Deliverable D4.2 Best-Practice Guide GEOSS/Copernicus

LOD-GEOSS – DLR Institute of Networked Energy Systems

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Introduction

This Best-Practice Guide is a result of the project Linked Open Data and use of the global earth observation system GEOSS in energy system analysis (LOD-GEOSS). The aim of LOD-GEOSS is to develop an interconnected database concept for input and result data of modelling in energy system analyses. In the area of energy research a large number of data is already available and is provided via standardized interfaces. So far these interfaces have hardly been used in energy system analysis. The goal of WP 4 is therefore to show within a Best-Practice Guide how these databases can be used. The product of WP 4.2 concentrates on the connection to existing database system with relevant time-resolved data for energy system analysis with a focus on the use of the GEOSS and the Copernicus system of the European Union.

Chapter 1 explains the concept of GEOSS and how the GEOSS Portal can be used. The following Chapters 2 to 4 contain examples for time-resolved data sets and how they can be accessed. First an ERA5 reanalysis data set will be presented in Chapter 2. A description of two CAMS radiation data sets can be found in Chapter 3. In the last Chapter of the Best-Practice Guide deterministic and probabilistic forecasts from ECMWF will be described and it is shown how to get access to the forecasts.

1. GEOSS

The Global Earth Observation System of Systems (GEOSS) is built by the Group on Earth Observations (GEO). In 2003 on the G8 summit in Evian, the need for a coordination of Earth observations was agreed. Two years later at the third Earth observation summit in Brussels almost 60 countries joined the GEOSS 10-Year Implementation Plan (GEO 2020). Since then the number of nations and organizations who support GEO and GEOSS is constantly growing. At this point more than 100 national governments and organizations work together in the GEO network. The goal is to improve the observation of the Earth with financial, political, and technical support and also with a better management of the existing data (ECMWF 2018).
Many institutions and scientific groups are providing data bases and portals which are related to Earth observation. Users can find on many different sides, data, images and analytical software packages that help them working on topics in the area of biodiversity, ecosystems, disasters, energy, agriculture, health, climate, weather and water. Since the range of the information is so wide, it can be difficult for the users to find exactly what they are looking for. GEOSS has the aim to link all these systems and to provide an easy access for a wide variety of users in both public and private sectors (GEO 2020). The users can find existing and planned observing systems from the whole world and everything is accessible at one single Internet access point, the GEOSS Portal. The System of systems helps thereby to access the variety of open data bases, makes it easier for the users to connect to others and it supports the development of new systems for a better understanding of our earth.

1.1. GEOSS Portal

The GEOSS Portal, which is accessible via geoportal.org, operates as an interface between data providers and users who are searching for data. The platform makes the data better visible to the users from all over the world. For the data providers this is a good possibility to spread their data and at the same time they remain the only owner of the shared resources (Joost Van Bemmelen 2017). But how is the GEOSS Portal working? When users open the website www.geoportal.org, which was refurbished during 2016 and 2017, a map and a search panel can be seen. On the right side the users can find a series of icons for basic GIS functionalities like Layer handling and a set of basemaps. The upper left corner shows a menu button, with options like search, info, contacting the helpdesk, statistics, terms and conditions and sign-in. The advanced search panel, which can be seen in Figure 1-1, gives the user the opportunity to itemize the search. Choosing an Earth observation catalog, itemizing the thematic area and defining the area of interest with the help of a bounding box or by choosing a country or continent and also defining the timeframe are all options the user can determine. Figure 1-2 shows how it would look like if a user would search for wind data in Europe. After typing wind in the search panel from Figure 1-1 the search panel from Figure 1-2 is opening. The user has now even more options to narrow the search by, for example, choosing a data format. After choosing one of the data sets, that are shown in the result list, the user has several options.

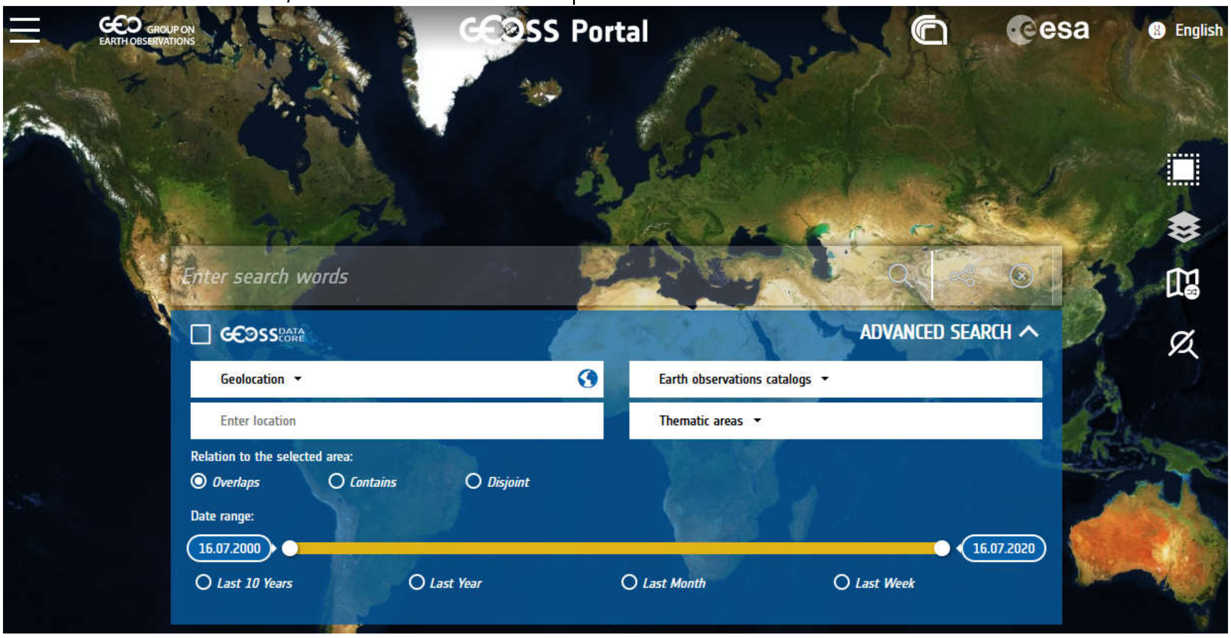

Figure 1-1: Website of the GEOSS Portal ([www.geoportal.org)](http://www.geoportal.org) with the advanced search panel

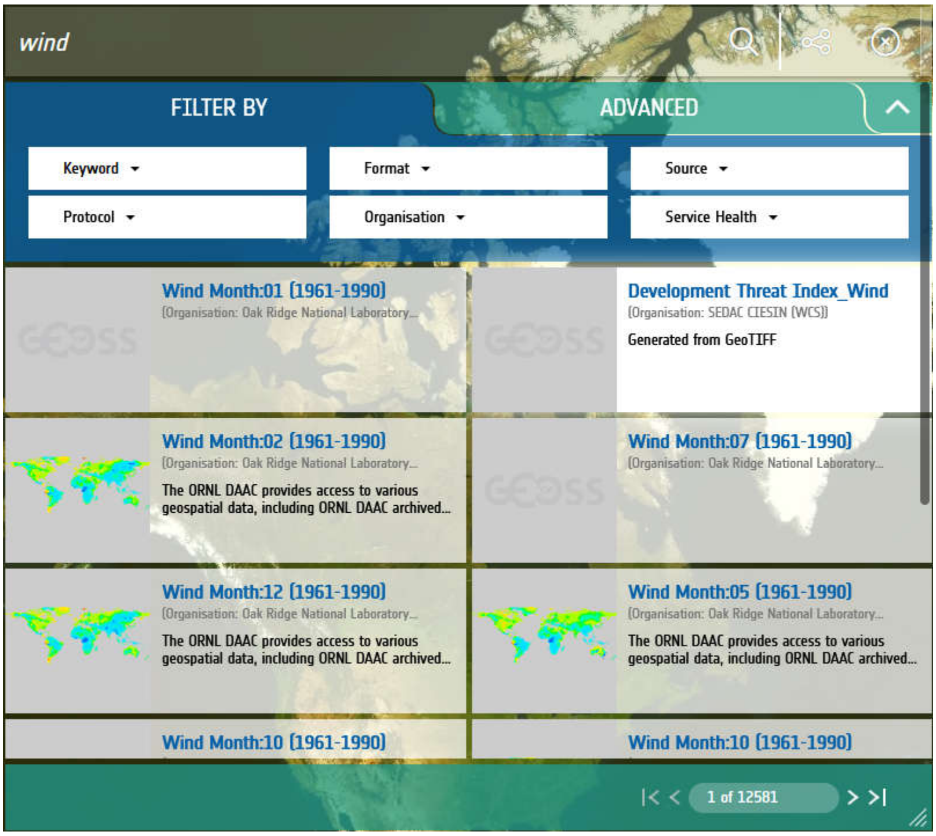

Figure 1-2: An example for a search for wind in the GEOSS-Portal. The different options that the user can select can be seen.

By clicking on the *See more* button a new window opens with information about the resource. This can be seen in Figure 1-3. In this new window the user gets general information about the resource, contact information, data identification and descriptive keywords. Download information or links to the Download Server of the wanted resource can also be found there.

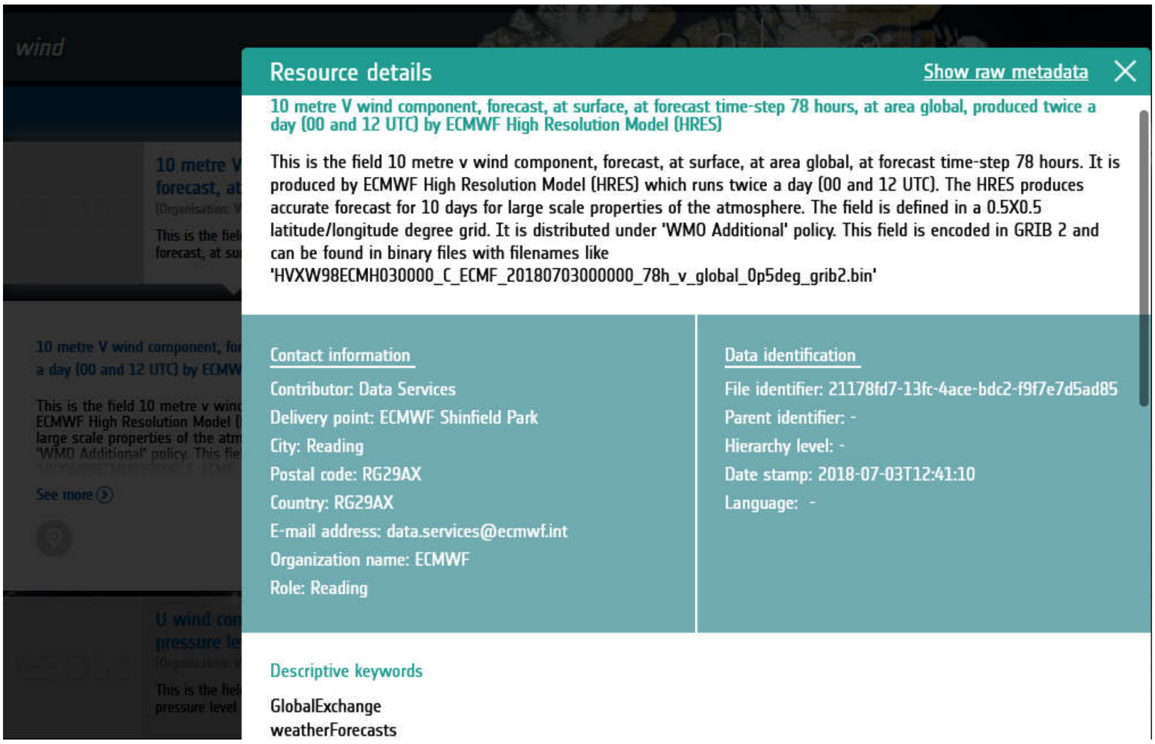

Figure 1-3: Detail window at the GEOSS-Portal that can be seen after clicking on the *See more* button of the wanted data set.

The GEOSS Portal provides an access to a wide range of data bases and portals. For an unexperienced user this can be quite overwhelming in the beginning. Just the search for wind gives more than 12000 result sides with 10 entries on each side. This makes it perhaps difficult for an energy modeller, who is new in this area, to find the right data set. Within LOD-GEOSS we worked on a request that uses the existing tools from GEOSS to select within the high amount of results. In the next Chapter 1.2, this method will be described in more detail.

1.2. Selecting data from the GEOSS Portal

The amount of results, which the user gets in the GEOSS Portal, is quite large. Since it can be difficult to have a look at more than 1000 data sets, the idea was to get the list of results in a machine readable list.

Usually the user just sees the Website of the GEOSS Portal. Behind that stands the GEO Discovery and Access Broker – the GEO DAB. The GEO DAB connects the requests from the users of the

GEOSS Portal with the resources of the GEOSS Providers. It is a middleware component which uses different APIs.
To get a machine-readable list from the results, the RESTful API and OpenSearch were used (Fabrizio Papeschi kein Datum). With the GEO DAB it was now, for example, possible to get a list with the results for the search item *wind*. All the results were now stored in a json file, which made it easier to work further with it. By having a look at the first sides with results for wind in the GEOSS Portal, it can be seen that many of the data sets had a pressure level, like 700 or 250hPa, in the header. Since we had now a machine readable list, it was easy to select maybe just the data sets that had wind and 850hPa in the title. This scaled the number of the results already down. Many data sets had a resolution in the title, which can also be used for selecting out all data sets with *2.5* and *1.5*, because this spatial resolution would not be high enough. Another sorting criterion would be the existence of a description. This can be continued for as many requirements as the user wants to have. This is still in the testing phase but it is already a good first approach for getting a better overview of the existing data. While working on the requests we also had contact to the GEOSS help desk. It is easy to contact them via Email and they were answering within a short amount of time and were always helpful. The help desk can be found in the menu of the GEOSS Portal. Users can also find videos about the Portal. More detailed information about GEOSS can be found in Van Bemmelen et al. and on this Website everything about the GEO DAB can be found.
If the user found a suitable data set from the result list, the data need to be downloaded in the next step. How this is done will be explained exemplarily for four data sets in the next Chapters.

2. ERA5-hourly data on single levels from 1979 to present

ERA5 is a global climate reanalysis, which combines observations with model data. This data set is a product of the ECMWF and contains many atmospheric, land and ocean climate variables in an hourly resolution. The spatial resolution of this global data set is 30x30km. Uncertainties for all variables are available at a reduced resolution (Copernicus Climate Data Store). For this best practice guide the *ERA5.hourly data on single levels from 1979 to present* were selected. Variables like, 100m wind, temperatures, solar radiation and many more can be found in this data set and they are easy to access. This makes ERA5 suitable for every energy system modeler. Table 2-1 shows some of the variables and their descriptions that could be of interest for energy system modelers. A description of the whole ERA5 data set and a list of all available variables can be found on the Copernicus Website.

Table 2-1: Table of variables of the *ERA5-hourly data on single levels from 1979 to present* data set that are of interest for energy modellers (Copernicus Climate Data Store).

Variable-Name	Unit	Description
100m u-component of wind	ms^{-1}	This parameter is the eastward component of the 100 m wind. It is the horizontal speed of air moving towards the east, at a height of 100 metres above the surface of the Earth, in metres per second. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter can be combined with the northward component to give the speed and direction of the horizontal 100 m wind.
100m v-component of wind	ms^{-1}	This parameter is the northward component of the 100 m wind. It is the horizontal speed of air moving towards the north, at a height of 100 metres above the surface of the Earth, in metres per second. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter can be combined with the eastward component to give the speed and direction of the horizontal 100 m wind.
10m u-component of neutral wind	ms^{-1}	This parameter is the eastward component of the "neutral wind", at a height of 10 metres above the surface of the

		Earth. The neutral wind is calculated from the surface stress and the corresponding roughness length by assuming that the air is neutrally stratified. The neutral wind is slower than the actual wind in stable conditions, and faster in unstable conditions. The neutral wind is, by definition, in the direction of the surface stress. The size of the roughness length depends on land surface properties or the sea state.
10m u-component of wind	ms^{-1}	This parameter is the eastward component of the 10m wind. It is the horizontal speed of air moving towards the east, at a height of ten metres above the surface of the Earth, in metres per second. Care should be taken when comparing this parameter with observations, because wind observations vary on small space and time scales and are affected by the local terrain, vegetation and buildings that are represented only on average in the ECMWF Integrated Forecasting System (IFS). This parameter can be combined with the V component of 10m wind to give the speed and direction of the horizontal 10m wind.
10m v-component of neutral wind	ms^{-1}	This parameter is the northward component of the "neutral wind", at a height of 10 metres above the surface of the Earth. The neutral wind is calculated from the surface stress and the corresponding roughness length by assuming that the air is neutrally stratified. The neutral wind is slower than the actual wind in stable conditions, and faster in unstable conditions. The neutral wind is, by definition, in the direction of the surface stress. The size of the roughness length depends on land surface properties or the sea state.
10m v-component of wind	ms^{-1}	This parameter is the northward component of the 10m wind. It is the horizontal speed of air moving towards the north, at a height of ten metres above the surface of the Earth, in metres per second. Care should be taken when comparing this parameter with observations, because wind observations vary on small space and time scales and are affected by the local terrain, vegetation and buildings that are represented only on average in the ECMWF Integrated Forecasting System (IFS). This parameter can be combined with the U component of 10m wind to give the speed and direction of the horizontal 10m wind.

2m temperature	K	This parameter is the temperature of air at 2m above the surface of land, sea or inland waters. 2m temperature is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. This parameter has units of kelvin (K). Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Mean runoff rate	$kgm^{-2}s^{-1}$	Some water from rainfall, melting snow, or deep in the soil, stays stored in the soil. Otherwise, the water drains away, either over the surface (surface runoff), or under the ground (sub-surface runoff) and the sum of these two is called runoff. This parameter is the mean over a particular time period which depends on the data extracted. It is the rate the runoff would have if it were spread evenly over the grid box. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point rather than averaged over a grid box. Runoff is a measure of the availability of water in the soil, and can, for example, be used as an indicator of drought or flood.
Surface runoff	m	Some water from rainfall, melting snow, or deep in the soil, stays stored in the soil. Otherwise, the water drains away, either over the surface (surface runoff), or under the ground (sub-surface runoff) and the sum of these two is called runoff. This parameter is accumulated over a particular time period which depends on the data extracted. For the reanalysis, the accumulation period is over the 1 hour up to the validity date and time. For the ensemble members, ensemble mean and ensemble spread, the accumulation period is over the 3 hours up to the validity date and time. The units of runoff are depth in metres of water. This is the depth the water would have if it were spread evenly over the grid box. Care should be taken when comparing model parameters with observations, because observations are often local to a particular point rather than averaged over a grid box. Observations are also often taken in different units, such as mm/day, rather than the accumulated metres produced here. Runoff is a measure of the availability of water in the soil, and can, for example, be used as an

		indicator of drought or flood.
Surface net solar radiation	Jm^{-2}	This parameter is the amount of solar radiation (also known as shortwave radiation) that reaches a horizontal plane at the surface of the Earth (both direct and diffuse) minus the amount reflected by the Earth's surface (which is governed by the albedo). Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The remainder is incident on the Earth's surface, where some of it is reflected. This parameter is accumulated over a particular time period which depends on the data extracted. For the reanalysis, the accumulation period is over the 1 hour up to the validity date and time. For the ensemble members, ensemble mean and ensemble spread, the accumulation period is over the 3 hours up to the validity date and time. The units are joules per square metre ($J\ m^{-2}$). To convert to watts per square metre ($W\ m^{-2}$), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Surface net solar radiation, clear sky	Jm^{-2}	This parameter is the amount of solar (shortwave) radiation reaching the surface of the Earth (both direct and diffuse) minus the amount reflected by the Earth's surface (which is governed by the albedo), assuming clear-sky (cloudless) conditions. It is the amount of radiation passing through a horizontal plane. Clear-sky radiation quantities are computed for exactly the same atmospheric conditions of temperature, humidity, ozone, trace gases and aerosol as the corresponding total-sky quantities (clouds included), but assuming that the clouds are not there. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface, where some of it is reflected. The difference between downward and reflected solar radiation is the surface net solar radiation. This parameter is accumulated over a particular time period which depends on the data extracted. For the reanalysis, the accumulation period is over the 1 hour up to the validity date and time.

		For the ensemble members, ensemble mean and ensemble spread, the accumulation period is over the 3 hours up to the validity date and time. The units are joules per square metre (J m^{-2}). To convert to watts per square metre (W m^{-2}), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Surface solar radiation downwards	Jm^{-2}	This parameter is the amount of solar radiation (also known as shortwave radiation) that reaches a horizontal plane at the surface of the Earth. This parameter comprises both direct and diffuse solar radiation. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface (represented by this parameter). To a reasonably good approximation, this parameter is the model equivalent of what would be measured by a pyranometer (an instrument used for measuring solar radiation) at the surface. However, care should be taken when comparing model parameters with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box. This parameter is accumulated over a particular time period which depends on the data extracted. For the reanalysis, the accumulation period is over the 1 hour up to the validity date and time. For the ensemble members, ensemble mean and ensemble spread, the accumulation period is over the 3 hours up to the validity date and time. The units are joules per square metre (J m^{-2}). To convert to watts per square metre (W m^{-2}), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Forecast albedo	Dimension-less	This parameter is a measure of the reflectivity of the Earth's surface. It is the fraction of solar (shortwave) radiation reflected by Earth's surface, across the solar spectrum, for both direct and diffuse radiation. The values of this parameter can range between zero and one. Typically, snow and ice have high reflectivity with albedo values of 0.8 and

	above, land has intermediate values between about 0.1 and 0.4 and the ocean has low values of 0.1 or less. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The remainder is incident on the Earth's surface, where some of it is reflected. The portion that is reflected by the Earth's surface depends on the albedo. In the ECMWF Integrated Forecasting System (IFS), a climatological background albedo (observed values averaged over a period of several years) is used, modified by the model over water, ice and snow. Albedo is often shown as a percentage (%).

2.1. Data Download

The *ERA5-hourly data on single levels from 1979 to present* can be found in the GEOSS portal. To download the data the user will be forwarded to the Climate Data Store (CDS). Furthermore, the link to the ERA5 documentation can be found on the GEOSS Portal (Figure 2-1).

Instructions for how to download the ERA5 data sets via the CDS can be found on the ECMWF website. The user can choose between the Web Interface and the CDS API Service to retrieve the data. In a first step the user needs to create a CDS account. This can be done here.

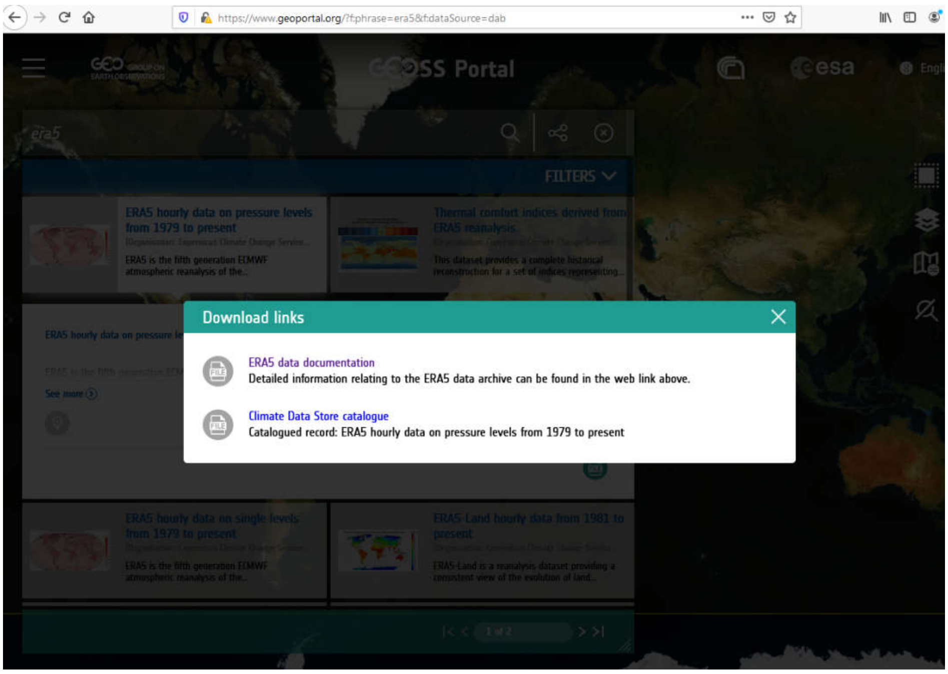

Figure 2-1: The GEOSS Portal gives links and information about the ERA5 data set and where it can be downloaded (Last request: july 2020).

2.1.1. CDS web interface

After creating a CDS account the user has to search for ERA5 in the search box of the C3S Climate Data Store. Figure 2-2 shows that the list of results contains 26 data sets. As already mentioned the *ERA5-hourly data on single levels from 1979 to present* data set was chosen as an example here. After selecting the desired data set, a side with detailed information appears (Figure 2-3).

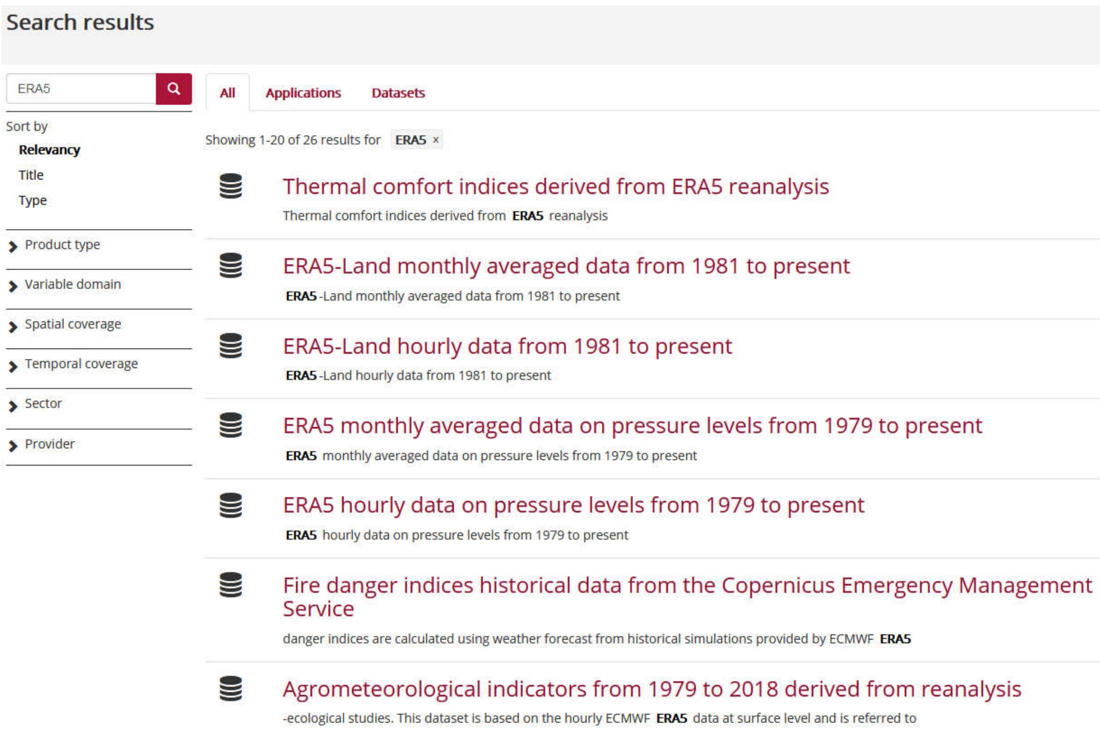

Figure 2-2: List of results of ERA5 data sets in the CDS.

The user can find there an overview of the data set, the documentation, and some examples and also contact and licence information. For getting the data the *Download data* tab is important now. By clicking on the *Download data* tab the user will find different boxes. Figure 2-4 shows some of the boxes. The user can select here different parameters that the data set should contain at the end. Those parameters include the product type, the variables, the year, month and day, the geographical area and the format of the data set. The user can choose between GRIB and NetCDF. The latter one works only when the request includes just one variable. If the required data set should contain more than one variable, the user has to choose the GRIB format.
If everything is selected, the data licenses must be accepted in terms of use. Now the download request can be sent via *Submit Form*. After the request has been processed, the Download button

appears. The selected ERA5 data can be downloaded now and the user is now ready to work further with the data.

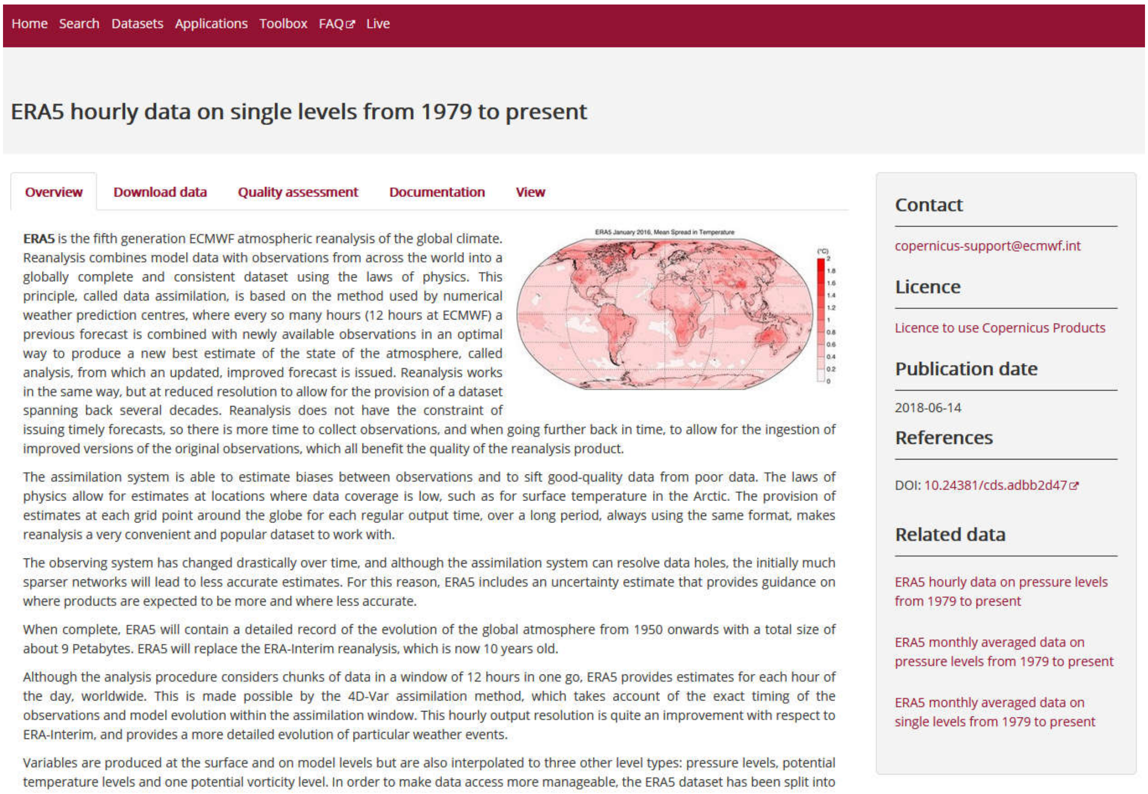

Figure 2-3: Information about the selected ERA5 data set that can be found at the [Website of the CDS](#) (Last request: july 2020).

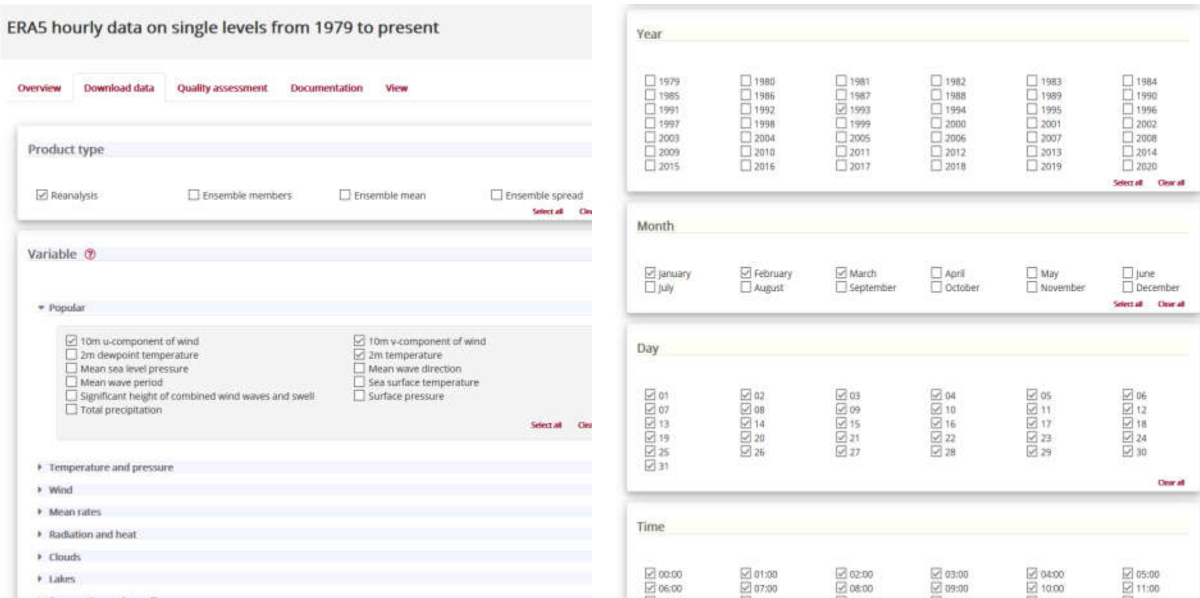

Figure 2-4: Downloading an ERA5 data set from the CDS. The web interface makes it easy to select the parameters that are needed.

2.1.2. CDS API

In addition to the CDS web interface it is also possible to use the CDS API for downloading ERA5 data with python scripts.
The first step here is to install the CDS API. Instructions on how to install it are available for linux, Windows and Mac users. The procedure for linux users will be explained now.
In the first step an empty file with the name *.cdsapirc* must be created in the user's home directory. The url and API key, which are individual for each user and which can be found by logging in to the CDS, need to be copied into this file. In the next step the *CDS API client*, which is a python based library, needs to be installed with *pip install cdsapi.* After installing the library the user is ready to request datasets from the CDS. The procedure is now almost the same as for the CDS web interface. The user has to select a data set from the CDS. In the next step, the user can select the desired parameters under the *Download Data* tab (Figure 2-3 and 2-4). At the bottom of this site the user will find the button *Show API request* (Figure 2-5).

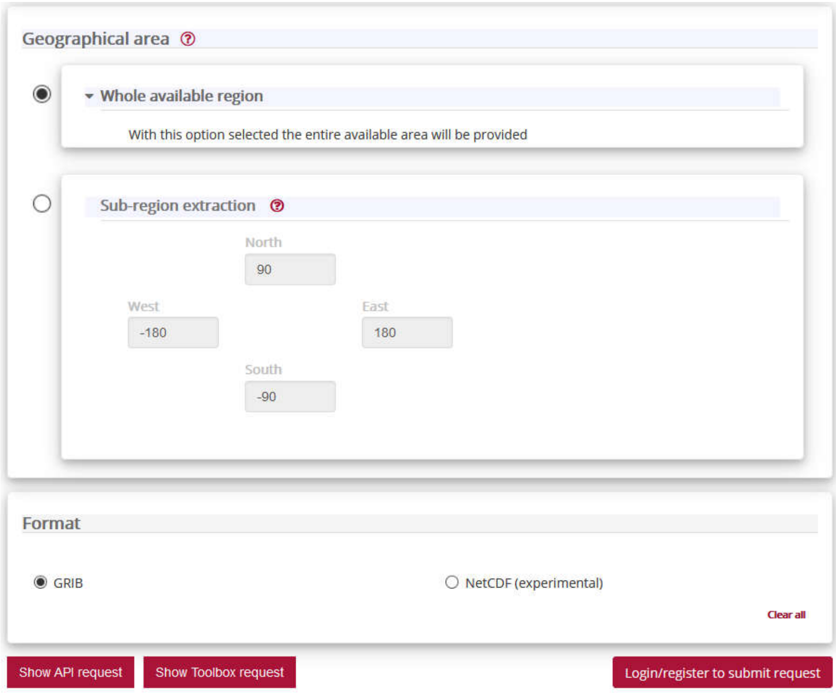

Figure 2-5: Downloading an ERA5 data set from the CDS. After selecting the needed parameters the API request can be created at the bottom of the website.

By clicking on that button the API request will be shown. This text needs to be copied into an empty file and saved as a *.py* file. By running this file with python you can download the data. An ERA5 API request example can be seen in Figure 2-6. The user can also create their own API by following the syntax in Figure 2-7. It is also necessary to agree to the Terms of Use when using the CDS API.

```
#!/usr/bin/envs/cdsapi python
import cdsapi

c = cdsapi.Client()

c.retrieve(
    'reanalysis-era5-single-levels',
    {
        'product_type': 'reanalysis',
        'variable': [
            '100m_u_component_of_wind', '100m_v_component_of_wind', '2m_temperature',
        ],
        'year': '1993',
        'month': [
            '01', '02', '03',
        ],
        'day': [
            '01', '02', '03',
            '04', '05', '06',
            '07', '08', '09',
            '10', '11', '12',
            '13', '14', '15',
        ],
        'time': [
            '00:00', '01:00', '02:00',
            '03:00', '04:00', '05:00',
            '06:00',
        ],
        'format': 'grib',
    },
    '/home/Data/ERA5/era5.grib')
```

Figure 2-6: Example for a CDS API request for the selected ERA5 data set.

```
import cdsapi
c = cdsapi.Client()

c.retrieve("dataset-short-name",
           {... sub-selection request ...},
           "target-file")
```

Figure 2-7: Syntax of the CDS API request (Copernicus Climate Data Store)

2.2. Converting GRIB to NetCDF

The ERA5 data can be downloaded as NetCDF or GRIB files. NetCDF can only be chosen when just one variable is required. In the case that the user wants to have several variables within one file than it is necessary to select the GRIB format. For further processing it is recommended to convert the GRIB file into NetCDF. This can be done with python. First install the *cfgrib package* with *pip install cfgrib* or *conda install –c conda-forge cfgrib*. (In the case that an error occurs, try to install this: *conda install –c conda-forge eccodes*). After installing the package, it is just needed to run the following lines:

```
import cfgrib
    ds = xr.open_dataset("era5_data.grib", engine="cfgrib")
    ds.to_netcdf("/home/place_to_save_nc/era5_data.nc")
```

The data are now converted to NetCDF. ECMWF lists on its website many other tools for working with GRIB data.

3. CAMS

In this Chapter the second and third data set, which are both products of CAMS, are presented. The Copernicus Atmosphere Monitoring Service (CAMS)) is a service that is implemented by the ECMWF and one of six services that form Copernicus. The Earth observation programme Copernicus has as a main goal to provide high quality information about the earth from satellite data, ground-based, airborne and seaborne measurements. More information about Copernicus can be found here. A short and compact description about CAMS and its different parts was written by Marion Schroedter-Homscheidt in the Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell (Schroedter-Homscheidt, The Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell 2018):

All-Sky Radiation Service in a nutshell

The atmosphere service of Copernicus combines state-of-the-art atmospheric modelling on aerosols with Earth observation data to provide information services covering European air quality, global atmospheric composition, climate, and UV and solar energy. The CAMS Radiation Service provides a fast parameterisation of the radiative transfer in the atmosphere (Fig. 3-1) and couples cloud-free sky parameters as aerosols, water vapour, and ozone with satellite-based cloud information (Fig. 3-2).

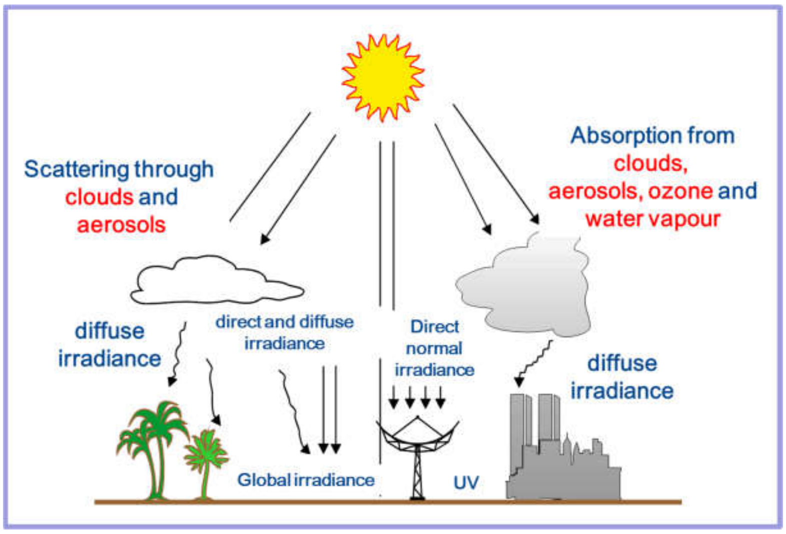

Figure 3-1: Principle of radiative transfer which is the basis of the CAMS Radiation Service

Within the radiation service, existing historical and daily updated databases HelioClim-3 and SOLEMI for monitoring incoming surface solar irradiance are further developed. The new service is jointly provided by DLR, Armines, and Transvalor. The Monitoring Atmospheric Composition and Climate (MACC) project series have been prepared for the service provision, which is now operational as part of the Copernicus programme.

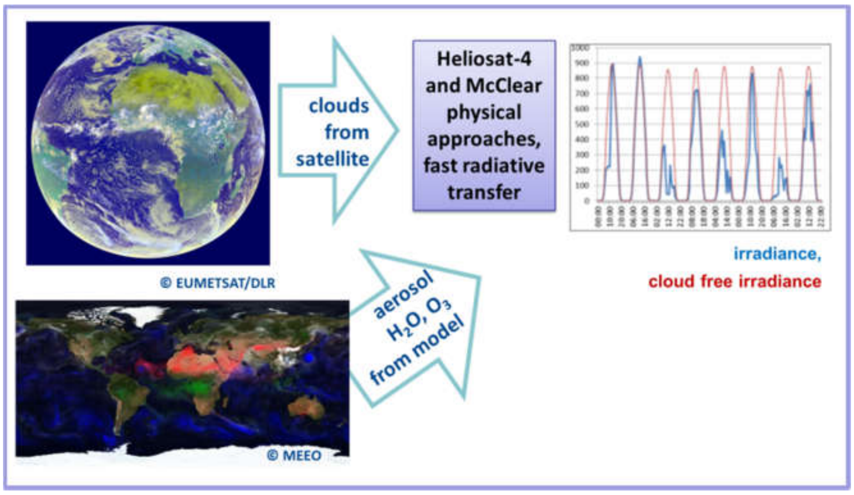

Figure 3-2: Combination of satellite-based cloud information with model based aerosol, water vapour and ozone information to derive time series of solar radiation at the surface in cloudy and cloud-free conditions.

Clear Sky Radiation Service in a nutshell

The fast clear-sky model called Copernicus McClear implements a fully physical modelling replacing empirical relations or simpler models used before. It exploits the recent results on aerosol properties and total column content in water vapour and ozone produced by the Copernicus service. It provides irradiances that would be observed in cloud-free conditions. Data are made available both via the Copernicus and the SoDa portal (Schroedter-Homscheidt, The Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell 2018).

The user can choose between two products from the radiation service which are the CAMS time series and the CAMS AGATE (Europe) and JADE (Africa) data sets. By choosing the time series the user gets the opportunity to determine the locations for which he wants the time series to be calculated by the CAMS Radiation Service. Furthermore the time steps, which are ranging from 1minute to 1month, can be selected by the user (Schroedter-Homscheidt, The Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell 2018).
The AGATE data set can be received at a fixed grid over Europe with a temporal resolution of 15minutes. Both data sets are described in more detail now Chapter 3.1 and 3.2.

3.1. Time Series

The CAMS time series consists mostly of radiation variables but it includes also all atmospheric input parameters used for clouds, aerosols, ozone, water vapour, non-bias corrected irradiation values and the surface reflective properties. Table 3-1 shows all the available variables.
The data cover Europe, Africa, the Atlantic Ocean and the Middle East (-66° to 66° in latitudes and longitudes). Within this area the user can define the locations for which he wants the time

series to be interpolated. Furthermore the user can choose the temporal resolution which is available for 1minute, 15minutes, 1hour, 1 day or 1 month. The temporal period spans the time from the 01.02.2004 up to two days ago (Schroedter-Homscheidt, User Guide to the CAMS Radiation Service (CRS) 2019). For further information of the time series have a look at the CAMS website.

Table 3-1: Variables of the CAMS time series

Variable name	**Abbreviation/ID**	**Unit**
Irradiation on horizontal plane at the top of atmosphere	TOA	Whm^{-2}
Clear sky global irradiation on horizontal plane at ground level	Clear sky GHI	Whm^{-2}
Clear sky beam irradiation on horizontal plane at ground level	Clear sky BHI	Whm^{-2}
Clear sky diffuse irradiation on horizontal plane at ground level	Clear sky DHI	Whm^{-2}
Clear sky beam irradiation on mobile plane following the sun at normal incidence	Clear sky BNI	Whm^{-2}
Global irradiation on horizontal plane at ground level	GHI	Whm^{-2}
Beam irradiation on horizontal plane at ground level	BHI	Whm^{-2}
Diffuse irradiation on horizontal plane at ground level	DHI	Whm^{-2}
Beam irradiation on mobile plane following the sun at normal incidence	BNI	Whm^{-2}
Proportion of reliable data in the summarization	Reliability	0-1
Solar zenithal angle for the middle of the summarization	sza	deg
1.0 means summer, 0.0 means winter	Summer/winter split	0,1
Total column content of ozone	tco3	Dobson unit
Total column content of water vapor	tcwv	Kgm^{-2}
Partial aerosol optical depth at 550 nm for	AOD BC	

black carbon		
Partial aerosol optical depth at 550 nm for dust	AOD DU	
Partial aerosol optical depth at 550 nm for sea salt	AOD SS	
Partial aerosol optical depth at 550 nm for organic matter	AOD OR	
Partial aerosol optical depth at 550 nm for sulphate	AOD SU	
Partial aerosol optical depth at 550 nm for nitrate	AOD NI	
Partial aerosol optical depth at 550 nm for ammonium	AOD AM	
Angstroem coefficient for aerosol	Alpha	
Ground albedo	Albedo	
value of the nearest acquisition time of the pixel	Cloud optical depth	
Cloud coverage of the pixel (percentage from 0 to 100, value of the nearest acquisition time of the pixel) -1=no value	Cloud coverage	Percentage
Cloud type (value of the nearest acquisition time of the pixel) -1=no value 0=no clouds 5=low-level cloud 6=medium-level cloud 7=high-level cloud 8=thin cloud	Cloud type	
Global irradiation without bias correction on horizontal plane at ground level	GHI no corr	Whm^{-2}
Beam irradiation without bias correction on horizontal plane at ground level	BHI no corr	Whm^{-2}
Diffuse irradiation without bias correction on horizontal plane at ground level	DHI no corr	Whm^{-2}
Beam irradiation without bias correction on mobile plane following the sun at normal incidence	BNI no corr	Whm^{-2}

3.1.1. Data Download

Downloading the time series of the CAMS radiation service is for free and requires only a registration on the website. Users need to agree to the CAMS data policy before sending a request. There a two options to get access to the data.

3.1.1.1. WPS

The first one is the WPS standard with which the user can invoke geospatial data. In this catalogue the services are described. If the user doesn't want to use that it is also possible to do it by hand as shown below:

curl -o output.xml -v -d @test_mcclear_params.xml -H "Content-Type: text/xml" http://www.soda-is.com/service/wps

or

curl -o output.xml -v -d @test_cams_radiation_params.xml -H "Content-Type: text/xml" http://www.soda-is.com/service/wps.

The output file *output.xml* contains the URL of the result. *Test_mcclear_params.xml* or *test_cams_radiation_params.xml* is the input file (Schroedter-Homscheidt, User Guide to the CAMS Radiation Service (CRS) 2019). The user has to select the inputs, which are the geographical coordinates of the site of interest, the elevation above sea-level of the requested site and the period of time. The User Guide to the CAMS Radiation Service (CRS) 2019 contains a more detailed description and the SoDa website provides more examples. Figure 3-3 shows one of those examples for the input curl.

3.1.1.2. WGET

The second option to download the data is wget which is a program for retrieving data (Schroedter-Homscheidt, User Guide to the CAMS Radiation Service (CRS) 2019). In a first step the user needs to download wget.exe into a directory. The second step is to create a text file in the same directory and copy-paste the following information in a single line:

**wget -O CAMS-radiation_Carpentras_2017-01-01_2017-01-05.csv http://www.soda-is.com/service/wps?Service=WPS&Request=Execute ...
&Identifier=get_cams_radiation&version=1.0.0&DataInputs=latitude=44.083;longitude=5.059;altitude=-999; ...
date_begin=2017-01-01;date_end=2017-01-05;time_ref=UT;summarization=PT15M;username=myemailaddress%%2540mycompany.com ...
&RawDataOutput=irradiation**

The green part needs to be the users email address. As already mentioned for the WPS the user also needs to define variables like latitude, longitude and time when using wget. The full list of variables that needs to be defined by the user and a more detailed description can be found at the SoDa Website. Due to safety and stability reasons every user has a restricted amount of 75 requests for the time series per day (MINES ParisTech 2020).


```xml
<?xml version="1.0" encoding="UTF-8" standalone="true"?>
- <wps:Execute xmlns:wps="http://www.opengis.net/wps/1.0.0" xsi:schemaLocation="http://www.opengis.net/wps/1.0.0 ../schemas/wps/1.0.0/wpsExecute_request.xsd"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:ows="http://www.opengis.net/ows/1.1" version="1.0.0" service="WPS">
    <ows:Identifier>get_cams_radiation</ows:Identifier>
  - <wps:DataInputs>
    - <wps:Input>
        <ows:Identifier>latitude</ows:Identifier>
      - <wps:Data>
          <wps:LiteralData>44.083</wps:LiteralData>
        </wps:Data>
      </wps:Input>
    - <wps:Input>
        <ows:Identifier>longitude</ows:Identifier>
      - <wps:Data>
          <wps:LiteralData>5.059</wps:LiteralData>
        </wps:Data>
      </wps:Input>
    - <wps:Input>
        <ows:Identifier>altitude</ows:Identifier>
      - <wps:Data>
          <wps:LiteralData>-999</wps:LiteralData>
        </wps:Data>
      </wps:Input>
    - <wps:Input>
        <ows:Identifier>date_begin</ows:Identifier>
      - <wps:Data>
          <wps:LiteralData>2017-01-01</wps:LiteralData>
        </wps:Data>
      </wps:Input>
    - <wps:Input>
        <ows:Identifier>date_end</ows:Identifier>
      - <wps:Data>
          <wps:LiteralData>2017-01-05</wps:LiteralData>
        </wps:Data>
      </wps:Input>
    - <wps:Input>
        <ows:Identifier>time_ref</ows:Identifier>
      - <wps:Data>
```


Figure 3-3: Example for a WPS Input request for a CAMS time series (MINES ParisTech 2020).

3.2. CAMS AGATE

The CAMS AGATE data set includes data on a fixed grid over Europe. The user can choose between eight radiation components:

- Global Horizontal Irradiation (GHI)
- Beam (direct) Horizontal Irradiation (BHI))
- Diffuse Horizontal Irradiation (DHI)
- Beam (direct) Normal Irradiation (BNI)
- Global Horizontal Irradiation in clear sky conditions (Gc)
- Beam (direct) Horizontal Irradiation in clear sky conditions (BHI)
- Diffuse Horizontal Irradiation in clear sky conditions (DHI)
- Beam (direct) Normal Irradiation in clear sky conditions (BNI)

The radiation components have a temporal resolution of 15minutes and span a temporal period of 2005 to 2018. There exists one hdf5 file per year for each component. The spatial resolution of the data is 0,2° (Schroedter-Homscheidt, The Copernicus Atmosphere Monitoring Service (CAMS) Radiation Service in a nutshell 2018). A more detailed description of AGATE can be found on the

SoDa website. Figure 3-4 shows the Global Horizontal Irradiation (GHI) over Europe for the 01.04.2005, which is one of the AGATE components.

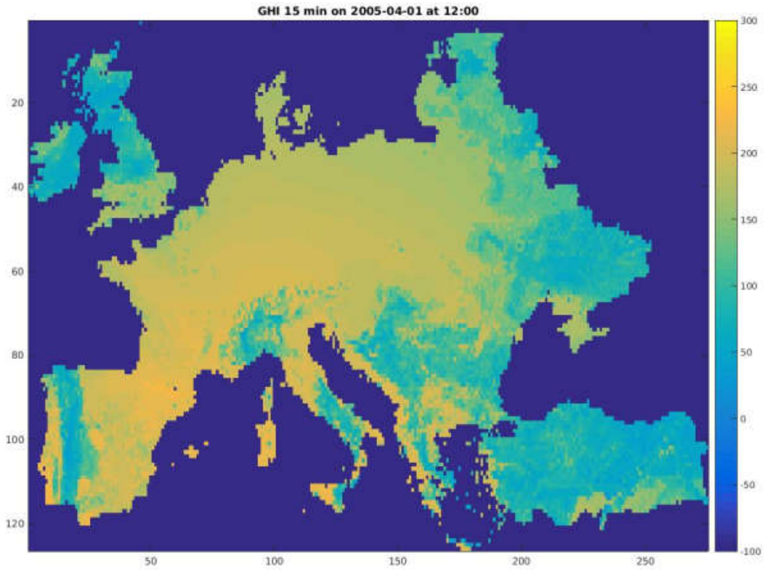

Figure 3-4: GHI on the 01.04.2005 from 11:45h to 12:00h from the AGATE data set. Values over the sea are not computed (MINES ParisTech 2019)

3.2.1. Data Download

The AGATE data set is available on the SoDa website. For retrieving the data the user needs to write an email-request to the following address: support-sales@soda-is.com. After sending the request the user will receive a link that comes with a username and a password which is valid for seven days. On the provided website the user will find one hdf5 file per year for each of the 8 variables. One file has a size of approximately 250MB.

4. ECMWF

The European Centre for Medium-Range Weather Forecasts (ECMWF), which is based in Reading, United Kingdom, is an independent intergovernmental organisation that is supported by 34 states. They have one of the largest supercomputer complexes in Europe and one of the largest archives of meteorological data in the world. On their supercomputer systems, ECMWF runs, among others, global numerical weather predictions (NWP) (ECMWF). The NWP model can be divided into two forecast types, deterministic and probabilistic forecasts. Chapter 4.1 deals with the first type, the deterministic ones. The probabilistic forecasts and examples of probabilistic forecasts from the ECMWF will be descripted in Chapter 4.2.

4.1. ECMWF deterministic forecasts

Numerical weather predictions have the goal to determine the state of the atmosphere for a point at a time in the future as accurate as possible. The quality of the NWP is dependent on many factors. One of them is the knowledge about the current condition of the atmosphere. This information will be used by a set of hydrodynamic equations that are combined with numerical methods within the NWP. Observations of wind, temperature, pressure and many other meteorological variables can describe the initial conditions best but they are not at all times and at every point on earth available. To get a good result anyway, the ECMWF is using data assimilation (ECMWF kein Datum). Observations and short-range forecasts are combined within the data assimilation to get the best possible initial atmospheric state. Within deterministic forecasts, the model uses only one initial state of the atmosphere to calculate one forecast for the weather of the future (J. L. Casado 2016)

4.1.1. HRES

The NWP model of ECMWF is called Integrated Forecast System (IFS) (ECMWF 2020). The deterministic product of this model is called High Resolution Forecast (HRES) and it provides a more detailed description of the future weather than the ENS which will be described in Chapter 4.2.1. HRES contains forecasts for up to 10 days with a spatial resolution of 9 km and 137 vertical levels. This high resolution, a very detailed orography and the good discrimination of land-sea differences are the advantages of HRES compared to ENS. On the other hand any individual forecast of HRES is mostly not as skilful as the results of the ENS member forecast (Owens, ECMWF Forecast User Guide - HRES - High-Resolution Forecast 2018).
The HRES product contains 4 forecast runs per day at 00, 06, 12 and 18 UTC. Energy modellers will probably find all the needed variables in this data set. Some of the meteorological variables that can be found in the HRES product are listed in Table 4-1 (Owens, ECMWF Forecast User Guide - HRES - High-Resolution Forecast 2018). A more detailed description of the HRES product and a complete list of the variables can be found on the ECMWF Website.

Compared to the CAMS and ERA5 data, the access to the HRES data is not completely open. For ECMWF members and their co-operating states historical forecasts which are older than 48 hours are available. To get access to the data the user needs a MARS account which can be obtained by contacting the Computing Representative (Simarro 2020).

Table 4-1: Meteorological variables which can be found in the HRES data set and which are suitable for energy modellers (ECMWF kein Datum).

Variable name	**Abbreviation/ID**	**Unit**
Albedo	al / 174	0-1
Soil type	slt/43	1-7
Total cloud cover	tcc/164	0-1
10 metre U-wind component	10u/165	ms^{-1}
10 metre V-wind-component	10v/166	ms^{-1}
100 metre U wind component	100u/228246	ms^{-1}
100 metre V wind component	100v/228247	ms^{-1}
200 metre U wind component	200u/228239	ms^{-1}
200 metre V wind component	200v/228240	ms^{-1}
Surface runoff	sro/8	m
Direct solar radiation	dsrp/47	Jm^{-2}
Downward UV radiation at the surface	uvb/57	Jm^{-2}
Surface net solar radiation	ssr/176	Jm^{-2}
Surface net solar radiation, clear sky	ssrc/210	Jm^{-2}

4.2. ECMWF probabilistic forecasts

The atmosphere as well as the ocean are no stable systems, quite the contrary, they are chaotic dynamical systems. This makes it difficult to make a precise forecast since already small changes can have a big impact. Deterministic forecasts have only one value as an output which makes it more difficult to reflect the chaotic system. Probabilistic forecast on the other hand are using several runs with slightly different initial conditions and have a probability as an output. This ensemble forecast allows modelling different states of the weather and makes the uncertainty of the forecast and the range that the future weather can have more visible to the user. Figure 4-1 illustrates that small differences in initial conditions of the ensemble can lead to large differences in the forecast of the weather (ECMWF kein Datum) (DWD kein Datum).

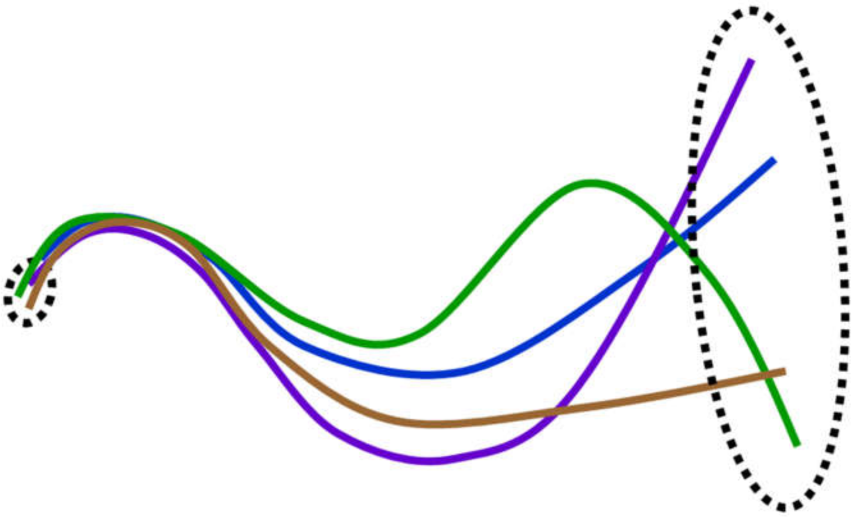

Figure 4-1: Ensemble of a probabilistic forecast. Small differences in the initial conditions can lead to big differences in the forecast due to the chaotic system of the atmosphere (DWD kein Datum).

4.2.1. ENS

The Ensemble forecast ENS is, as well as the HRES, a configuration of the IFS. The ENS consists of an ensemble of 51 forecasts and is run two times per day. One of the members is an unperturbed member, the control run (CTRL). The other 50 are perturbed members with perturbed initial states and model physics. This helps the user to see the range of uncertainty in the forecasts and to see the range that the possible future weather can have (Owens, ECMWF Forecast User Guide - ENS - Ensemble Forecast 2018).This is one of the biggest differences to the HRES. With a horizontal resolution of 18 km and 91 vertical levels it has a smaller resolution then HRES but the ENS has a forecasting horizon of 15 days. (Owens, ECMWF Forecast User Guide - ENS - Ensemble Forecast 2018). Energy modellers will find in the ENS data set, which is available in the GRIB format, the same variables of the atmospheric fields as in the HRES product (ECMWF kein Datum). The ENS product provides additional the probabilities of the occurrence of weather events at each grid point. The whole list of available variables can be found here. To access the ENS product the user needs, as well as for the HRES data, a MARS-account. ECMWF also provides data sets that are open accessible for the public without creating a MARS account. This will be explained in the next Chapter.

4.2.2. Public data sets

Not all of ECMWF products are accessible to the public but the user can also find open data sets that are easy to access. The list of public data sets contains many global reanalysis, like for example the ERA-Interim data but also regional reanalysis and atmospheric compositions. Forecast products can also be found in the list, like the TIGGE data. How users can download the public data sets will be explained on the TIGGE data in the next Chapter.

4.2.2.1. TIGGE

The International Grand Global Ensemble (TIGGE) is a public product from the ECMWF and is therefore accessible for every user. Ensemble forecasts from twelve global NWP centres, like UKMO and NCEP, are combined within the TIGGE data set since October 2006. This data set was developed within the world weather research programme THORPEX which was working on the improvements in the accuracy of 1- day to 2 week weather forecasts (Mladek, ECMWF - TIGGE archive - Description 2016).
Since this data set is open to the public the number of variables is smaller compared to HRES or ENS. Users find a smaller amount of radiation variables and only 10m but not 100m wind values in the TIGGE data but it is still an interesting data set for energy modellers (Mladek, ECMWF TIGGE archive - Parameters 2019). Table 4-2 shows all the variables that the user receives by downloading the TIGGE data.

Table 4-2: Variables of the TIGGE data set (Mladek, ECMWF TIGGE archive - Parameters 2019)

Variable name	Abbreviation	Unit
Geopotential height	gh	Gpm
Specific humidity	q	$Kgkg^{-1}$
Temperature	t	K
U-velocity	u	ms^{-1}
V-velocity	v	ms^{-1}
Potential vorticity	pv	$Km^2kg^{-1}s^{-1}$
10 meter u-velocity	10u	ms^{-1}
10 meter v-velocity	10v	ms^{-1}
Convective available potential energy	cape	Jkg^{-1}
Convective inhibition	ci	Jkg^{-1}
Field capacity	cap	kgm^{-3}
Land-sea mask	lsm	Proportion

Mean sea level pressure	msl	Pa
Orography	orog	gpm
Skin temperature	skt	K
Snow depth water equivalent	sd	kgm^{-2}
Snow fall water equivalent	sf	kgm^{-2}
Soil moisture	sm	kgm^{-3}
Soil temperature	st	K
Sunshine duration	sund	s
Surface air dew point temperature	2d	K
Surface air maximum temperature	mx2t6	K
Surface air minimum temperature	mn2t6	K
Surface air temperature	2t	K
Surface pressure	sp	Pa
Time-integrated outgoing long wave radiation	ttr	$Wm^{-2}s$
Time-integrated surface latent heat flux	slhf	$Wm^{-2}s$
Time-integrated surfacesolar radiaton	ssr	$Wm^{-2}s$
Time-integrated surface net thermal radiation	str	$Wm^{-2}s$
Time-integrated surface sensible heat flux	sshf	$Wm^{-2}s$
Total cloud cover	tcc	%
Total column water	tcw	kgm^{-2}
Total precipitation	tp	kgm^{-2}
Wilting point	wilt	kgm^{-3}

4.2.2.1.1. Data Download

The TIGGE data set can be found on the GEOSS-Portal as shown in Figure 4-2. To get access to the data the user first need to create an account on the ECWMF website. After the registration the data can be requested with an API. This is similar to the CDS API described in Chapter 2.1.2. In a first step the user needs to save an empty file in the Home directory as *.ecmwfapirc*. Into this file the user has to write his API key credentials which can be found here or here. The next step is to install the API client with *pip install ecmwf-api-client*. After installing the library the user is ready to request one of the public datasets. By choosing one dataset the user can select which kind of data is needed. Several parameters as the month of year, the amount of steps, the calculation times and also the variables can be selected. A small part of this selection side of the TIGGE data set is shown in Figure 4-3.
At the bottom of the side with the parameters the user finds two buttons. This can be seen in Figure 4-4. The first one is *Retrive GRIB*. By clicking on that one the user can directly download the data as a GRIB file. The second one says *View data retrieval request*. By clicking on this one the user will get the Python script for the request. This text needs to be copied and pasted into an empty file, which can be named for example *tigge.py*. It is important to change the target entry with the directory where the user want the data to be saved and the name that the data file should have at the end (Figure 4-5). This file needs to have the ending *.grib*, since the data have the GRIB format. Now the *tigge.py* file needs to be run within your ECMWF-API environment with *python tigge.py*. It can now take some time until the data are downloaded. On the ECMWF-Website the download process is also explained. Users can also find there script examples for the by ECMWF provided public data sets.

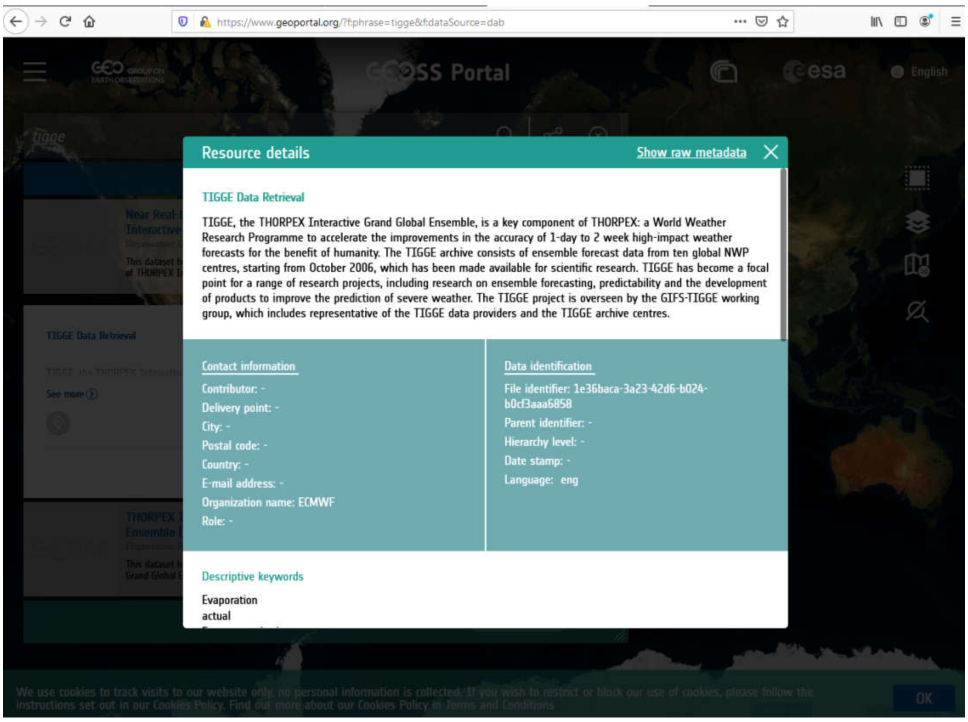

Figure 4-2: The TIGGE data set can be found in the GEOSS Portal.

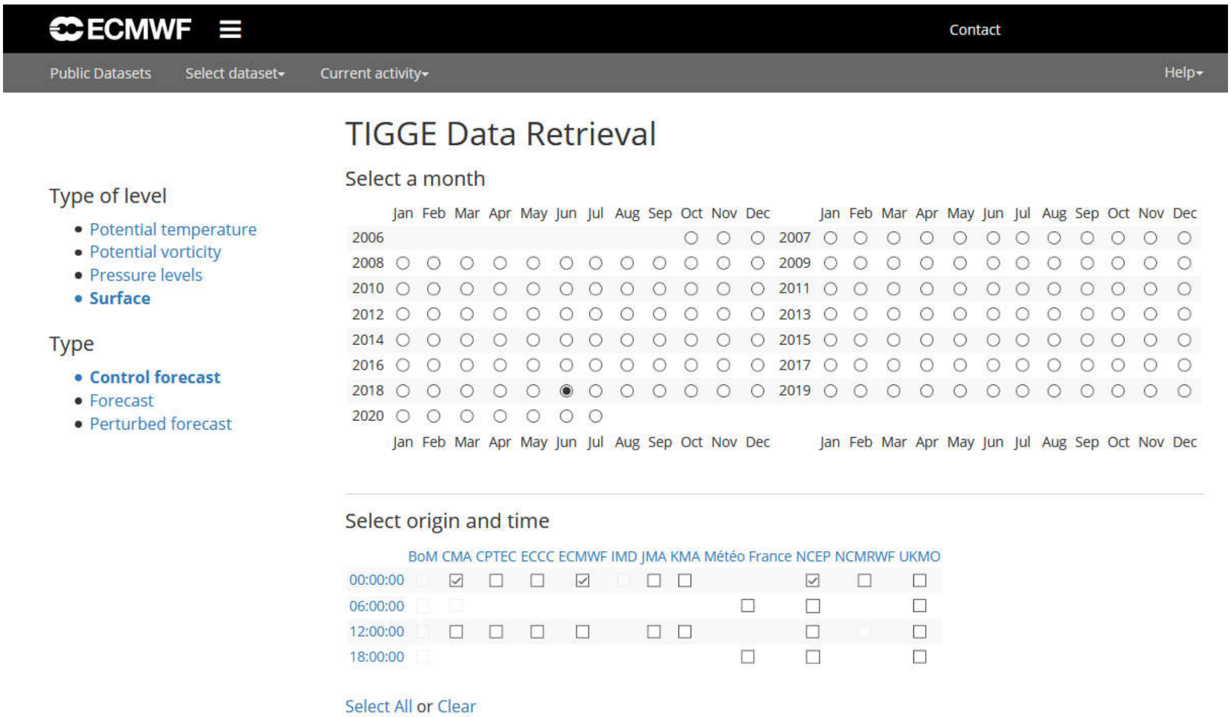

Figure 4-3: [Downloading TIGGE](#) data from ECMWF. Several parameters can be selected by the user.

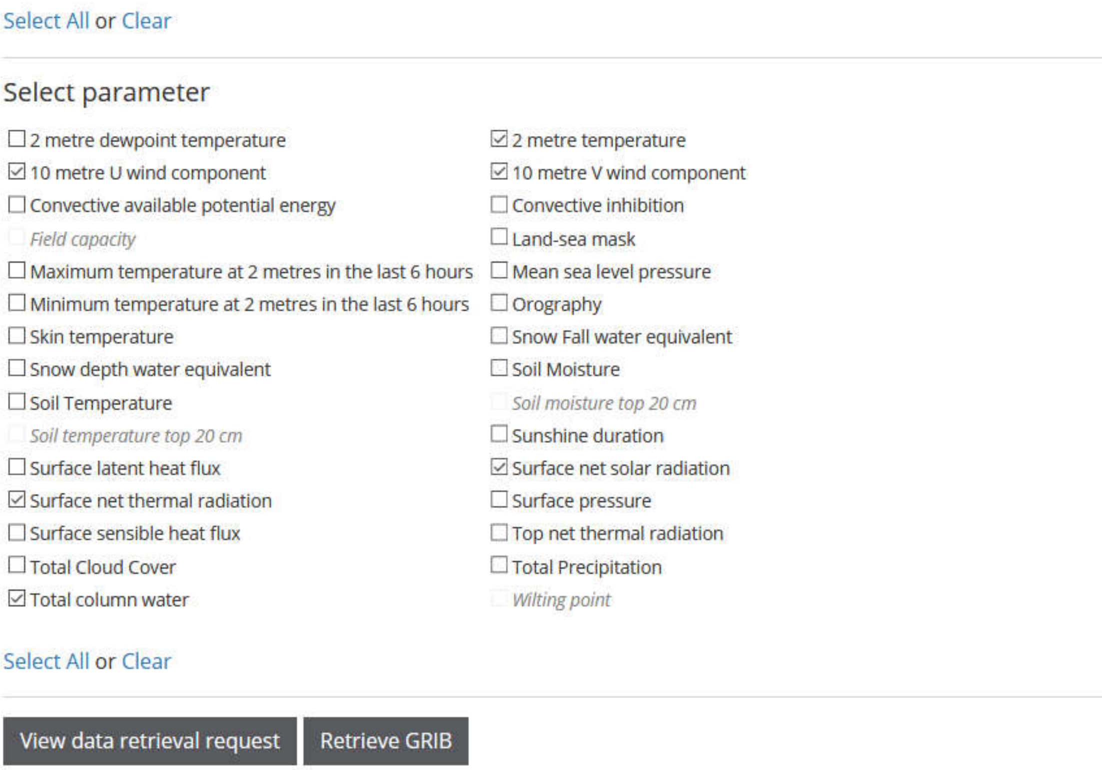

Figure 4-4: Downloading TIGGE data from ECMWF. After choosing the wanted parameters the user can download the data directly (Retrieve GRIB) or get the data retrieval request.

request

Estimated number of fields: 540

Python script MARS request

For more information on how to retrieve data programmatically, in Python, please go to Access ECMWF Public Datasets.

```
#!/usr/bin/env python
from ecmwfapi import ECMWFDataServer
server = ECMWFDataServer()
server.retrieve({
    "class": "ti",
    "dataset": "tigge",
    "date": "2018-06-01/to/2018-06-30",
    "expver": "prod",
    "grid": "0.5/0.5",
    "levtype": "sfc",
    "origin": "babj/ecmf/kwbc",
    "param": "136/165/166/167/176/177",
    "step": "24",
    "time": "00:00:00",
    "type": "cf",
    "target": "output",
})
```

Figure 4-5: Data retrieval request that the user gets by cklicking choosing *View data retrieval request* (Figure 4-4).

Register of illustrations

List of tables

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List of abbreviations

API .... *Application programming interface*
BHI .... *Beam Horizontal Irradiation*
BNI .... *Beam Normal Irradiation*
CAMS .... *Copernicus Atmosphere Monitoring Service*
CDS .... *Climate Data Store*
DHI .... *Diffuse Horizontal Irradiation*
ECMWF .... *Euopean Climate Weather Forecast*
ERA .... *EZMWF Re-Analysis*
GEO .... Group on Earth Observations
GEO DAB .... *GEO Discovery and Access Broker*
GEOSS .... *Global Earth Observation System of Systems*
GHI .... *Global Horizontal Irradiation*
HRES .... *High Resolution Forecast System*
IFS .... *Integrated Forecast System*
LOD-GEOSS .... *Linked open data GEOSS*
NWP .... *Numerical Weather Prediction*
WPS .... *Web Processing Service*