Solar Technical Specifications

Definitions and methodology of your solar product

0 Introduction

0.1 Company

meteoblue is a Swiss specialist company producing high precision weather data for the entire world, using observation data, high-resolution Numerical Weather Predictions (NWP) and specialised data output methods adapted to the needs of different user groups. Based on these simulations, meteoblue produces solar radiation forecast and data validation services.

meteoblue produces weather data since 2007, and produces the largest daily available data volume of any private EU weather service. The available weather archives cover 30 years in maximum detail which is important for any verification purposes. Quality verification results are shown on:

https://content.meteoblue.com/en/verified-quality/verification.

0.2 Distribution

meteoblue offers products, services and project resources to clients worldwide.

For representation in certain countries or market segments, meteoblue works with selected distributors, who represent, sell and service meteoblue products, services and /or project resources.

meteoblue offers datafeeds specifically designed for the needs of solar power generators, electricity traders, grid or building management. More information is provided in the documents:This document contains the specifications for radiation simulations and comparative measurements, and for related services.

More product information is provided in the documents:

>>meteoblue_Solar_Controlled_Quality_EN.pdf<<

>> meteoblue_Solar_Forecast_Pricing+Ordering_EN.pdf<<

>> meteoblue_Solar_History_Pricing+Ordering_EN.pdf<<

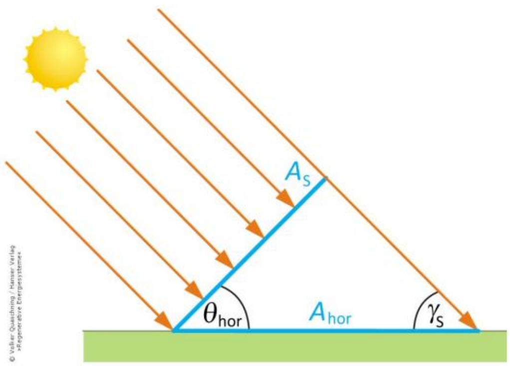

Fig. 0.1: Schematic diagram for solar radiation on horizontal and on tilted plane (Bührer, 2010).

1 Definitions

1.1 Radiation

Solar radiation in this document is defined as the amount of energy reaching the Earth surface, and measured in Watt per square meter (W/m^2). It contains several wavelengths and it reaches the Top of the Atmosphere (ToA) as "Extra-Terrestrial" radiation (ExRAD) and the ground as Global Horizontal Irradiation (GHI). It can be divided into Direct (Beam) and Diffuse radiation (DIF). Beside this radiation measures on horizontal surfaces, meteoblue offers parameters on inclined or normal (to sun angle) surfaces like Global Tilted Irradiation (GTI), Global Normal Irrradiation (GNI) and Direct Normal Irradiation (DNI).

1.2 Power

Power in this document is defined as the electricity output of a given device, at a specified point of measure (PoM) in kilo-Watt hours (kWh).

1.3 Angles

For the projection on tilted surfaces the exposition of the plane and the position of the sun need to be defined by two angles:

- Slope angle / Sun height (0°=horizontal - 90°=vertical)
- Orientation angle / Solar azimuth (0°=facing north, 90°=E, 180°=S, 270°=W)

Angles of incidence are measured relative to the Earth's surface. A slope Angle of 0° is parallel to the surface, 90° is perpendicular to the surface. Orientation Angles are measured from facing North (0°) clockwise. Angles measurements are used for position of the sun, inclination of a solar collector (Photovoltaic system), or a measurement device.

1.4 Horizon

Often the horizon is not flat but elevated because ground surface is complex or obstacles are in the sight. This can affect the sunshine intensity and thus the typical daily curves. The exact definition of the horizon is used to optimize simulation accuracy. The horizon is defined with 12 numbers that turn clockwise (compare orientation angle) from North 0° and its value defines the horizon height in degrees (from 0°-60°):

- horizon= [N,NNE,NEE,E,ESE,SSE,S,SSW,SWW,W,WNW,NNW)
- e.g. horizon=[0,0,0,0,20,30,40,30,20,0,0,0]

1.5 Position

Position is defined by the geographic location (coordinate) and the elevation (altitude) of the point considered, be on the surface or in the atmosphere.

Coordinates are latitude (North, South) and longitude (East, West) given in degrees and decimals. Formats are:

- Latitude: from -90.0000° (South) to 90.0000° (North);
- Longitude: from -180.0000° (West) to 180.0000° (East);

Altitude is defined in meters above sea level (m.asl).

More information is available under: https://content.meteoblue.com/en/help/standards/position

1.6 Data API

Data API is an Application Programming Interface, which enables access to a defined datafeed in a regular automated way.

1.7 Datafeed

Datafeed is a determined set of parameters available through an API in a regular automated format.

1.8 Parameters

Parameter is a measurable factor that helps in defining a particular system. It is standardised and varies over time, during the course of observation . Radiation, cloud cover, humidity, wind, and others are weather related parameters to define relevant physical information.

1.9 Time Stamps

Accurate time stamps are essential for correct measurement and forecast of radiation.

Parameter values are usually displayed in UTC (Coordinated Universal Time). Local time is used if required by specification, and if precise conversion tables from local into UTC are available. Information on conversion of UTC in local time can be found under www.timeanddate.com//worldclock/.

Local forecasts are adjusted to the local time zone using the selected place or location. In some cases, local timezone management and switches of standard to summer time may lead to inaccuracies of +/-1 hour (see also timezone explanation under http://en.wikipedia.org/wiki/Timezone).

1.10 Time Stamps: Important Notice

Radiation observations might be instantaneous values (inaccurate) or averages over a certain time period (**interval**). If the observations are averages, it is **very** important to know if the 10:00 value represents a previous average from 9:00 to 10:00, a centred average (from 9:30 – 10:30) or a forward average (from 10:00-11:00). Also note that depending on the datafeed type, the time might be in UTC or in local time. The feed header will indicate the time offset to UTC.

1.11 Time Averaging

There is two common methods of time averaging:

- Backward Averaging: time stamp represents preceding time range

  In hourly resolution 12:00 represents 11:00-11:59. The standard time convention of meteoblue archive data is: **Hourly Backward Averages in UTC**
- Instantaneous Averaging: timestamp represents time range before and after the time stamp; values are better to be compared with instantaneous observations then Backward Averages.

  In hourly resolution 12:00 represents 11:30-12:29. The standard time convention of meteoblue radiation datafeed provides both conventions so the data can be compared either with the archived data or instant measurement values.

1.12 meteoblue Datafeeds: Timestamps

All solar radiation and power forecasts are average values centred on the indicated time. Thus: the 11:00 value represents the mean value observed between 10:30 and 11:30 if the time resolution of the feed is one hour (dt=1), or the mean value between 10:55 and 11:05 if the time resolution is 10-minutes (dt=0.166666). This centred averages allow to directly compare meteoblue forecast values with instantaneous values valid at the time indicated. Note, that for dt=0.5 or smaller, the forecast time steps between the full hour will be interpolated, and therefore have no higher accuracy than the orginal hourly resolution.

1.13 meteoblue Archives: Timestamps

The meteoblue radiation archive data are accumulated values of the previous hour. Thus: the 11:00 value represents the average value observed between 10:00 and 11:00. This form is used to make radiation archives consistent with the principle that measurements can be taken only after the conclusion (end) of the measurement period. All archive time stamps refer to UTC.

1.14 Customer Observation Data: Timestamps

For observation data provided by our customer the same time convention than for meteoblue archives are valid, as statistical post processing routines are trained on our archive data. If possible all observation data should be provided in as hourly backward averages with UTC time stamp. Inconsistent time stamps and temporal offsets will be detected by our QC routines.

2 Solar position

2.1 Definitions

Solar position changes as a function of the Earth rotation and orbit around the sun, relative to the Earth surface and (measurement) modules, and is described by the following parameters (see Fig. 2.1):

Symbol	Description	Unit
rlt	real local time.	hh:mm:ss
UTC	Universal time convention	hh:mm:ss
α_E	Azimuth of (measurement) module.	°
α_S	Solar azimuth	°
δ_S	Solar declination	° (Geographical Coordinate)
Φ_T	Inclination of the Earth axis (relative to the sun)	°
Θ_{gen}	Incidence angle on (measurement) module	°
n	Normal vector of (measurement) module.	n.a.
Y_E	Inclination of (measurement) module.	°
$Y_{S(t)}$	Sun height (at a particular time)	°
$Y_{Z(t)}$	Zenith angle of the Sun (90°-$Y_{S(t)}$)	°

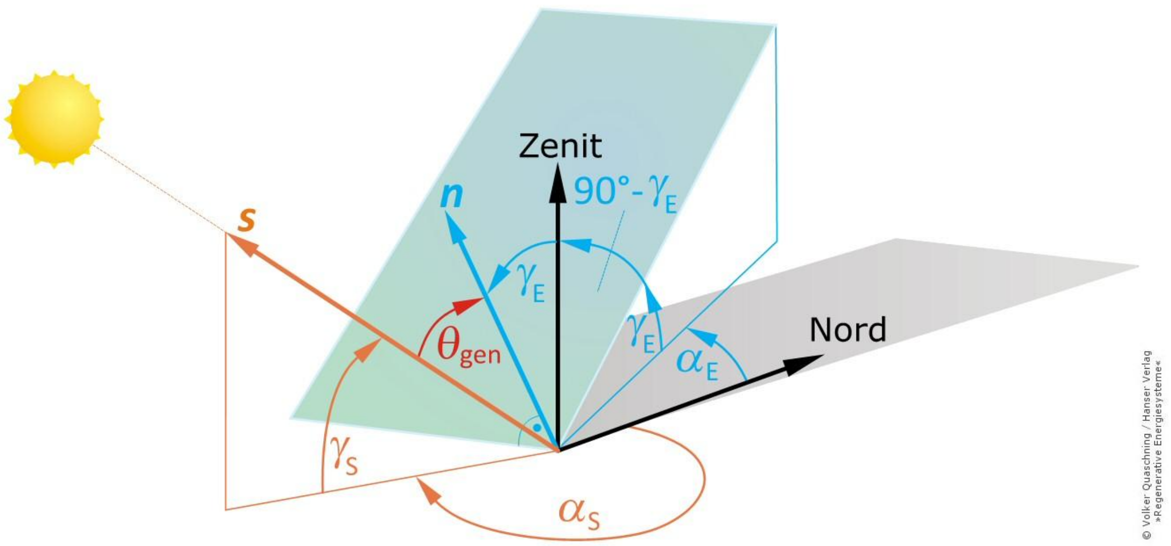

Fig. 2.1: Definitions for solar position (QUASCHNING 2009 in Bührer, 2010).

2.2 Sun height or Solar angle

The sun height or Solar angle $Y_{S(t)}$ is defined as the angle between the horizon and the sun position at a specific point of time. Examples:

- At sunrise, the **Sun height** is 0° on a flat surface (like the sea). The sun position is exactly parallel to the Earth Surface.
- At equinox noontime, the **Sun height** is 90°. The sun position is exactly vertical to the Earth Surface.

2.3 Sun zenith angle

Zenith angle of the Sun $Y_{Z(t)}$ is defined as (90°-$Y_{S(t)}$) at perfect noontime (in “real local time”). Examples:

- At sunrise on the sea, the **zenith angle** is 90-0 = 90°. The sun position is parallel to the Earth Surface.
- At equinox noontime, the **zenith angle** is 90-90 = 0°. The sun position is vertical to the Earth Surface.

2.4 Sun azimuth

meteoblue defines Solar clockwise from North. Thus North is 0°, East 90°, South 180° and West 270°. Examples:

- At astronomical (perfect) noontime, **azimuth** is always 180° North of the tropic of Cancer.
- At astronomical (perfect) noontime, **azimuth** is always 0° South of the tropic of Capricorn.
- On the equator, sunrise during equinox occurs with **azimuth** of 90° and sunset with 270°.

To calculate the local sun azimuth in UTC, the correction from “real local time” to UTC has to be made. Some systems use South as the reference (0°), with Eastern azimuths being positive (1 to 180°) and Western azimuths being negative (-1 to -180°). Also used is a convention that defines the azimuth as the difference from the noontime azimuth (0°). If such a system is used, the degrees provided have to be converted accordingly.

2.5 Solar declination

The Solar declination is the geographical latitude, in which the sun reaches the 90° Zenit on a given day. Solar declination can therefore vary between 23°(North) and -23° (South).
At the beginning of spring and fall (Solar equinox), the sun declination is zero (latitude 0° = equator), since the sun is placed exactly over the equator (STULL 2000) and changes as a function of the Earth rotation and transladation around the sun.

Formula for calculation of solar declination: $\delta = \phi_r \cdot \cos\left[\frac{360°\cdot(d_y - d_r)}{365}\right].$

Usually, Solar declination is used for calculations of the sun position during the year, to describe the changes in highest angle between days.

2.6 Performance ratio (PR)

The performance ratio describes the efficiency of a power plant. It is calculated with the quotient of the effective efficiency and the theoretical efficiency of a power plant:

$$SP = \frac{\eta_{prakt}}{\eta_{MPP}}$$

The performance ratio varies significantly within different weather conditions. meteoblue solar forecast simulates the PR dynamically for crystalline modules including:

- Module Temperature based on ambient temperature, wind speed and radiation
- Spectral sensitivity
- Reflection losses on the module surface

The sensitivity of non-crystalline modules to spectral composition and module temperature can differ from the applied algorithms. To implement their behaviour in your forecast meteoblue recommends statistical optimization (MOS).
The default mean PR is 85 % but can also be adjusted using a specific keyword.

2.7 Snow Cover

Losses due to snow cover can be implemented in the forecast with a specific keyword. The PVpro feed contains snow cover and therefore allows the customer to adjust the forecast himself. Snow cover can be erroneous in mountainous regions.

3 Solar radiation

3.1 Definition

Solar radiation in this document is defined as the amount of energy reaching the Earth surface, and measured in Watt per square meter (W/m^2). Maximum radiation intensity reaching the Earth atmosphere is the extraterrestrial Solar constant of 1368 W/m^2 (1321 to 1413 W/m^2 depending on distance of the Earth to the sun). Technically, it is also referred to as GHI = Global Horizontal Irradiance (see 1.3).

3.2 Parameterisation

Solar radiation is measured on horizontal surfaces by the following parameters.

- GHI = Global Horizontal Irradiance (total short-wave radiation energy received).
- DIF = Diffuse Horizontal Irradiance (model acc. to Reindl).
- DIR = Direct Irradiance = GHI-DIF

Projections on normal surfaces (perpendicular to the sun) are defined as

- GNI = Global Normal Irradiation: Global irradiance on normal surfaces (tracking the sun);
- DNI = Direct Normal Irradiance: Direct irradiance on normal surfaces (tracking the sun), of interest mainly for solar thermal and concentrated Photovoltaic power generation.

Therefore, DNI can be (much) larger than GHI, if the Sun height (at a particular time) is low (see 2.1.), because the same area of horizontal surface receives only a fraction of the sunlight, compared to a normal surface.

Top-of-Atmosphere (ToA) or Extra-Terrestrial (ExRAD) radiation can be calculated from the solar constant (section) and the Solar position (section Time Averaging.). The resulting curves are free of any interference by atmosphere factors and can therefore be used for calibration purposes and quality control.

3.3 Measurement

Solar radiation is measured using pyranometers (see Fig. 3.1), except DNI which is measured with a pyrheliometer. Measurements are given either in W/m^2 for a particular time, or as the average W/m^2 for the preceding time interval. Measurement is a very sensitive process, since the intensity is affected by several processes:

- Solar angle: energy incidence changes with the height (“angle”) and direction (“azimuth”) of the sun (see 1.3. and 2.1.).
- Inclination of measurement device towards the sun: typically, measurements are made in horizontal position. “Normal” measurements are always oriented towards the sun.
- Time interval: radiation can change rapidly within seconds, so the interval and integration of individual measurements has an influence on the result;
- Air pollution: turbidity and aerosols influence the amount of energy reaching the surface;
- Instrument pollution: Particle and aerosol deposits may reduce instrument sensitivity;
- Instrument age: deterioration of instrument components may change sensitivity.

In summary, radiation measurements are amongst the most difficult to calibrate amongst all meteorological parameters and the quality of measurement data usually varies substantially.

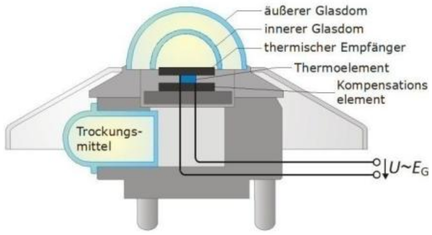

Fig. 3.1: Schematic Design of Pyranometer (QUASCHNING 2009 in Bührer, 2010).

4 Simulation methods

4.1 NEMS and NMM modelling.

The model has been adapted to mesoscale, and calibrated for various parameters since 2004. The process is described in several publications (see Janjic 2003)

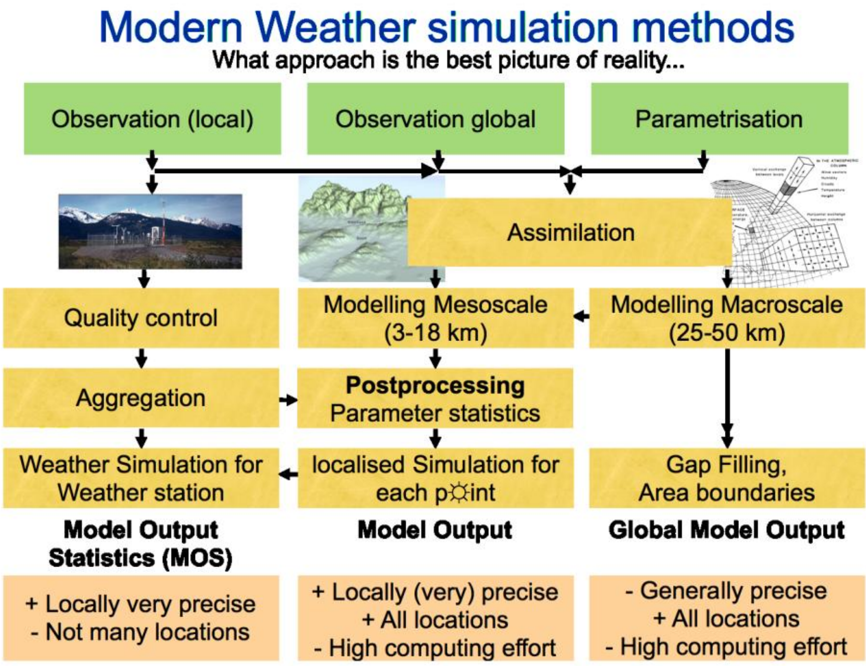

Fig. 4.1: NEMS and NMM Modelling and calibration procedure.

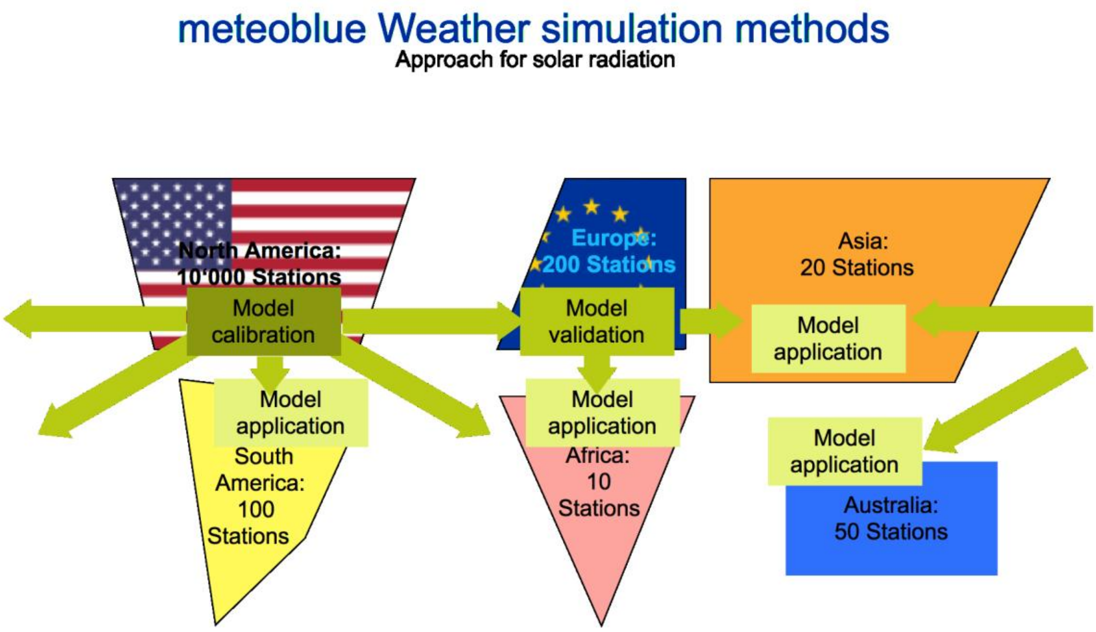

Fig. 4.2: NEMS and NMM Radiation forecast calibration procedure .

4.2 Satellite monitoring

For real-time monitoring, satellite observations are used. The resolution of available imagery varies by region. At the current state of development in 2016 real time matching with satellite observation was implemented for the area of the MSG (Meteosat Second Generation). For more information see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Satellite images must be converted into radiation through appropriate clear-sky functions and calibrated conversion processes and show different errors for different locations (see Fig. 4.3).

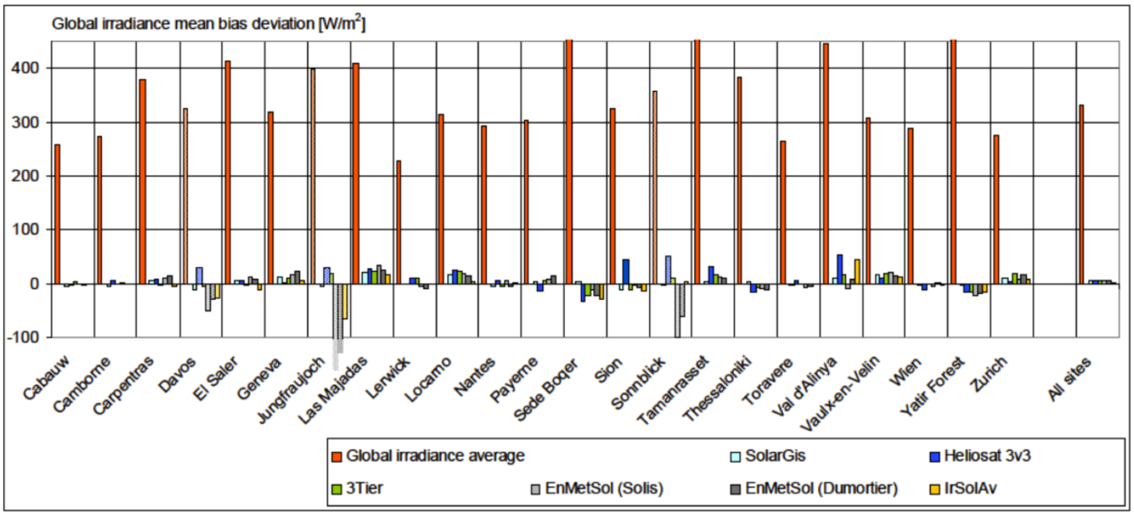

Fig. 4.3: Average global radiation and absolute mean bias difference of 5 satellite radiation simulations compared to surface measurements (Ineichen, 2011).

4.3 Modelling comparisons

A comparison of different methods is shown in Fig. 4.4.

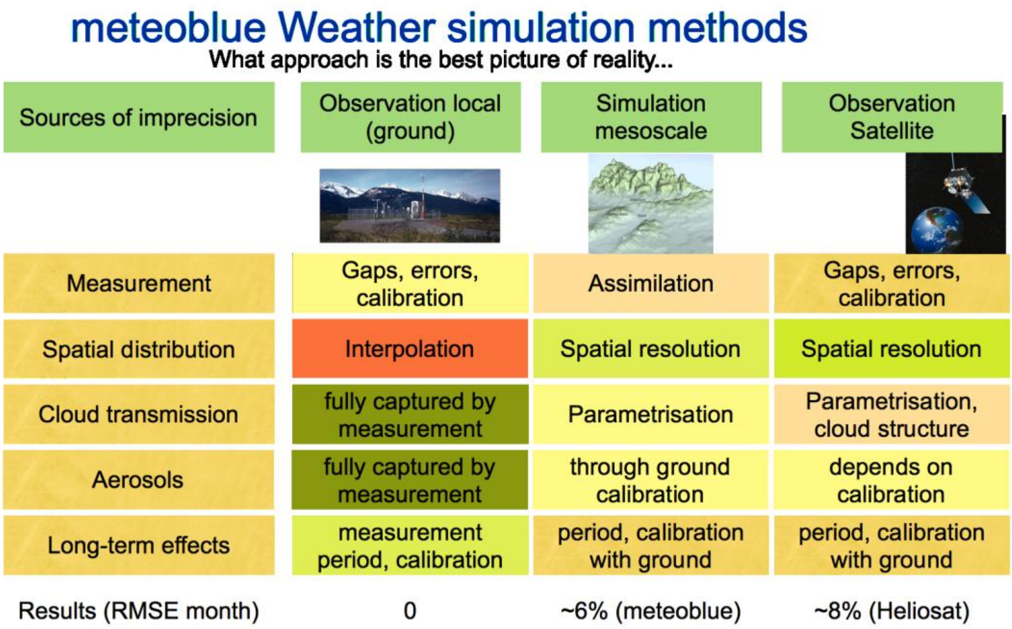

Fig. 4.4: Method comparison for Radiation forecast application to large areas. Green: low source of errors, red: large sources of error.

5 Applications

5.1 General

Radiation simulations and measurement serve to assess the influence of the sun on the weather, Earth surface, vegetation, buildings, as well as on other human activity. There is a very wide range of application like:

- Site search and assessment
- System layout
- Long term yield prospection
- System failure detection
- Measurement quality controlling
- Real time monitoring
- Electricity balancing and trading
- Operational Management

5.2 Energy generation

Beside different radiation forecast and parameterisations, meteoblue offers electricity forecast for single Photovoltaic systems and for system aggregations in a defined grid area. These forecasts are based on the same algorithms, using projection on fix inclined surfaces. Diffuse and direct radiation shares are used to calculate the radiation on a specified module surface. Based on position, system size (kWp) and sun exposition, the electricity output is modelled. For further information, on electricity forecasts check the specific product documentation.

5.3 Other

Testing in other applications is recommended. ExRAD can be used for calibration of radiation and power measurements, especially to detect time shifts, system configuration differences and calibration problems.

5.4 Reference system

For radiation measurements, the following reference systems are recommended:

1. Extra-terrestrial radiation: available worldwide, minimal error source (but not at surface);
2. Surface measurements: these are most accurate, but seldom available and subject to large methodical errors.
3. Satellite observations: widely available, but need constant calibration. They are used for real time correction and for short-range forecasting up to 5 hours.
4. Other forecasts: these may be available, but are not always consistent with reality. They may be needed to calculate probabilities;
5. Other reference systems, such as heating consumption, PV power production. However problems with data collection , normalization and consistency are substantial.

In summary, a forecast can only be validated if it is compared to a valid reference system.

5.5 Improvements

If a valid reference system exists, simulation and forecast can be improved using statistical post-processing methods like MOS (model output statistics) or neural networking techniques (more speculative). Such improvement are only applied on hourly resolution data. As at least one year of quality controlled measurement data is necessary, such post-processing is only applied for high value projects.

6 Process of application

6.1 Data archive

Meteoblue data is available in hourly resolution since 1986 with an availability of 100 %. The coverage is worldwide with a spatial resolution 3-25 km. Based on this enormous meteorological database meteoblue offers beside its raw data various data aggregations, tools, images report customized for different applications.

6.2 Applications for climatic assessment

For site search and assessment maps and long term time series of data are used:

6.2.1 Maps

Maps of mean annual GHI sums are useful to find the optimum location. Variability maps help to find optimized operation strategies (see Fig. 6.1). Other maps can be customized on request.

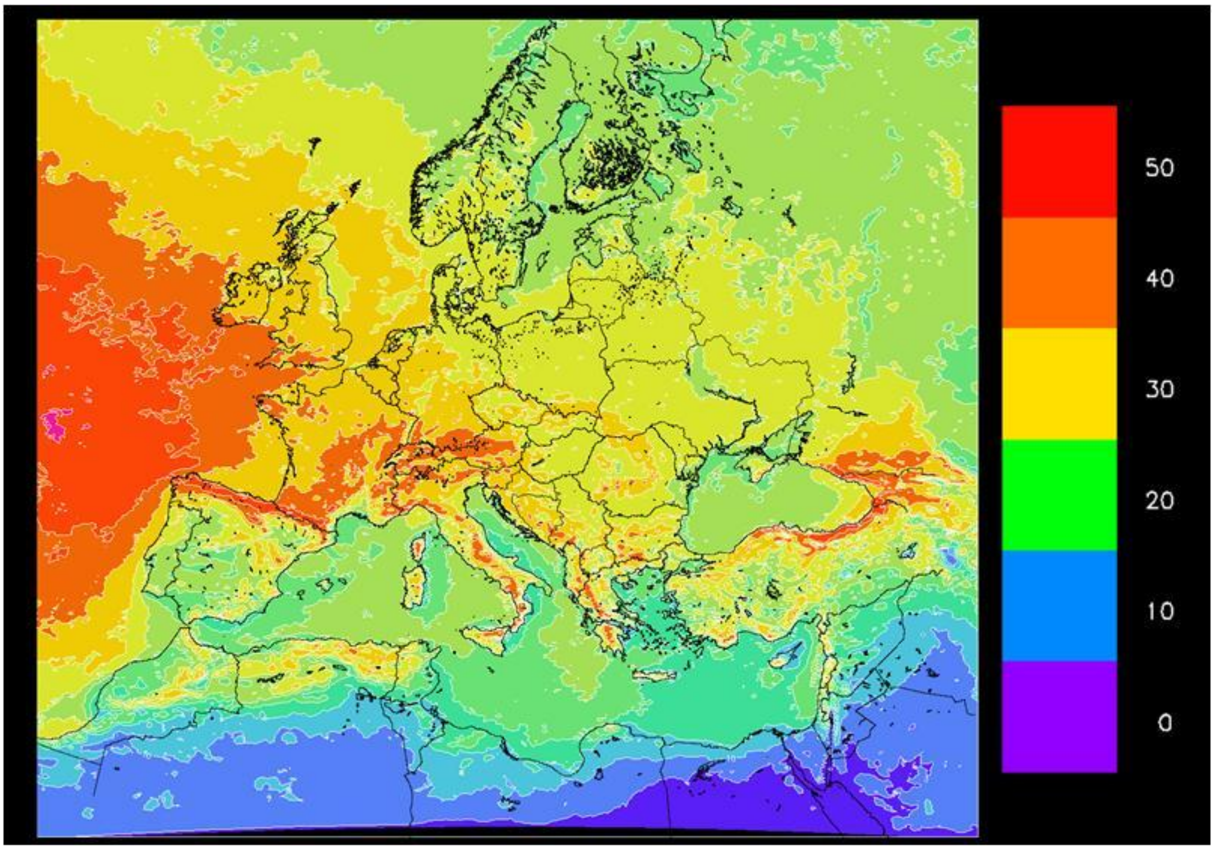

Fig. 6.1: Variability map of Europe. The colors vary from deep blue (0-5) to pink (50-55). The values represent the number of days with weather changes in percent.

6.2.2 TMY (Typical Meteorological Year)

A TMY is a hourly dataset that contains one year with 8760 data values which is considered as typical for the specific location. Based on a long term time series (10, 20 or 30 years) cumulative distribution function of each month are calculated. With the so called SANDIA method the 12 typical months with minimal Finkelstein-Schäfer distance are chosen and merged to the TMY.

6.2.3 Aggregated time series

meteoblue offers daily and monthly data aggregations of radiation parameters and reference yield simulations. As all aggregation are based on hourly data variability information like standard deviation, confidence intervals or min-max values can also be delivered. An example of a monthly aggregated TMY of PV reference yield simulation is the Meteogram solPVsimple (see chapter 8.5).

6.2.4 Solar report - climatology and variability

Based on hourly long term radiation data the variability of irradiation of a certain location is analysed on different time scale (Inter-annual, seasonal and intra-daily variability). The results are visualized with comprehensible graphics and summarized in a report. An example of typical intra-daily profiles is shown in Fig. 6.2:

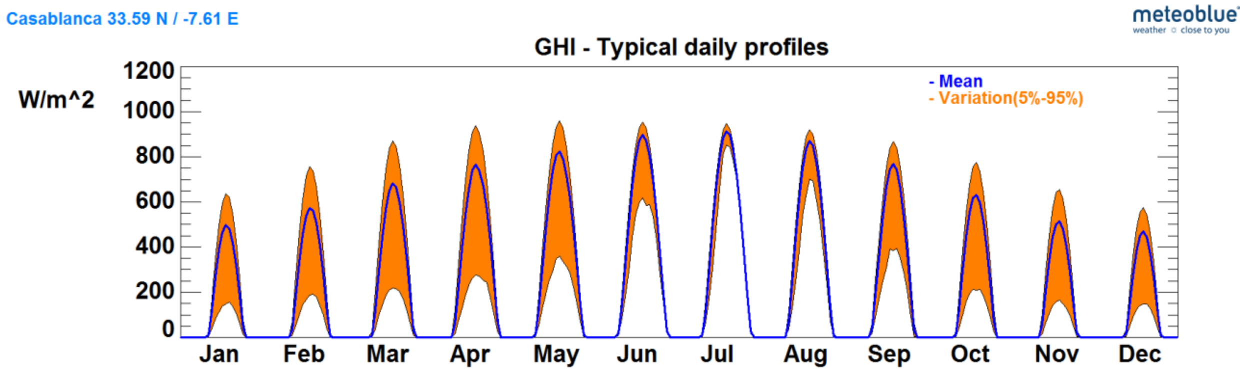

Fig. 6.2: 30 year typical daily profile (blue) and their variation (orange) for GHI in Casablanca, Maroc.

6.3 Time series

6.3.1 Reference data sets

Time series for any specific time range are used as reference to benchmark measurement data, detect system failure or asset power plant production. Furthermore comparison of PV production data and simulations are helpful to calibrate forecast services and for validation purposes.

6.3.2 Solar report - Quality control

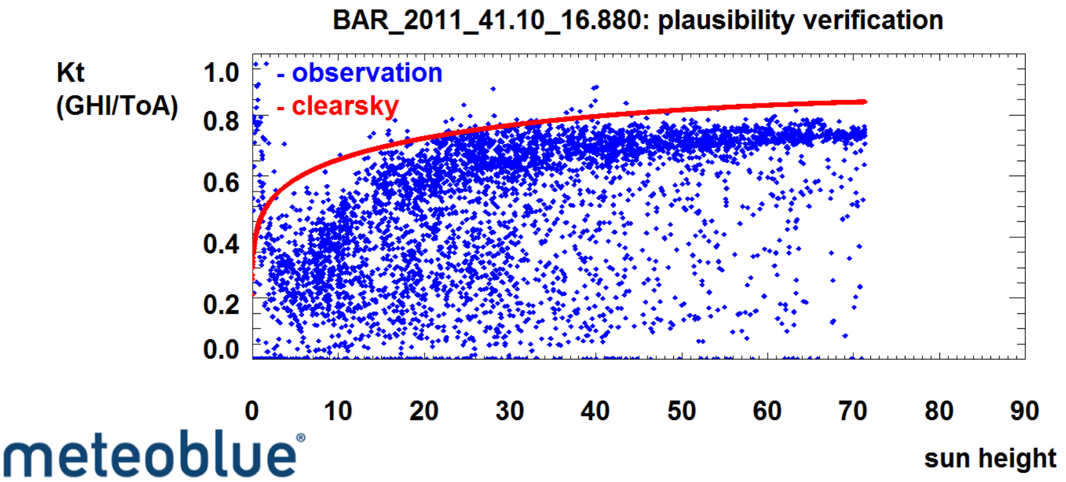

Fig. 6.3: Plausibility verification of measurement data from Bari, Italy.

Based on reference systems meteoblue offer quality controlling of radiation and PV production data. These reports help to optimize measurement layout and find errors of temporal allocation and data irregularities. Quality controlling is inevitable, when measurement are used for post processing purposes.

6.3.3 Solar report - Model validation

A validation report compares simulation data to on site measurement. It supports your system operation and power management decision with forecast accuracy assessments. Every Validation Report contains:

- Monthly graphic comparison detects seasonal malfunction of your system or microclimatic forecast mismatch (see Fig. 6.4).
- Daily analysis show every day forecast performance and system outages while the intraday graphics can detect time of day shadings.
- Precision of forecast and possible measures for improvement.

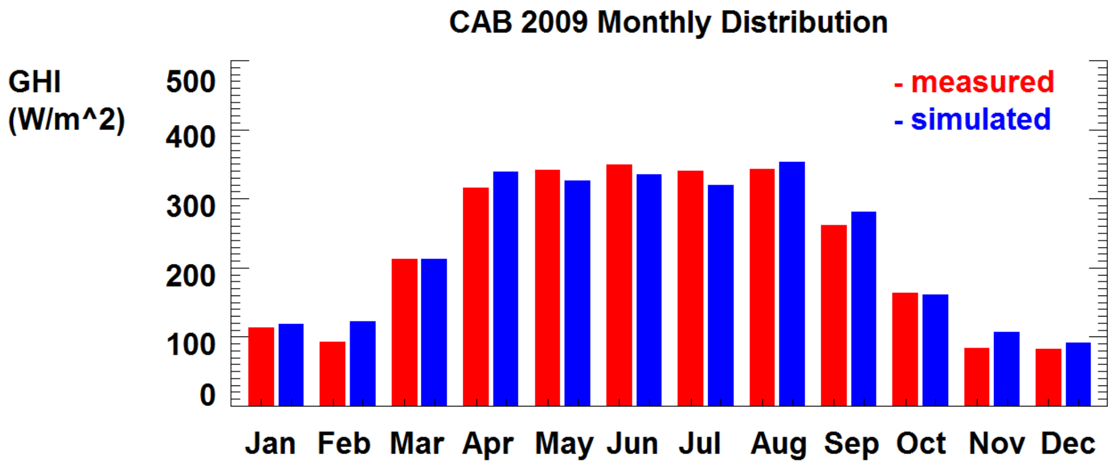

Fig. 6.4: Graphical comparison of monthly GHI sums in 2009 in Cabauw, Netherlands.

6.4 Real time monitoring

The nowcasting function of all solar APIs offers an excellent reference for real time monitoring of measurement instrument or power plant production. As the delay of satellite data availability is not constant it is recommended to retrieve monitoring data once a day 2 hours after sunset. Then the API contains satellite observation for the past day and forecast values for the next days.

6.5 Forecast

The Intraday and Day Ahead forecast of the solar forecast API is offered worldwide. It contains various parameters in customized time resolution for current day to 6 days ahead. It is used for many applications like:

- Electricity Trading
- Grid Management
- Maintenance scheduling
- Reporting to grid operator
- Optimisation of own consumption
- Building management
- Heating and Cooling control

For more information read chapter 8.

7 Statistical post processing

7.1 General

Radiation and power forecasts can be optimized by using statistical post-processing algorithms. The improvement of the forecast is depending on several site specific conditions. In average an improvement of 10% (range of MAE: 5%-25%) is realistic. To assure the functionality of the post-processing algorithms a Quality-Control report of the measurement data is obligatory. Furthermore it is recommended to purchase a Validation report which includes the quality of standard and optimized forecast and a product recommendation. meteoblue recommends the following procedure:

1. Delivery of measurement data in standard format
2. Preparation of QC-Report
3. Preparation of Validation-Report
4. Preparation of API due to product recommendation

7.2 Methodology

meteoblue algorithms use a conditional MOS, which combines a simple neural network with improved meteoblue MOS technology. The algorithms differentiate between multiple sky conditions to find the best fit of linear regression for more than 30 weather parameters. The resulting forecast model is individually designed for the specific site and provides the best possible forecast (state of the art) via a special API set for the specific application and location.

7.3 Input data

It is recommended to provide at least one year of data in hourly time resolution to train the MOS. The data should be provided in a standard format using comma separated files (.csv). Especially designed routines will be applied to detect completeness, time-shift and plausibility of the time series. Apart from radiation and/or production time series, the minimal metadata (header information) have to be supplied.

7.4 Improvements

The value of statistical post processing differs depending on location and input data (measurements). To assess the actual benefit of statistical post processing, we recommend our Validation-Report. Differences in site results are shown in Fig. 7.1.

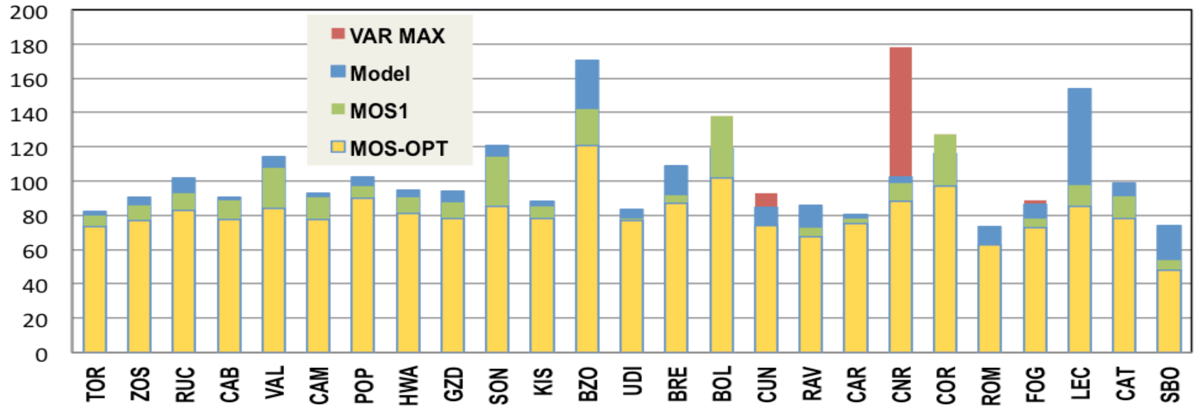

Fig. 7.1: MAE of radiation forecast of raw model (blue), simple MOS (green) worst MOS (red) and optimized MOS (yellow) Vertical axis shows MAE (in W/m^2) of hourly forecast over a full year. Stations sorted from North to South.

8 Solar forecast API

8.1 Description

The meteoblue solar forecast APIs offer a localized PV reference yield forecast based on the radiation forecast of NMM weather models and satellite based nowcasting. It reproduces local radiation development for 144 hours ahead in 1 hour intervals, which can be further refined into 15-10 minute intervals.

The spatial resolution depends on the model coverage. The current status of model coverage is displayed and continuously updated on page:

https://content.meteoblue.com/research-development/data-sources/nmm-modelling/model-domain

The process of solar power forecasting model is determined by a simple algorithm, which includes the capacity of the photovoltaic systems (kWp), the performance ratio (default= 85 %) and the solar irradiance on tilted surfaces. The main modelling procedure is the transformation of global radiation to irradiance on a tilted surface. First, the diffuse fraction of the global radiation must be estimated. If the diffuse and direct fractions of the global radiation are known, they can be projected on inclined module surfaces.

For single locations, the orientation and the inclination angle are needed. Power output is calculated on an hourly basis . It may be downscaled to 15 or 10 Minute intervals.

8.2 Forecast Parameters

The possible forecast parameters and range/intervals are:

- GHI = global horizontal irradiation (W/m^2): 144 h ahead, 24 updates per day.
- GNI = global normal irradiation (W/m^2): 144 h ahead, 24 updates per day.
- DNI = direct normal irradiation (W/m^2): 144 h ahead, 24 updates per day.
- DIF = diffuse irradiation (W/m^2): 144 h ahead, 24 updates per day.
- ExRAD = Extraterrestrial Irradiation (W/m^2): 144 h ahead.
- PVpp = Photovoltaic reference yield (kW): 144 h ahead, 24 updates per day.
- GTI = global tilted irradiation (W/m^2): 144 h ahead, 24 updates per day.
- mT = module temperature (°C): 144 h ahead, 24 updates per day.
- IAM = incidence angle modifier: 144 h ahead, 2 updates per day.
- SC = snow cover (mm) 144 h ahead, 2 updates per day.
- PR = performance ratio 144 h ahead, 24 updates per day.

Other parameters can be supplied on request.

8.3 Expected precision

The NMM (Numerical Mesoscale model) has been adapted to mesoscale, and calibrated for various parameters since 2004. The process is described in several publications (see Janjic 2003). The radiation forecast has been calibrated on 10'000 stations, and validated in 4 other continents Thus the expected precision of the solar forecast is between 10 and 35% rMAE (Relative Mean Absolute Error) on an hourly basis for 2-24 hour forecast, depending on location and year. For detailed quality description see >>meteoblue_Solar_Controlled_Quality_EN.pdf<<

8.4 Meteogram solpoint

Apply: &type=meteogram_solpoint

Special parameters: &params=kWp,facing angle, slope angle.

URL example:

http://my.meteoblue.com/fcgi/dispatch.pl?apikey=xxxxxxxx&mac=visimage&type=meteogram_solpoint&paramtype=imagefeed&lat=47.5582&lon=7.5881&asl=260&tz=Europe_Zurich&city=Basel&params=13.454,180,20

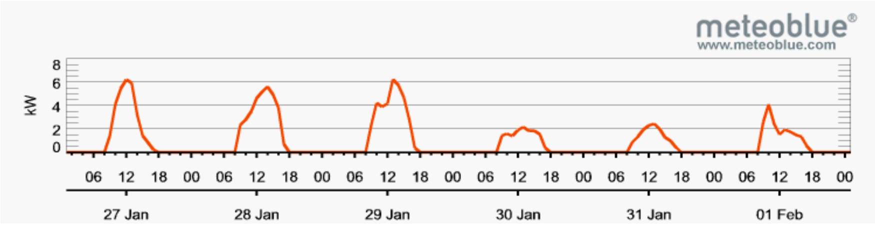

Fig. 8.1: meteoblue API image "meteogram_solpoint"

8.5 Meteogram solar_PVsimple

Apply: &type=solar_PVsimple

Special parameters: &params=kWp,facing angle,slope angle

URL example:

http://my.meteoblue.com/fcgi/dispatch.pl?apikey=xxxxxxx&mac=visimage&type=solar_PVsimple&paramtype=imagefeed&lat=47.5582&lon=7.5881&asl=260&tz=Europe_Zurich&city=Basel&params=100,180,40

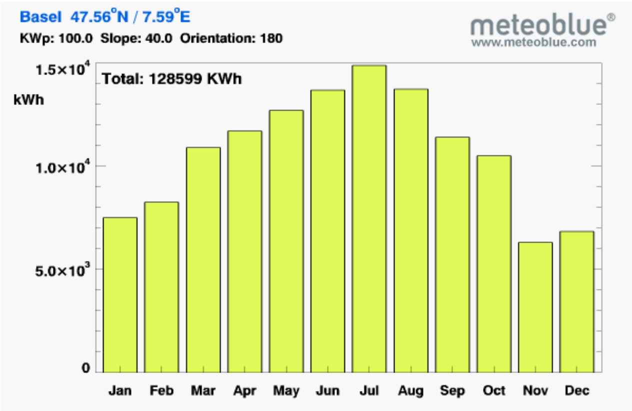

Fig. 8.2: meteoblue API image "solar_PVsimple"

8.6 API data package: Solar

Table 8.1: meteoblue API data package list "solar"

#	Parameter	Unit	Description	Intervals in minutes	Intervals in hours	Daily aggregations
1.	GHI (Solar radiation)	W/m2	Global Horizontal Radiation	5, 10, 15,	1, 24	Total
2.	DIF	W/m2	Diffuse Radiation	5, 10, 15,	1, 24	Total
3.	DNI	W/m2	Direct Normalized Irradiance (Radiation)	5, 10, 15,	1, 24	Total
4.	GNI	W/m2	Global Normalized Irradiance (Radiation)	5, 10, 15,	1, 24	Total
5.	ExRAD	W/m2	Extraterrestrial solar radiation	5, 10, 15,	1, 24	Total

Example API-URL:

http://my.meteoblue.com/packages/solar-1h?name=Basel&lat=47.5584&lon=7.57327&asl=279&tz=Europe%2FZurich&format=csv&apikey= personalAPIkey

Example API output (&format=csv):

```
time,gni_instant,gni_backwards,dni_instant,dni_backwards,dif_instant,dif_backwards,ghi_instant,ghi_backwards,extraterrestrialradiatio
2016-05-12 03:00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2016-05-12 04:00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2016-05-12 05:00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2016-05-12 06:00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2016-05-12 07:00,26.95,23.57,8.07,16.06,27.03,11.62,28.32,13.14,212.36,104.29
2016-05-12 08:00,51.39,39.32,6.68,7.88,62.02,45.88,64.20,47.78,436.40,326.33
2016-05-12 09:00,99.04,71.86,9.42,7.32,113.72,84.79,118.30,87.82,651.77,547.23
2016-05-12 10:00,205.06,144.08,31.97,15.01,198.13,156.18,218.28,164.82,843.81,751.91
2016-05-12 11:00,214.92,233.07,4.75,33.15,237.38,224.62,240.93,247.26,999.45,926.44
2016-05-12 12:00,217.24,205.49,10.84,10.24,225.14,216.42,234.11,224.53,1108.09,1058.95
2016-05-12 13:00,236.87,235.33,11.29,11.98,241.66,240.92,251.46,251.13,1162.36,1140.42
2016-05-12 14:00,213.79,223.92,8.60,9.57,220.28,229.51,227.72,237.84,1158.57,1165.32
2016-05-12 15:00,139.00,185.29,2.77,6.33,149.72,193.86,151.99,199.25,1097.01,1131.97
2016-05-12 16:00,67.16,92.84,1.05,1.09,76.20,102.76,76.97,103.61,981.88,1042.67
2016-05-12 17:00,35.64,53.71,0.72,0.94,43.83,62.91,44.27,63.54,821.06,903.52
2016-05-12 18:00,16.60,22.06,0.50,0.53,23.21,28.69,23.44,28.98,625.51,724.02
2016-05-12 19:00,13.99,16.22,0.76,0.65,23.12,24.41,23.35,24.66,408.59,516.43
2016-05-12 20:00,3.51,8.86,0.89,0.51,11.20,18.08,11.33,18.19,185.09,294.89
```

8.7 API data package: PVpro

Table 8.2: meteoblue API data package parameter list: "pvpro"

#	Parameter	Unit	Description	Intervals in minutes	Intervals in hours	Daily aggregations
1.	PV power	kWh	Photovoltaic power	5, 10, 15,	1, 24	Total
2.	GTI	W/m^2	Global Tilted Irradiance (Radiation)	5, 10, 15,	1, 24	Total
3.	PR	%	Performance ratio	5, 10, 15,	1	Mean
4.	mT	°C	Module temperature	5, 10, 15,	1, 24	Mean
5.	IAM	%	Incidence Angle Modifier	5, 10, 15,	1	Mean
6.	Snow cover	cm	On the PV modules	5, 10, 15,	1, 24	Mean

Special parameters: &params=kWp,facing angle,slope angle

Example API-URL:

http://my.meteoblue.com/packages/pvpro-1h?name=Basel&lat=47.5584&lon=7.57327&asl=279&tz=Europe%2FZurich&format=csv&apikey= personalAPIkey

Example API output ((&format=csv):

```
time,pvpower_backwards,pvpower_instant,gti_backwards,gti_instant,moduletemperature_backwards,moduletemperature_i
2016-05-12 03:00,-999.00,-999.00,0.00,0.00,8.91,8.84,79,0.88,0.00,0.84
2016-05-12 04:00,-999.00,-999.00,0.00,0.00,9.07,9.63,91,0.93,0.00,0.93
2016-05-12 05:00,-999.00,-999.00,0.00,0.00,11.03,12.40,93,0.95,0.00,0.93
2016-05-12 06:00,-999.00,-999.00,0.00,0.00,12.94,13.05,94,0.95,0.00,0.93
2016-05-12 07:00,-999.00,-999.00,23.08,26.85,13.07,13.11,94,0.95,0.00,0.83
2016-05-12 08:00,-999.00,-999.00,37.86,47.99,13.44,13.83,94,0.95,0.00,0.92
2016-05-12 09:00,-999.00,-999.00,64.54,86.34,14.69,15.83,94,0.95,0.00,0.93
2016-05-12 10:00,-999.00,-999.00,121.66,170.81,17.52,19.37,94,0.94,0.00,0.92
2016-05-12 11:00,-999.00,-999.00,187.74,166.92,20.45,20.52,93,0.93,0.00,0.88
2016-05-12 12:00,-999.00,-999.00,155.37,160.95,20.30,20.58,89,0.85,0.00,0.89
2016-05-12 13:00,-999.00,-999.00,171.44,170.48,20.32,19.45,74,0.59,0.00,0.74
2016-05-12 14:00,-999.00,-999.00,160.39,153.14,18.17,16.82,23,0.00,0.00,0.45
2016-05-12 15:00,-999.00,-999.00,134.20,102.78,14.45,11.97,0,0.00,0.00,0.43
2016-05-12 16:00,-999.00,-999.00,70.15,52.13,11.16,11.36,0,0.00,0.00,0.43
2016-05-12 17:00,-999.00,-999.00,43.22,30.36,11.57,11.43,0,0.00,0.00,0.43
2016-05-12 18:00,-999.00,-999.00,20.01,16.24,11.40,11.46,0,0.00,0.00,0.43
2016-05-12 19:00,-999.00,-999.00,17.04,16.11,11.03,10.31,0,0.00,0.00,0.43
2016-05-12 20:00,-999.00,-999.00,12.59,7.83,9.39,8.55,0,0.00,0.00,0.43
```

8.8 General API configuration

This is an overview of the API-URL. **Blue and bold** means that this is fix and can't be changed by the customer. *Italic and light blue* means that can be changed by the customer. This example API-URL is an invalid demo URL.

Description:

- "**http://my.meteoblue.com/packages/**solar-1h**?**" address and packages
- "**&lat=**47.5584" coordinates
- "**&lon=**7.57327" coordinates
- "**&asl=**279" altitude
- "**&apikey=**personalAPIkey" Personal APIkey

Optional settings

- "**&tz=**Europe%2FZurich" time zone
- "**&name=**Basel" location name, label your forecast, has no effect on data
- "**&timeformat=**Y-M-D" Time format
- "**&format=**json" Output format

For correct daily aggregations it is best to **omit the "&tz=" parameter**, as then everything will be in local time including daylight saving (however over the ocean everything will be in UTC if you omit the tz).

8.8.1 Geographic coordinates

Position is defined by the geographic location (coordinate) and the elevation (altitude) of the point considered, be on the surface or in the atmosphere.
Coordinates are latitude (North, South) and longitude (East, West) given in degrees and decimals. Formats are:

- Latitude: from -90.0000° (South) to 90.0000° (North) - **Apply:** &lat=...
- Longitude: from -180.0000° (West) to 180.0000° (East) - **Apply:** &lon=...

A wrong configuration of the position of your system will lead to a substantial loss of accuracy. To verify the position of your site you can use the <What's here> function of Google maps as shown in Fig. 8.3:

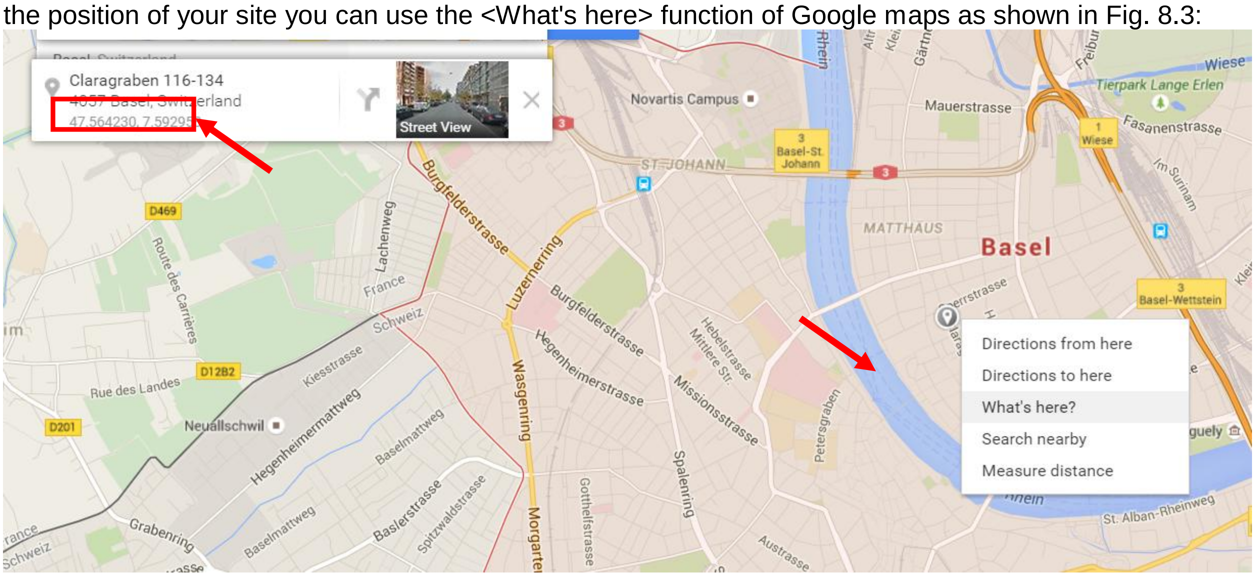

Fig. 8.3: The correct decimal coordinates of your site can be detected using the <What's here> function in Google maps. The coordinates are displayed in grey below the address.

8.8.2 Time zone (tz)

The time zone is used to provide data in local time. For autonomous systems we recommend to use UTC. Daylight saving time might otherwise cause problems as in a data shift of one hour.
For user interfaces data in local time is desired. You can provide “tz=Europe%2FZurich” to get data in CET or CEST timezone. “%2F” is an URL encoded slash “/”.
If the time zone is not provided to an API request, a time-zone database is used to get the time zone. For coastal areas UTC might be selected incorrectly. We recommend to provide the time zone, if available.
For fixed time offsets use for example GTM+2 for -02:00 UTC offset or GTM+ 02:30 for -02:30 offset.
A complete list of possible time zones can be found at Wikipedia.

8.8.3 Time format

You can choose between the following time formats: YYYY-MM-DD hh:mm (default), YYYYMMDD hh:mm, UTC timestamp (seconds or milliseconds), ISO 8601

Examples:

- YYYY-MM-DD hh:mm: 2016-02-10 03:00
- YYYYMMDD hh:mm: 20160210 03:00
- Time stamp_utc: 1455069600
- Time stamp_ms_utc: 1455069600000
- iso8601: 2016-02-10T03:00+01:00

Note: Time stamps are always returned in UTC time zone per definition. To get local time you have to apply the time zone-offset manually.

8.8.4 Output format (format)

Currently only json and csv are supported. Additional formats might follow as per customer requirements. csv output format only supports a single time-resolution. In order to request “daily” and “3-hourly” data, you would have to make two API requests.

8.9 PVpro: characterization of your PV forecast

To characterize your PV system within the solar forecast API you need to verify the following parameters, which are specified by keywords (kwp, slope, facing**). Example for a PV system with 125 kWp facing 27° towards South: &kWp=125&facing=180&slope=27**

8.9.1 Capacity (kWp)

The peak value of your system referring to the maximum AC output. The implemented kWp (kiloWatt peak) value is used as upper limit of your forecast.
Apply: &kWp=...

8.9.2 Exposition

For the projection on tilted surfaces the exposition of the plane and the position of the sun need to be defined by two angles:

- Slope angle / Sun height (0°=horizontal - 90°=vertical) - **Apply:** &slope=...
- Orientation angle / Solar azimuth (0°=facing north, 90°=E, 180°=S, 270°=W) - **Apply:** &facing=...

Angles of incidence are measured relative to the Earth's surface. Aslope Angle of 0° is parallel to the surface, 90° is perpendicular to the surface. Orientation Angles are measured from facing North (0°) clockwise. Angles measurements are used for position of the sun, inclination of a solar collector (Photovoltaic system), or a measurement device. The wrong definition of the exposition will lead to a systematically wrong daily curve as shown in Fig. 8.4 & Fig. 8.5.

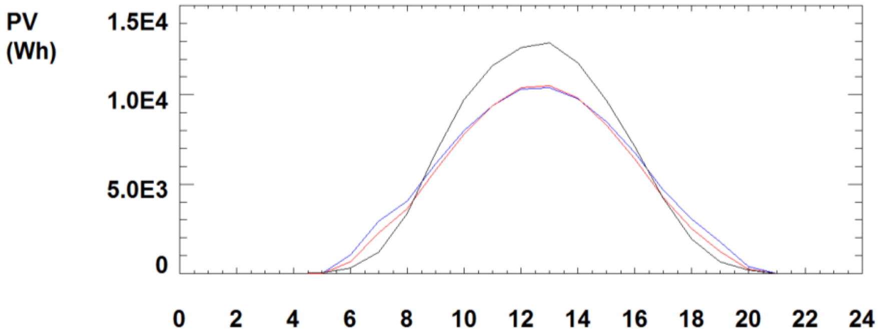

Fig. 8.4: The simulation (red&blue) underestimates the midday peak of the actual PV-production (black), because the configuration of the slope angle is too low.

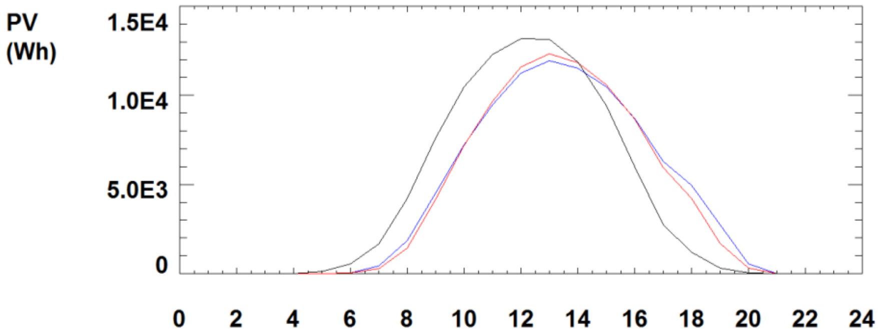

Fig. 8.5: The midday peak of the simulation (red&blue) is late compared to the actual PV-production (black), because the configuration of the orientation angle is too high.

8.9.3 Keyword: snow

Since 2015 meteoblue offers the option to detect snow and automatically reduce the resulting forecast of PV-pp. It is assumed, that a snow cover of 40mm or more results is completely intransparent for any light. Malfunction of the meltdown function can lead to substantial errors especially in mountainous regions.
Default: disabled
Apply: &snow=1

8.9.4 Keyword: power_efficiency

As the efficiency of a specific PV systems is depending on many factors like layout, age, shading etc. we offer its manual implementation. The power efficiency factor applied is a mean value and will still be varied by module temperature, IAM and others to simulate the actual PR. All values are allowed but values above 1 are not logical, but might be useful for systems with capped production curves as the simulation will not exceed the peak capacity (see chapter 8.9.1)
Default: 85%
Apply: &power:efficiency=0.85

8.9.5 Keyword: horizon

Shading is one of the most common restriction of optimum PV yield for a specific PV system. Even though small obstacles like antennas or electricity masts can't be taken into account at least we can offer correction of horizon constraints. In mountainous regions or locations with high buildings or trees the typical daily profile is strongly affected be these obstacles. The exact definition of the horizon is used to optimize simulation accuracy. The horizon is defined with 12 numbers the turn clockwise (compare orientation angle) from North 0° and its value defines the horizon height in degrees (from 0°-60°). The directions of the horizon are defined as:

- horizon= [N,NNE,NEE,E,ESE,SSE,S,SSW,SWW,W,WNW,NNW)

Default: disabled
Apply: & e.g. &horizon=[0,0,0,10,20,0,40,0,10,10,20,10] (Big obstacle (40°) in Southern direction)

9 Statistical optimization (MOS)

9.1 Description

MOS (Model output statistics) is a localized power forecast based on the radiation forecast of NMM weather models and historical power measurements. Thereby, the model output is corrected statistically by the function developed from the measurement data (Model Output Statistics), using the NMM model radiation as a basis. The forecast is adjusted to the local Station, using quality controlled measurements from the station, available for minimum 1 year, in hourly intervals.
https://content.meteoblue.com/research-development/data-sources/nmm-modelling/mos

9.2 Forecast Parameters

The possible forecast parameters and range/intervals are:

- PV_MOS: Energy_kWh; kWp
  (Availability parameter is necessary to calculate kWh/kWp)
- GHI_MOS: GHI
  (ExRad for quality control is processed afterwards)

Other parameters can be supplied on request.

9.3 Expected precision

The expected precision of radiation or power forecast with the MOS forecast is between 10 and 25% NMAE on an hourly basis for 2-24 hour forecast, depending on location and year.

9.4 Configuration process

The MOS power forecasting model is determined based on a radiation forecast. This radiation forecast is adjusted to the local power plant by a statistical function, derived from past measurements, as follows:

1. Customer provides location information: position, altitude (exposition).
2. Customer provides historic radiation and/or production data: radiation and/or electricity (power) output for at least 1 hour, in 10 -60 minute intervals: as .csv or .txt. files. Data should be provided with comma separator “;” (not “,”) to avoid formatting mistakes.
3. meteoblue conducts data quality control, to ensure a good return on investment .
4. meteoblue extracts radiation archive data and matches to radiation / production.
5. meteoblue implements correction factors in system.

meteoblue provides corrected MOS power forecast with 24 updates per day.

9.5 Observation data format

The observation data for MOS configuration should support following requirements:

- standard text format: .csv oder .txt
- one file for each site, that contains full available timerange
- FILENAME: Site-ID_LAT_LON_timerange_type_parameter_aggregation_generationdate.csv
- e.g.: MB-4412_42.75_12.86_20130523-20141218_OBS_PV_HOUR_20141218z1200.csv
- The file contains SITE_ID, date and time (in UTC) and the target parameters. PVpp is always delivered with system availability (=available capacity (kWp) at a given time stamp).

Sample:

```
ID_MB;date;UTC;Energy_kWh;kWp
1557_65_10;23.05.2013;12:00:00;0.12;87.98
1557_65_10;23.05.2013;13:00:00;0.63;87.98
1557_65_10;23.05.2013;14:00:00;0.04;87.98
1557_65_10;23.05.2013;15:00:00;4.92;87.98
1557_65_10;23.05.2013;16:00:00;11.63;87.98
```

10 Nowcasting

10.1 Description

Nowcasting is the combination of localized power forecast based on the radiation forecast of NMM weather models with real time satellite observations collected every 15 minutes. Thereby, the model radiation output of the present day is corrected in real time with the satellite derived radiation. Based on the actual cloud pattern and wind vectors a so called cloud motion forecast is processed which optimizes the forecast accuracy of the next 5 hours. Depending on the actual weather situation persistence, cloud motion and the model output are weighted differently for the time horizons of the next hours. The combination of these techniques is summarized with the term: **nowcasting**.

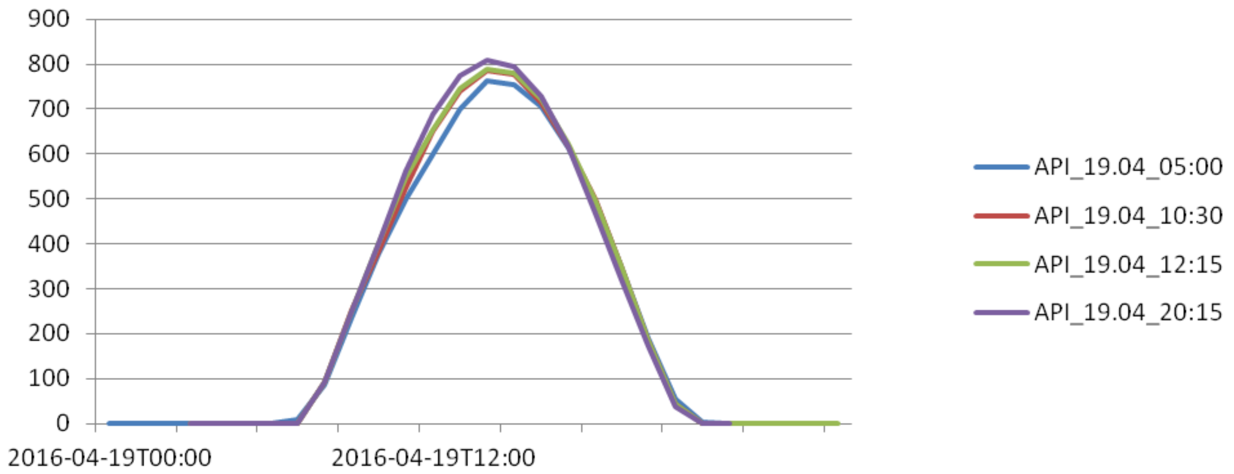

Fig. 10.1: The solar forecast retrieved before sunrise (blue), in the morning (red) at noon (green) and after sunset (violet) of the same day.

The instant of time that are already past contain the actual satellite observation. Thus the solar forecast API contains only observation values after sunset and is therefore combines forecast and **monitoring** within the same datafeed. The effects of nowcasting are depending on the accuracy of the NMM forecast accuracy. If the day ahead forecast is correct, nowcasting has almost no impact (see Fig. 10.1), otherwise the nowcast is strongly changing the content of the API (see Fig. 10.2).

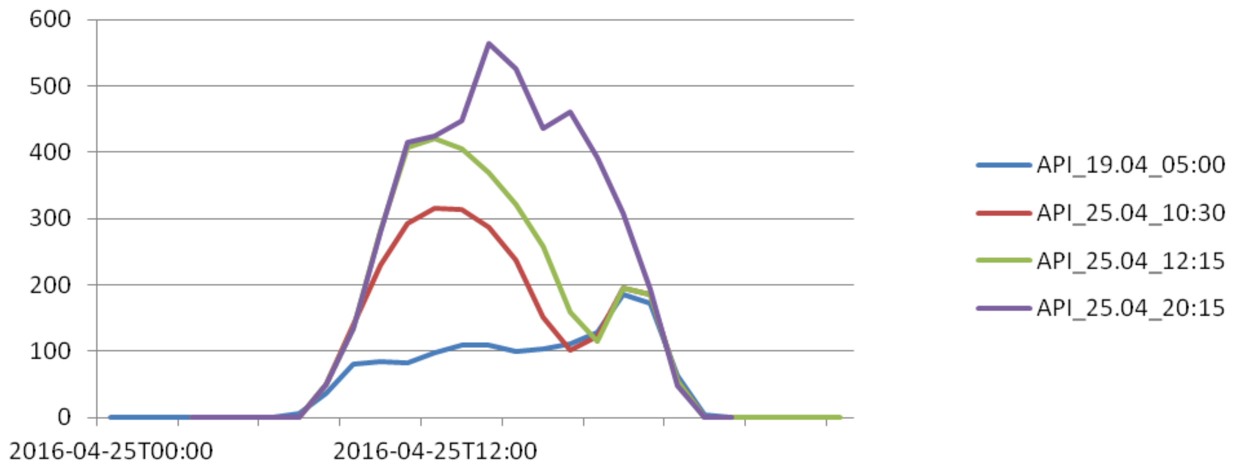

Fig. 10.2: The solar forecast retrieved before sunrise (blue), in the morning (red) at noon (green) and after sunset (violet) of the same day.

10.2 Nowcasting availability

Presently the nowcasting technology is automatically implemented in the API for all locations within sight of the Meteosat Second Generation (MSG). Thus it covers Europe, the Arabian peninsula, Africa, Brazil, and parts of its neighbouring countries (see Fig. 10.3).

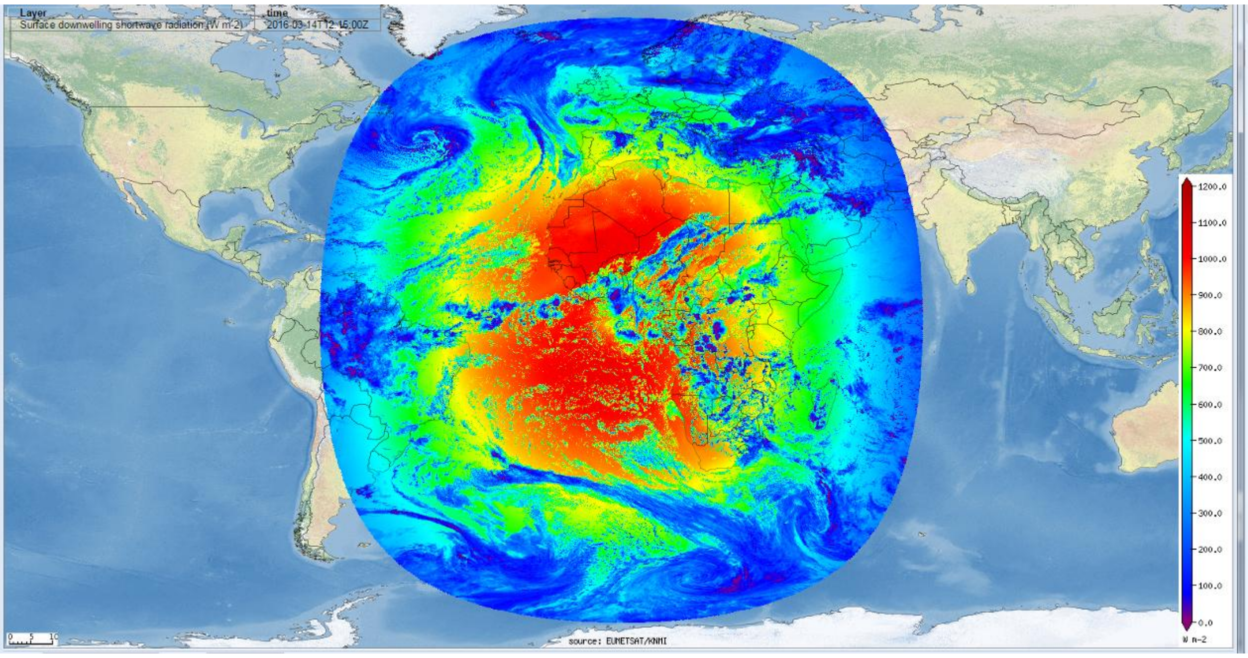

Fig. 10.3: The full MSG disc of Global Horizontal Radiation (GHI) at 2016-03-16 15:00 UTC (Source: KNMI).

10.3 Forecast Parameters

The nowcasting is effected on all radiation parameters and PV power simulations.

10.4 Used Parameters

The used observation parameters, accessed on from satellite observations are:

- Global Horizontal Irradiation (GHI)
- Clear Sky Global Horizontal Irradiation (GHI_CS)
- Cloud top-height (CTH)

The used simulation parameters, from NEMSGLOBAL are:

- Global Horizontal Irradiation (GHI)
- Clear Sky Global Horizontal Irradiation (GHI_CS)
- Wind vectors u & v on different levels

10.5 Cloud motion vectors (CMV)

Based on the image of the cloud-top level (see Fig. 10.4) the wind vectors (see Fig. 10.5) of the next 6 hours is extracted for the specific cloud height of each point. A cloud motion vector (wind trajectory) is calculated for each time horizon of 1-6 hours.

10.6 Solar radiation nowcast based on cloud motion vectors (CMV)

Based on the six wind trajectories, the referring pixel layer is chosen for each time horizon (1-6 hours). This pixel is used to calculate the expected radiation. The result is a radiation forecast for the next 6 hours. Cloud motion nowcasting works only after sunrise, when the referring satellite data is available.

10.7 Persistence solar radiation nowcast

For the persistence solar radiation nowcast the radiation of the last 4 hours is used (without any cloud motion) and weighted.

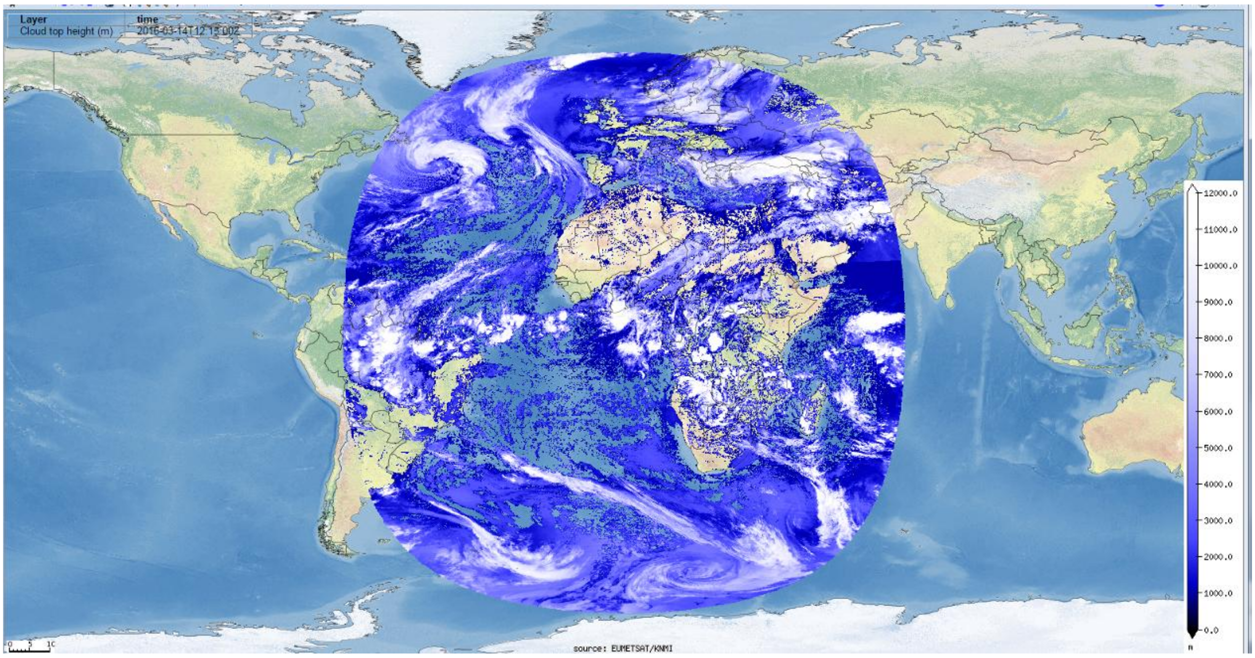

Fig. 10.4: The full MSG disc of cloud top height (CTH) at 2016-03-16 15:00 UTC (Source: KNMI).

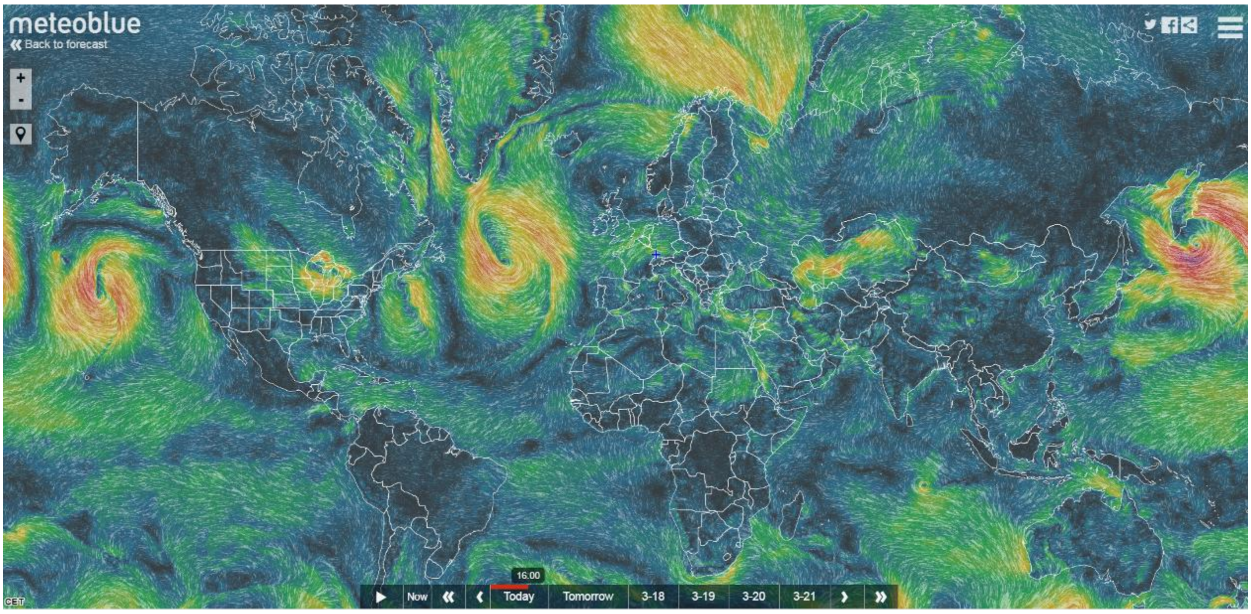

Fig. 10.5: Wind speed and trajectories at 600 hPa level on 2016-03-16 15:00 UTC.

10.8 Combined solar radiation nowcast

For different time horizons and weather situation the weighing of persistence, cloud motion and numerical weather prediction is changing. It is useful to combine the different approaches to minimize errors. Weather variability could be classified with the clearness index of the surrounding satellite pixels.

10.9 Expected precision

The expected precision of radiation or power forecast with nowcasting is between 5 and 20% NMAE on an hourly basis for 0-5 hour forecast, depending on location and satellite availability. The accuracy of nowcast is declining with forecast horizon (see Fig. 10.6). After 5 hours the NMM model is performing better than the nowcast.

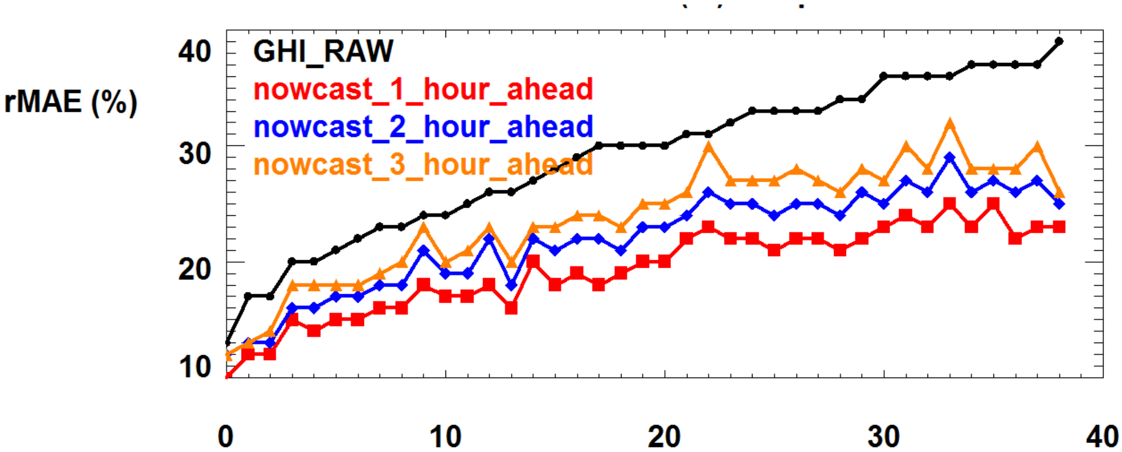

Fig. 10.6: Nowcasting (red: 1h, blue:2h, orange:3h) improves performance of solar forecast service (black line). Vertical axis shows MAE (in %) of hourly forecast over a full year. Stations sorted in order of ascending error.

11 Sources

A publication list is shown in Table 11.1:

Table 11.1: Publication list.

#	Title[1])	Author[2])	Year[3])	Publisher [4])	Comment
1.	Solarstrom – Vorhersage und Markteinbindung	Michael Bührer	2010	Masterarbeit, 69 pp. Universität Basel	
2.	A new simplified Version of the Perez diffuse irradiance model for tilted surfaces.	Perez, R. et al.	1987	Solar Energy, Vol. 39, 1987; p. 221-231	
3.	Modeling daylight availability and irradiance components from direct and global irradiance	Perez, R. et al.	1990	Solar Energy, Vol. 44, 1990; p. 271-289	
4.	Regenerative Energiesysteme: Technologie - Berechnung - Simulation	Quaschning, V.	2009	Hanser, München	
5.	Diffuse fraction correlations.	Reindl D.T: et al.	1990	Solar Energy, Vol. 45, 1990; p. 1-7.	
6.	Five satellite products deriving beam and global irradiance validation on data from 23 ground stations.	Ineichen P,	2011	University of Geneva, 40 pp.	

Notes: [1]) As published [2]) Full name of first author. [3]) Publication. [4]) Publisher: Company or Institution.

– End of document –