOR FUTURE RESEARCH

Energy Meteorology is an application-oriented research field and as such has to be oriented along the needs of tomorrow's energy supply systems. These requirements therefore will define the short-, mid- and long-term research activities.

The research needs for Energy Meteorology are application-oriented and strongly coupled with the future development of energy technologies, their role in a global energy system, and the degree of its intelligent use.
As an high-grade interdisciplinary research field, Energy Meteorology's future research will need know-how from a multitude of disciplines of which meteorology/physics, engineering and computer science provide the core. A close cooperation with technological reseach activities in the specific areas will be of great importance.

Solar Energy

An important short-term focus has to be on improving solar radiation forecasting. Its need is driven by applications of electric power production (i.e., grid integration of PV and STPP), control of power systems (mainly STPP) and building control systems.

Different approaches should be analyzed regarding their potential: "All-in-one" methods based on advanced numerical weather prediction (ensemble prediction: ECMWF, COSMO LEPS) together with statistical post-processing as well as a component's approach (seperate cloud and aerosol forecasts as input in radiative transfer model). Also the potential benefit of meso-scale models for improving cloud and irradiance parameterization needs to be investigated.

Aerosol forecasting specific to the needs of solar irradiance modeling needs a better near-real time data base. Once available through new remote sensing capabilities, this information has to be analyzed and integrated into existing forecasting methods.

Very short range prediction (< 4 h) based on satellite data calls for a combination of the so far applied motion vector approach with mesoscale models to better represent cloud processes, fill the gap in the forecasting time scale, improve error analysis and reduce phase erors in 1-to-2-day forecasts.

Solar thermal power plants and future generations of photovoltaic converters using optical concentration make use of direct solar radiation only. In addition, concentrating systems will also use spectrally highly selective cells. This demands high-quality direct solar irradiance data and spectral information for both resource assessment and forecasting. Satellite techniques have to be expanded to provide this data with necessary accuracy.

Radiative transfer modeling (RTM) as the scientific basis of most meteorological questions raised by solar energy has to be used more intensely to provide a detailed view of the irradiance conditions at solar energy systems. High-resolution modelling of 3-D-irradiance, parameterization of cloud effects, and modeling of local radiation fields may improve the estimation of relevant radiative quantities. For specific purposes simple and fast tailor-made RTM models need to be developed.

Further application-oriented R&D is necessary in the exploitation/conditioning of available earth observation data. For example, a day-by-day analysis of solar radiant fluxes at various spatial and temporal scales would significantly improve the exploitation of the solar energy resource. The set-up of an high resolution archive of global databases and of operational near-real time assessments is an obvious prerequisite.

Wind Energy

Estimation of the wind resource is the first step for a successful exploitation of wind energy. Therefore maximum availability of wind resource data has to be ensured. New methods to provide new data and to combine existing data sources as reanalysis modeling data, satellite data and in situ measurement data have to be introduced.

The value of wind power is directly related to the accuracy of wind power forecasts. Here, the combination of various numerical models as well as true ensemble forecasting techniques are promising steps towards higher accuracy. Statistical methods to dynamically describe forecast accuracy are needed as well as methods to integrate this information into energy management schemes.

Especially offshore wind power applications call for a more precise description of small-scale flow pattern e.g. within wind farms to estimate mechanical turbine loads. New measuremet techniques (e.g., LIDAR) and modelling approaches (e.g., LES) may provide a more detailed insight. Turbulent charateristics and extreme events are of special interest in this domain.

The use of remote sensing techniques to precisely derive boundary layer wind fields would be a major step towards a high-resolution data base for resource assesment and forecasting.

The potential change in wind power availability in decadal time scales needs to be investigated in the context of regional climate modeling. Both, quantitative (e.g., long-term average wind speed) and qualitative (e.g., probability of extreme events) information should be provided.

Biomass

Again, providing an adequate data basis for assessing and planning of biomass use is a prominent need. Steps towards integration of land-use classification data, information on primary production and of its non-energetic use, etc. into a GIS-based modeling scheme should be forced. Recent knowledge gained with respect to the bioshere – atmosphere inteaction needs to be incorporated into corresponding methods.

Long-term research needs are – in the context of climate change – regarding the influence of changes in the spatial distribution of the most relevant meteorological parameter on primary production and its consequences for energetic use.

General Long-term Reseach

Efforts on the medium to long-term should be made to provide appropriate information for future large-scale energy distribution systems which will include large amounts of decentralized components. Satellite technologies show potential due to its high quality to provide complete energy-specific data with superior spatial and temporal resolution.

The feasibility of energy-specific space-born sensor systems should be investigated. They may be integrated in already planned satellite platforms or even placed in specifically designed satellites.

The long-range forecasting (up to seasonal) of renewable energy production (solar, wind, hydro, biomass) should be targeted as a long-range research aim. A respective product would be of extraordinary high value for the energy industry.

Spatial and Temporal Characteristics of Renewable Energy Production

Decentralized power production mainly from renewable sources will contribute in large amounts to future's energy supply. Optimizing this new structure will need complete information on renewable power production in various spatial and temporal scales. Advanced statistical methods have to be used to reduce this information in order to describe this simultaneous production and to derive figures for capacity effects, extreme value statistics, and threshold probabilities.

Energy-efficient Buildings

The large potential to reduce energy consumption in the buiding sector is partially only achievable by introducing intelligent methods including meteorological information. A new strategy combines forecasting with nowcasting methodologies specific to the building control needs. This has to be implemeted into control strategies especially for buildings with both heating and cooling loads.

4 EDUCATION AND TEACHING

vIEM offers a range of events to spread the knowledge and to educate young scientists. Major prgrammes to which vIEM contributes are the two Renewable Energy Master Courses offered at Oldenburg University. Members of vIEM supervise both diploma and PhD theses (*see chapter „Publications“*).

European Master in Renewable Energy:
The European Master in Renewable Energy is an initiative proposed and developed by the European Renewable Energy Centres (EUREC) Agency and the associated universities Ecole de Mines de Paris, Loughborough University, University of Zaragoza, Oldenburg University, University of Athens, Kassel University, National Technical University of Athens and the University of Northumbria (http://www.eurec.be/REMaster).

Postgraduate Programme Renewable Energy (PPRE):
An MSc programme of 16 months (3 terms) designed for scientists and engineers, intending to prepare for a professional career in the field of renewable energy (http://www.ppre.de).
The students in the international MSc programmes PPRE and EUREC at Oldenburg University study energy meteorology in the mandatory modules of "Solar Thermal & Energy Meteorology" and "Wind Energy & Energy Meteorology". The lectures, conducted in English, are given by Dr. Detlev Heinemann. In a "Measurement Seminar" the students become familiar with relevant instruments and satellite-based irradiance estimation. In an outdoor lab session, the students operate a meteorological station and learn to record and analyze meteorological data.

Physics Master:
The students in the physics master programme at Oldenburg University are offered a course in Energy Meteorology, which is taught by Dr. Detlev Heinemann in German for a mainly German audience.

Energy Meteorology for schools:
As an annual event Oldenburg University invites schools to take part at the „Tag der Physik“. This one-day-open-house-event intends to stimulate young peoples interest in studying science. In November 2005 and 2006 a few hundred pupils from Oldenburg and its vicinity had the opportunity to learn about energy meteorology in a poster exhibition and about eighty of them were guided through the topics solar energy and satellite information.

Beside these regular courses, vIEM members give lectures about energy meteorology in one-time events like summer schools or special courses.

Workshops:
Three workshops have been performed for vIEM members. The first one in November 2005 was about Radiative Transport in Clouds. More than 30 scientists joined this workshop with presentations about 3D radiative transport, cloud optical properties from SEVIRI data and inhomogeneous cloudiness and its impact on global and diffuse irradiance. The event about Wind Energy in December 2005 was joined by more than 20 participants with presentations in the fields of wind measurement, wind profiles, wind field modeling with mesoscale models, wind power forecasting and shadowing effects and increasing turbulence in wind parks. 15 members of vIEM and WISENT joined the workshop on Parallelising and Grid Technologies in November 2006, covering subjects such as parallel programming, parallelisation with grid technologies and introduction and experiences with Condor software.

Beside these recurring activities vIEM will contribute to a beginning activity aiming at the creation of a graduate school. This will deepen the joined mentoring of PhD students.

Current diploma and PhD theses:

Yvonne Scholz, Development of a GIS-based, high temporal and spatial resolution model for optimising the integration of renewable energies into the European electricity- and heat supply. PhD thesis, Univ. Stuttgart/DLR

Hanne Breitkreuz, Irradiance forecasts based on chemical transport models. PhD thesis, Univ. Würzburg/DLR

Klemen Zaksek, Air temperature based on satellite retrievals for energy and traffic applications. PhD thesis, Slovenian Academy of Science/Univ. Ljubljana/DLR

Susanne Bernhardt, Earth Observation and adaptation strategies to climate change in the energy sector. Diploma thesis, Univ. Göttingen/DLR

Georg Wirth, Snow covered photovoltaic systems. Diploma thesis, FH München/ DLR

Johannes Hurka, Improvement of solar irradiation forecast by statistical post-processing. PhD thesis, Univ. Oldenburg

Anja Drews, GIS-based analysis of solar radiation from satellite data and ground measurements. PhD thesis, Univ. Oldenburg

Axel Kemper, Satellite derived diffuse irradiance and cloud effects. Diploma thesis, Univ. Oldenburg

Kay Suselj, Investigation of wind resources over the North Sea in past and future climates. PhD thesis, Univ. Oldenburg

Michael Schmidt, The influence of surface conditions on planetary boundary layer winds in offshore and coastal regions. Diploma thesis, Univ. Oldenburg

Jethro Betcke, Quality control of grid-connected photovoltaic energy systems, PhD thesis. Univ. Utrecht /Univ. Oldenburg

Diego Sanchez, SOLIS Satellite-based Spectral Solar Irradiance for Characterization of Thin Film Photovoltaic Modules, Master thesis, Univ. Oldenburg.

5 COOPERATIONS AND PROJECTS

Members of vIEM are involved in various national, European and international research projects. They work together with other scientific institutions in Greek, Denmark, Italy, France, Norway, Switzerland, The Netherlands, Canada, Spain, and the USA as well as with companies from Switzerland, Italy, Austria, France and Germany. Projects are agreed up until the year 2010.

ENVISOLAR (ESA): ENVISOLAR aims at the increased use of satellite based solar radiation information for the solar energy sector. Improvements of existing services and market trials for new services are in the focus. Solar energy technologies are currently turning from an idealistically driven to a financially driven european market. Therefore, investment assurance and the integration of larger shares of solar energy in the electricity grid are necessary. ENVISOLAR services provide the required support for investment decisions such as site selection and auditing, plant management, load and solar production forecasting and consultancy. The project is led by DLR-DFD and runs from 2004 to 2007. Earth observation providers are besides DLR the Ecole des Mines de Paris and Oldenburg University. Industrial partners are Meteocontrol GmbH (Augsburg, Germany), Enecolo AG (Mönchaltorf, Switzerland), Flyby s.r.l. (Livorno, Italy), Edisun Power AG (Zürich, Switzerland), ENEL (Montorio al Vomano, Italy), Enercity Stadtwerke Hannover AG (Hannover, Germany), SAG Solarstrom Franchisegesellschaft mbH (Freiburg, Germany), Stromaufwärts GmbH (Rankweil, Austria), and Tecsol S.A. (Perpignan, France)

ESA project Space4Energy (ESA): The main objective of this ESA project is to evaluate the contribution of space technologies to the electrical power grid management. Satellite technologies such as earth observation, telecommunications and navigation are used when distributed renewable energy plants are connected to the grid. The project is led by Carlo Gavazzi Space (Milano, Italy), a space engineering industry with expertise in EO, NAV and TLC. Partners are TERNA (Rome, Italy), the German Aerospace Center (DLR), the Greek Center of Renewable Energy Sources (CRES) and the danisch RISOE National Laboratory. This project runs 2006-2007.

Heliosat-3 (EU FP 5): The principle objective of HELIOSAT-3 was to support the solar energy community in its efforts for increasing the efficiency and costeffectiveness of solar energy systems and improving the acceptability of renewables by providing detailed knowledge of the solar resource. HELIOSAT-3 supplied high-quality solar radiation data gained from the exploitation of existing earth observation technologies taking advantage of the enhanced capabilities of the new Meteosat Second Generation (MSG) satellites. The project ran 2001-2005. Oldenburg University was co-ordinator of this project. Partners were DLR, Ecole des mines de Paris, University of Bergen, University of Geneva, Fraunhofer-Institut für Solare Energiesysteme (FhG-ISE), Ecole Nationale des Travaux Publics de l'Etat (ENTPE), Instituto Tecnológico de Canarias, S.A. (ITC), and Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES). (www.heliosat3.de)

PVSAT-2 (EU FP 5): In the project PVSAT-2 an automated performance check for small grid connected PV systems, based on satellite data, was developed. In this project Oldenburg University focused on the development of an enhanced procedure to calculate irradiance from satellite data including accuracy information. The project ran 2002-2005. Oldenburg University was coordiantor of this project. Further research groups involved in the project were University of Utrecht, Fraunhofer-Institut für Solare Energiesysteme (FhG-ISE), and Hochschule Magdeburg-Stendal. Industrial partners were Meteocontrol GmbH (Augsburg), and Enecolo AG (Mönchaltorf, Switzerland). (www.pvsat.com)

MESOR (EU FP 6): Large steps in research have been made for the benefit of renewable energy industry, policy making and the environment. Nevertheless, these multiple efforts have led to a fragmentation and uncoordinated access. The project MESOR aims at improving the management of the solar energy resource knowledge. The project includes activities in user guidance (benchmarking of models and data sets; handbook; best practices) and unification of access to information (use of advanced information technologies; offering one-stop-access to several databases). To that purpose, FH Magdeburg-Stendal, ENTOE, Armines, Icons, CIEMAT, EC JRC, Univ. Navarra, Univ. Oldenburg, Meteocontrol GmbH, Meteotest AG, CUEPE, WRDC and Univ. Presov have teamed. The project is led by DLR-TT and runs 2007 - 2009.

"Solar Resource Knowledge Management" (IEA): The IEA SHC Task 36 "Solar Resource Knowledge Management" is an international programme, which coordinates worldwide activities to develop, improve and standardize methods to derive solar resources. The IEA Task is led by the IEA Solar Heating & Cooling Programme (SHC). As solar resources are important for all solar energy technologies the IEA Task also collaborates with the IEA Programme on Photovoltaic Power Systems (PVPS) and Solar PACES (Solar Power and Chemical Systems). vIEM is contributing mainly to the research part, which is Subtask C "Improved techniques for solar resource characterization and forecasts". Subtask C was led by Richard Meyer from DLR-PA until October 2006, followed by Detlev Heinemann from Oldenburg University. The project runs 2005-2010. Besides Germany, also Austria, Canada, France, the Joint Research Centre of the European commsion (JRC/EU), Spain, Switzerland and USA are contributing to the task.

ANKE: Within the project "Anpassungsstrategien an den Klimawandel in der Energiewirtschaft" (ANKE) DLR-DFD provides consultancy to support the use of remote sensing data for regional climate modelling. Regional climate modelling results are used as a basis for adaptation strategies on climate change for the energy sector. The project took place in 2007 2007. Cooperation partners were the European Institute for Energy Research (EIfER) and Energie Baden-Württemberg (EnBW).

Climagy: In the project Climagy (Adaptation Strategies on Climate Change for the Energy Sector) DLR provides consultancy to build up and strengthen competencies in using remote sensing data and services for adaptation strategies on Climate Change for the Energy Sector. This project was performed in 2006. Project partners are the European Institute for Energy Research (EIfER) and Electricité de France (EdF).

DLR Center of Excellence 'Konzentrierende Solarsysteme': The DLR Center of Excellence 'Concentrating Solar Power' deals with the whole spectrum of concentrating solar power from design and simulation of both components and complete power plants to the testing of systems on the Plataforma Solar in Almeria (Spain). Futher activities are system analysis and market development based e.g. on the satellite-based SOLEMI data base describing the solar resource in Europe and Africa. The Center of Excellence was awarded for the period 2006-2008. It consists of the DLR Institutes for Technical Thermodynamics, for Physics of the Atmosphere and the German Remote Sensing Data Center.

WISENT – Network of Knowledge in Energy Meteorology (BMBF): WISENT's main aim is the establishment of a modern IT infrastructure for collaboration in the distributed research and application community of energy meteorology. This includes adaptation and application of CSCW (Computer Supported Cooperative Work) tools to the special requirements of the community, as well as adaptation and application of distributed computing technologies (e.g. grid technologies) in order to exploit the data storage and compute ressources already available at the partners' locations to satisfy the strong computing needs. (http://wisent.d-grid.de). The joint project WISENT is funded by the German Federal Ministry of Research and Education (BMBF) and runs from October 2005 until September 2008. Partners are all vIEM, members, the computing science institute OFFIS (Oldenburg) and the industrial partner meteocontrol GmbH (Augsburg).

6 PUBLICATIONS

Members of vIEM are presenting their results to scientific audiencies and to the general public. Several members of the Virtual Institute act as reviewers for internationals journals. The first workshop dedicated to Energy Meteorology has been held in Berlin. All relevant publications and activities are listed below.

Peer reviewed journal papers

Breitkreuz, H., Schroedter-Homscheidt, M., Holzer-Popp, T. (2007): A Case Study to Prepare for the Utilization of Aerosol Forecasts in Solar Energy Industries. Solar Energy, in print.

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Public Outreach Activities

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Workshop on Energy Meteorology

A prominent workshop on Energy Meteorology was organized by vIEM in November 2006 in Berlin. About 60 guests from industry, science, politics and the media took the chance to learn about weather conditions and energy production. It was the first of its kind, specifically adressing industry and politics. Key notes were given by Joachim Luther (Fraunhofer-ISE) und Erik Lundtang Peterson (Risø), speakers from vIEM and from other research institutions followed (ISET in Kassel, University of Applied Science Magdeburg), as well as from industry (RWE Transportnetz Strom GmbH und meteocontrol GmbH). The workshop aimed to raise awareness about the relatively new research field of „Energy Meteorology“. The workshop showed a wide range of existing applications of energy meteorology as well as many open questions which need further research.

7 ORGANISATION AND MEMBERS OF STAFF

The Virtual Institute of Energy Meteorology is a group of several research institutions in Germany. A range of various interdisciplinary scientists contribute to the results. Currently, 30 people are involved in work related to vIEM, which is represented by the speaker Dr. Detlev Heinemann (Oldenburg University) and the deputy speaker Carsten Hoyer (DLR-TT). Both speakers are members of the Executive Board consisting of leading vIEM scientists. The Executive Board continually accompanies ongoing research projects and develops future projects. Recommendations on new directions for future research and development of vIEM are provided by the advisory board. Members of vIEM are all scientists within the partner institutions which are working in vIEM's research fields.

Member institutions of vIEM are:
Energy and Semiconductor Research Laboratory,
Institute of Physics, Oldenburg University
Institute of Atmospheric Physics,
DLR Oberpfaffenhofen (DLR IPA)
German Remote Sensing Data Center,
DLR Oberpfaffenhofen (DLR DFD)
Institute of Technical Thermodynamics,
DLR Oberpfaffenhofen (DLR TT)

Organisational structure of the vIEM
Members of the Executive Board of vIEM are:
Dr. Detlev Heinemann (Speaker), Oldenburg University
Carsten Hoyer (Vice Speaker), Oldenburg University
Dr. Annette Hammer, Oldenburg University
Dr. Elke Lorenz, Oldenburg University
Dr. Richard Meyer DLR-IPA (until10/2006)
Dr. Bernhard Mayer, DLR-IPA (since 11/2006)
Marion Schroedter-Homscheidt, DLR-DFD

The following scientists, students and technicians were members of vIEM during the reporting period:
Susanne Bernhardt, DLR-DFD and Göttingen University, geographer
Jethro Betcke, Oldenburg University, physicist
Dr. Lüder von Bremen, Oldenburg University, meteorologist
Hanne Breitkreuz, DLR-DFD and Würzburg University, geographer
Dr. Luca Bugliaro, DLR-IPA, physicist
Anja Drews, Oldenburg University, geographer
Ehlert Engel, Univ. Oldenburg University, physicist
Thilo Erbertseder, DLR-DFD, geographer
Dr. Marco Girodo, Univ. Oldenburg University, physicist
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Dr. Detlev Heinemann, Oldenburg University, meteorologist
Susanne Heinicke, Oldenburg University, physicist
Carsten Hoyer-Klick, DLR-TT, physicist
Tanja Kaminiski, Oldenburg University, environmental scientist
Axel Kemper, Oldenburg University, cand. student of physics
Michael Krug, DLR-IPA: internship, cand. student of physics
Stefan Kronshage, DLR-TT, scientist
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Dr. Richard Meyer, DLR-IPA, geographer and meteorologist
Dr. Sibylle Petrak, Oldenburg University, physicist
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Dr. Thomas Scheidsteger, Oldenburg University, physicist
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Dr. Franz Trieb, DLR-TT, mechanical engineer
Dr. Klaus Wisskirchen, DLR-DFD, meteorologist
Dr. Tobias Zinner, DLR-IPA, meteorologist

The Advisory Board of vIEM comprises the following scientists:
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Prof. Dr. Ulrich Schumann, director of DLR-IPA
PD Dr. Michael Bittner, head of DLR-DFD, Climate and Atmospheric Products section
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Prof. Dr. Joachim Peinke, Oldenburg University, head of Hydrodynamics and Wind Energy Group
Prof. Dr. Joachim Luther, em. director of Fraunhofer-ISE, Freiburg

Members of vIEM are represented in
ISES International Solar Energy Society
„Young ISES" Young members of ISES
Deutsche Meteorologische Gesellschaft
Global Earth Observation System of Systems (GEOSS) User Interface Committee
GEOSS Energy Community of Practise
FVS (ForschungsVerbund Sonnenenergie)
BWE (Bundesverband Windenergie)
EUREC (European Renewable Energy Centres Agency)
EAWE (The European Academy of Wind Energy)

The work of several members of vIEM was acknowledged with the following awards:
The Solar Research Division of DLR has been awarded as a „Center of Excellence" within DLR. vIEM has been contributing to the work which has been awarded.
The Deutsche Solarpreis was granted to Oldenburg University for its Postgraduate Programme Renewable Energy (PPRE). Energy Meteorology is an important part of the curriculum. 30 international students join the course every year.
Hanne Breitkreuz from DLR-DFD won the fourth prize of the Shell She-Study Awards 2005 with her diploma thesis on „Einfluss atmosphärischer Partikel auf das solare Strahlungsangebot in Europa"
Anja Drews from Oldenburg University together with H.G. Beyer and U. Rindelhardt won the Poster Award at the 21th European Photovoltaic Solar Energy Conference in September 2006 in Dresden for their poster on „Irradiance Maps Applied for the Performance Assessment of PV-Systems. A Case Study for the German Federal State of Saxony".

Members of vIEM act as reviewers for internationals journals such as
Annales Geophysicae
Applied Optics
Atmospheric Chemistry and Physics
Environmental Research Letters
Geophysical Research Letters
IEEE Geoscience and Remote Sensing Letters
Journal of Applied Meteorology
Journal of Atmospheric Chemistry
Journal of Geophysical Research
Metrologia
Optical Engineering
Quarterly Journal of the Royal Meteorological Society
Solar Energy
Zeitschrift für Meteorologie

Members of vIEM at an assembly at Oldenburg University.

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