KEPLER Deliverable Report

Report on Deliverable D2.1

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Context of deliverable within Work Package

Within WP2, which provides a description of Polar Regions provision in Copernicus services, the Task 2.1 undertakes an inventory of current products and services from the land service and related European programmes. This task also undertakes new products and services in light of potential Copernicus and other planned satellite missions. Gap analysis and synthesis among Copernicus services are handled in WP3 and WP5.

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Explanation of delays / disclaimers

This final deliverable report is based on a Milestone draft report that was due by the 1st GA in November 2019. No delays are to be reported here. This report concerns only a status on the variables present in the CLMS portfolio and related activities such as Copernicus Climate Change Service and ESA-CCI.

Executive summary

During a recent Council meeting in November 2019 the Member States have emphasised the crucial role of space-based observations and subsequent solutions for an integrated EU Arctic policy. Many of the challenges and needs of the Arctic are related to the currently rather poor knowledge of this harsh and rapidly changing environment and poor skills of current operational observing systems combined with an increasing demand related to sustainable economic development. In Europe, the main backbone for such space-based observations are the Copernicus services operated by the European Commission in collaboration with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.

This report gives an overview of the 'service' provided by the global Copernicus Land Monitoring Service (CLMS). The evolution of the future Copernicus service that KEPLER is working towards (WP5) has then to take into account the components of all the relevant services, and thus this deliverable report feeds into the roadmap developed in WP5.

A comprehensive description is given on the various products and the data sources disseminated in the CLMS catalogue. There are only a few products in CLMS specifically listed as 'Cryosphere' products (Lake Ice Extent, Snow cover Extent and Snow Water Equivalent). However, essentially all variables provided in the global CLMS are relevant because of the land areas in the Arctic. Also, the list here is not restricted to CLMS but includes also other relevant Copernicus services such as C3S and CEMS and also other product providers such as the ESA Climate Change Initiative (CCI) are taken into account. A data policy including a commitment to open data access and to the monitoring of product quality fully supports this portfolio, as well as the data provision via the cloud-based Data and Information Access Service (DIAS) platforms. The DIAS platforms should become increasingly important in the future for accessing Copernicus data as demonstrated by the user survey undertaken by KEPLER.

Copernicus services are user-driven and, as such, we have submitted a questionnaire on Polar observational needs to the European Commission’s Joint Research Centre (JRC) as an intermediate user and as the service provider of the Copernicus Global Land Service. In addition, we have made use of the general user survey undertaken by WP1, a dedicated round table discussion at the Arctic Frontiers 2020 conference for the evolution of CLMS for the Arctic environment, as well as the gap

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analysis done by the Polar Expert Group (Duchossois 2018a, Duchossois 2018b). The Expert group identified a list of variables to be included in the future evolvement of CLMS (glaciers, caps and ice-sheet parameters, surface albedo, surface freshwater, snow and permafrost). Of particular interest to potential users (this came out as one of the results of the round table discussion at the Arctic Frontiers 2020 conference) are in this context products that are currently not available at all (i.e. not provided by any service), e.g. avalanche risk as part of the snow variables group. Another outcome of this round table discussion points to the ease of finding relevant products and how the different service and product providers (e.g. Copernicus and ESA CCI) could be better streamlined to create a one-stop-shop, allowing the users to access all Arctic-related products at a central place/service. From a more general user's feedback, the recurrent demand of very high spatial resolution (< 100m) for snow related products should be noted.

Together with WP3 findings, the observation capacities of the HPCMs in terms of providing relevant Arctic land products are highlighted. Three missions (CIMR, CRISTAL, ROSE-L) are in particular targeting certain high-priority requirements from key Arctic user communities and respond to the recommendations outlined in the two reports from the group of European Polar Experts (Duchossois 2018a, Duchossois 2018b). To take full benefits of these missions will require substantial developments of the service in concert with the requirements from intermediate users. In situ observatories (e.g. super-sites) in the Arctic could play a valuable role in cal-val activities when developing services and algorithms applicable for the Arctic regions.

The possibility of having these 3 missions in synergy brings tremendous opportunities for CLMS in terms of extension of the service with important improved capacities. This synergy will likely be further reinforced by the overarching HPCM mission on monitoring atmospheric greenhouse gases (CO2M) that links the three Copernicus services CMEMS, CLMS and C3S. CO2M is designed to observe atmospheric CO_2 for quantifying anthropogenic CO_2 emissions. The CO2M instrument is also capable of measuring atmospheric CH_4. Both these greenhouse gases are also relevant for Arctic regions and the CO2M mission provides a link between the marine and land services by the integrating capacity of the atmosphere for the greenhouse gases. This synergy should be handled in the roadmap of the end-to- end operational system foreseen in WP5.

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Table 1: Acronyms most commonly used in the present report

Acronym	Definition	Link
C3S	Copernicus Climate Change Services	https://climate.copernicus.eu/
CEMS	Copernicus Emergency Management Service	https://emergency.copernicus.eu
CDS	Climate Data Store	https://cds.climate.copernicus.eu/
CGLS	Copernicus Global Land Service	https://land.copernicus.eu/global
CMEMS	Copernicus Marine Environmental Monitoring Services	http://marine.copernicus.eu/
CLMS	Copernicus Land Monitoring Services	https://land.copernicus.eu/
ECV	Essential Climate variable	https://gcos.wmo.int/en/essential-climate-variables
ESA CCI	European Space Agency Climate Change Initiative	http://cci.esa.int/
GCOS	The Global Climate Observing System	www.gcos.wmo.int/
PEG	Polar Expert Group	
NH	Northern Hemisphere	
GTN-P	Global Terrestrial Network for Permafrost	https://gtnp.arcticportal.org
CALM	Circumpolar Active Layer Monitoring Network	https://www2.gwu.edu/~calm/

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Report

Variables included

The Copernicus Land Monitoring Service (CLMS) is divided into three components differentiated by their spatial extent: global, pan-European and local. Further on, the global CLMS (also called Copernicus Global Land Service, CGLS) product portfolio is structured into several themes, among them “Cryosphere” that includes only three variables (Lake Ice Extent, Snow cover Extent and Snow Water Equivalent). However, essentially all variables provided in the global CLMS are relevant because of the land areas in the Arctic regions. Therefore we have considered all variables currently present in the global Copernicus Land Monitoring System. We have not considered any variables of the pan-European or local CLMS here, because of the limited spatial extent, i.e. their products do not cover the Arctic region.

Because of their importance for the Arctic, we have additionally included the Global Climate Observing System (GCOS) list of Cryosphere Essential Climate Variables (ECVs) that are not yet part of the global CLMS (essentially permafrost and glaciers/ice sheets). These variables are already pre-selected by the scientific community for the feasibility/maturity of the observing systems (glaciers/ice sheets) or for their importance in the Earth system context (permafrost).

Atmosphere ECVs are out of scope for the KEPLER project.

Few ECVs have been ignored because they were deemed scientifically too far from the present scope of Copernicus services (not feasible as of the present phase of Copernicus). The inclusion of these variables would entail a shift in the strategy of Copernicus services. For the land service, this concerns soil carbon and evaporative fluxes.

There are differences in terminology used in GCOS and Copernicus documents (see table below), we have hereafter adopted the Copernicus terminology:

GCOS	**Copernicus**	**Example**
Variable	Product	Snow
Product	Variable	Snow water equivalent

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According to the global CLMS we have separated our list of variables in 4 themes (see Table1 in Annex 1): Vegetation, Energy, Water, and Cryosphere. We have listed variables not currently present in the CLMS portfolio under the relevant theme (e.g. permafrost under the theme Cryosphere).

Type of CLMS variables

The Copernicus Global Land Service (CGLS) provides a set of biophysical variables that describe the state and the evolution of the vegetation, the energy budget, the water cycle and the cryosphere over the land surface at a global scale. There is no specific focus on the Arctic, but since the products are provided at a global scale the Arctic is mostly covered as well. Unlike in CMEMS and C3S, CLMS variables are all satellite-based observations and no forecasts or reanalysis products derived from data assimilation are included in the current global CLMS product catalogue.

The derivation of these data products involves the use of Earth Observation (mainly satellite) retrieval algorithms and possibly spatial and temporal interpolation algorithms but no dynamical, prognostic model together with a data assimilation framework is employed. The products are available NRT, which, for most of the products, means within 3 days after the end of the synthesis period. The Cryosphere variables are, however, available within 1 day of the last observation.

CLMS data source

The global Copernicus Land Monitoring Service relies on a network of European land data producers. However, the main contractor for the implementation and data production is the Belgian company VITO which takes care of the systematic production, archiving and distribution. Details on the instrument/mission sources for the available global CLMS products are included in the table of annex 1.

CLMS Organisation Overview

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Other data sources considered

- We have taken the European perspective, i.e. reviewing initiatives from the European Commission, not individual states.
- Other (satellite) data services have been considered that:
    - Include the Arctic (possibly as part of a global dataset). Where available, regional Arctic products have been preferred over global products.
    - Are based on a pan-European or global collaboration.
    - Are representing the European Commission and/or the European Space Agency (ESA), and/or EUMETSAT.
    - Are meant to be sustained. An exception has been made for the ESA CCIs, which are projects limited in time but which deliver a reference data product brokered and sometimes maintained by the Copernicus Services.
    - Address users at a similar level, namely that of processed, quality controlled, geophysical values. i.e. the satellite ground segments are ignored.
- No mention has been made of upcoming satellites, sensors, instruments except for a brief description of the relevant Copernicus High-Priority Candidate Missions (HPCM). Descriptions of new satellite missions (including a more detailed description of the HPCMs) are done within WP3.
- When in situ observations are involved, different databases may be more or less complete or have different quality control practices. We have not entered these topics here as this is part of WP3.
- Several other pan-European databases are relevant for the present Arctic inventory (PANGAEA, ENACT among others) but there are so many of those that they could not have been reviewed exhaustively. We have concentrated on the main “meta-portals”, the most federated ones for which the synchronization to Copernicus services has been on the table.
- Arctic cluster projects INTAROS and Nunataryuk do not constitute databases per se but do contribute continuously to the federated databases used here. Their public deliverables as of December 2019 have been taken into account.

CLMS Data Policy

The data and information delivered by the Copernicus Space infrastructure and the Copernicus services are made available and accessible to any citizen and any organisation around the world on a free, full and open access basis. A “Service Level Agreement” (SLA) or “Agreement” is established between the User and the Copernicus Land Monitoring Service for the provision of any Copernicus Land services. Its purpose is to outline the range and level of services that the Copernicus Land Service will supply to the User.

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The issues of data ownership, correct acknowledgment and traceability have not been considered here.

CLMS Data Quality - Monitoring the products quality

The quality of the data products and the production chain is monitored in accordance with CLMS guidelines and metrics. Each product is accompanied by technical descriptions of the products and validation reports. The validation is done in a variety of ways depending on the nature of the products, but often they use either in situ data or other types of remote sensing data.

Validation of CLMS products using in situ data

In many cases in situ data from point measurements are used to validate products. The CLMS Snow water equivalent product uses measurements from snow stretches (i.e. typically 1 km stretch sounded regularly every 10m to capture the average within a pixel). Only a few regions are tested (Canada, Russia and Finland).

Validation of CLMS products using independent EO data

Some CLMS products can be validated using independent EO data. For example, HR optical data (Sentinel-2 and Landsat-8) is used to validate the accuracy (RMS-value) of the MODIS based (500m resolution) snow extent product. Here a variety of validation sites can be selected based on the simultaneous availability of MODIS and HR data. The HR data are regarded as ground truth, and RMS values are calculated. The accuracies are then compared with the requirements from GCOS.

CLMS access of the service and products format

Copernicus Global Land Products are made available through (1) an online web catalogue and (2) GEONETCast satellite broadcast. The products are delivered in a ZIP archive that contains data files in either HDF4 (version 0), HDF5 (version 1) or GeoTiff format. They are searchable, visualisable and accessible through an interactive webpage (that is the online web catalogue: https://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home). INSPIRE compliant metadata is provided for download as well from the web catalogue. To be able to order the data users have to register and login to the catalogue. Users can also subscribe to getting the latest products in near real-time via FTP.

Data and Information Access Services (DIAS)

To facilitate and standardise access to data, the European Commission has funded the deployment of cloud-based platforms providing centralised access to Copernicus data and information, as well as processing tools.

The DIAS online platforms allow users to discover, manipulate, process and download Copernicus data and information. All DIAS platforms provide access to Copernicus Sentinel data, as well as to the

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information products from Copernicus' six operational services, together with cloud-based tools (open source and/or on a pay-per-use basis).

Each of the five competitive platforms also provides access to additional commercial satellite or non-space data sets as well as premium offers in terms of support or priority. Thanks to a single access point for the entire Copernicus data and information, DIAS allows the users to develop and host their own applications in the cloud while removing the need to download bulky files from several access points and process them locally.

CLMS Users

Current State of CLMS cryosphere products users

The CLMS portal https://land.copernicus.eu/global/ states that 94 TB of data were downloaded in the 2nd quarter of 2019. There are 5000 registered users. However, this concerns the whole global CLMS, no details are provided for just the cryosphere products users.

User Uptake and Use Cases

The CLMS portal provides a separate "Use case" section https://land.copernicus.eu/global/use-cases, where users can show how they use the CLMS products. There are only a few use cases published there at present time (07.11.2019) and none of them are related to Cryosphere or Polar regions.

Feedback of Users Questionnaire

We have submitted a questionnaire on polar observational needs to the European Commission's Joint Research Centre (JRC) as an intermediate user and as the service provider of the Copernicus Global Land Service. The key messages of the feedback provided to us can be summarized as follows:

The EC identified a strong interest for polar and snow satellite missions, and in 2017 created a group of European Polar Experts with a mandate to provide a detailed review and prioritization of users' needs for Arctic observations, an analysis of observation gaps, and recommendations for Copernicus Sentinel expansion missions to close these gaps, and to ensure continuity. The results of this group have been published in Duchossois et al. (2018a) and Duchossois et al. (2018b). In addition to the parameters identified in these reports as "high priority", JRC's product on the global surface water extent will be proposed as a new Copernicus product. It is planned to provide these products within the next 5-10 years, using both existing missions as well as three proposed Copernicus expansion missions with a specific Arctic relevance (see below). Relevant existing missions include Sentinel-1/2/3, MetOp, TanDEM-X, ICESat-2, and CryoSat-2. "Near real-time" in the context of the global CLMS is understood to be 10 days. Interoperability among existing and future data is key for long term monitoring, and it requires a lot of work to make the datasets of earlier sensors/instruments compatible with the newer ones, which are usually provided at a higher spatial

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resolution. It is foreseen that all future products will be made available through the current web portal or an updated version of it: https://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home

In addition, an increased role of the DIAS systems is anticipated, enabling users to retrieve both the raw and thematic data through these systems and to process the data according to their needs. Also, it is expected that the uptake of the downstream industry will increase, and more data will be used for apps.

Copernicus expansion missions

Six *high-priority candidate missions* (HPCM) have been studied to address EU policy and gaps in Copernicus user needs and to expand the current capabilities of the Copernicus space component. Out of these six HPCMs, three (CIMR, CRISTAL, ROSE-L) are specifically designed to address certain high-priority requirements from key Arctic user communities and respond to the recommendations outlined in the two reports from the group of European Polar Experts (Duchossois 2018a, Duchossois 2018b). A fourth mission (CO2M) is designed to observe atmospheric CO2 for quantifying anthropogenic CO_2 emissions. The CO2M instrument is also capable of measuring atmospheric CH_4. Both these greenhouse gases are also relevant for Arctic regions and the CO2M mission provides a link between the marine and land services by the integrating capacity of the atmosphere for the greenhouse gases. More details on the potential products from these HPCMs are given in the deliverable report D3.3.

CIMR (**C**opernicus **I**maging **M**icrowave **R**adiometer):

The CIMR mission [Donlon 2019] is foreseen to carry a multi-frequency microwave radiometer. While the main focus will be on the provision of ocean and sea ice-related parameters, it would also observe terrestrial snow cover and water equivalent, soil moisture, land surface temperature, and terrestrial surface water extent. CIMR will provide 95% global all-weather coverage every day with one satellite and complete (no hole-at-the-pole) sub-daily coverage (~5-6 hours) of the polar regions. CIMR will operate in synergy with the EUMETSAT MetOp-SG(B) mission so that over the polar regions (>60N and 60S) collocated and contemporaneous measurements between CIMR and MetOp Microwave Imager and SCA scatterometer measurements will be available within 10 min.

CRISTAL (**C**opernicus pola**R** **I**ce and **S**now **T**opography **A**ltimeter):

CRISTAL [Kern 2019] is foreseen to carry a multi-frequency radar altimeter and microwave radiometer to measure and monitor changes in - among others - the height of ice sheets and glaciers around the world. It would also contribute to the observation of land elevation and snow structure changes in regions underlain by permafrost.

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ROSE-L (L-band synthetic aperture **R**adar **O**bserving **S**ystem for **E**urope):

ROSE-L (Davidson et al., 2019) is foreseen to carry an L-band SAR. Since the longer L-band signal can penetrate through many natural materials such as vegetation, dry snow, and ice, the mission would provide additional information that cannot be gathered by the Copernicus Sentinel-1 C-band radar mission. It would be used in support of forest management, to monitor ground movement, landslides, and soil moisture, and to discriminate crop types for precision farming and food security. In addition, the mission would contribute to the monitoring of polar ice sheets and ice caps, and of seasonal snow. Potential areas of terrestrial application are agriculture and forestry.

Future planned development of CLMS with respect to polar provisions

In order to improve the description of the land part of the Polar Regions, it is recommended to extend the current parameters available within CLMS with a set of new land variables, see below. Since these variables are currently scattered among the portals of various projects (e.g. ESA-CCi projects, C3S), the provision of these variables should be streamlined such that they can all be accessed in one single cloud-type repository, preferably via the DIAS platforms. Ideally, an Arctic service could be added to Copernicus and made available by the DIAS platforms, where all the Arctic-relevant land and marine parameters would be accessible within one unified framework.

In detail, the recommendations for the future description of the Polar Regions' land part in Copernicus are as follows:

- Include the existing CLMS variables, with the exception of surface soil moisture, lake ice extent, and land surface temperature, which shall be replaced with their equivalents from the respective ESA-CCI projects.
- Include products from the following ESA-CCI projects, as they become available:
- Permafrost, Glaciers, Lakes, Soil moisture, Biomass, Land surface temperature, Snow, Land cover, Fire (the latter three are already included in CLMS, hence the recommendation is to harmonize with the existing products).
- Include the following parameters from C3S: snow cover extent, land cover, surface soil moisture, and surface albedo.
- Include the products from the GlobPermafrost project until the products of ESA-CCI permafrost have been evaluated sufficiently.
- Include products from the Global Wildfire Information System (GWIS), a Copernicus/GEO/NASA collaboration, in particular active fires, burnt areas, and fire danger forecast. This would also be relevant for the Copernicus Emergency Management Service (EMS) in the Arctic.

Another recommendation is related to the foreseen European Ground Motion Service. It would be beneficial if this service could be extended to the Circumpolar Arctic Region, providing data products

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on-ground dynamics related to the ongoing thawing of permafrost. These products would be very valuable to local communities and government organizations to evaluate the safety of existing and planned constructions and contribute to the Copernicus EMS.

Since the foreseen lifetime of the ESA-CCI projects is relatively short, extensions to the current Copernicus framework contracts should be considered, such that the continuity and stability of the data provision are guaranteed by Copernicus after these projects have terminated.

Gap analysis in CLMS polar provisions

In this section we give the main outlines of a first gap analysis for CLMS products regarding feedbacks from CLMS users questionnaire (see above) and from the round table discussion organised as a side event at the Arctic Frontiers 2020 conference (see M6.3). A wider gap analysis has already been prepared by the Polar Experts group mandated by the European Commission. In their report the group identified a set of missing ”high priority" variables that should become available in the medium-term future. These observables include various kinds of variables related to glaciers, caps and ice-sheet parameters, surface albedo, surface freshwater, snow and permafrost (for details see Table 5 in Duchossoy et al., 2018a). Many of these variables are already existing and availables, however, there is only a very limited range of products available within CLMS focusing specifically on the cryosphere. In fact, CLMS only provides three products (snow cover extent, snow water equivalent and lake ice extent) under the Cryosphere theme. However, an extensive list of products that are also of relevance for polar regions is available within CLMS. These products cover aspects of land hydrology, vegetation and energy exchange and are listed in Annex 1.

Besides these land products from CLMS there are a whole range of relevant products available from other Copernicus services as well as other providers such as the ESA-CCI. In that sense the obstacle with products relevant for polar regions is not so much gaps in available products (except for avalanches, see below) but rather a diversity of providers (CLMS, C3S, ESA-CCI, CEMS) and a range of access points for obtaining the products. This is illustrated by the results of a survey held at the Kepler side event at the Arctic Frontiers Conference 2020 where the audience was asked to rate the importance of having some selected products available. These products were: permafrost extent, permafrost active layer thickness, ground motion, lake ice thickness, snowmelt (dry and wet), avalanche risk, glacier extent, and soil moisture. Out of these products avalanche risk is the only product which is not available at all, the other products are mostly available from other data providers. The result of the short interactive survey (see also Appendix 4 and for more details the M6.3 report) shows that the most important data needs were concerned with snowmelt followed by avalanche risk and lake ice thickness. Therefore the outcome of this survey with respect to gaps in CLMS polar provisions points not primarily to gaps in the availability of products but rather to how the different service and product providers (e.g. Copernicus and ESA CCI) could be better streamlined to create a one-stop-shop, allowing the users to access all Arctic-related products. A key point here is a seamlessly integrated access point where users and data providers can share their

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measurement data in a standardized format. Hence, interoperability among data products (existing and future) is a key requirement for long-term monitoring as envisioned by Copernicus.

One more aspect crystallised in this gap analysis: There seems to be a clear gap in requirements of very high spatial resolution products (less than 100m) in the snow products of CLMS (and other providers); these are currently only available at resolutions down to ~1 km.

Avalanches: Avalanche monitoring in Polar regions by Sentinel-1 could be included as a CLMS polar service or in a wider global/pan-european service, however due to the short time-series of S1 data (since 2014) it makes more sense at present stage to include it as a EMS service.

CEMS polar provisions

Avalanche: An ongoing EU call on extensions of CEMS services also asks for new emergency monitoring services, and we feel that avalanche monitoring has both the maturity and the importance of being taken into consideration. A global CEMS service on avalanche monitoring should also have provisions for polar regions.

Fire: The EFFIS (https://effis.jrc.ec.europa.eu/) burnt area and fire danger index products based on MODIS/VIIRS seems to have also provision for polar regions.

Flood: The EFAS (https://www.efas.eu/efas_frontend/#/home) flood monitoring and forecast system have limited coverage in Arctic regions but covers Europe. Coverage in Polar regions should be granted.

Commentary on the inventory

The inventory tables are provided in Annex 1 (CLMS) and 2 (other providers) of this report.

From the EC final report on high-level mission requirements (Duchossoy et al., 2018a) a list of high priority parameters together with their associated performance requirements was established taking into account the high-level objectives of the EU Arctic policy communication as well as those of the Copernicus programme for the provision of operational products and services to well-identified user communities. The PEG report distinguishes several geophysical themes relevant for the polar regions, among them are 'Land Surface and vegetation', 'Permafrost and soils', 'Ice sheets', 'Glaciers and ice caps' and 'Snow'; for the purpose of this report these themes are all considered under land monitoring. With this assumption the list of parameters includes in order of priority the following elements for the land component:

- Glaciers, caps and ice-sheet parameters
- Surface albedo
- Surface freshwater
- Snow

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- Permafrost

These parameters have been marked with an * in the inventory tables.

The assumptions

- We have listed the inventory mainly as of today (no major upgrades foreseen in CLMS) with the exception of the permafrost parameters.
- We considered all ongoing and relevant ESA CCI projects.
- We did not consider variables (or flag these) if the coverage does not extend beyond 60° N.
- Atmospheric parameters are not taken into account, these are provided by the C3S reanalysis. However, a number of parameters in the reanalysis products, especially the land reanalysis product of C3S (ERA5-Land), pertaining to the land surface are considered as well as other relevant C3S products (such as FAPAR etc).
- Differences in grid resolution, data coverage (global or regional Arctic), time coverage, choice of methods or ancillary data sources and other technical differences between services are not specifically highlighted.

Parameter Specification

- Bartsch et al. (2019) discuss several ways to generate permafrost ECVs (ground temperature, active layer thickness, permafrost fraction) and conclude that the optimal approach consists of combining ensemble runs of a transient permafrost model (CryoGrid CCI) with input datasets based on EO from ESA LC_cci (land-cover), ESA LST_cci (land surface temperature), ESA Snow_cci, and a ground stratigraphy compiled from various measurements. Using an ensemble approach enables the representation of a range of temperatures per grid cell, and thus the specification of a permafrost fraction/extent. Validation of ground temperature and active layer thickness products will be based on borehole data from the GTN-P and CALM networks, respectively. A more detailed discussion of the aspects of a potential Copernicus permafrost product is included in the deliverable report D3.3.
- The spatial resolution given in the tables is usually the size of the grid mesh.
- The ESA-CCI LAKES will establish a lake ice cover product during the next years. The project started earlier this year, hence not much information on the specifications of the product are available. Most likely the product will be based on optical sensors and lack information in the NH winter.
- The ESA-CCI SNOW is still running but has produced first products based on AVHRR GAC data. It will deliver both snow cover extent as well as snow water equivalent. Since the product will be based on optical sensors it will provide only limited information in the NH winter.
- C3S provides as part of their ERA5-Land reanalysis (i.e. model results) a number of relevant products:

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- Evaporation (bare soil, top of canopy, open water, vegetation)
- Albedo (forecasted)
- Lake ice (depth, temperature)
- Snow (albedo, cover, density, depth, depth water equivalent, evaporation, snowfall, snowmelt)

- Both ESA-CCI and C3S provide additional variables that are not mentioned in the PEG report, for instance, land cover type (C3S, ESA-CCI), surface soil moisture (C3S, ESA-CCI), burnt area (ESA-CCI), above-ground biomass (ESA-CCI) and land surface temperature (ESA-CCI), but are relevant and of interest for the Polar region.

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Related Publications and Dissemination Output

N/A

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Annex 1: Land Variables Table (included in global CLMS)

Asterisks (*) refer to variables defined in Duchossoy et al., 2018.

Theme	Parameter	Units	Spatial resolution	Temporal coverage and period	Observation (main mission)	Remarks (i.e. coverage)
Hydrology	Water level *	m	300 m	10d, 28d, 35d; Lakes 1992-09 - 2019; Rivers 2002-05 - 2019	satellite altimeters (Topex/Poseidon, Envisat, Sentinel-3A, Jason-3)	global, non-gridded
	Water Bodies	index (0=Sea, 70=Water, 251=No data, 255=No water)	300 m and 1 km	10d, 2014-01 - 2019	PROBA-V	up to 75 N
	Lake Surface Water Temperature	K	1 km	10d, 2002-05 - 2012-03, 2018-4 - 2019	ENVISAT AATSR, Sentinel3/SLSTR	global
	Lake Water Quality	NTU	300 m and 1 km	10d, 2002-05 - 2012-03, 2016-05 - 2019	ENVISAT MERIS, Sentinel3 OLCI	global; NTU = Nephelometric Turbidity Units
Vegetation	Land cover	%	100 m	yearly, 2015	PROBA-V and several external datasets	[-60,78.25]; fractional cover for land cover types from UN-FAO LCCS scheme
	Burnt area	binary value (0 or 1)	300 m and 1 km	10d, 2014-04 - 2019, 2014-04 - 2018-08	PROBA-V	[-56,75]
	Fraction of photosynthetically active radiation absorbed by the vegetation	fraction	300 m and 1 km	10d, 2014-01 - 2019, 1999-2019	PROBA-V, SPOT-VGT	[-60,80]
	Fraction of green vegetation cover	fraction	300 m and 1 km	10d, 2014-01 - 2019, 1999 - 2019	PROBA-V, SPOT-VGT	[-60,80]
	Leaf Area index	m2/m2	300 m and 1 km	10d, 2014-01 - 2019, 1999 - 2019	PROBA-V, SPOT-VGT	[-60,80]
	Normalized Difference Vegetation Index	index	300 m and 1 km	10d, 2016-02 - 2019, 1998-04 - 2019	PROBA-V, SPOT-VGT	[-56,75]
	Vegetation	index	1 km	10d, 2013-01 -	SPOT/VEGETATION	[-60,75]

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	Condition Index			2014-05, 2014-06 - 2019	, PROBA-V	
	Vegetation Productivity Index	%	1 km	10d, 2013-01 - 2018-08	PROBA-V, SPOT-VGT	[-60,75]
	Dry Matter Productivity	kg/ha/day	300 m and 1 km	10d, 2014-2019, 1999 - 2019	PROBA-V, SPOT-VGT and PROBA-V	[-60,80]
	Surface soil moisture	%	1km (only for Europe)	1-6days depending on latitude, 2015-01 - 2019	Sentinel-1 C-SAR	Only for Europe
Cryosphere	Snow cover extent *	%	1 km	Daily, 2018-01 - 2019	SNPP VIIRS	[25,84]
	Snow water equivalent *	mm	5 km	Daily (late September to early June), 2006-01 - 2019	SSMIS, VIIRS, and snow depth from ground stations	[35,85]
	Lake Ice Extent	index (1=fully snow covered ice, partially snow covered, open water)	250m (only for Baltic Sea Region)	Daily, 2017-03 - 2019	MODIS	Only for Baltic Sea Region
Energy	Surface albedo *	fraction	1 km	10d, 1998-12 - 2014-05, 2014-6 - 2019	SPOT/VEGETATION , PROBA-V	[-60,75]
	Land Surface Temperature	K	5 km	hourly, 2010-10 - 2019	geostationary satellites: MSG, GOES, Himawari	[-60,70]
	Top Of Canopy Reflectance	fraction	1 km	10d, 1999 - 2018-08	SPOT-VGT, PROBA-V	[-60,75]

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Annex 2: Land Variables Table (not yet included in global CLMS)

Asterisks (*) refer to variables defined in Duchossoy et al., 2018.

Others	Theme	Parameter	Units	Spatial resolution	Temporal coverage and period	Observation (main mission)	Remarks (i.e. coverage)
Permafrost - GlobPermafrost (released)	Cryosphere	Mean annual ground temperature at the top of permafrost	°C	1 km	Average of years 2000-2016	MODIS, ERA-Interim data, ESA CCI landcover, TTOP permafrost model	NH
		Permafrost occurrence probability	fraction	1 km	Average of years 2000-2016	MODIS, ERA-Interim data, ESA CCI landcover, TTOP permafrost model	NH
		Permafrost zone	continuous, discontinuous, sporadic, isolated	1 km	Average of years 2000-2016	MODIS, ERA-Interim data, ESA CCI landcover, TTOP permafrost model	NH
Permafrost - ESA-CCI (planned)	Cryosphere	Ground temperature at certain depth	°C	1 km	annual average	CryoGrid CCI model; land-cover, snow and land surface temperature from ESA CCI; ground stratigraphy from various measurements.	First Pan-Arctic and last decade, then global and 1979-present
		Active layer thickness	m	1 km	annual maximum		
		Permafrost fraction *	fraction	1 km	annual minimum		
		Permafrost-free fraction	fraction	1 km	annual maximum		
		Fraction underlain by talik	fraction	1 km			
		Permafrost zone *	continuous, discontinuous, sporadic, isolated	1 km			

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Greenland Icesheet (ESA-CCI)	Cryosphere	Surface elevation change *	m/yr	5 km x 5km	5-yearly running means for 1992-2012	radar altimetry measurements from ERS, EnviSat and CryoSat	covering Greenland only
		Ice velocity (northing, easting and vertical) *	m/day	500 m	different time periods for various parts of Greenland	ERS, EnviSat, Palsar, S1	long time series (1991 to 2010) for 9 major galciers, optical ice velocity for 10 major glaciers from S2 for 2016
		Calving Front Location *	delineations	22 of the 28 main outlet glaciers	annual	ERS, EnviSat, Landsat 5/7/8	
Glaciers (C3S)	Cryosphere	Elevation and mass change	Shape file	individual glaciers	annual-decadal, 1850-2020	in-situ, Landsat, ASTER	Randolph Glacier Inventory
		Distribution	Shape file	individual glaciers	2000	Landsat, ASTER	
Lake ice (ESA-CCI)	Cryosphere	Lake ice cover	Binary	250m	Daily, 2000-2020		Limitations at high latitudes in wintertime
Snow cover extent (ESA-CCI)	Cryosphere	Snow cover fraction *	%	500m	Daily, 2000-2020	AVHRR GAC	Limitations at high latitudes in wintertime
Snow cover extent (C3S)	Cryosphere	Snow cover fraction *	%	500m	Daily, 2000-2020		Limitations at high latitudes in wintertime
Snow water eq. (ESA-CCI)	Cryosphere	Snow water equivalent *	mm	5km, Northern hemisphere	Daily in the winter, 1991-2020	Kriging using snow depths from WMO station network	
Vegetation state (C3S)	Vegetation	Leaf Area Index	$m^2\ m^{-2}$	1-4 km	10 daily, 1998 to present	SPOT-VGT, PROBAV, AVHRR	v0 brokered dataset from CLMS, v1 and v2 produced by C3S
		Fraction of photosynthetically active radiation (FAPAR)	unitless, between 0-1				
Land Cover (ESA-CCI)	Vegetation	Land Cover typ based on the United Nations Land Cover Classification System (UN-LCCS)	value corresponding to the label of a UN-LCCS classifier	300 m	annual	satellite data (SPOT-VGT, PROBA-V, MERIS)	All terrestrial zones of the Earth between the parallels 90°N and 90°S.
		Climatological NDVI seasonality	unitless, between 0 and 1	1km	weekly, average over 1992-2012	based on SPOT-VGT	

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	Vegetation/Hydrology	permanent water bodies	land/inland water/ocean with inland water fraction, in percent	150 m	permanent map 2010	Envisat ASAR	forms class "Water Bodies" of the global annual, after resampling to 300 m using an average algorithm
Land Cover (C3S)	Vegetation	invariant: type of high veg, type of low veg, soil type	category	31km globally	hourly, 1950 to near-realtime		these are static, soil type from FAO/UNESCO Digital Soil Map of the World, vegetation type fromGLCC1.2
Surface soil moisture (ESA-CCI)	Vegetation/Hydrology	surface soil moisture, 3 products	percent of saturation [%]	0.25 deg globally	daily, 19910805 - 20180630	AMI-WS and ASCAT	based on active instruments, uncertainties are provided based on error propagation
			volumetric units [m3m-3]	0.25 deg globally	daily, 19781101 - 20180630	SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, and SMOS	based on passive instruments, uncertainties are provided based on error propagation
			volumetric units [m3m-3]	0.25 deg globally	daily, 19781101 - 20180630	AMI-WS, ASCAT, SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, and SMOS	combined, uncertainties are provided based on error propagation
Surface soil moisture (C3S)	Vegetation/Hydrology	Volumetric soil water in 4 layers	volumetric units [m3m-3]	31km globally	hourly, 1950 to near-realtime	scatterometer ERS AMI, METOP A/B ASCAT	
Fire/Burnt area (ESA-CCI)	Vegetation	Pixel burned area, date of detection	day of the year (0 not burned, -1 not observed, -2 not burnable, e.g. water)	0.0022457331 deg (~250 m at the Equator)	monthly composites, 2001-2018	MODIS RED and NIR bands, ESA Land Cover CCI	GeoTIFF with three layers, 57S-83N
		Pixel burned area, confidence level	0-100 (0 not observed,	0.0022457331 deg (~250 m at the Equator)	monthly composites, 2001-2018	MODIS RED and NIR bands, ESA Land Cover CCI	GeoTIFF with three layers

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			1-100 probabilty of pixel burned)				
		Pixel burned area, land cover	0-N (0 not burned, 10-180 land cover type as in UN-LCCS)	0.0022457331 deg (~250 m at the Equator)	monthly composites, 2001-2018	MODIS RED and NIR bands, ESA Land Cover CCI	GeoTIFF with three layers
		Gridded burned area	m^2 (sum of area of all 250m pixels detected as burned)	0.25 deg	monthly composites, 2001-2018	MODIS RED and NIR bands, ESA Land Cover CCI	standard error based on confidence level of the pixel product
Fire (C3S)	Vegetation	Fire danger index	dimension less	0.25 deg	daily, 1979-present	Produced by the Copernicus Emergency Managment Service for the European Forest Fire Information System (EFFIS) based on ERA5 reanalysis input	Fire danger index is a metric related to chances of a fire starting, rate of spread, intensity, and difficulty of suppression. Open ended scale, a value of > 50 is considered extreme
		burned area	m^2	0.25 deg	15-daily, 2001-2017	MODIS, Sentinel-3 OLCI	Global gridded, pixel based product exists as well
Above-ground biomass (ESA-CCI)	Vegetation	global maps of above-ground biomass	Mg C ha-1	500m	4 epochs (mid 1990s, 2007-2010, 2017/2018 and 2018/2019)	optical sensors (e.g., Sentinel 2A/B), C-band (Sentinel 1A & B) and L-band Synthetic Aperture Radar (ALOS-2 PALSAR-2) and spaceborne LIDAR (e.g. NASA's Global Ecosystem Dynamics Investigation Lidar [GEDI])	ongoing

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Land surface temperature (ESA-CCI)	Energy	Temperature of land surface	K, Kelvin	1km	Daily, 1995-2020		
Surface Albedo or analogue (C3S)	Energy	Spectral directional and hemispherical albedos *	- (no unit: value between 0-1)	1km	Every 10 days,1998-2020	SPOT/VGT, PROBA-V	Limitations at high latitudes in wintertime

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Annex 3: ERA5-Land Variables Table

ERA5-Land is a reanalysis dataset providing a consistent view of the evolution of land variables over several decades at a higher resolution than the ERA5 reanalysis. ERA5-Land has been produced by replaying the land component of the ECMWF ERA5 climate reanalysis. ERA5-Land uses as input to control the simulated land fields ERA5 atmospheric variables, i.e. the atmospheric forcing.

DATA DESCRIPTION	
Data type	Gridded
Horizontal coverage	Global
Horizontal resolution	0.1°x0.1°; Native resolution is 9 km.
Vertical coverage	From 2 m above the surface level, to a soil depth of 289 cm.
Vertical resolution	4 levels of the ECMWF surface model: Layer 1: 0 -7cm, Layer 2: 7 -28cm, Layer 3: 28-100cm, Layer 4: 100-289cm Some parameters are defined at 2 m over the surface.
Temporal coverage	January 1981 to present
Temporal resolution	Hourly
File format	GRIB
Update frequency	Monthly with a delay of about three months relatively to actual date.

MAIN VARIABLES		
Name	**Units**	**Description**
10m u-component of wind	$m\ s^{-1}$	Eastward component of the 10m wind. It is the horizontal speed of air moving towards the east, at a height of ten metres above the surface of the Earth, in metres per second. Care should be taken when comparing this variable with observations, because wind observations vary on small space and time scales and are affected by the local terrain, vegetation and buildings that are represented only on average in the ECMWF Integrated Forecasting System. This variable can be combined with the V component of 10m wind to give the speed and direction of the horizontal 10m wind.

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10m v-component of wind	m s^{-1}	Northward component of the 10m wind. It is the horizontal speed of air moving towards the north, at a height of ten metres above the surface of the Earth, in metres per second. Care should be taken when comparing this variable with observations, because wind observations vary on small space and time scales and are affected by the local terrain, vegetation and buildings that are represented only on average in the ECMWF Integrated Forecasting System. This variable can be combined with the U component of 10m wind to give the speed and direction of the horizontal 10m wind.
2m dewpoint temperature	K	Temperature to which the air, at 2 metres above the surface of the Earth, would have to be cooled for saturation to occur.It is a measure of the humidity of the air. Combined with temperature and pressure, it can be used to calculate the relative humidity. 2m dew point temperature is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
2m temperature	K	Temperature of air at 2m above the surface of land, sea or in-land waters. 2m temperature is calculated by interpolating between the lowest model level and the Earth's surface, taking account of the atmospheric conditions. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Evaporation	m of water equivalent	Accumulated amount of water that has evaporated from the Earth's surface, including a simplified representation of transpiration (from vegetation), into vapour in the air above. This variable is accumulated from the beginning of the forecast to the end of the forecast step. The ECMWF Integrated Forecasting System convention is that downward fluxes are positive. Therefore, negative values indicate evaporation and positive values indicate condensation.
Evaporation from bare soil	m of water equivalent	The amount of evaporation from bare soil at the top of the land surface. This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Evaporation from open water surfaces excluding oceans	m of water equivalent	Amount of evaporation from surface water storage like lakes and inundated areas but excluding oceans. This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Evaporation from the top of canopy	m of water equivalent	The amount of evaporation from the canopy interception reservoir at the top of the canopy. This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Evaporation from vegetation transpiration	m of water equivalent	Amount of evaporation from vegetation transpiration. This has the same meaning as root extraction i.e. the amount of water extracted from the different soil layers. This variable is accumulated from the beginning of the forecast time to the end of the forecast step.

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Forecast albedo	dimensionless	Is a measure of the reflectivity of the Earth's surface. It is the fraction of solar (shortwave) radiation reflected by Earth's surface, across the solar spectrum, for both direct and diffuse radiation. Values are between 0 and 1. Typically, snow and ice have high reflectivity with albedo values of 0.8 and above, land has intermediate values between about 0.1 and 0.4 and the ocean has low values of 0.1 or less. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface, where some of it is reflected. The portion that is reflected by the Earth's surface depends on the albedo. In the ECMWF Integrated Forecasting System (IFS), a climatological background albedo (observed values averaged over a period of several years) is used, modified by the model over water, ice and snow. Albedo is often shown as a percentage (%).
Lake bottom temperature	K	Temperature of water at the bottom of inland water bodies (lakes, reservoirs, rivers) and coastal waters. ECMWF implemented a lake model in May 2015 to represent the water temperature and lake ice of all the world's major inland water bodies in the Integrated Forecasting System. The model keeps lake depth and surface area (or fractional cover) constant in time.
Lake ice depth	m	The thickness of ice on inland water bodies (lakes, reservoirs and rivers) and coastal waters. The ECMWF Integrated Forecasting System (IFS) represents the formation and melting of ice on inland water bodies (lakes, reservoirs and rivers) and coastal water. A single ice layer is represented. This parameter is the thickness of that ice layer.
Lake ice temperature	K	The temperature of the uppermost surface of ice on inland water bodies (lakes, reservoirs, rivers) and coastal waters. The ECMWF Integrated Forecasting System represents the formation and melting of ice on lakes. A single ice layer is represented. The temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Lake mix-layer depth	m	The thickness of the upper most layer of an inland water body (lake, reservoirs, and rivers) or coastal waters that is well mixed and has a near constant temperature with depth (uniform distribution of temperature). The ECMWF Integrated Forecasting System represents inland water bodies with two layers in the vertical, the mixed layer above and the thermocline below. Thermoclines upper boundary is located at the mixed layer bottom, and the lower boundary at the lake bottom. Mixing within the mixed layer can occur when the density of the surface (and near-surface) water is greater than that of the water below. Mixing can also occur through the action of wind on the surface of the lake.
Lake mix-layer temperature	K	The temperature of the upper most layer of inland water bodies (lakes, reservoirs and rivers) or coastal waters) that is well mixed. The ECMWF Integrated Forecasting System represents inland water bodies with two layers in the vertical, the mixed layer above and the thermocline below. Thermoclines upper boundary is located at the mixed layer bottom, and the lower boundary at the lake bottom. Mixing within the mixed layer can occur when the density of the surface (and near-surface) water is greater than that of the water below. Mixing can also occur through the action of wind on the surface of the lake. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Lake shape factor	dimensionless	This parameter describes the way that temperature changes with depth in the thermocline layer of inland water bodies (lakes, reservoirs and rivers) and coastal waters. It is used to calculate the lake bottom temperature and other lake-related parameters. The ECMWF Integrated Forecasting System represents inland and coastal water bodies with two layers in the vertical, the mixed layer above and the thermocline below where temperature changes with depth.

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Lake total layer temperature	K	The mean temperature of total water column in inland water bodies (lakes, reservoirs and rivers) and coastal waters. The ECMWF Integrated Forecasting System represents inland water bodies with two layers in the vertical, the mixed layer above and the thermocline below where temperature changes with depth. This parameter is the mean over the two layers. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Leaf area index, high vegetation	$m^2 m^{-2}$	One-half of the total green leaf area per unit horizontal ground surface area for high vegetation type.
Leaf area index, low vegetation	$m^2 m^{-2}$	One-half of the total green leaf area per unit horizontal ground surface area for low vegetation type.
Potential evaporation	m	Potential evaporation (pev) in the current ECMWF model is computed, by making a second call to the surface energy balance routine with the vegetation variables set to "crops/mixed farming" and assuming no stress from soil moisture. In other words, evaporation is computed for agricultural land as if it is well watered and assuming that the atmosphere is not affected by this artificial surface condition. The latter may not always be realistic. Although pev is meant to provide an estimate of irrigation requirements, the method can give unrealistic results in arid conditions due to too strong evaporation forced by dry air. This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Runoff	m	Some water from rainfall, melting snow, or deep in the soil, stays stored in the soil. Otherwise, the water drains away, either over the surface (surface runoff), or under the ground (sub-surface runoff) and the sum of these two is simply called 'runoff'. This variable is the total amount of water accumulated from the beginning of the forecast time to the end of the forecast step. The units of runoff are depth in metres. This is the depth the water would have if it were spread evenly over the grid box. Care should be taken when comparing model variables with observations, because observations are often local to a particular point rather than averaged over a grid square area. Observations are also often taken in different units, such as mm/day, rather than the accumulated metres produced here. Runoff is a measure of the availability of water in the soil, and can, for example, be used as an indicator of drought or flood. More information about how runoff is calculated is given in the IFS Physical Processes documentation.
Skin reservoir content	m of water equivalent	Amount of water in the vegetation canopy and/or in a thin layer on the soil. It represents the amount of rain intercepted by foliage, and water from dew. The maximum amount of 'skin reservoir content' a grid box can hold depends on the type of vegetation, and may be zero. Water leaves the 'skin reservoir' by evaporation.
Skin temperature	K	Temperature of the surface of the Earth. The skin temperature is the theoretical temperature that is required to satisfy the surface energy balance. It represents the temperature of the uppermost surface layer, which has no heat capacity and so can respond instantaneously to changes in surface fluxes. Skin temperature is calculated differently over land and sea. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Snow albedo	dimensionless	It is defined as the fraction of solar (shortwave) radiation reflected by the snow, across the solar spectrum, for both direct and diffuse radiation. It is a measure of the reflectivity of the snow covered grid cells. Values vary between 0 and 1. Typically, snow and ice have high reflectivity with albedo values of 0.8 and above.

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Snow cover	%	It represents the fraction (0-1) of the cell / grid-box occupied by snow (similar to the cloud cover fields of ERA5).
Snow density	kg m^{-3}	Mass of snow per cubic metre in the snow layer. The ECMWF Integrated Forecast System (IFS) model represents snow as a single additional layer over the uppermost soil level. The snow may cover all or part of the grid box.
Snow depth	m	Instantaneous grib-box average of the snow thickness on the ground (excluding snow on canopy).
Snow depth water equivalent	m of water equivalent	Depth of snow from the snow-covered area of a grid box. Its units are metres of water equivalent, so it is the depth the water would have if the snow melted and was spread evenly over the whole grid box. The ECMWF Integrated Forecast System represents snow as a single additional layer over the uppermost soil level. The snow may cover all or part of the grid box.
Snow evaporation	m of water equivalent	Evaporation from snow averaged over the grid box (to find flux over snow, divide by snow fraction). This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Snowfall	m of water equivalent	Accumulated total snow that has fallen to the Earth's surface. It consists of snow due to the large-scale atmospheric flow (horizontal scales greater than around a few hundred metres) and convection where smaller scale areas (around 5km to a few hundred kilometres) of warm air rise. If snow has melted during the period over which this variable was accumulated, then it will be higher than the snow depth. This variable is the total amount of water accumulated from the beginning of the forecast time to the end of the forecast step. The units given measure the depth the water would have if the snow melted and was spread evenly over the grid box. Care should be taken when comparing model variables with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box and model time step.
Snowmelt	m of water equivalent	Melting of snow averaged over the grid box (to find melt over snow, divide by snow fraction). This variable is accumulated from the beginning of the forecast time to the end of the forecast step.
Soil temperature level 1	K	Temperature of the soil in layer 1 (0 - 7 cm) of the ECMWF Integrated Forecasting System. The surface is at 0 cm. Soil temperature is set at the middle of each layer, and heat transfer is calculated at the interfaces between them. It is assumed that there is no heat transfer out of the bottom of the lowest layer. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.
Soil temperature level 2	K	Temperature of the soil in layer 2 (7 -28cm) of the ECMWF Integrated Forecasting System.
Soil temperature level 3	K	Temperature of the soil in layer 3 (28-100cm) of the ECMWF Integrated Forecasting System.

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Soil temperature level 4	K	Temperature of the soil in layer 4 (100-289 cm) of the ECMWF Integrated Forecasting System.
Sub-surface runoff	m	Some water from rainfall, melting snow, or deep in the soil, stays stored in the soil. Otherwise, the water drains away, either over the surface (surface runoff), or under the ground (sub-surface runoff) and the sum of these two is simply called 'runoff'. This variable is accumulated from the beginning of the forecast time to the end of the forecast step. The units of runoff are depth in metres. This is the depth the water would have if it were spread evenly over the grid box. Care should be taken when comparing model variables with observations, because observations are often local to a particular point rather than averaged over a grid square area. Observations are also often taken in different units, such as mm/day, rather than the accumulated metres produced here. Runoff is a measure of the availability of water in the soil, and can, for example, be used as an indicator of drought or flood. More information about how runoff is calculated is given in the IFS Physical Processes documentation.
Surface latent heat flux	J m^{-2}	Exchange of latent heat with the surface through turbulent diffusion. This variables is accumulated from the beginning of the forecast time to the end of the forecast step. By model convention, downward fluxes are positive.
Surface net solar radiation	J m^{-2}	Amount of solar radiation (also known as shortwave radiation) reaching the surface of the Earth (both direct and diffuse) minus the amount reflected by the Earth's surface (which is governed by the albedo).Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface, where some of it is reflected. The difference between downward and reflected solar radiation is the surface net solar radiation. This variable is accumulated from the beginning of the forecast time to the end of the forecast step. The units are joules per square metre (J m-2). To convert to watts per square metre (W m-2), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Surface net thermal radiation	J m^{-2}	Net thermal radiation at the surface. Accumulated field from the beginning of the forecast time to the end of the forecast step. By model convention downward fluxes are positive.
Surface pressure	Pa	Pressure (force per unit area) of the atmosphere on the surface of land, sea and in-land water. It is a measure of the weight of all the air in a column vertically above the area of the Earth's surface represented at a fixed point. Surface pressure is often used in combination with temperature to calculate air density. The strong variation of pressure with altitude makes it difficult to see the low and high pressure systems over mountainous areas, so mean sea level pressure, rather than surface pressure, is normally used for this purpose. The units of this variable are Pascals (Pa). Surface pressure is often measured in hPa and sometimes is presented in the old units of millibars, mb (1 hPa = 1 mb = 100 Pa).

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Surface runoff	m	Some water from rainfall, melting snow, or deep in the soil, stays stored in the soil. Otherwise, the water drains away, either over the surface (surface runoff), or under the ground (sub-surface runoff) and the sum of these two is simply called 'runoff'. This variable is the total amount of water accumulated from the beginning of the forecast time to the end of the forecast step. The units of runoff are depth in metres. This is the depth the water would have if it were spread evenly over the grid box. Care should be taken when comparing model variables with observations, because observations are often local to a particular point rather than averaged over a grid square area. Observations are also often taken in different units, such as mm/day, rather than the accumulated metres produced here. Runoff is a measure of the availability of water in the soil, and can, for example, be used as an indicator of drought or flood. More information about how runoff is calculated is given in the IFS Physical Processes documentation.
Surface sensible heat flux	$J\ m^{-2}$	Transfer of heat between the Earth's surface and the atmosphere through the effects of turbulent air motion (but excluding any heat transfer resulting from condensation or evaporation). The magnitude of the sensible heat flux is governed by the difference in temperature between the surface and the overlying atmosphere, wind speed and the surface roughness. For example, cold air overlying a warm surface would produce a sensible heat flux from the land (or ocean) into the atmosphere. This is a single level variable and it is accumulated from the beginning of the forecast time to the end of the forecast step. The units are joules per square metre (J m-2). To convert to watts per square metre (W m-2), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Surface solar radiation downwards	$J\ m^{-2}$	Amount of solar radiation (also known as shortwave radiation) reaching the surface of the Earth. This variable comprises both direct and diffuse solar radiation. Radiation from the Sun (solar, or shortwave, radiation) is partly reflected back to space by clouds and particles in the atmosphere (aerosols) and some of it is absorbed. The rest is incident on the Earth's surface (represented by this variable). To a reasonably good approximation, this variable is the model equivalent of what would be measured by a pyranometer (an instrument used for measuring solar radiation) at the surface. However, care should be taken when comparing model variables with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box and model time step. This variable is accumulated from the beginning of the forecast time to the end of the forecast step. The units are joules per square metre (J m-2). To convert to watts per square metre (W m-2), the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Surface thermal radiation downwards	$J\ m^{-2}$	Amount of thermal (also known as longwave or terrestrial) radiation emitted by the atmosphere and clouds that reaches the Earth's surface. The surface of the Earth emits thermal radiation, some of which is absorbed by the atmosphere and clouds. The atmosphere and clouds likewise emit thermal radiation in all directions, some of which reaches the surface (represented by this variable). This variable is accumulated from the beginning of the forecast time to the end of the forecast step. The units are joules per square metre (J m-2). To convert to watts per square metre (W m-2),the accumulated values should be divided by the accumulation period expressed in seconds. The ECMWF convention for vertical fluxes is positive downwards.
Temperature of snow layer	K	This variable gives the temperature of the snow layer from the ground to the snow-air interface. The ECMWF Integrated Forecast System (IFS) model represents snow as a single additional layer over the uppermost soil level. The snow may cover all or part of the grid box. Temperature measured in kelvin can be converted to degrees Celsius (°C) by subtracting 273.15.

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Total precipitation	m	Accumulated liquid and frozen water, including rain and snow, that falls to the Earth's surface. It is the sum of large-scale precipitation (that precipitation which is generated by large-scale weather patterns, such as troughs and cold fronts) and convective precipitation (generated by convection which occurs when air at lower levels in the atmosphere is warmer and less dense than the air above, so it rises). Precipitation variables do not include fog, dew or the precipitation that evaporates in the atmosphere before it lands at the surface of the Earth. This variable is accumulated from the beginning of the forecast time to the end of the forecast step. The units of precipitation are depth in metres. It is the depth the water would have if it were spread evenly over the grid box. Care should be taken when comparing model variables with observations, because observations are often local to a particular point in space and time, rather than representing averages over a model grid box and model time step.
Volumetric soil water layer 1	$m^3\ m^{-3}$	Volume of water in soil layer 1 (0 - 7 cm) of the ECMWF Integrated Forecasting System. The surface is at 0 cm. The volumetric soil water is associated with the soil texture (or classification), soil depth, and the underlying groundwater level.
Volumetric soil water layer 2	$m^3\ m^{-3}$	Volume of water in soil layer 2 (7 -28 cm) of the ECMWF Integrated Forecasting System.
Volumetric soil water layer 3	$m^3\ m^{-3}$	Volume of water in soil layer 3 (28-100 cm) of the ECMWF Integrated Forecasting System.
Volumetric soil water layer 4	$m^3\ m^{-3}$	Volume of water in soil layer 4 (100-289 cm) of the ECMWF Integrated Forecasting System.

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Annex 3: Parameter Specification Scheme adapted by the PEG survey

Table : Parameter specification scheme adapted by the PEG survey (Duchossoy et al., 2018).

AOI (coverage)	Area Of Interest to be covered, options are: [0] global, [1] high latitude (>60), [2] regional - in this case provide details (bounding box, shapefile) or map (raster mask at 10-100km resolution)
Spatial Resolution	the sampling distance of measurements in [m], equal spacing in x and y is assumed
TOY (seasonality)	Time Of Year for measurements, options are: [0] year round, [1] seasonal - in this case provide the time window for measurements (months)
Frequency	temporal frequency, options are: [0] 'on demand' acquisitions - estimate nr of acquisitions per year, [1] regular measurements - provide repetition rate in [mn, hr, dy, mo, yr]
Leadtime	in case of 'on demand', what should be the minimum lead time for an acquisition to be scheduled in [hr]
Timeliness	how long after acquisition should the product be available, options are: [0] non time critical, [1] NRT within 6hr [2] QRT within 1hr
Unit	how is the variable assessed [0] as continuous scale, in this case give (physical) units (SI) [1] in different categorical classes - in this case provide reference
Range	dynamic range of measurements in physical units or number (and name) of categories
Accuracy	95% confidence interval for uncertainty (continuous scale variable) or commission and omission errors (categorical variable)
In situ (I)	availability of in-situ observations, options are: [0] hardly accessible, [1] irregular measurements available, [2] various sources exist and (non-harmonised) data are made available on a regular basis, [3] international standardised network
Status (S)	is variable currently monitored by means of EO: [0] no [1] experimental research ongoing, [2] operational service, (ATBDs available); for [1] and [2] provide references
Gaps	If variable is currently observed, give actual specs if different from requirements listed under 1-8 above
Continuity (C)	what are the expectations with respect to future availability of this variable: [0] current status of EO and IS ensured or likely to improve, [1] in-situ at risk, [2] EO not available or at risk

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	[3] availability/quality of both IS and EO at risk to deteriorate
Priority (P)	[0] low, nice to have, dispensable, models and/or proxies available [1] low, but continuity must be guaranteed [2] high, improvements are essential for progress in the domain

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Annex 4: Extract from the survey held at the Arctic Frontiers 2020 Kepler side event

The above graph is an extract from the survey held at the Arctic Frontiers 2020 Kepler side event, the complete results of the survey are available in the Milestone report M6.3 presenting the meeting minutes of the side event organised by KEPLER at the Arctic Frontiers Conference 2020 held on 29 January in Tromsø, Norway.

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