ERA5: data documentation

Last modified on Feb 19, 2024 16:53

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Introduction

Here, we document the ERA5 dataset, which covers the period from January 1940 to the present and continues to be extended forward in near real time. For up to date information on ERA5, please consult the C3S Announcements on the Copernicus user forum.

ERA5 is produced using 4D-Var data assimilation and model forecasts in CY41R2 of the ECMWF Integrated Forecast System (IFS), with 137 hybrid sigma/pressure (model) levels in the vertical and the top level at 0.01 hPa. Atmospheric data are available on these levels and they are also interpolated to 37 pressure, 16 potential temperature and 1 potential vorticity level(s) by FULL-POS in the IFS. "Surface or single level" data are also available, containing 2D parameters such as precipitation, top of atmosphere radiation and vertical integrals over the entire depth of the atmosphere. The atmospheric model in the IFS is coupled to a land-surface model (HTESSEL), which produces parameters such as 2m temperature and soil temperatures, and an ocean wave model (WAM), the parameters of which are also designated as "Surface or single level" parameters.

The ERA5 dataset contains one (hourly, 31 km) high resolution realisation (referred to as "reanalysis" or "HRES") and a reduced resolution ten member ensemble (referred to as "ensemble" or "EDA"). The ensemble is required for the data assimilation procedure, but as a by-product also provides an estimate of the **relative, random uncertainty**. Generally, the data are available at a sub-daily and monthly frequency and consist of **analyses** and short (18 hour) **forecasts**, initialised twice daily from analyses at 06 and 18 UTC. Most analysed parameters are also available from the forecasts. However, there are a number of forecast parameters, e.g. mean rates/fluxes and accumulations, that are not available from the analyses.

The data are archived in the ECMWF data archive (MARS) and a pertinent sub-set of the data, interpolated to a regular latitude/longitude grid, has been copied to the **C3S Climate Data Store (CDS) disks**. On the CDS disks, where single level and pressure level data are available, analyses are provided rather than forecasts, unless the parameter is only available from the forecasts. The interpolation software (MIR) was updated when the ERA5 production was moved to the new ATOS HPC on 24 October 2022.

ERA5.1 is a re-run of ERA5, for the years **2000 to 2006** only, and was produced to improve upon the cold bias in the lower stratosphere seen in ERA5 during this period.

The original ERA5 release contained data from 1979 onwards. The final ERA5 back extension for 1940-1978 has been produced and is available alongside the original/main release.

An ERA5 back extension 1950-1978 (Preliminary version) was produced. Although in many other respects the quality was relatively good, this preliminary data did suffer from excessively intense tropical cyclones. This dataset is now deprecated.

Data update frequency

Initial release data, i.e. data no more than three months behind real time, is called ERA5T.

Both for the CDS and MARS, daily updates for ERA5T are available about 5 days behind real time and monthly mean updates are available about 5 days after the end of the month.

> *The daily updates for ERA5T data on the CDS occur at no fixed time during the day. However, although it is not guaranteed, the D-5 data are typically available by 12UTC. We are working on reducing the variability of the update time.*

For the CDS, ERA5T data for a month is overwritten with the final ERA5 data about two months after the month in question.

For MARS, the final ERA5 data are available about two months after the month in question. In addition, the last few months of data are kept online and can be accessed much quicker than older data on tape.

In the event that serious flaws are detected in ERA5T, the latter could be different to the final ERA5 data. Based on experience with the production of ERA5 so far (and ERA-Interim in the past), our expectation is that such an event would not occur often. So far, it has only occurred once:

- from **1 September to 13 December 2021, the final ERA5 product is different to ERA5T** due to the correction of the assimilation of incorrect snow observations in central Asia. Although the differences are mostly limited to that region and mainly to surface parameters, in particular snow depth and soil moisture and to a lesser extent 2m temperature and 2m dewpoint temperature, all the resulting reanalysis fields can differ over the whole globe but should be within their range of uncertainty (which is estimated by the ensemble spread and which can be large for some parameters). On the CDS disks, the initial, ERA5T, fields have been overwritten (with the usual 2-3 month delay), i.e., for these months, access to the original CDS disk, ERA5T product is not possible after it has been overwritten. Potentially incorrect snow observations have been assimilated in ERA5 up to this time, when the effects became noticeable. The quality control of snow observations has been improved in ERA5 from September 2021 and from 15 November 2021 in ERA5T.

For the **hourly products on CDS disks** for both single and pressure levels, **some local differences** exist between ERA5 and ERA5T **for 1 to 24 October 2022 due to a change of the regridding software (MIR)** when the ERA5 production was changed from the Cray to ATOS. Differences are not meteorologically significant. For October 2022, there is no difference for the data in native resolution (ERA5-complete).

The IFS and data assimilation

For ERA5, the IFS documentation for CY41R2 should be used.

The twice daily, short (18 hour) forecasts are run from the 06 and 18 UTC analyses.

The 4D-Var data assimilation uses 12 hour windows from 09 UTC to 21 UTC and 21 UTC to 09 UTC (the following day).

The **model time step is 12 minutes for the HRES and 20 minutes for the EDA**, though occasionally these numbers are adjusted to cope with instabilities.

Data assimilation is a process whereby a model forecast is blended with observations to obtain the best fit to both the forecast and the observations, given the known uncertainties of both. The result is called an analysis (of the state of the atmosphere). For the atmospheric parameters in ERA5, the 4D-Variational (4D-Var) data assimilation windows are 12 hours long, commencing after the first 3 hours of the short forecasts. All the available observations within each 12 hour window are considered by the system, though some might be discarded for various reasons, such as quality control. Some of the parameters under the category "Surface or single level" parameters, are produced by the Land-surface scheme, which uses 1D and 2D Optimal Interpolation and Extended Kalman Filter, data assimilation. The ERA5 MARS archive contains both the analyses and short forecasts. On the CDS disks, where single level and pressure level data are available, analyses are provided rather than forecasts, unless the parameter is only available from the forecasts.

The above data assimilation process, or something similar, is performed for Numerical Weather Prediction (NWP), which provides real time forecasts (and analyses) for many purposes and applications. It would be tempting to use the data produced therein, for climate purposes. However, NWP systems are being improved on a regular basis - typically twice per year at ECMWF. Therefore, the NWP data contain various abrupt changes, due to system improvements, which are mixed in with changes in the climate. Reanalysis avoids this problem by using a fixed NWP system to "re-analyse" the state of the atmosphere for long periods in the past. It should be remembered, however, that spurious changes will still be included in the reanalysis, due to changes in the observing system. The ERA5 data assimilation and forecasting system was used operationally for NWP in 2016. Once this fixed system becomes too old, the reanalysis should be re-done with a more modern, fixed system. Although "reanalysis" suggests that only analyses are provided, the short forecasts are also made available, as noted above.

Data format

Model level parameters are archived in GRIB2 format. All other parameters are in GRIB1 unless otherwise indicated, see Parameter listings.

In the CDS, there is the option of retrieving the data in netCDF format.

For GRIB, ERA5T data can be identified by the key expver=0005 in the GRIB header. ERA5 data is identified by the key expver=0001.

For netCDF data requests which return just ERA5 or just ERA5T data, there is no means of differentiating between ERA5 and ERA5T data in the resulting netCDF files.

For netCDF data requests which return a mixture of ERA5 and ERA5T data, the origin of the variables (1 or 5) will be identifiable in the resulting netCDF files. See this link for more details.

Data organisation and how to download ERA5

The full ERA5 and ERA5T datasets are held in the ECMWF data archive (MARS) and a pertinent sub-set of these data, interpolated to a regular latitude /longitude grid, has been copied to the C3S Climate Data Store (CDS) disks. ERA5.1 is not available from the CDS disks, but is available from MARS (for advice on using ERA5.1 in conjunction with ERA5, CDS data, see "ERA5: mixing CDS and MARS data" in Guidelines). On the CDS disks, where most single level and pressure level parameters are available, analyses are provided rather than forecasts, unless the parameter is only available from the forecasts.

ERA5 (and recent ERA5T) data on the CDS disks can be downloaded either from the relevant CDS download page or using the CDS API.

Getting data from the CDS disks provides the fastest access to ERA5.

ERA5 data on the CDS disks can be downloaded either from the relevant CDS download page or, for larger data volumes in particular, using the CDS API. Subdivisions of the data are labelled using dataset and product_type.

Datasets **reanalysis-era5-single-levels** and **reanalysis-era5-pressure-levels** contain the following (sub-daily) product types:

- reanalysis
- ensemble_mean
- ensemble_spread
- ensemble_members

Datasets **reanalysis-era5-single-levels-monthly-means** and **reanalysis-era5-pressure-levels-monthly-means** contain the following (monthly) product types:

- monthly_averaged_reanalysis
- monthly_averaged_reanalysis_by_hour_of_day
- monthly_averaged_ensemble_members
- monthly_averaged_ensemble_members_by_hour_of_day

ERA5 data in MARS can be accessed using the CDS API, but access is relatively slow.

ERA5 data in MARS can be accessed with the CDS API by specifying dataset whereas member state users can access data in MARS by specifying class and expver, according to the following table:

	CDS API access to MARS **(specify the dataset)**	**Member state access to MARS** **(specify class and expver)**
ERA5	reanalysis-era5-complete	class=ea, expver=0001
ERA5.1	reanalysis-era5.1-complete	class=ea, expver=0051
ERA5T	reanalysis-era5-complete[1]	class=ea, expver=0005

[1]ERA5T data for a month is overwritten with the final ERA5 data about two months after the month in question.

Subdivisions of the data are labelled using the keywords stream, type and levtype:

Stream:

- oper (HRES sub-daily)
- wave (HRES sub-daily, for waves)
- mnth (HRES synoptic monthly means, ie by hour of day)
- moda (HRES monthly means of daily means)
- wamo (HRES synoptic monthly means, ie by hour of day, for waves)
- wamd (HRES monthly means of daily means, for waves)
- enda (EDA sub-daily)
- ewda (EDA sub-daily, for waves)
- edmm (EDA synoptic monthly means, ie by hour of day)
- edmo (EDA monthly means of daily means)
- ewmm (EDA synoptic monthly means, ie by hour of day, for waves)
- ewmo (EDA monthly means of daily means, for waves)

Type:

- an: analyses
- fc: forecasts
- em: ensemble mean
- es: ensemble standard deviation

Levtype:

- sfc: surface or single level
- pl: pressure levels
- pt: potential temperature levels
- pv: potential vorticity level
- ml: model levels

Documentation is available on How to download ERA5.

Date and time specification

In MARS: the date and time of the data is specified with three MARS keywords: date, time and (forecast) step. For analyses, step=0 hours so that date and time specify the analysis date/time. For forecasts, date and time specify the forecast start time and step specifies the number of hours since that start time. The combination of date, time and step defines the validity date/time. For analyses, the validity date/time is equal to the analysis date/time.

In the CDS: analyses are provided rather than forecasts, unless the parameter is only available from the forecasts. The date and time of the data is specified using the validity date/time, so step does not need to be specified. For forecasts, steps between 1 and 12 hours have been used to provide data for all the validity times in each 24 hours, see Table 0 below.

CDS date time	**MARS** date time step		**CDS** date time	**MARS** date time step
date 00	date-1 18 06		date 12	date 06 06
date 01	date-1 18 07		date 13	date 06 07
date 02	date-1 18 08		date 14	date 06 08
date 03	date-1 18 09		date 15	date 06 09
date 04	date-1 18 10		date 16	date 06 10
date 05	date-1 18 11		date 17	date 06 11
date 06	date-1 18 12		date 18	date 06 12
date 07	date 06 01		date 19	date 18 01
date 08	date 06 02		date 20	date 18 02
date 09	date 06 03		date 21	date 18 03
date 10	date 06 04		date 22	date 18 04
date 11	date 06 05		date 23	date 18 05

Temporal frequency

For sub-daily data for the HRES (stream=oper/wave) the analyses (type=an) are available hourly. The short forecasts, run twice daily from 06 and 18 UTC, provide hourly output forecast steps from 0 to 18 hours (only steps 1 to 12 hours are available on the CDS disks). For the EDA, the sub-daily non-wave data (stream=enda) are available every 3 hours but the sub-daily wave data (stream=ewda) are available hourly in MARS and 3 hourly on the CDS disks.

Spatial grid

The ERA5 HRES atmospheric data has a resolution of 31km, 0.28125 degrees, and the EDA has a resolution of 63km, 0.5625 degrees. (Depending on the parameter, the data are archived either as spectral coefficients with a triangular truncation of T639 (HRES) and T319 (EDA) or on a reduced Gaussian grid with a resolution of N320 (HRES) and N160 (EDA). These grids are so called "linear grids", sometimes referred to as TL639 (HRES) and TL319 (EDA).)

The wave data are produced and archived on a different grid to that of the atmospheric model, namely a reduced latitude/longitude grid with a resolution of 0.36 degrees (HRES) and 1.0 degree (EDA).

ERA5 data available from the CDS disks has been pre-interpolated to a regular latitude/longitude grid appropriate for that data.

The interpolation method is based on the MIR software. For the production on the Cray HPC (1 January 1940 to 24 October 2022 inclusive) this was an early version of MIR, while for the production on ATOS (25 October 2022 onwards) this is based on the MIR version of the ECMWF MARS client. Differences between both versions are in general small, very localized and not meteorologically significant. For data on pressure levels, differences are mainly limited to the exact north and south pole (90N and 90S). For single-level data, for some fields there are differences at the poles as well, while for some other fields, there are additional sets of isolated points with differences. In both cases this represents an improvement of the interpolation software.

The article Model grid box and time step might be useful.

Surface elevation datasets used by ERA5

In order to define the surface geopotential in ERA5, the IFS uses surface elevation data interpolated from a combination of SRTM30 and other surface elevation datasets. For more details please see the IFS documentation, Cycle 41r2, Part IV. Physical processes, section 11.2.2 Surface elevation data at 30 arc seconds.

Spatial reference systems and Earth model

The IFS assumes that the underlying shape of the Earth is a perfect sphere, of radius 6371.229 km, with the surface elevation specified relative to that sphere. The geodetic latitude/longitude of the surface elevation datasets are used as if they were the spherical latitude/longitude of the IFS.

ERA5 data is referenced in the horizontal with respect to the WGS84 ellipse (which defines the major/minor axes) and in the vertical it is referenced to the EGM96 geoid over land but over ocean it is referenced to mean sea level, with the approximation that this is assumed to be coincident with the geoid. For more information on the relationship between mean sea level and the geoid, see for example Gregory et al. (2019).

For data in GRIB1 format the earth model is a sphere with radius = 6367.47 km (note, this is inconsistent with what is actually used in the IFS),, as defined in the WMO GRIB Edition 1 specifications, Table 7, GDS Octet 17.

For data in GRIB2 format the earth model is a sphere with radius = 6371.2229 km (note, this is consistent with what is actually used in the IFS), as defined in the WMO GRIB2 specifications, section 2.2.1, Code Table 3.2, Code figure 6.

For data in NetCDF format (i.e. converted from the native GRIB format to NetCDF), the earth model is inherited from the GRIB data.

Production experiments

In order to speed up production, the historic ERA5 data was produced by running several parallel experiments which were then spliced together to form the final product.

A discontinuity can occur at the transition between the different experiments. Please see the Known issues for an example. The degree of discontinuity depends on how well the experiments were "spun-up". How well "spun-up" an experiment is, depends on the initial, chosen, state of the atmosphere and land surface at the beginning of the experiment, how long the experiment is run for, before being used for production, and the parameter(s) of interest - some parameters, such as those for the deeper soil and for the higher atmospheric levels, take longer to spin-up than others.

The information below gives the date ranges for the various production experiments (and hence the transition points) for the final version of ERA5 and also indicates when the computing system changed from the Cray to the ATOS.

Start date (YYYYMMDD)	Start time (UTC)	End date (YYYYMMDD)	End time (UTC)	Computing system
19400101	00	19431231	21	Cray
19431231	22	19481231	21	Cray
19481231	22	19531231	21	Cray
19531231	22	19581231	21	Cray
19581231	22	19631231	21	Cray
19631231	22	19681231	21	Cray
19681231	22	19731231	21	Cray
19731231	22	19781231	23	Cray
19790101	00	19810630	23	Cray
19810701	00	19860331	23	Cray
19860401	00	19880930	23	Cray
19881001	00	19930731	23	Cray
19930801	00	19950831	23	Cray
19950901	00	19991231	23	Cray
20000101	00	20000930	23	Cray
20001001	00	20010930	23	Cray
20011001	00	20020930	23	Cray
20021001	00	20030930	23	Cray
20031001	00	20040930	23	Cray
20041001	00	20050930	23	Cray
20051001	00	20060930	23	Cray
20061001	00	20071231	23	Cray

20080101	00	20091231	23	Cray
20100101	00	20141231	23	Cray
20150101	00	20190228	23	Cray
20190301	00	20210831	23	Cray
20210901	00	20211231	23	Cray
20220101	00	20221023	21	Cray
20221023	22	ongoing	ongoing	ATOS

Start date (YYYYMMDD)	Start time (UTC)	End date (YYYYMMDD)	End time (UTC)	Computing system
19400101	00	19431231	21	Cray
19440101	00	19481231	21	Cray
19490101	00	19531231	21	Cray
19540101	00	19581231	21	Cray
19590101	00	19631231	21	Cray
19640101	00	19681231	21	Cray
19690101	00	19731231	21	Cray
19740101	00	19781231	21	Cray
19790101	00	19860331	21	Cray
19860401	00	19930731	21	Cray
19930801	00	19991231	21	Cray
20000101	00	20091231	21	Cray
20100101	00	20141231	21	Cray
20150101	00	20190228	21	Cray
20190301	00	20210831	21	Cray
20210901	00	20211231	21	Cray
20220101	00	20221023	21	Cray
20221024	00	ongoing	ongoing	ATOS

Note, that forecasts start from the relevant analysis at the forecast start date/time, so the provenance of the whole of each forecast is the same as that of the analysis at the forecast start date/time.

Accuracy and uncertainty

ERA5 is produced using 4D-Var data assimilation and model forecasts in CY41R2 of the IFS. The 4D-Var in ERA5 utilises 12 hour assimilation windows from 9-21 UTC and 21-9 UTC, where the background forecast and all the observations falling within a time window are used to specify all the analyses during that window. However, the accuracy of the analyses is not uniform throughout each window. If the model and observations are unbiased and their errors follow Gaussian distributions and if the observations are homogeneous in space and time, then the analysis error will be smallest in the middle of the assimilation window. However, because none of these assumptions are actually true in the IFS, the particular parameter and location of interest are important, too. Knowing that, a careful study should show at which points during the assimilation windows the analysis is most accurate.

The 10 member ensemble is required for the data assimilation procedure. However, as a useful by-product, this ensemble also provides an estimate of the **relative, random uncertainty**. The "spread" of the 10 member ensemble, encapsulated by the standard deviation, provides a measure of this uncertainty and is larger for time periods and spatial locations where the uncertainty is relatively large and is smaller when and where there is more certainty in the analysed/forecast values. The spread is a measure of the relative uncertainty, so the numbers do not provide the absolute uncertainty. On the whole, the uncertainty becomes larger as you go back in time, when the observing system was not as good as in the present day, and in data sparse locations such as the pre-satellite era, southern hemisphere. In general, apart from that for the sea surface temperature, the spread does not represent systematic uncertainty, only random, or "synoptic", uncertainty. For more information, see ERA5: uncertainty estimation.

Instantaneous parameters

All the analysed parameters and many of the forecast parameters are described as "instantaneous". For more information on what instantaneous means, see Parameters valid at the specified time. Such instantaneous parameters may, or may not, have been averaged in time, to produce monthly means.

Mean rates/fluxes and accumulations

Such parameters, which are only available from forecasts, have undergone particular types of statistical processing (temporal mean or accumulation, respectively) over a period of time called the processing period. In addition, these parameters may, or may not, have been averaged in time, to produce monthly means.

The accumulations (over the accumulation/processing period) in the short forecasts (from 06 and 18 UTC) of ERA5 are treated **differently** compared with those in ERA-Interim and operational data (where the accumulations are from the beginning of the forecast to the validity date/time). In the short forecasts of ERA5, the accumulations are since the previous post processing (archiving), so for:

- reanalysis: accumulations are over the hour (the accumulation/processing period) ending at the validity date/time
- ensemble: accumulations are over the 3 hours (the accumulation/processing period) ending at the validity date/time
- Monthly means (of daily means, stream=moda/edmo): accumulations have been scaled to have an "effective" processing period of one day, see section Monthly means

Mean rate/flux parameters in ERA5 (e.g. Table 4 for surface and single levels) provide similar information to accumulations (e.g. Table 3 for surface and single levels), except they are expressed as temporal means, over the same processing periods, and so have units of "per second".

- **Mean rate/flux parameters are easier to deal with than accumulations because the units do not vary with the processing period.**
- The mean rate hydrological parameters (e.g. the "Mean total precipitation rate") have units of "kg m^{-2} s^{-1}", which are equivalent to "mm s^{-1}". They can be multiplied by 86400 seconds (24 hours) to convert to kg m^{-2} day^{-1} or mm day^{-1}.

Note that:

- For the CDS time, or validity time, of 00 UTC, the mean rates/fluxes and accumulations are over the hour (3 hours for the EDA) ending at 00 UTC i.e. the mean or accumulation is during part of the previous day.
- Mean rates/fluxes and accumulations are not available from the analyses.
- Mean rates/fluxes and accumulations at step=0 have values of zero because the length of the processing period is zero.

Minimum/maximum since the previous post processing

The short forecasts of ERA5 contain some surface and single level parameters that are the minimum or maximum value since the previous post processing (archiving), see Table 5 below. So, for:

- reanalysis: the minimum or maximum values are in the hour (the processing period) ending at the validity date/time
- ensemble: the minimum or maximum values are in the 3 hours (the processing period) ending at the validity date/time

Wave spectra

The ocean wave model used in ERA5 (WAM, which is included in the IFS) provides wave spectra with 24 directions and 30 frequencies (see "2D wave spectra (single)", Table 7).

Download from ERA5

ERA5 wave spectra data is not available from the CDS disks. However, it is available in MARS and can be accessed through the CDS API. For more information see Data organisation and how to download ERA5 and How to download ERA5 (Option B: Download ERA5 family data that is NOT listed in the CDS online catalogue - SLOW ACCESS.

Decoding 2D wave spectra in GRIB

To decode wave spectra in GRIB format we recommend ecCodes. Wave spectra are encoded in a specific way that other tools might not decode correctly.

In GRIB, the parameter is called 2d wave spectra (single) because in GRIB, the data are stored as a single global field per each spectral bin (a given frequency and direction), but in NetCDF, the fields are nicely recombined to produce a 2d matrix representing the discretized spectra at each grid point.

The wave spectra are encoded in GRIB using a local table specific to ECMWF. Because of this, the conversion of the meta data containing the information about the frequencies and the directions are not properly converted from GRIB to NetCDF format. So rather than having the actual values of the frequencies and directions, values show index numbers (1,1) : first frequency, first direction, (1,2) first frequency, second direction, etc ....

For ERA, because there are a total of 24 directions, the direction increment is 15 degrees with the first direction given by half the increment, namely 7.5 degree, where direction 0. means going towards the north and 90 towards the east (Oceanographic convention), or more precisely, this should be expressed in gradient since the spectra are in m^2 /(Hz radian)
The first frequency is 0.03453 Hz and the following ones are : f(n) = f(n-1)*1.1, n=2,30

Also note that it is NOT the spectral density that is encoded but rather log10 of it, so to recover the spectral density, expressed in m^2 /(radian Hz), one has to take the power 10 (10^) of the NON missing decoded values. Missing data are for all land points, but also, as part of the GRIB compression, all small values below a certain threshold have been discarded and so those missing spectral values are essentially 0. m^2 /(gradient Hz).

Decoding 2D wave spectra in NetCDF

The NetCDF wave spectra file will have the dimensions longitude, latitude, direction, frequency and time.

However, the direction and frequency bins are simply given as 1 to 24 and 1 to 30, respectively.

The direction bins start at 7.5 degree and increase by 15 degrees until 352.5, with 90 degree being towards the east (Oceanographic convention).

The frequency bins are non-linearly spaced. The first bin is 0.03453 Hz and the following bins are: f(n) = f(n-1)*1.1; n=2,30. The data provided is the log10 of spectra density. To obtain the spectral density one has to take to the power 10 (10 ** data). This will give the units 2D wave spectra as m**2 s radian**-1 . Very small values are discarded and set as missing values. These are essentially 0 m**2 s radian**-1.

This recoding can be done with the Python xarray package, for example:

```
import xarray as xr
import numpy as np
da = xr.open_dataarray('2d_spectra_201601.nc')
da = da.assign_coords(direction=np.arange(7.5, 352.5 + 15, 15))
da = da.assign_coords(frequency=np.full(30, 0.03453) * (1.1 ** np.arange(0, 30)))
da = 10 ** da
da = da.fillna(0)
da.to_netcdf(path='2d_spectra_201601_recoded.nc')
```

Units of 2D wave spectra

Once decoded, the units of 2D wave spectra are m^2 s $radian^{-1}$

Monthly means

In addition to the sub-daily data, most analysed and forecast parameters are also available as monthly means. For the surface and single level parameters, there are some exceptions which are listed in Table 8.

Monthly means are available in two forms:

- Synoptic monthly means, for each particular time and forecast step (stream=mnth/wamo/edmm/ewmm) - in the CDS, referred to as "monthly averaged by hour of day".
- Monthly means (of daily means, stream=moda/wamd/edmo/ewmo) for the month as a whole - in the CDS, referred to as "monthly averaged". These monthly means are created from all the hourly (3 hourly for the ensemble) data in the month.

Monthly means for:

- forecast parameters are created using the first 12 hours of the twice daily short forecasts (beginning at 06 and 18 UTC).
- analysis and instantaneous forecast parameters are created from data with a validity time in the month, between 00 and 23 UTC, which excludes the time 00 UTC on the first day of the following month.
- accumulation and mean rate/flux forecast parameters are created from data with processing periods that fall within the month.
- monthly means of daily means, for accumulations and mean rates/fluxes are created from contiguous data with processing periods spanning from 00 UTC on the first day of the month to 00 UTC on the first day of the following month i.e. they are accumulations or mean rates/fluxes for the complete, whole month.

The accumulations in monthly means (of daily means, stream=moda/edmo) have been scaled to have an "effective" processing period of one day, so for accumulations in these streams:

- The hydrological parameters have effective units of "m of water per day" and so they should be multiplied by 1000 to convert to $kgm^{-2}day^{-1}$ or $mmday^{-1}$.
- The energy (turbulent and radiative) and momentum fluxes should be divided by 86400 seconds (24 hours) to convert to the commonly used units of Wm^{-2} and Nm^{-2}, respectively.

Ensemble means and standard deviations

For the EDA sub-daily data (stream=enda/ewda), compared with HRES sub-daily data (stream=oper/wave), ensemble means and standard deviations (type=em/es) are also available. Both these quantities are calculated from all the 10-members (i.e., including the control).

Ensemble standard deviation is often referred to as ensemble spread and is calculated with respect to the ensemble mean. The ensemble standard deviation is not the sample stdv, so we divide by 10 rather than 9 (N-1).

Ensemble means and standard deviations contain analysed parameters when step=0, otherwise they contain forecast parameters. However, only surface and pressure level data (levtype=sfc/pl) contain forecast steps beyond 3 hours. There are no monthly means for ensemble means and standard deviations.

Level listings

Pressure levels (hPa): 1000/975/950/925/900/875/850/825/800/775/750/700/650/600/550/500/450/400/350/300/250/225/200/175/150/125/100/70/50/30/20/10/7/5/3/2/1

Potential temperature levels (K): 265/275/285/300/315/320/330/350/370/395/430/475/530/600/700/850

Potential vorticity level (10^{-9} K m^2 kg^{-1} s^{-1} or 10^{-3} PVU): 2000 (which is representative of the dynamical tropopause)

Model levels: 1/to/137, which are described at L137 model level definitions and ERA5: compute pressure and geopotential on model levels, geopotential height and geometric height. The model levels are hybrid pressure/sigma. For more information, see the documentation of the underlying model, ECMWF's IFS, CY41R2, Part III. Dynamics and numerical procedures, Chapter 2 Basic equations and discretisation.

Parameter listings

Tables 1-6 below describe the surface and single level parameters (levtype=sfc), Table 7 describes wave parameters, Table 8 describes the monthly mean exceptions for surface and single level and wave parameters and Tables 9-13 describe upper air parameters on various levtypes.

Information on all ECMWF parameters (e.g. columns shortName and paramId) is available from the ECMWF parameter database

Table 1: surface and single level parameters: invariants (in time)

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=sfc)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	Lake cover	(0 - 1)	lake_cover	cl	26	x	x
2	Lake depth	m	lake_depth	dl	228007	x	x
3	Low vegetation cover	(0 - 1)	low_vegetation_cover	cvl	27	x	
4	High vegetation cover	(0 - 1)	high_vegetation_cover	cvh	28	x	
5	Type of low vegetation	~	type_of_low_vegetation	tvl	29	x	
6	Type of high vegetation	~	type_of_high_vegetation	tvh	30	x	
7	Soil type[1]	~	soil_type	slt	43	x	
8	Standard deviation of filtered subgrid orography	m	standard_deviation_of_filtered_subgrid_orography	sdfor	74	x	
9	Geopotential	m**2 s**-2	geopotential	z	129	x	x
10	Standard deviation of sub-gridscale orography	~	standard_deviation_of_orography	sdor	160	x	
11	Anisotropy of sub-gridscale orography	~	anisotropy_of_sub_gridscale_orography	isor	161	x	
12	Angle of sub-gridscale orography	radians	angle_of_sub_gridscale_orography	anor	162	x	
13	Slope of sub-gridscale orography	~	slope_of_sub_gridscale_orography	slor	163	x	
14	Land-sea mask	(0 - 1)	land_sea_mask	lsm	172	x	x

[1]Soil type (texture) determines the saturation, field capacity and permanent wilting point at all the soil levels, see Table 8.9 in Chapter 8 Surface parametrization, Part IV Physical Processes of the IFS documentation (CY41R2 for ERA5).

Table 2: surface and single level parameters: instantaneous

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=sfc)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	Convective inhibition	J kg**-1	convective_inhibition	cin	228001		x
2	Friction velocity	m s**-1	friction_velocity	zust	228003		x
3	Lake mix-layer temperature	K	lake_mix_layer_temperature	lmlt	228008	x	x
4	Lake mix-layer depth	m	lake_mix_layer_depth	lmld	228009	x	x
5	Lake bottom temperature	K	lake_bottom_temperature	lblt	228010	x	x
6	Lake total layer temperature	K	lake_total_layer_temperature	ltlt	228011	x	x
7	Lake shape factor	dimensionless	lake_shape_factor	lshf	228012	x	x
8	Lake ice temperature	K	lake_ice_temperature	lict	228013	x	x
9	Lake ice depth	m	lake_ice_depth	licd	228014	x	x
10	UV visible albedo for direct radiation	(0 - 1)	uv_visible_albedo_for_direct_radiation	aluvp	15	x	x

11	Minimum vertical gradient of refractivity inside trapping layer	m**-1	minimum_vertical_gradient_of_refractivity_inside_trapping_layer	dndzn	228015		x
12	UV visible albedo for diffuse radiation	(0 - 1)	uv_visible_albedo_for_diffuse_radiation	aluvd	16	x	x
13	Mean vertical gradient of refractivity inside trapping layer	m**-1	mean_vertical_gradient_of_refractivity_inside_trapping_layer	dndza	228016		x
14	Near IR albedo for direct radiation	(0 - 1)	near_ir_albedo_for_direct_radiation	alnip	17	x	x
15	Duct base height	m	duct_base_height	dctb	228017		x
16	Near IR albedo for diffuse radiation	(0 - 1)	near_ir_albedo_for_diffuse_radiation	alnid	18	x	x
17	Trapping layer base height	m	trapping_layer_base_height	tplb	228018		x
18	Trapping layer top height	m	trapping_layer_top_height	tplt	228019		x
19	Cloud base height	m	cloud_base_height	cbh	228023		x
20	Zero degree level	m	zero_degree_level	deg0l	228024		x
21	Instantaneous 10 metre wind gust	m s**-1	instantaneous_10m_wind_gust	i10fg	228029		x
22	Sea ice area fraction	(0 - 1)	sea-ice_cover	ci	31	x	x
23	Snow albedo	(0 - 1)	snow_albedo	asn	32	x	x
24	Snow density	kg m**-3	snow_density	rsn	33	x	x
25	Sea surface temperature	K	sea_surface_temperature	sst	34	x	x
26	Ice temperature layer 1	K	ice_temperature_layer_1	istl1	35	x	x
27	Ice temperature layer 2	K	ice_temperature_layer_2	istl2	36	x	x
28	Ice temperature layer 3	K	ice_temperature_layer_3	istl3	37	x	x
29	Ice temperature layer 4	K	ice_temperature_layer_4	istl4	38	x	x
30	Volumetric soil water layer 1[1]	m**3 m**-3	volumetric_soil_water_layer_1	swvl1	39	x	x
31	Volumetric soil water layer 2[1]	m**3 m**-3	volumetric_soil_water_layer_2	swvl2	40	x	x
32	Volumetric soil water layer 3[1]	m**3 m**-3	volumetric_soil_water_layer_3	swvl3	41	x	x
33	Volumetric soil water layer 4[1]	m**3 m**-3	volumetric_soil_water_layer_4	swvl4	42	x	x
34	Convective available potential energy	J kg**-1	convective_available_potential_energy	cape	59	x	x
35	Leaf area index, low vegetation[3]	m**2 m**-2	leaf_area_index_low_vegetation	lai_lv	66	x	x
36	Leaf area index, high vegetation[3]	m**2 m**-2	leaf_area_index_high_vegetation	lai_hv	67	x	x
37	Neutral wind at 10 m u-component	m s**-1	10m_u-component_of_neutral_wind	u10n	228131	x	x
38	Neutral wind at 10 m v-component	m s**-1	10m_v-component_of_neutral_wind	v10n	228132	x	x
39	Surface pressure	Pa	surface_pressure	sp	134	x	x
40	Soil temperature level 1[1]	K	soil_temperature_level_1	stl1	139	x	x
41	Snow depth	m of water equivalent	snow_depth	sd	141	x	x
42	Charnock	~	charnock	chnk	148	x	x
43	Mean sea level pressure	Pa	mean_sea_level_pressure	msl	151	x	x
44	Boundary layer height	m	boundary_layer_height	blh	159	x	x
45	Total cloud cover	(0 - 1)	total_cloud_cover	tcc	164	x	x
46	10 metre U wind component	m s**-1	10m_u_component_of_wind	10u	165	x	x
47	10 metre V wind component	m s**-1	10m_v_component_of_wind	10v	166	x	x
48	2 metre temperature	K	2m_temperature	2t	167	x	x
49	2 metre dewpoint temperature	K	2m_dewpoint_temperature	2d	168	x	x
50	Soil temperature level 2[1]	K	soil_temperature_level_2	stl2	170	x	x
51	Soil temperature level 3[1]	K	soil_temperature_level_3	stl3	183	x	x
52	Low cloud cover	(0 - 1)	low_cloud_cover	lcc	186	x	x
53	Medium cloud cover	(0 - 1)	medium_cloud_cover	mcc	187	x	x
54	High cloud cover	(0 - 1)	high_cloud_cover	hcc	188	x	x
55	Skin reservoir content	m of water equivalent	skin_reservoir_content	src	198	x	x
56	Instantaneous large-scale surface precipitation fraction	(0 - 1)	instantaneous_large_scale_surface_precipitation_fraction	ilspf	228217		x
57	Convective rain rate	kg m**-2 s**-1	convective_rain_rate	crr	228218		x
58	Large scale rain rate	kg m**-2 s**-1	large_scale_rain_rate	lsrr	228219		x
59	Convective snowfall rate water equivalent	kg m**-2 s**-1	convective_snowfall_rate_water_equivalent	csfr	228220		x
60	Large scale snowfall rate water equivalent	kg m**-2 s**-1	large_scale_snowfall_rate_water_equivalent	lssfr	228221		x
61	Instantaneous eastward turbulent surface stress	N m**-2	instantaneous_eastward_turbulent_surface_stress	iews	229	x	x

62	Instantaneous northward turbulent surface stress	N m**-2	instantaneous_northward_turbulent_surface_stress	inss	230	x	x
63	Instantaneous surface sensible heat flux	W m**-2	instantaneous_surface_sensible_heat_flux	ishf	231	x	x
64	Instantaneous moisture flux	kg m**-2 s**-1	instantaneous_moisture_flux	ie	232	x	x
65	Skin temperature	K	skin_temperature	skt	235	x	x
66	Soil temperature level 4[1]	K	soil_temperature_level_4	stl4	236	x	x
67	Temperature of snow layer	K	temperature_of_snow_layer	tsn	238	x	x
68	Forecast albedo	(0 - 1)	forecast_albedo	fal	243	x	x
69	Forecast surface roughness	m	forecast_surface_roughness	fsr	244	x	x
70	Forecast logarithm of surface roughness for heat	~	forecast_logarithm_of_surface_roughness_for_heat	flsr	245	x	x
71	100 metre U wind component	m s**-1	100m_u-component_of_wind	100u	228246	x	x
72	100 metre V wind component	m s**-1	100m_v-component_of_wind	100v	228247	x	x
73	Precipitation type[2]	code table (4.201)	precipitation_type	ptype	260015		x
74	K index[2]	K	k_index	kx	260121		x
75	Total totals index[2]	K	total_totals_index	totalx	260123		x

Layer	Range
Layer 1	0 - 7 cm
Layer 2	7 - 28 cm
Layer 3	28 - 100 cm
Layer 4	100 - 289 cm

Please note that in GRIB1, the largest value which can be stored in 1 octet is 255, so the layer 4 bottom value is set to "missing" (rather than 289). Some software can therefore give incorrect values for the lower boundary of this layer (e.g. CDO reports the value as 255). Please see https://confluence.ecmwf.int/x/uqOGC for more details.

[2]GRIB2 format

[3]**Leaf Area Index (LAI)** parameters are based on a monthly climatology. Users will only see monthly variability, but not inter-annual variability.

Table 3: surface and single level parameters: accumulations

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=sfc)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	Large-scale precipitation fraction	s	large_scale_precipitation_fraction	lspf	50		x
2	Downward UV radiation at the surface	J m**-2	downward_uv_radiation_at_the_surface	uvb	57		x
3	Boundary layer dissipation	J m**-2	boundary_layer_dissipation	bld	145		x
4	Surface sensible heat flux	J m**-2	surface_sensible_heat_flux	sshf	146		x
5	Surface latent heat flux	J m**-2	surface_latent_heat_flux	slhf	147		x
6	Surface solar radiation downwards	J m**-2	surface_solar_radiation_downwards	ssrd	169		x
7	Surface thermal radiation downwards	J m**-2	surface_thermal_radiation_downwards	strd	175		x
8	Surface net solar radiation	J m**-2	surface_net_solar_radiation	ssr	176		x
9	Surface net thermal radiation	J m**-2	surface_net_thermal_radiation	str	177		x
10	Top net solar radiation	J m**-2	top_net_solar_radiation	tsr	178		x
11	Top net thermal radiation	J m**-2	top_net_thermal_radiation	ttr	179		x
12	Eastward turbulent surface stress	N m**-2 s	eastward_turbulent_surface_stress	ewss	180		x
13	Northward turbulent surface stress	N m**-2 s	northward_turbulent_surface_stress	nsss	181		x
14	Eastward gravity wave surface stress	N m**-2 s	eastward_gravity_wave_surface_stress	lgws	195		x
15	Northward gravity wave surface stress	N m**-2 s	northward_gravity_wave_surface_stress	mgws	196		x
16	Gravity wave dissipation	J m**-2	gravity_wave_dissipation	gwd	197		x
17	Top net solar radiation, clear sky	J m**-2	top_net_solar_radiation_clear_sky	tsrc	208		x
18	Top net thermal radiation, clear sky	J m**-2	top_net_thermal_radiation_clear_sky	ttrc	209		x
19	Surface net solar radiation, clear sky	J m**-2	surface_net_solar_radiation_clear_sky	ssrc	210		x
20	Surface net thermal radiation, clear sky	J m**-2	surface_net_thermal_radiation_clear_sky	strc	211		x

21	TOA incident solar radiation	J m**-2	toa_incident_solar_radiation	tisr	212		x
22	Vertically integrated moisture divergence	kg m**-2	vertically_integrated_moisture_divergence	vimd	213		x
23	Total sky direct solar radiation at surface	J m**-2	total_sky_direct_solar_radiation_at_surface	fdir	228021		x
24	Clear-sky direct solar radiation at surface	J m**-2	clear_sky_direct_solar_radiation_at_surface	cdir	228022		x
25	Surface solar radiation downward clear-sky	J m**-2	surface_solar_radiation_downward_clear_sky	ssrdc	228129		x
26	Surface thermal radiation downward clear-sky	J m**-2	surface_thermal_radiation_downward_clear_sky	strdc	228130		x
27	Surface runoff	m	surface_runoff	sro	8		x
28	Sub-surface runoff	m	sub_surface_runoff	ssro	9		x
29	Snow evaporation	m of water equivalent	snow_evaporation	es	44		x
30	Snowmelt	m of water equivalent	snowmelt	smlt	45		x
31	Large-scale precipitation	m	large_scale_precipitation	lsp	142		x
32	Convective precipitation	m	convective_precipitation	cp	143		x
33	Snowfall	m of water equivalent	snowfall	sf	144		x
34	Evaporation	m of water equivalent	evaporation	e	182		x
35	Runoff	m	runoff	ro	205		x
36	Total precipitation	m	total_precipitation	tp	228		x
37	Convective snowfall	m of water equivalent	convective_snowfall	csf	239		x
38	Large-scale snowfall	m of water equivalent	large_scale_snowfall	lsf	240		x
39	Potential evaporation	m	potential_evaporation	pev	228251		x

The accumulations in **monthly means of daily means (stream=moda/edmo)**, see monthly means, have been scaled to have units that include "per day", **so for accumulations in these streams:**

- Most hydrological parameters are in units of "m of water per day", so these should be multiplied by 1000 to convert to kg m^{-2} day^{-1} or mm day^{-1}.
- Energy (turbulent and radiative) and momentum fluxes should be divided by 86400 seconds (24 hours) to convert to the commonly used units of W m^{-2} and N m^{-2}, respectively.

Table 4: surface and single level parameters: mean rates/fluxes

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=sfc)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	Mean surface runoff rate	kg m**-2 s**-1	mean_surface_runoff_rate	msror	235020		x
2	Mean sub-surface runoff rate	kg m**-2 s**-1	mean_sub_surface_runoff_rate	mssror	235021		x
3	Mean snow evaporation rate	kg m**-2 s**-1	mean_snow_evaporation_rate	mser	235023		x
4	Mean snowmelt rate	kg m**-2 s**-1	mean_snowmelt_rate	msmr	235024		x
5	Mean large-scale precipitation fraction	Proportion	mean_large_scale_precipitation_fraction	mlspf	235026		x
6	Mean surface downward UV radiation flux	W m**-2	mean_surface_downward_uv_radiation_flux	msdwuvrf	235027		x
7	Mean large-scale precipitation rate	kg m**-2 s**-1	mean_large_scale_precipitation_rate	mlspr	235029		x
8	Mean convective precipitation rate	kg m**-2 s**-1	mean_convective_precipitation_rate	mcpr	235030		x
9	Mean snowfall rate	kg m**-2 s**-1	mean_snowfall_rate	msr	235031		x
10	Mean boundary layer dissipation	W m**-2	mean_boundary_layer_dissipation	mbld	235032		x
11	Mean surface sensible heat flux	W m**-2	mean_surface_sensible_heat_flux	msshf	235033		x
12	Mean surface latent heat flux	W m**-2	mean_surface_latent_heat_flux	mslhf	235034		x
13	Mean surface downward short-wave radiation flux	W m**-2	mean_surface_downward_short_wave_radiation_flux	msdwswrf	235035		x
14	Mean surface downward long-wave radiation flux	W m**-2	mean_surface_downward_long_wave_radiation_flux	msdwlwrf	235036		x
15	Mean surface net short-wave radiation flux	W m**-2	mean_surface_net_short_wave_radiation_flux	msnswrf	235037		x
16	Mean surface net long-wave radiation flux	W m**-2	mean_surface_net_long_wave_radiation_flux	msnlwrf	235038		x
17	Mean top net short-wave radiation flux	W m**-2	mean_top_net_short_wave_radiation_flux	mtnswrf	235039		x
18	Mean top net long-wave radiation flux	W m**-2	mean_top_net_long_wave_radiation_flux	mtnlwrf	235040		x
19	Mean eastward turbulent surface stress	N m**-2	mean_eastward_turbulent_surface_stress	metss	235041		x
20	Mean northward turbulent surface stress	N m**-2	mean_northward_turbulent_surface_stress	mntss	235042		x
21	Mean evaporation rate	kg m**-2 s**-1	mean_evaporation_rate	mer	235043		x

22	Mean eastward gravity wave surface stress	N m**-2	mean_eastward_gravity_wave_surface_stress	megwss	235045		x
23	Mean northward gravity wave surface stress	N m**-2	mean_northward_gravity_wave_surface_stress	mngwss	235046		x
24	Mean gravity wave dissipation	W m**-2	mean_gravity_wave_dissipation	mgwd	235047		x
25	Mean runoff rate	kg m**-2 s**-1	mean_runoff_rate	mror	235048		x
26	Mean top net short-wave radiation flux, clear sky	W m**-2	mean_top_net_short_wave_radiation_flux_clear_sky	mtnswrfcs	235049		x
27	Mean top net long-wave radiation flux, clear sky	W m**-2	mean_top_net_long_wave_radiation_flux_clear_sky	mtnlwrfcs	235050		x
28	Mean surface net short-wave radiation flux, clear sky	W m**-2	mean_surface_net_short_wave_radiation_flux_clear_sky	msnswrfcs	235051		x
29	Mean surface net long-wave radiation flux, clear sky	W m**-2	mean_surface_net_long_wave_radiation_flux_clear_sky	msnlwrfcs	235052		x
30	Mean top downward short-wave radiation flux	W m**-2	mean_top_downward_short_wave_radiation_flux	mtdwswrf	235053		x
31	Mean vertically integrated moisture divergence	kg m**-2 s**-1	mean_vertically_integrated_moisture_divergence	mvimd	235054		x
32	Mean total precipitation rate	kg m**-2 s**-1	mean_total_precipitation_rate	mtpr	235055		x
33	Mean convective snowfall rate	kg m**-2 s**-1	mean_convective_snowfall_rate	mcsr	235056		x
34	Mean large-scale snowfall rate	kg m**-2 s**-1	mean_large_scale_snowfall_rate	mlssr	235057		x
35	Mean surface direct short-wave radiation flux	W m**-2	mean_surface_direct_short_wave_radiation_flux	msdrswrf	235058		x
36	Mean surface direct short-wave radiation flux, clear sky	W m**-2	mean_surface_direct_short_wave_radiation_flux_clear_sky	msdrswrfcs	235059		x
37	Mean surface downward short-wave radiation flux, clear sky	W m**-2	mean_surface_downward_short_wave_radiation_flux_clear_sky	msdwswrfcs	235068		x
38	Mean surface downward long-wave radiation flux, clear sky	W m**-2	mean_surface_downward_long_wave_radiation_flux_clear_sky	msdwlwrfcs	235069		x
39	Mean potential evaporation rate	kg m**-2 s**-1	mean_potential_evaporation_rate	mper	235070		x

The mean rates/fluxes in Table 4 provide similar information to the accumulations in Table 3, except they are expressed as temporal averages, and so have units of "per second". The mean rate hydrological parameters have units of "kg m^{-2} s^{-1}" and so they can be multiplied by 86400 seconds (24 hours) to convert to kg m^{-2} day^{-1} or mm day^{-1}.

Table 5: surface and single level parameters: minimum/maximum

(stream=oper/enda, levtype=sfc)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	10 metre wind gust since previous post-processing	m s**-1	10m_wind_gust_since_previous_post_processing	10fg	49		x
2	Maximum temperature at 2 metres since previous post-processing	K	maximum_2m_temperature_since_previous_post_processing	mx2t	201		x
3	Minimum temperature at 2 metres since previous post-processing	K	minimum_2m_temperature_since_previous_post_processing	mn2t	202		x
4	Maximum total precipitation rate since previous post-processing	kg m**-2 s**-1	maximum_total_precipitation_rate_since_previous_post_processing	mxtpr	228226		x
5	Minimum total precipitation rate since previous post-processing	kg m**-2 s**-1	minimum_total_precipitation_rate_since_previous_post_processing	mntpr	228227		x

Table 6: surface and single level parameters: vertical integrals and total column: instantaneous

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=sfc - vertical integrals not available for type=em/es
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	Vertical integral of mass of atmosphere	kg m**-2	vertical_integral_of_mass_of_atmosphere	vima	162053	x	x
2	Vertical integral of temperature	K kg m**-2	vertical_integral_of_temperature	vit	162054	x	x
3	Vertical integral of kinetic energy	J m**-2	vertical_integral_of_kinetic_energy	vike	162059	x	x
4	Vertical integral of thermal energy	J m**-2	vertical_integral_of_thermal_energy	vithe	162060	x	x
5	Vertical integral of potential+internal energy	J m**-2	vertical_integral_of_potential_and_internal_energy	vipie	162061	x	x
6	Vertical integral of potential+internal+latent energy	J m**-2	vertical_integral_of_potential_internal_and_latent_energy	vipile	162062	x	x
7	Vertical integral of total energy	J m**-2	vertical_integral_of_total_energy	vitoe	162063	x	x
8	Vertical integral of energy conversion	W m**-2	vertical_integral_of_energy_conversion	viec	162064	x	x

9	Vertical integral of eastward mass flux	kg m**-1 s**-1	vertical_integral_of_eastward_mass_flux	vimae	162065	x	x
10	Vertical integral of northward mass flux	kg m**-1 s**-1	vertical_integral_of_northward_mass_flux	viman	162066	x	x
11	Vertical integral of eastward kinetic energy flux	W m**-1	vertical_integral_of_eastward_kinetic_energy_flux	vikee	162067	x	x
12	Vertical integral of northward kinetic energy flux	W m**-1	vertical_integral_of_northward_kinetic_energy_flux	viken	162068	x	x
13	Vertical integral of eastward heat flux	W m**-1	vertical_integral_of_eastward_heat_flux	vithee	162069	x	x
14	Vertical integral of northward heat flux	W m**-1	vertical_integral_of_northward_heat_flux	vithen	162070	x	x
15	Vertical integral of eastward water vapour flux	kg m**-1 s**-1	vertical_integral_of_eastward_water_vapour_flux	viwve	162071	x	x
16	Vertical integral of northward water vapour flux	kg m**-1 s**-1	vertical_integral_of_northward_water_vapour_flux	viwvn	162072	x	x
17	Vertical integral of eastward geopotential flux	W m**-1	vertical_integral_of_eastward_geopotential_flux	vige	162073	x	x
18	Vertical integral of northward geopotential flux	W m**-1	vertical_integral_of_northward_geopotential_flux	vign	162074	x	x
19	Vertical integral of eastward total energy flux	W m**-1	vertical_integral_of_eastward_total_energy_flux	vitoee	162075	x	x
20	Vertical integral of northward total energy flux	W m**-1	vertical_integral_of_northward_total_energy_flux	vitoen	162076	x	x
21	Vertical integral of eastward ozone flux	kg m**-1 s**-1	vertical_integral_of_eastward_ozone_flux	vioze	162077	x	x
22	Vertical integral of northward ozone flux	kg m**-1 s**-1	vertical_integral_of_northward_ozone_flux	viozn	162078	x	x
23	Vertical integral of divergence of cloud liquid water flux	kg m**-2 s**-1	vertical_integral_of_divergence_of_cloud_liquid_water_flux	vilwd	162079	x	x
24	Vertical integral of divergence of cloud frozen water flux	kg m**-2 s**-1	vertical_integral_of_divergence_of_cloud_frozen_water_flux	viiwd	162080	x	x
25	Vertical integral of divergence of mass flux	kg m**-2 s**-1	vertical_integral_of_divergence_of_mass_flux	vimad	162081	x	x
26	Vertical integral of divergence of kinetic energy flux	W m**-2	vertical_integral_of_divergence_of_kinetic_energy_flux	viked	162082	x	x
27	Vertical integral of divergence of thermal energy flux	W m**-2	vertical_integral_of_divergence_of_thermal_energy_flux	vithed	162083	x	x
28	Vertical integral of divergence of moisture flux	kg m**-2 s**-1	vertical_integral_of_divergence_of_moisture_flux	viwvd	162084	x	x
29	Vertical integral of divergence of geopotential flux	W m**-2	vertical_integral_of_divergence_of_geopotential_flux	vigd	162085	x	x
30	Vertical integral of divergence of total energy flux	W m**-2	vertical_integral_of_divergence_of_total_energy_flux	vitoed	162086	x	x
31	Vertical integral of divergence of ozone flux	kg m**-2 s**-1	vertical_integral_of_divergence_of_ozone_flux	viozd	162087	x	x
32	Vertical integral of eastward cloud liquid water flux	kg m**-1 s**-1	vertical_integral_of_eastward_cloud_liquid_water_flux	vilwe	162088	x	x
33	Vertical integral of northward cloud liquid water flux	kg m**-1 s**-1	vertical_integral_of_northward_cloud_liquid_water_flux	vilwn	162089	x	x
34	Vertical integral of eastward cloud frozen water flux	kg m**-1 s**-1	vertical_integral_of_eastward_cloud_frozen_water_flux	viiwe	162090	x	x
35	Vertical integral of northward cloud frozen water flux	kg m**-1 s**-1	vertical_integral_of_northward_cloud_frozen_water_flux	viiwn	162091	x	x
36	Vertical integral of mass tendency	kg m**-2 s**-1	vertical_integral_of_mass_tendency	vimat	162092	x	
37	Total column cloud liquid water	kg m**-2	total_column_cloud_liquid_water	tclw	78	x	x
38	Total column cloud ice water	kg m**-2	total_column_cloud_ice_water	tciw	79	x	x
39	Total column supercooled liquid water	kg m**-2	total_column_supercooled_liquid_water	tcslw	228088		x
40	Total column rain water	kg m**-2	total_column_rain_water	tcrw	228089	x	x
41	Total column snow water	kg m**-2	total_column_snow_water	tcsw	228090	x	x
42	Total column water	kg m**-2	total_column_water	tcw	136	x	x
43	Total column water vapour	kg m**-2	total_column_water_vapour	tcwv	137	x	x
44	Total column ozone	kg m**-2	total_column_ozone	tco3	206	x	x

Table 7: wave parameters: instantaneous

(stream=wave/ewda/wamo/wamd/ewmm/ewmo)
(The native grid is the reduced latitude/longitude grid of 0.36 degrees (1.0 degree for the EDA))

count	name	units	Variable name in CDS	shortName	paramId	an	fc

1	Significant wave height of first swell partition	m	significant_wave_height_of_first_swell_partition	swh1	140121	x	x
2	Mean wave direction of first swell partition	degrees	mean_wave_direction_of_first_swell_partition	mwd1	140122	x	x
3	Mean wave period of first swell partition	s	mean_wave_period_of_first_swell_partition	mwp1	140123	x	x
4	Significant wave height of second swell partition	m	significant_wave_height_of_second_swell_partition	swh2	140124	x	x
5	Mean wave direction of second swell partition	degrees	mean_wave_period_of_second_swell_partition	mwd2	140125	x	x
6	Mean wave period of second swell partition	s	mean_wave_period_of_second_swell_partition	mwp2	140126	x	x
7	Significant wave height of third swell partition	m	significant_wave_height_of_third_swell_partition	swh3	140127	x	x
8	Mean wave direction of third swell partition	degrees	mean_wave_direction_of_third_swell_partition	mwd3	140128	x	x
9	Mean wave period of third swell partition	s	mean_wave_period_of_third_swell_partition	mwp3	140129	x	x
10	Wave Spectral Skewness	dimensionless	wave_spectral_skewness	wss	140207	x	x
11	Free convective velocity over the oceans	m s**-1	free_convective_velocity_over_the_oceans	wstar	140208	x	x
12	Air density over the oceans	kg m**-3	air_density_over_the_oceans	rhoao	140209	x	x
13	Normalized energy flux into waves	dimensionless	normalized_energy_flux_into_waves	phiaw	140211	x	x
14	Normalized energy flux into ocean	dimensionless	normalized_energy_flux_into_ocean	phioc	140212	x	x
15	Normalized stress into ocean	dimensionless	normalized_stress_into_ocean	tauoc	140214	x	x
16	U-component stokes drift	m s**-1	u_component_stokes_drift	ust	140215	x	x
17	V-component stokes drift	m s**-1	v_component_stokes_drift	vst	140216	x	x
18	Period corresponding to maximum individual wave height	s	period_corresponding_to_maximum_individual_wave_height	tmax	140217	x	x
19	Maximum individual wave height	m	maximum_individual_wave_height	hmax	140218	x	x
20	Model bathymetry	m	model_bathymetry	wmb	140219	x	x
21	Mean wave period based on first moment	s	mean_wave_period_based_on_first_moment	mp1	140220	x	x
22	Mean zero-crossing wave period	s	mean_zero_crossing_wave_period	mp2	140221	x	x
23	Wave spectral directional width	Radians	wave_spectral_directional_width	wdw	140222	x	x

24	Mean wave period based on first moment for wind waves	s	mean_wave_period_based_on_first_moment_for_wind_waves	p1ww	140223	x	x
25	Mean wave period based on second moment for wind waves	s	mean_wave_period_based_on_second_moment_for_wind_waves	p2ww	140224	x	x
26	Wave spectral directional width for wind waves	Radians	wave_spectral_directional_width_for_wind_waves	dwww	140225	x	x
27	Mean wave period based on first moment for swell	s	mean_wave_period_based_on_first_moment_for_swell	p1ps	140226	x	x
28	Mean wave period based on second moment for swell	s	mean_wave_period_based_on_second_moment_for_wind_waves	p2ps	140227	x	x
29	Wave spectral directional width for swell	Radians	wave_spectral_directional_width_for_swell	dwps	140228	x	x
30	Significant height of combined wind waves and swell	m	significant_height_of_combined_wind_waves_and_swell	swh	140229	x	x
31	Mean wave direction	degrees	mean_wave_direction	mwd	140230	x	x
32	Peak wave period	s	peak_wave_period	pp1d	140231	x	x
33	Mean wave period	s	mean_wave_period	mwp	140232	x	x
34	Coefficient of drag with waves	dimensionless	coefficient_of_drag_with_waves	cdww	140233	x	x
35	Significant height of wind waves	m	significant_height_of_wind_waves	shww	140234	x	x
36	Mean direction of wind waves	degrees	mean_direction_of_wind_waves	mdww	140235	x	x
37	Mean period of wind waves	s	mean_period_of_wind_waves	mpww	140236	x	x
38	Significant height of total swell	m	significant_height_of_total_swell	shts	140237	x	x
39	Mean direction of total swell	degrees	mean_direction_of_total_swell	mdts	140238	x	x
40	Mean period of total swell	s	mean_period_of_total_swell	mpts	140239	x	x
41	Mean square slope of waves	dimensionless	mean_square_slope_of_waves	msqs	140244	x	x

42	This 10m wind parameter is the wind speed that has been used by the wave model, which is coupled to the atmospheric model. For this reason: • it is archived on the wave model's native grid, with the same land-sea mask as that model. Therefore, this parameter is not defined over land and wherever else the wave model is not defined, where it is encoded as missing data. Improper decoding of the missing value usually results in very large values being given for these land points. • the wave model resets all values below 2 m/s to 2m/s. The reason for this is that as the winds become weak, the long waves (swell) try to drive the wind from below but this is not modelled in the IFS, as it assumes that the wind profile should be logarithmic (+- stability correction). To account for this effect, the whole of the boundary layer scheme would need to be revised. A simple trick to avoid the problem is to boost the weak winds to 2m/s, which is outside the range where the waves can potentially drive the wind. • this parameter is actually the 10m neutral wind speed as determined from the atmospheric surface stress (see documentation on Ocean Wave model output parameters). • If wave altimeter data were assimilated, the analysis of this parameter also contains wind speed updates that come directly out of the wave height updates. This parameter should not be used for looking at the quality of reanalysis surface wind - the u and v components of the 10m wind (atmospheric parameters 165 and 166) should be used instead.	m s**-1	ocean_surface_stress_equivalent_10m_neutral_wind_speed	wind	140245	x	x
43	10 metre wind direction	degrees	ocean_surface_stress_equivalent_10m_neutral_wind_direction	dwi	140249	x	x
44	Wave spectral kurtosis	dimensionless	wave_spectral_kurtosis	wsk	140252	x	x
45	Benjamin-Feir index	dimensionless	benjamin_feir_index	bfi	140253	x	x
46	Wave spectral peakedness	dimensionless	wave_spectral_peakedness	wsp	140254	x	x
47	Altimeter wave height	m	Not available from the CDS disks	awh	140246	x	
48	Altimeter corrected wave height	m	Not available from the CDS disks	acwh	140247	x	
49	Altimeter range relative correction	~	Not available from the CDS disks	arrc	140248	x	
50	2D wave spectra (single)[1]	m**2 s radian**-1	Not available from the CDS disks	2dfd	140251	x	

[1] for 30 frequencies and 24 directions

Table 8: monthly mean surface and single level and wave parameters: exceptions from Tables 1-7

(stream=mnth/moda/edmm/edmo, levtype=sfc or wamo/wamd/ewmm/ewmo)

count	name	units	Variable name in CDS	shortName	paramId	an	fc
1	UV visible albedo for direct radiation	(0 - 1)	uv_visible_albedo_for_direct_radiation	aluvp	15	x	no mean
2	UV visible albedo for diffuse radiation	(0 - 1)	uv_visible_albedo_for_diffuse_radiation	aluvd	16	x	no mean
3	Near IR albedo for direct radiation	(0 - 1)	near_ir_albedo_for_direct_radiation	alnip	17	x	no mean
4	Near IR albedo for diffuse radiation	(0 - 1)	near_ir_albedo_for_diffuse_radiation	alnid	18	x	no mean
5	Magnitude of turbulent surface stress[1]	N m**-2 s	magnitude of turbulent surface stress	magss	48		x
6	Mean magnitude of turbulent surface stress[2]	N m**-2	mean magnitude of turbulent surface stress	mmtss	235025		x
7	10 metre wind gust since previous post-processing	m s**-1	10m_wind_gust_since_previous_post_processing	10fg	49		no mean
8	Maximum temperature at 2 metres since previous post-processing	K	maximum_2m_temperature_since_previous_post_processing	mx2t	201		no mean
9	Minimum temperature at 2 metres since previous post-processing	K	minimum_2m_temperature_since_previous_post_processing	mn2t	202		no mean
10	10 metre wind speed[3]	m s**-1	10m wind speed	10si	207	x	x

11	Maximum total precipitation rate since previous post-processing	kg m**-2 s**-1	maximum_total_precipitation_rate_since_previous_post_processing	mxtpr	228226		no mean
12	Minimum total precipitation rate since previous post-processing	kg m**-2 s**-1	minimum_total_precipitation_rate_since_previous_post_processing	mntpr	228227		no mean
13	Altimeter wave height	m	Not available from the CDS disks	awh	140246	no mean	
14	Altimeter corrected wave height	m	Not available from the CDS disks	acwh	140247	no mean	
15	Altimeter range relative correction	~	Not available from the CDS disks	arrc	140248	no mean	
16	2D wave spectra (single)	m**2 s radian**-1	Not available from the CDS disks	2dfd	140251	no mean	

[1]Accumulated parameter
[2]Mean rate/flux parameter
[3]Instantaneous parameter

Table 9: pressure level parameters: instantaneous

(stream=oper/enda/mnth/moda/edmm/edmo, levtype=pl)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA) or T639 spherical harmonics (T319 for the EDA), as indicated)

count	name	units	variable name in CDS	shortName	paramId	native grid	an	fc
1	Potential vorticity	K m**2 kg**-1 s**-1	potential_vorticity	pv	60	N320 (N160)	x	x
2	Specific rain water content	kg kg**-1	specific_rain_water_content	crwc	75	N320 (N160)	x	x
3	Specific snow water content	kg kg**-1	specific_snow_water_content	cswc	76	N320 (N160)	x	x
4	Geopotential	m**2 s**-2	geopotential	z	129	T639 (T319)	x	x
5	Temperature	K	temperature	t	130	T639 (T319)	x	x
6	U component of wind	m s**-1	u_component_of_wind	u	131	T639 (T319)	x	x
7	V component of wind	m s**-1	v_component_of_wind	v	132	T639 (T319)	x	x
8	Specific humidity	kg kg**-1	specific_humidity	q	133	N320 (N160)	x	x
9	Vertical velocity	Pa s**-1	vertical_velocity	w	135	T639 (T319)	x	x
10	Vorticity (relative)	s**-1	vorticity	vo	138	T639 (T319)	x	x
11	Divergence	s**-1	divergence	d	155	T639 (T319)	x	x
12	Relative humidity	%	relative_humidity	r	157	T639 (T319)	x	x
13	Ozone mass mixing ratio	kg kg**-1	ozone_mass_mixing_ratio	o3	203	N320 (N160)	x	x
14	Specific cloud liquid water content	kg kg**-1	specific_cloud_liquid_water_content	clwc	246	N320 (N160)	x	x
15	Specific cloud ice water content	kg kg**-1	specific_cloud_ice_water_content	ciwc	247	N320 (N160)	x	x
16	Fraction of cloud cover	(0 - 1)	fraction_of_cloud_cover	cc	248	N320 (N160)	x	x

Table 10: potential temperature level parameters: instantaneous

(not available from the CDS disks)
(stream=oper/enda/mnth/moda/edmm/edmo, levtype=pt)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA) or T639 spherical harmonics (T319 for the EDA), as indicated)

count	name	units	shortName	paramId	native grid	an	fc
1	Montgomery potential	m**2 s**-2	mont	53	T639 (T319)	x	
2	Pressure	Pa	pres	54	T639 (T319)	x	
3	Potential vorticity	K m**2 kg**-1 s**-1	pv	60	N320 (N160)	x	
4	U component of wind	m s**-1	u	131	T639 (T319)	x	
5	V component of wind	m s**-1	v	132	T639 (T319)	x	
6	Specific humidity	kg kg**-1	q	133	N320 (N160)	x	
7	Vorticity (relative)	s**-1	vo	138	T639 (T319)	x	
8	Divergence	s**-1	d	155	T639 (T319)	x	
9	Ozone mass mixing ratio	kg kg**-1	o3	203	N320 (N160)	x	

Table 11: potential vorticity level parameters: instantaneous

(not available from the CDS disks)
(stream=oper/enda/mnth/moda/edmm/edmo, levtype=pv)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA) or T639 spherical harmonics (T319 for the EDA), as indicated)

count	name	units	shortName	paramId	native grid	an	fc
1	Potential temperature	K	pt	3	T639 (T319)	x	
2	Pressure	Pa	pres	54	T639 (T319)	x	
3	Geopotential	m**2 s**-2	z	129	T639 (T319)	x	
4	U component of wind	m s**-1	u	131	N320 (N160)	x	
5	V component of wind	m s**-1	v	132	N320 (N160)	x	
6	Specific humidity	kg kg**-1	q	133	N320 (N160)	x	
7	Ozone mass mixing ratio	kg kg**-1	o3	203	N320 (N160)	x	

Table 12: model level parameters: instantaneous

(GRIB2 format)
(not available from the CDS disks)
(stream=oper/enda/mnth/moda/edmm/edmo, levtype=ml)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA) or T639 spherical harmonics (T319 for the EDA), as indicated)

count	name	units	shortName	paramId	native grid	an	fc
1	Specific rain water content	kg kg**-1	crwc	75	N320 (N160)	x	x
2	Specific snow water content	kg kg**-1	cswc	76	N320 (N160)	x	x
3	Eta-coordinate vertical velocity	s**-1	etadot	77	T639 (T319)	x	x
4	Geopotential[1]	m**2 s**-2	z	129	T639 (T319)	x	x
5	Temperature	K	t	130	T639 (T319)	x	x
6	U component of wind	m s**-1	u	131	T639 (T319)	x	x
7	V component of wind	m s**-1	v	132	T639 (T319)	x	x
8	Specific humidity	kg kg**-1	q	133	N320 (N160)	x	x
9	Vertical velocity	Pa s**-1	w	135	T639 (T319)	x	x
10	Vorticity (relative)	s**-1	vo	138	T639 (T319)	x	x
11	Logarithm of surface pressure[1]	~	lnsp	152	T639 (T319)	x	x
12	Divergence	s**-1	d	155	T639 (T319)	x	x
13	Ozone mass mixing ratio	kg kg**-1	o3	203	N320 (N160)	x	x
14	Specific cloud liquid water content	kg kg**-1	clwc	246	N320 (N160)	x	x
15	Specific cloud ice water content	kg kg**-1	ciwc	247	N320 (N160)	x	x
16	Fraction of cloud cover	(0 - 1)	cc	248	N320 (N160)	x	x

[1]Only archived on level=1.

Table 13: model level parameters: mean rates/fluxes

(GRIB2 format)
(not available from the CDS disks)
(stream=oper/enda/mnth/moda/edmm/edmo, levtype=ml)
(The native grid is the reduced Gaussian grid N320 (N160 for the EDA))

count	name	units	shortName	paramId	an	fc
1	Mean temperature tendency due to short-wave radiation	K s**-1	mttswr	235001		x
2	Mean temperature tendency due to long-wave radiation	K s**-1	mttlwr	235002		x
3	Mean temperature tendency due to short-wave radiation, clear sky	K s**-1	mttswrcs	235003		x
4	Mean temperature tendency due to long-wave radiation, clear sky	K s**-1	mttlwrcs	235004		x
5	Mean temperature tendency due to parametrisations	K s**-1	mttpm	235005		x
6	Mean specific humidity tendency due to parametrisations	kg kg**-1 s**-1	mqtpm	235006		x
7	Mean eastward wind tendency due to parametrisations	m s**-2	mutpm	235007		x
8	Mean northward wind tendency due to parametrisations	m s**-2	mvtpm	235008		x

9	Mean updraught mass flux[1]	kg m**-2 s**-1	mumf	235009		x
10	Mean downdraught mass flux[1]	kg m**-2 s**-1	mdmf	235010		x
11	Mean updraught detrainment rate	kg m**-3 s**-1	mudr	235011		x
12	Mean downdraught detrainment rate	kg m**-3 s**-1	mddr	235012		x
13	Mean total precipitation flux[1]	kg m**-2 s**-1	mtpf	235013		x
14	Mean turbulent diffusion coefficient for heat[1]	m**2 s**-1	mtdch	235014		x

[1]These parameters provide data for the model half levels - the interfaces of the model layers.

Observations

The observations (satellite and in-situ) used as input to ERA5 are listed below. For more information on the observational input to ERA5, including dates when particular sensors or observation types were used, please see Section 5 in the ERA5 journal article, The ERA5 global reanalysis.

Table 14: Satellite Data

Sensor	**Satellite**	**Satellite agency**	**Data provider+**	**Measurement** **(sensitivities exploited in ERA5 / variables analysed)**
Satellite radiances (infrared and microwave)				
AIRS	AQUA	NASA	NOAA	BT (T, humidity and ozone)
AMSR-2	GCOM-W1*	JAXA		BT (column water vapour, cloud liquid water, precipitation and ocean surface wind speed)
AMSRE	AQUA*	JAXA		BT (column water vapour, cloud liquid water, precipitation and ocean surface wind speed)
AMSUA	NOAA-15/16/17/18/19, AQUA, METOP-A/B	NOAA,ESA, EUMETSAT		BT (T)
AMSUB	NOAA-15/16/17	NOAA		BT (humidity)
ATMS	NPP	NOAA		BT (T and humidity)
CRIS	NPP	NOAA		BT (T, humidity and ozone)
HIRS	TIROS-N, NOAA-6 /7/8/9/11/14	NOAA		BT (T, humidity and ozone)
IASI	METOP-A/B	EUMETSAT/ESA	EUMETSAT	BT (T, humidity and ozone)
GMI	GPM	NASA/JAXA		BT (humidity, column water vapour, cloud liquid water, precipitation, ocean surface wind speed)
MHS	NOAA-18/19, METOP-A/B	NOAA, EUMETSAT /ESA		BT (humidity and precipitation)
MSU	TIROS-N, NOAA-6 to 12, NOAA-14			BT (T)
MWHS	FY-3-A/B	NRSCC		BT (humidity)
MWHS2	FY-3-C	CMA		BT (T, humidity and precipitation)
MWTS	FY-3A/B	NRSCC		BT (T)
MWTS2	FY-3C	CMA		BT (T)
SSM/I	DMSP-08*/10*/11*/13*/14*/15*	US Navy	NOAA, CMSAF*	BT (column water vapour, cloud liquid water, precipitation and ocean surface wind speed)

SSMIS	DMSP-16/17/18	US Navy	NOAA	BT (T, humidity, column water vapour, cloud liquid water, precipitation and ocean surface wind speed)
SSU	TIROS-N, NOAA-6/7/8/9/11/14	NOAA		BT (T)
TMI	TRMM	NASA/JAXA		BT (column water vapour, cloud liquid water, precipitation, ocean surface wind speed)
MVIRI	METEOSAT 5/7	EUMETSAT/ESA	EUMETSAT	BT (water vapour, surface/cloud top T)
SEVIRI	METEOSAT-8*/9*/10	EUMETSAT/ESA	EUMETSAT	BT (water vapour, surface/cloud top T)
GOES IMAGER	GOES-8/9/10/11/12/13/15	NOAA	CIMMS, NESDIS	BT (water vapour, surface/cloud top T)
MTSAT IMAGER	MTSAT-1R/MTSAT-2	JMA		BT (water vapour, surface/cloud top T)
AHI	Himawari-8	JMA		BT (water vapour, surface/cloud top T)
Satellite retrievals from radiance data				
MVIRI	METEOSAT-2*/3*/4*/5*/7*	EUMETSAT/ESA	EUMETSAT	wind vector
SEVIRI	METEOSAT-8*/9*/10	EUMETSAT/ESA	EUMETSAT	wind vector
GOES IMAGER	GOES-4-6/8*/9*/10*/11*/12*/13*/15*	NOAA	CIMMS*, NESDIS	wind vector
GMS IMAGER	GMS-1*/2/3*/4*/5*	JMA		wind vector
MTSAT IMAGER	MTSAT-1R*/MTSAT2	JMA		wind vector
AHI	Himawari-8	JMA	JMA	wind vector
AVHRR	NOAA-7 /9/10/11/12/14 to 18, METOP-A	NOAA	CIMMS, EUMETSAT	wind vector
MODIS	AQUA/TERRA	NASA	NESDIS, CIMMS	wind vector
GOME	ERS-2*	ESA		Ozone
GOME-2	METOP*-A/B	ESA/EUMETSAT		Ozone
MIPAS	ENVISAT*	ESA		Ozone
MLS	EOS-AURA*	NASA		Ozone
OMI	EOS-AURA*	NASA		Ozone
SBUV,SBUV-2	NIMBUS-7*,NOAA*9/11/14/16/17/18 /19	NOAA	NASA	Ozone
SCIAMACHY	ENVISAT*	ESA		Ozone
TOMS	NIMBUS-7*,METEOR-3-5,ADEOS-1*, EARTH PROBE	NASA		Ozone
Satellite GPS-Radio Occultation data				
BlackJack	CHAMP,GRACE*-A/B,SAC-C*	DLR,NASA/DLR,NASA /COMAE	GFZ,UCAR*	Bending angle
GRAS	METOP-A/B	EUMETSAT/ESA	EUMETSAT	Bending angle
IGOR	TerraSAR-X*, TanDEM-X, COSMIC*-1 to 6	NSPO/NOAA	GFZ,UCAR*	Bending angle
Satellite scatterometer data				
AMI	ERS-1,ERS-2	ESA		Backscatter sigma0, soil moisture
ASCAT	METOP-A/B*	EUMETSAT/ESA	EUMETSAT /TU Wien	Backscatter sigma0, soil moisture
OSCAT	OCEANSAT-2	ISRO	KNMI	Backscatter sigma0, vector wind
SEAWINDS	QUIKSCAT	NASA	NASA	Backscatter sigma0
Satellite Altimeter data				
RA	ERS-1*/2*	ESA		Wave Height
RA-2	ENVISAT*	ESA		Wave Height
Poseidon-2	JASON-1*	CNES/NASA	CNES	Wave Height

Poseidon-3	JASON-2	CNES/NOAA/NASA /EUMETSAT	NOAA /EUMETSAT	Wave Height
SIRAL	CRYOSAT-2	ESA		Wave Height
AltiKa	SARAL	CNES/ISRO	EUMETSAT	Wave Height

* reprocessed dataset
+ when different than the satellite agency

Table 15: In-situ data, provided by WMO WIS

Dataset name	Observation type	Measurement
SYNOP	Land station	Surface Pressure, Temperature, humidity
METAR	Land station	Surface Pressure, Temperature, humidity
DRIBU/DRIBU-BATHY/DRIBU-TESAC/BUFR Drifting Buoy	Drifting buoys	10m-wind, Surface Pressure
BUFR Moored Buoy	Moored buoys	10m-wind, Surface Pressure
SHIP	ship station	Surface Pressure, Temperature, wind, humidity
Land/ship PILOT	Radiosondes	wind profiles
American Wind Profiler	Radar	wind profiles
European Wind Profiler	Radar	wind profiles
Japanese Wind Profiler	Radar	wind profiles
TEMP SHIP	Radiosondes	Temperature, wind, humidity profiles
DROP Sonde	Radiosondes	Temperature, wind, humidity profiles
Land/Mobile TEMP	Radiosondes	Temperature, wind, humidity profiles
AIREP	Aircraft data	Temperature, wind
AMDAR	Aircraft data	Temperature, wind
ACARS	Aircraft data	Temperature, wind, humidity
WIGOS AMDAR	Aircraft data	Temperature, wind, humidity
TAMDAR	Aircraft data	Temperature, wind
ADS-C	Aircraft data	Temperature, wind
Mode-S	Aircraft data	Wind
Ground based radar	Radar precipitation composites	Rain rates

Table 16: Snow data

Dataset name	Observation type	Measurement
SYNOP	Land station	Snow depth
Additional national reports	Land station	Snow depth
NOAA/NESDIS IMS	Merged satellite	Snow cover (NH only)

Guidelines

The following advice is intended to help users understand particular features of the ERA5 data:

1. In general, we recommend that the hourly (analysed) "2 metre temperature" be used to construct the minimum and maximum over longer periods, such as a day, rather than using the forecast parameters "Maximum temperature at 2 metres since previous post-processing" and "Minimum temperature at 2 metres since previous post-processing".
2. ERA5: compute pressure and geopotential on model levels, geopotential height and geometric height
3. ERA5: How to calculate wind speed and wind direction from u and v components of the wind?

4. Sea surface temperature and sea-ice cover (sea ice area fraction), see Table 2 above, are available at the usual times, eg hourly for the HRES, but their content is only updated once daily. However, for inland water bodies (lakes, reservoirs, rivers and coastal waters) the FLake model calculates the surface temperature (ie the lake mixed-layer temperature or lake ice temperature) and does include diurnal variations.
5. Mean rates/fluxes and accumulations at step=0 have values of zero because the length of the processing period is zero.
6. Convective Inhibition (CIN). A missing value is assigned to CIN for values of CIN > 1000 **or** where there is no cloud base. This can occur where convective available potential energy (CAPE) is low.
7. In the ECMWF data archive (MARS), ERA5 data is archived on various native grids. For the CDS disks, ERA5 data have been interpolated and are stored on regular latitude/longitude grids. For more information, see Spatialgrid.

   Storing the data on these different grids can cause incompatibilities, particularly when comparing native spherical harmonic, pressure level, MARS data with CDS disk data on a third, coarse grid.

   Native spherical harmonic, pressure level parameters are comprised of: Geopotential, Temperature, U component of wind, V component of wind, Vertical velocity, Vorticity, Divergence and Relative humidity. When these parameters are retrieved from MARS and a coarse output grid is specified, the default behaviour is that the spherical harmonics are truncated to prevent aliasing on the output grid. The coarser the output grid, the more severe the truncation. This truncation removes the higher wavenumbers, making the data smoother. However, the CDS disk data has been simply interpolated to the third grid, without smoothing.

   This incompatibility is particularly relevant when comparing ERA5.1 data (which are only available from MARS - see DataorganisationandhowtodownloadERA5 - and only for 2000-2006) with ERA5 data on the CDS disks.

   The simplest means of minimising such incompatibilities is to retrieve the MARS data on the same grid as that used to store the ERA5 CDS disk data.
8. The land-sea mask in ERA5 is an invariant field.

   This parameter is the proportion of land, as opposed to ocean or inland waters (lakes, reservoirs, rivers and coastal waters), in a grid box.

   This parameter has values ranging between zero and one and is dimensionless.

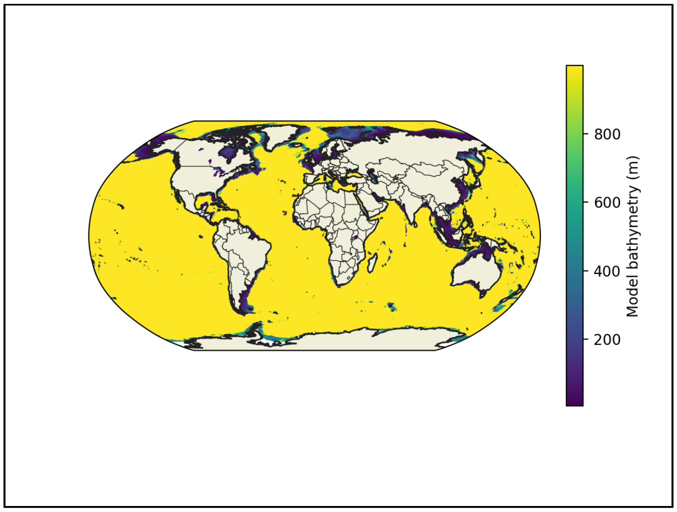
   In cycles of the ECMWF Integrated Forecasting System (IFS) from CY41R1 (introduced in May 2015) onwards, grid boxes where this parameter has a value **above 0.5** can be comprised of a mixture of land and inland water but not ocean. Grid boxes with **a value of 0.5 and below** can only be comprised of a water surface. In the latter case, the lake cover is used to determine how much of the water surface is ocean or inland water.

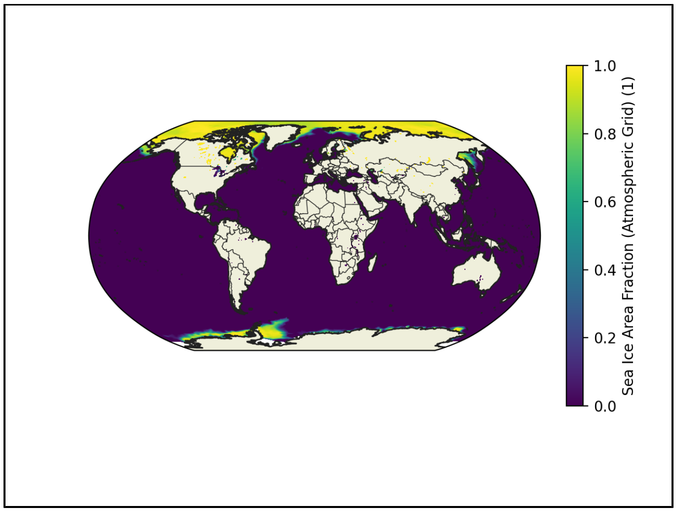
   The ERA5 land-sea mask provided is not suitable for direct use with wave parameters, as the time variability of the sea-ice cover needs to be taken into account and wave parameters are undefined for non-sea points.

   In order to produce a land-sea mask for use with wave parameters, users need to download the following ERA5 data (for the required period):

   a. the model bathymetry (Model bathymetry. Fig 1)
   b. the sea-ice cover (Sea ice area fraction, Fig 2)

   and combine these data to produce the land-sea mask (Fig 3). See attached pictures:





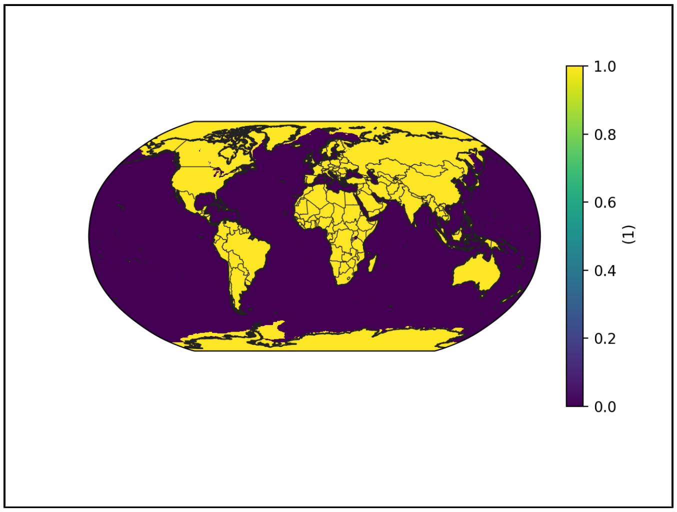


Fig 1: Model bathymetry

Fig 2: Sea-ice cover

Fig 3: Combined mask

> ⚠ Please note that sea-ice cover is only updated once daily.

Please see the Toolbox workflow below to see a possible way to proceed. The results is a carousel of land-sea mask for each time step requested:

Toolbox workflow

```
import cdstoolbox as ct

@ct.application(title='Download data')
@ct.output.download()
@ct.output.carousel()

def download_application():
    count = 0
    years=['1980']
    months = [
            '01', #'02', '03',
        #    '04', '05', '06',
        #    '07', '08', '09',
        #    '10', '11', '12'
    ]
# For hourly data hourly=True
# For monthly data monthly=True
    hourly = True
    monthly = False
    for yr in years:
        for mn in months:
            if hourly == True:
                mb,si = get_hourly_data(yr, mn)
            elif monthly == True:
                mb,si = get_monthly_data(yr, mn)
            print(mb)
# Check values are >= 0.0 in the model bathymetry mask
            compare_ge_mb = ct.operator.ge(mb, 0.0)
            print(si)
# Check values are > 0.5 in the sea ice mask
            compare_ge_si = ct.operator.gt(si, 0.500)

# Invert model bathymetry mask
            new =  ct.operator.add(compare_ge_mb, -1.0)
            new1 =  ct.operator.mul(new, -1.0)
# Add the Bathymetry Mask to the Sea Ice Mask
            new_all = ct.operator.add(compare_ge_si,new1)
# Reset scale to land=1, ocean=0
            new_all_final = ct.operator.ge(new_all, 1.0)
            print(new_all_final)

            if count == 0:
               combined_mask = new_all_final
            else:
               combined_mask = ct.cube.concat([combined_mask, new_all_final], dim = 'time')
            count =  count + 1

    renamed_data = ct.cdm.rename(combined_mask, "wavemask")
    new_data = ct.cdm.update_attributes(renamed_data, attrs={'long_name': 'Wave Land Sea Mask'})
    combined_mask = new_data
    print("combined_mask")
    print(combined_mask)

# Plot mask for first timestep

    fig_list = ct.cdsplot.geoseries(combined_mask)
    return combined_mask, fig_list

def get_monthly_data(y,m):
    m,s = ct.catalogue.retrieve(
        'reanalysis-era5-single-levels-monthly-means',
        {
            'product_type': 'monthly_averaged_reanalysis',
            'variable': [
                'model_bathymetry', 'sea_ice_cover',
            ],
            'year': y,
            'month': m,
            'time': '00:00',
        }
```

```
    )
    return m, s

def get_hourly_data(y,m):
    m,s = ct.catalogue.retrieve(
        'reanalysis-era5-single-levels',
        {
            'product_type': 'reanalysis',
            'variable': [
                'model_bathymetry', 'sea_ice_cover',
            ],
            'year': y,
            'month': m,
            'day': [
            '01', '02', '03',
            '04', '05', '06',
            '07', '08', '09',
            '10', '11', '12',
            '13', '14', '15',
            '16', '17', '18',
            '19', '20', '21',
            '22', '23', '24',
            '25', '26', '27',
            '28', '29', '30',
            '31',
            ],
            'time': [
            '00:00', '01:00', '02:00',
            '03:00', '04:00', '05:00',
            '06:00', '07:00', '08:00',
            '09:00', '10:00', '11:00',
            '12:00', '13:00', '14:00',
            '15:00', '16:00', '17:00',
            '18:00', '19:00', '20:00',
            '21:00', '22:00', '23:00',
            ],

            }
            )
    return m, s
```

9. The following wave parameters are sparse observations, or quantities derived from the observations, that have been interpolated to the wave model grid and contain many missing values:

    - altimeter_wave_height (140246)
    - altimeter_corrected_wave_height (140247)
    - altimeter_range_relative_correction (140248)

    These parameters are not available from the CDS disks but can be retrieved from MARS using the CDS API.
10. Near-surface humidity is not archived directly in ERA datasets, but the archive contains near-surface (2m from the surface) temperature (T) and dew point temperature (Td), and also surface pressure (sp), from which you can calculate specific and relative humidity at 2m.

    - **Specific humidity** can be calculated using equations 7.4 and 7.5 from Part IV, Physical processes section (Chapter 7, section 7.2.1b) in the documentation of the IFS for CY41R2. Use the 2m dew point temperature and surface pressure (which is approximately equal to the pressure at 2m) in these equations. The constants in 7.4 are to be found in Chapter 12 (of Part IV: Physical processes) and the parameters in 7.5 should be set for saturation over water because the dew point temperature is being used.
    - **Relative humidity** should be calculated from: RH = 100 * es(Td)/es(T)

    Relative humidity can be calculated with respect to saturation over water, ice or mixed phase by defining es(T) with respect to saturation over water, ice or mixed phase (water and ice). The usual practice is to define near-surface relative humidity with respect to saturation over water. Note that in ERA5, the relative humidity on pressure levels has been calculated with respect to saturation over mixed phase.
11. In the ECMWF model (IFS), snow is represented by an additional layer on top of the uppermost soil level. The whole grid box may not be covered in snow. The snow cover gives the fraction of the grid box that is covered in snow.

    For ERA5, the snow cover (SC) is computed using snow water equivalent (ie parameter SD (141.128)) as follows:

ERA5 Snow cover formula
snow_cover (SC) = min(1, (RW*SD/RSN) / 0.1)
where RW is density of water equal to 1000 and RSN is density of snow (parameter 33.128).

ERA5 physical depth of snow where there is snow cover is equal to RW*SD/(RSN*SC).

12. The parameter "Forecast albedo" is only for diffuse radiation and assuming a fixed spectrum of downward short-wave radiation at the surface. The true broadband, all-sky, surface albedo can be calculated from accumulated parameters:

    (SSRD-SSR)/SSRD

    where SSRD is parameter 169.128 and SSR is 176.128. This true surface albedo cannot be calculated at night when SSRD is zero. For more information, see Radiation quantities in the ECMWF model and MARS.
13. **Actual evapotranspiration** in the ERA5 single levels datasets is called "Evaporation" (param ID 182) and is the sum of the following four evaporation components (which are not available separately in ERA5 but only for ERA5-Land):

    a. Evaporation from bare soil
    b. Evaporation from open water surfaces excluding oceans
    c. Evaporation from the top of canopy
    d. Evaporation from vegetation transpiration

    For the ERA5 single levels datasets, actual evapotranspiration can be downloaded from the C3S Climate Data Store (CDS) under the category heading "Evaporation and Runoff", in the "Download data" tab.

    For details about the computation of actual evapotranspiration, please see Chapter 8 of Part IV : Physical processes, of the IFS documentation:

    ERA5 IFS cycle 41r2

    The potential evapotranspiration in the ERA5 single levels CDS dataset is given by the parameter potential evaporation (pev).

    Pev data can be downloaded from the CDS under the category heading "Evaporation and Runoff", in the "Download data" tab for the ERA5 single levels datasets.

    The definitions of potential and reference evapotranspiration may vary according to the scientific application and can have the same definition in some cases. Users should therefore ensure that the definition of this parameter is suitable for their application.

    Please note that based on ERA5 atmospheric forcing, other independent (offline) methods such us "Priesley-Taylor[1] (1972) , Schmidt[2] (1915) or de Bruin[3] (2000)" can also be used to estimate Potential evapotranspiration.

    [1]PRIESTLEY, C. H. B., & TAYLOR, R. J. (1972). On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters, *Monthly Weather Review*, *100*(2), 81-92. Retrieved Aug 27, 2021, from https://journals.ametsoc.org/view/journals/mwre/100/2/1520-0493_1972_100_0081_otaosh_2_3_co_2.xml

    [2]Schmidt, W., 1915: Strahlung und Verdunstung an freien Wasserflächen; ein Beitrag zum Wärmehaushalt des Weltmeers und zum Wasserhaushalt der Erde (Radiation and evaporation over open water surfaces; a contribution to the heat budget of the world ocean and to the water budget of the earth). *Ann. Hydro. Maritimen Meteor.*, **43**, 111–124, 169–178.

    [3]de Bruin, H. A. R., , and Stricker J. N. M. , 2000: Evaporation of grass under non-restricted soil moisture conditions. *Hydrol. Sci. J.*, **45**, 391–406, doi:10.1080/02626660009492337.

14. The "Instantaneous moisture flux" (units: kg m^{-2} s^{-1}; paramId=232) incorporates the same processes as "Evaporation" (units: m of water equivalent; paramId=182), but the latter is accumulated over a particular time period (during the hour preceeding the validity date/time, in the ERA5 HRES), whereas the former is an instantaneous parameter. Note, the different units of these two parameters.

    For the atmosphere, these two parameters only involve water vapour. Cloud liquid does not sediment and the cloud ice sedimentation flux is included in the snowfall flux.

    Here are some further details about the processes in the "Instantaneous moisture flux" and "Evaporation":

Surface characteristics	Process from surface to atmosphere (defined to be negative)	Process from atmosphere to surface (defined to be positive)
Warm surface	Evaporation from liquid water to water vapour	Dew deposition from water vapour
Cold vegetation surface	Evaporation from liquid water to water vapour	Dew deposition from water vapour
Ice surface	Sublimation from ice to water vapour	Ice deposition from water vapour
Snow surface	Sublimation from snow to water vapour	Snow deposition from water vapour

Known issues

Currently, we are aware of these issues with ERA5:

1. ERA5T: from **1 September to 13 December 2021, the final ERA5 product is different to ERA5T** due to the correction of the assimilation of incorrect snow observations in central Asia. Although the differences are mostly limited to that region and mainly to surface parameters, in particular snow depth and soil moisture and to a lesser extent 2m temperature and 2m dewpoint temperature, all the resulting reanalysis fields can differ over the whole globe but should be within their range of uncertainty (which is estimated by the ensemble spread and which can be large for some parameters). On the CDS disks, the initial, ERA5T, fields have been overwritten (with the usual 2-3 month delay), i.e., for these months, access to the original CDS disk, ERA5T product is not possible after it has been overwritten. Potentially incorrect snow observations have been assimilated in ERA5 up to this time, when the effects became noticeable. The quality control of snow observations has been improved in ERA5 from September 2021 and from 15 November 2021 in ERA5T.
2. ERA5 uncertainty: although small values of ensemble spread correctly mark more confident estimates than large values, numerical values are over confident. The spread does give an indication of the relative, random uncertainty in space and time.
3. ERA5 suffers from an overly strong equatorial mesospheric jet, particularly in the transition seasons.
4. From 2000 to 2006, ERA5 has a poor fit to radiosonde temperatures in the stratosphere, with a cold bias in the lower stratosphere. In addition, a warm bias higher up persists for much of the ERA5 period. The lower stratospheric cold bias was rectified in a re-run for the years 2000 to 2006, called ERA5.1, see "Resolved issues" below.
5. Discontinuities in ERA5: The historic ERA5 data was produced by running several parallel experiments, each for a different period, which were then spliced together to create the final product. This can create discontinuities at the transition points.
6. The analysed "2 metre temperature" can be larger than the forecast "Maximum temperature at 2 metres since previous post-processing".
7. The analysed 10 metre wind speed (derived from the 10 metre wind components) can be larger than the forecast "10 metre wind gust since previous post-processing".
8. ERA5 diurnal cycle for near surface winds: the hourly data reveals a mismatch in the analysed near surface wind speed between the end of one assimilation cycle and the beginning of the next (which occurs at 9:00 - 10:00 and 21:00 - 22:00 UTC). This problem mostly occurs in low latitude oceanic regions, though it can also be seen over Europe and the USA. We cannot rectify this problem in the analyses. The forecast near surface winds show much better agreement between the assimilation cycles, at least on average, so if this mismatch is problematic for a particular application, our advice would be to use the forecast winds. The forecast near surface winds are available from MARS, see the section, Data organisation and how to download ERA5.
9. ERA5 diurnal cycle for near surface temperature and humidity: some locations do suffer from a mismatch in the analysed values between the end of one assimilation cycle and the beginning of the next, in a similar fashion to that for the near surface winds (see above), but this problem is thought not to be so widespread as that for the near surface winds. The forecast values for near surface temperature and humidity are usually smoother than the analyses, but the forecast low level temperatures suffer from a cold bias over most parts of the globe. The forecast near surface temperature and humidity are available from MARS, see the section Data organisation and how to download ERA5.
10. ERA5: large 10m winds: up to a few times per year, the analysed low level winds, eg 10m winds, become very large in a particular location, which varies amongst a few apparently preferred locations. The largest values seen so far are about 300 ms^{-1}.
11. ERA5 rain bombs: up to a few times per year, the rainfall (precipitation) can become extremely large in small areas. This problem occurs mostly over Africa, in regions of high orography.
12. Large values of CAPE: occasionally, the Convective available potential energy in ERA5 is unrealistically large.
13. Ship tracks in the SST: prior to September 2007, in the period when HadISST2 was used, ship tracks can be visible in the SST.
14. Prior to 2014, the SST was not used over the Great Lakes to nudge the lake model. Consequently, the 2 metre temperature has an annual cycle that is too strong, with temperatures being too cold in winter and too warm in summer.
15. The Potential Evaporation field (pev, parameter Id 228251) is largely underestimated over deserts and high-forested areas. This is due to a bug in the code that does not allow transpiration to occur in the situation where there is no low vegetation.
16. Wave parameters (Table 7 above) for the three swell partitions: these parameters have been calculated incorrectly. The problem is most evident in the swell partition parameters involving the mean wave period: Mean wave period of first swell partition, Mean wave period of second swell partition and Mean wave period of third swell partition, where the periods are far too long.
17. Surface photosynthetically available radiation (PAR) is too low in the version (CY41R2) of the ECMWF Integrated Forecasting System (IFS) used to produce ERA5, so PAR and clear sky PAR have not been published in ERA5. There is a bug in the calculation of PAR, with it being taken from the wrong parts of the spectrum. The shortwave bands include 0.442-0.625 micron, 0.625-0.778 micron and 0.778-1.24 micron. PAR should be coded to be the sum of the radiation in the first of these bands and 0.42 of the second (to account for the fact that PAR is normally defined to stop at 0.7 microns). However, in CY41R2, PAR is in fact calculated from the sum of the second band plus 0.42 of the third. We will try to fix this in a future cycle.
18. The ERA5 analysed and forecast step=0, instantaneous surface stress components and surface roughness and the forecast step=0, friction velocity (friction velocity is not available from the analyses in ERA5) tend to suffer from values that are too low over the oceans.

    The analysis for such parameters is obtained by running the surface module to connect the surface with the model level analysed variables.

    However, at that stage, the surface aero-dynamical roughness length scale (z0) over the **oceans** is not initialised from its actual value but a constant value of 0.0001 is used instead.

    This initial value of z0 is needed to determine the initial value of u* and the surface stress based on solving for a simple logarithmic wind profile between the surface and the lowest model level. This initial u* is in turn used to determine an updated value of z0 based on the input Charnock parameter and then the value of the exchange coefficients needed to determine the output 10m winds (normal and neutral) and u* (see (3.91) to (3.94) with (3.26) in the IFS documentation). The surface stress is output as initialised.

    This initial value for z0 is generally too low (by one order of magnitude or more):

    Over the oceans, for winds above few m/s, z0 is modelled using the Charnock relation:

    $z0 \sim (alpha/g)\ u*^2$

    where alpha is the Charnock parameter, g is gravity, and u* is the friction velocity

    with typical values of

    alpha ~ 0.018

    g=9.81

    $u*^2 = Cd\ U10^2$

    where Cd is the drag coefficient

Cd ~ 0.008 + 0.0008 U10

for U10=10m/s => z0 ~ 0.003

As a consequence, the analysed instantaneous surface stress components will tend to be too low and even the updated value of z0 (surface roughness) will also tend to be too low.

For forecast, instantaneous surface stress components, surface roughness and friction velocity, the same problem affects step 0. However, this problem will not affect the accumulated surface stress parameters (recall the accumulated parameters are produced by running short range forecasts), because the accumulation starts from the first time step (i.e. at time step 0 all accumulated variables are initialised to 0).

This problem can easily be fixed, by using the initial value of Charnock that is available at the initial time.

Note, in ERA5 the parameter for surface roughness is called "forecast surface roughness", even when it's analysed.

19. ERA5 forecast parameters are missing for the validity times of 1st January 1940 from 00 UTC to 06 UTC (except for forecast step=0). This problem occurs because the first forecast in ERA5 was initiated from 1st January 1940 at 06 UTC.
20. Maximum temperature at 2 metres since previous post-processing: in a small region over Peru, at 19 UTC, 2 August 2013, this forecast parameter exhibited erroneous values, which were greater than 50C. This occurrence is under investigation. Note, in general, we recommend that the hourly (analysed) "2 metre temperature" be used to construct the minimum and maximum over longer periods, such as a day.
21. The ERA5 monthly means are calculated from the hourly (3 hourly for the EDA) data, on the native grid (including spherical harmonics) from the GRIB data, in each production "stream" or experiment. This can give rise to inconsistencies between the sub-daily data and their monthly mean, particularly in the CDS. In general, the inconsistencies will be small.

    - In the CDS, the ERA5 data (sub-daily and monthly mean) has been interpolated to a regular latitude/longitude grid. This interpolated sub-daily data will be slightly different to the native sub-daily data used in the production of the ERA5 monthly means.
    - The netCDF data available in the CDS has been packed, see What are NetCDF files and how can I read them, which states "*unpacked_data_value = (packed_data_value * scale_factor) + add_offset*" and "*packed_data_value = nint((unpacked_data_value - add_offset) / scale_factor)*". This netCDF packing will change the sub-daily values slightly, compared with the native sub-daily data used in the production of the ERA5 monthly means.
    - The GRIB data in the ERA5 monthly means (and sub-daily data) has been packed using a binning algorithm (which is different to the netCDF packing algorithm). Monthly means produced in other formats, such as netCDF, will differ from the ERA5 monthly means because of this packing.
    - Finally, there is a further reason why monthly mean values might be different to the mean of the sub-daily values, which even occurs in MARS. This cause only affects forecast parameters (the CDS provides analysed parameters unless the parameter is only available from the forecasts), such as the Total precipitation, and only occurs sporadically. In order to speed up production, ERA5 is produced in several parallel "streams" or experiments, which are then spliced together to produce the final product. Consider, the "stream" change at the beginning of 2015. The ERA5 forecast monthly means for January 2015 have been produced from the sub-daily data from that "stream", the first few hours of which (up until 06 UTC on 1st January 2015) come from the 18 UTC forecast on 31 December 2014. However, the sub-daily forecast data published in ERA5, is based on the date of the start of the forecast, so these first few hours of 2015 originate from the "stream" that produced December 2014. These two "streams" are different experiments, with different data values. The resulting inconsistencies might be larger than for the other three causes, above, depending on how consistent the two streams are.
22. ERA5 sea-ice cover and 2 metre temperature: in the period 1979-1989, in a region just to the north of Greenland, the sea-ice cover outside of the melt season is too low and hence the 2 metre temperature is too high. For more information, see Section 3.5.4 of Low frequency variability and trends in surface air temperature and humidity from ERA5 and other datasets
23. ERA5 sea-ice cover is missing in the Caspian Sea from late 2007 to 2013, inclusive.
24. ERA5 sea-ice surface temperature (skin temperature) in the Arctic, during winter, can have a warm bias of 5K or more. This issue is most pronounced over thick snow-covered sea ice under cold clear-sky conditions, when the modelled conductive heat flux from the warm ocean underneath the ice and snow layer is too high. More information can be found in Batrak and Müller (2019) and Zampieri et al., (2023), the latter of which, also describes a method to improve on this bias.
25. Altimeter wave height observations have not been available for ERA5 in the following periods (since coverage began in mid-1991): early February 2021 to mid-January 2022; mid-October 2023 onwards.
26. ERA5 CDS: wind values are far too low on pressure levels at the poles in the CDS

Resolved issues

1. **ERA5.1** is a re-run of ERA5, for the years **2000 to 2006** only, and was produced to improve upon the cold bias in the lower stratosphere seen in ERA5.

    ERA5.1 is a re-run of ERA5 for the years **2000 to 2006** only. ERA5.1 was produced to improve upon the cold bias in the lower stratosphere exhibited by ERA5 during this period. Moreover, ERA5.1 analyses have a better representation of the following features:

    - upper stratospheric temperature
    - stratospheric humidity

    The lower and middle troposphere in ERA5.1 are similar to those in ERA5, as is the synoptic evolution in the extratropical stratosphere.

    For access to ERA5.1 data read Data organisation and how to download ERA5. The dataset is 'reanalysis-era5.1-complete' in the CDS API.
2. ERA5.1 CDS: If you retrieved ERA5.1 using the CDS API anytime before 20/05/2020 08:00 UTC, for any stream other than oper (i.e. streams: wave, enda, edmo, ewmo, edmm, ewmm, ewda, moda, wamd, mnth, wamo), you will need to request the data again. Prior to this date, stream oper would be delivered regardless of which stream was requested.
3. ERA5 CDS: incorrect values of U/V on pressure levels in the CDS
4. ERA5 CDS: Data corruption

User support

There is a range of user support available for ERA5, including a Knowledge Base (where this article resides), a Forum and a ticketed system for questions - for more information see the C3S Help and Support Page.

How to acknowledge and cite ERA5

If you have downloaded ERA5 data on the "CDS disks" and/or downloaded ERA5 data in MARS, using either the CDS API (`'reanalysis-era5-complete'` or`'reanalysis-era5.1-complete'`) or via authorised direct access to MARS, please follow the instructions below:

In addition to the terms and conditions of the license(s), users **must**:

- cite the CDS catalogue entry;
- provide clear and visible attribution to the Copernicus programme and attribute each data product used;

Step 1: Check the licence to use Copernicus Products for attribution/reference clause

Step 2: Cite the CDS catalogue entry (as traceable source of data). Note that a catalogue entry for ERA5-complete and ERA5.1 is now also available in the CDS.

Step 3: Provide clear and visible attribution to the Copernicus programme and attribute each data product used (to accredit the creators of the data). Throughout the content of your publication, the dataset used is referred to as Author (YYYY)

The 3-steps procedure above is illustrated with this example: Use Case 2: ERA5 hourly data on single levels from 1940 to present

For complete details, please refer to How to acknowledge and cite a Climate Data Store (CDS) catalogue entry and the data published as part of it.

References

The ERA5 global reanalysis

The ERA5 global reanalysis: Preliminary extension to 1950

Global stratospheric temperature bias and other stratospheric aspects of ERA5 and ERA5.1

Low frequency variability and trends in surface air temperature and humidity from ERA5 and other datasets

Further ERA5 references are available from the ECMWF website.

This document has been produced in the context of the Copernicus Climate Change Service (C3S).

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Related articles

- ERA5: How to calculate wind speed and wind direction from u and v components of the wind?
- Parameters valid at the specified time
- Convective and large-scale precipitation
- Model grid box and time step
- ERA5: data documentation