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Mesoscale Climate Datasets for Building Modelling and Simulation

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Abstract

This work presents a method to make use of gridded historical mesoscale datasets for energy and hygrothermal building modelling and simulation purposes by transforming, merging and formatting them into time series. The main result of this work is a web tool, https://rokka.shinyapps.io/shinyweatherdata, allowing users to create actual climate dataset for any location in North Europe in file formats used by common building simulations tools. A review is conducted on freely available gridded mesoscale datasets/model systems for north Europe: the modelling systems MESAN and STRÅNG currently used as data source for the developed web tool as well as the SARAH model system and MESAN/MESCAN reanalysis datasets.

Keywords – weather data; mesoscale; time series; building simulation

1. Introduction

Building simulation and modelling tools rely on climate datasets. These models, and the climate datasets they rely on, play an important role in providing basis for planning, design, and cost analysis.

This work presents a method to make use of gridded historical meteorological datasets for energy and hygrothermal building modelling and simulation by transforming, merging and formatting them into time series. The main result of this work is a web tool, https://rokka.shinyapps.io/shinyweatherdata, allowing users to easily create actual climate dataset for any location in North Europe in file formats used by common building simulations tools.

Swedish Meteorological and Hydrological Institute (SMHI) recently made archived dataset of climate parameters from their mesoscale analysis systems freely available. These are stored as gridded datasets in formats not commonly used by the buildings simulation community. To get time series of one full year for a certain location requires downloading large amount of data (about 20-30 GB) and knowledge in specialised data handling tools. It is a tedious task prone to faults – a task that is better off handled by computers.

A review is conducted on freely available gridded mesoscale datasets for north Europe, their usability as input to energy and hygrothermal modelling and simulation.

1. Methods

The modelling system MESAN's [1] historical analysis data is stored formatted as GRIB 1, a concise data format used in meteorology to store historical and forecast weather data. Parameters selection, backward transformation of velocity components U and V from a rotated spherical system to a geographical system, time merging and formatting into the file format netCDF-4 is performed with the CDO tool [2].

The radiation data from the modelling system STRÅNG [3] is imported to the R software as fixed width ASCII, rotated to have the same grid orientation as the MESAN data and then both datasets are merged into netCDF-4 files, using the R-package ncdf4 [4], with the chunking set to go along the time dimension.

The STRÅNG model calculates the parameters DNI (direct normal irradiance) and GHI (global horizontal irradiance). But building simulation tools uses DNI and DHI (diffuse horizontal irradiance). To calculate DHI following relationship between the radiation parameters is utilised (omitting that for practical purposes insignificant reflected radiation)

$$DHI = GHI - DNI * \sin(sunElev) \quad (1)$$

Where *sunElev* refers to the sun's true (not accounting for atmospheric refraction) elevation angle. The sun's position is calculated based on the formulas given in [5] and checked against the NREL's SPA (Solar Position Algorithm) online calculator [6].

$$\sin(sunElev) = sin(latitude) * cos(declination) + cos(latitude) * cos(declination) * cos(HRA) \quad (2)$$

The declination is calculated by $deg2rad * 23.45 * sin(2 * pi * (284 + doy)/365)$, where deg2rad is a constant transforming degree to radians, *doy* is the day of the year as an integer value of 1..366. *HRA* is the hour angle denoting the number of degrees from solar noon, calculated as *HRA=deg2rad*15°*(LST-12-shift)*, where 15° is the earth's hourly rotation speed, *shift* takes the value 0 if full hours are of interest and 0.5 if integrated values between full hours are of interest. *LST* denotes the local solar time in fractional hours and is calculated by *LST = (time + (longitudeDeg*4 + EoT)/60) mod 24*, where *time* is the UTC time of interest. Parameter *longitudeDeg* is the longitude in degrees, *mod* denotes the modulo operator which keeps the resulting value between 0..23.99. EoT is the equation of time correcting for the eccentricity of the earth's orbit and the earth's axial tilt, calculated by the empirical formula $EoT = 9.87 * sin(2 * B) - 7.53 * cos(B) - 1.5 * \sin(B)$, where $B = deg2rad * (360/365 * (doy - 81))$.

There are a few shorter gaps of missing values in the MESAN dataset and a longer gap of 48 hours. For building simulations it is usually desirable to get time series for a full period, therefore some basic missing data handling is implemented. Standard spline interpolation is used for gaps shorter than 6 hours. For longer gaps the function *na.interp* from the forecast package [7] is used. It uses linear interpolation together with periodic stl decomposition (frequency set to 24 hours) which catches the auto-correlative nature of climate parameters. There are more elaborate ways of dealing with missing data, but the gaps in the datasets are so few and short that these methods are consider to be sufficient.

2. Result and discussion

The main result is the web tool https://rokka.shinyapps.io/shinyweatherdata. It provides users an easy to use interface from which they can access gridded historical climate datasets as time series by searching after address, searching by coordinates or by an interactive map. The final data output is formatted in file formats commonly used by energy and hygrothermal building simulations tools. In time of writing the tool utilise gridded data from the SMHI's MESAN and STRÅNG modelling systems.

Since late 1990 SMHI has utilised a mesoscale analyses system called MESAN [1,8]. MESAN is based on statistical interpolation for each studied meteorological parameter, where observations at each time are used together with a background field (first guess field). The system have been used for weather now-casting in order to obtain information of higher quality compared to the numerical weather prediction system, and also as historical meteorological input data for assessment studies [9]. The spatial resolution of the gridded data is about 22 x 22 km for the period 1998 to 2007 and 11 x 11 km after that. Data is made available daily for the previous day. The area covered is shown in Fig. 1.

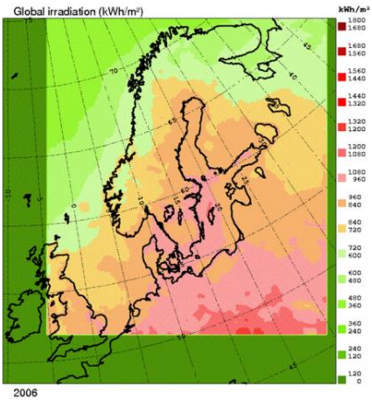

Fig. 1. Map of area covered by the SMHI's modelling systmes MESAN and STRÅNG. Green area shows post 2007 coverage and coloured area the coverage for 1998-2007.

The SMHI's modelling system STRÅNG [3,10] produces hourly instantaneous fields of radiations parameters of which global horizontal irradiance (GHI) and direct normal irradiance (DNI) are of interest for building simulation applications. Clear-sky condition is modelled with the spectral clear-sky model SMART2. The output is then multiplied by a neural network function which captures the influence of clouds and precipitation. The cloud information is taken from MESAN and is an assimilation of data from polar and geostationary satellites as well as ground based observations. The resolution and coverage is the same as for MESAN. According to Tomas Landelius at

SMHI (personal communication 2016-01-29) STRÅNG will be updated during 2016. After the update the model will start using SMHI's new numerical weather prediction system called AROME. The horizontal resolution will increase to 2.5 km, but covered area will decrease and only cover the Nordic countries.

For solar radiation and cloud data CM SAF have a model system called SARAH [11] which can produce hourly average datasets with the horizontal resolution of 5.5 km, covering the area shown in Fig. 2. Higher latitudes give poorer quality, due to the increased viewing angle of the used geostationary satellites. But up to about 60° latitudes models using geostationary satellites are preferable as the geostationary satellites have better temporal coverage than polar satellites. In time of writing (2016-01-30) hourly data is available from 1983 until 2014.

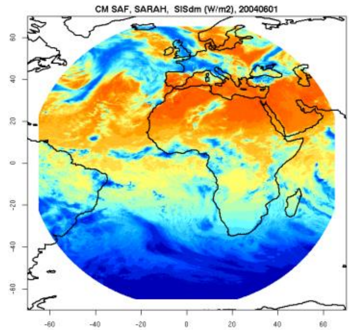

Fig. 2. Coverage area of the SARAH cloud and radiation model (full disk of the geostationary MSG satellites).

The MESAN 2D reanalysis dataset [12] provides gridded climate parameter downscaled to the horizontal resolution of 5.5 km for whole Europe as shown in Fig. 3. The temporal resolution is 3-hours besides precipitation which comes as daily values. Météo France will continue this work with a MESCAN downscaling [13], which is expected to result in a reanalysis stretching all way back to 1961 to present time. The advantage of reanalysis datasets vs historical analysis data from operational modelling systems are that reanalysis have more metered data as input and better handling of erroneous data. If reanalysis datasets are available they are better suited than operational data for buildings modelling purposes.

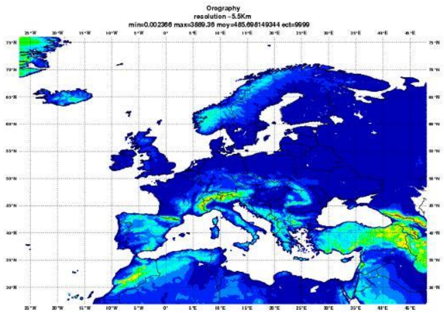

Fig. 3. Area covered by the MESAN and MESCAN reanalysis systems.

Table 1 shows a summary of the studied datasets/model system

Table 1. Gridded mesoscale datasets/models or North Europe, useful for energy and hygrothermal building modelling

Dataset/model	MESAN	STRÅNG	MESAN/MESCAN reanalysis	SARAH
Area covered	North Europe/Scandinavia	Same as MESAN	Europe, north Africa	Full disk
Time period covered	Since 1999 until present (one day delay)	Same as MESAN	1961 until present time, update rate unknown	1983 until 2014, updates sparse
Horizontal and temporal resolution	11 km since 2007, hourly	11 km since 2007 (soon 2.5 km), hourly	5.5 km, sub-daily	5.5 km, Hourly average
Relevant parameter	Temperature, humidity, precipitation, wind, air pressure and cloud cover	Global horizontal and direct normal radiation	Temperature, humidity, precipitation and wind	Global horizontal and direct normal radiation and cloud albedo
Access policy	Free	Free	?	Free

3. Conclusions

Continuous development of mesoscale analysis systems employed in meteorology result in higher spatial and temporal resolution and better accuracy. Using these modelled climate datasets for energy and hygrothermal modelling is useful as they allow creating time series for locations where metered datasets are lacking or of poor quality. It is also possible to combine modelled and on-site metered data, for example use metered data for temperature which is cheap and simple to meter and modelled data for solar which is more expensive to meter.

For the Nordic countries MESAN and STRÅNG appears to be the best source of gridded mesoscale climate data, especially after the planed update of the STRÅNG model system. These datasets stretches back relatively far in time and are continuously updated with new data, and can therefore be used both for validating building models (recent data usually needed) and to create extreme or typical weather years files (long series needed).

For Europe the ongoing MESCAN reanalysis project together with SARAH solar model seems promising. But for some energy modelling purposes new data needs to be made available more frequently than it is the case currently for these systems. Combining SARAH solar data with metered meteorological data is also an approach worth further consideration.

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