Comments from Public Consultation on ECV Requirements 13/01 – 13/03 2020 for:

# Permafrost

## ECV Product: Permafrost extent

### Comment 1

|  |  |
| --- | --- |
| Author: Annett Bartsch | Email: Annett.Bartsch@polarresearch.at |
| See Comment and Table below | |

In addition to the parameters listed in GCOS-200, GCOS-107 mentions permafrost extent. It corresponds to the aerial fraction within an area at which the definition for the existence of permafrost (ground temperature < 0 ºC for two consecutive years) is fulfilled. The characterization of the permafrost extent in terms of aerial coverage has been employed for decades in the permafrost community, e.g. in the classic IPA permafrost map displaying classes of continuous, discontinuous, sporadic and isolated permafrost. No specific requirements for permafrost extent are available through GCOS to date. Permafrost extent is, however, the sole target parameter listed in the WMO RRR database ([https://www.wmo-sat.info/oscar/variables/view/124](https://www.google.com/url?q=https%3A%2F%2Fwww.wmo-sat.info%2Foscar%2Fvariables%2Fview%2F124&sa=D&sntz=1&usg=AFQjCNGlC-uFp-boIr0tnCwFBEjLglBppQ)), where differing requirements are listed for the application areas Hydrology and Climate-TOPC. Temporal resolution requirements are very high (target 6 hours), reflecting the velocity of atmospheric processes and so the drivers in modelling or the dynamics of seasonally frozen soil (e.g., to account for the number of freezing and thawing days). However, permafrost is a sub-surface property and the relationships between the frozen ground and the relevant climatic elements, are complex. The source of the WMO RRR requirements is unknown and they have been so far not confirmed in published user surveys regarding permafrost.

Permafrost extent has been further identified as a target parameter for a potential future satellite mission within the framework of Copernicus (Duchossois et al. 2018). Horizontal resolution requirements have been defined with threshold 10 m and goal 1 m. Temporal resolution has been defined with 10 years as threshold and 1 year as target. Accuracy should be 85% and 95% respectively. Permafrost extent has been also included as required parameter in the report with 1m - 10m (local) and 100m (circumpolar) required horizontal resolution and annual temporal resolution. Further on, permafrost extent with respect to satellite observations is discussed in NRC (2014) and Bartsch et al. (2014, 2016, 2019).

It is therefore suggested to also **include permafrost extent as additional product** (see table 1) and to further reconcile relevant existing user requirement collection activities.

**Table 1:**Suggestions for new Permafrost associated product: Permafrost extent

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Permafrost extent | | | | |
| **Definition** | Fraction of permafrost-underlain area within a grid cell's horizontal area. Permafrost is subsurface earth material that remains continuously at or below 0°C throughout at least two consecutive years, usually for extended time periods up to many millennia. | | | | |
| **Unit** | fraction | | | | |
| **Note** | The requirements for permafrost extent reflect the determination through models which use relevant satellite observations as input in the context of permafrost monitoring | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | m | Size of grid cell | G | 1 | Expert survey results documented in Duchossois et al.( 2018) and in NRC (2014) |
| B | 10 | Expert survey results documented in NRC (2014) |
| T | 100 | Expert survey results documented in NRC (2014) |
| **Vertical Resolution** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Temporal Resolution** | years |  | G | 1 | Expert survey results documented in Duchossois et al. (2018) |
| B |  |  |
| T | 10 | Expert survey results documented in Duchossois et al. (2018) |
| **Timeliness** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Required Measurement Uncertainty** | % | Accuracy | G | 95 | Expert survey results documented in Duchossois et al. (2018) |
| B |  |  |
| T | 85 | Expert survey results documented in Duchossois et al. (2018) |
| **Stability** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. The direct link between summer heat waves and rock fall frequency is well established. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |

**References in addition to GCOS documents**

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Bartsch, A.; Grosse, G.; Kääb, A.; Westermann, S.; Strozzi, T.; Wiesmann, A.; Duguay, C.; Seifert, F. M.; Obu, J.; Goler, R. (2016): GlobPermafrost – How space-based earth observation supports understanding of permafrost. Proceedings of the ESA Living Planet Symposium, pp. 6. <http://www.globpermafrost.info/cms/documents/publications/publication-results-of-the-user-survey-in-the-esa-special-publication-proceedings>

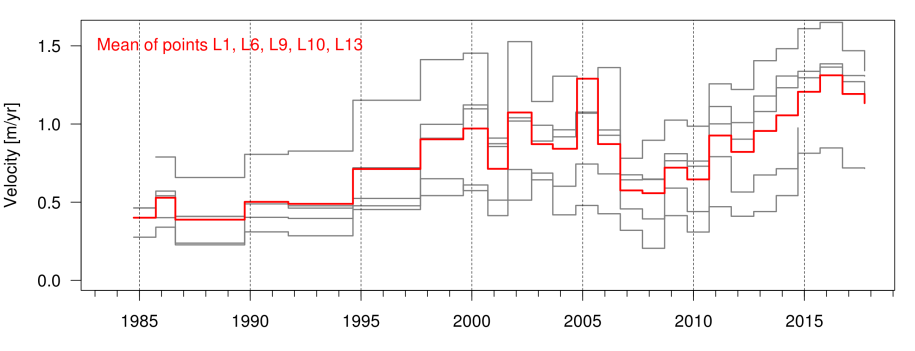
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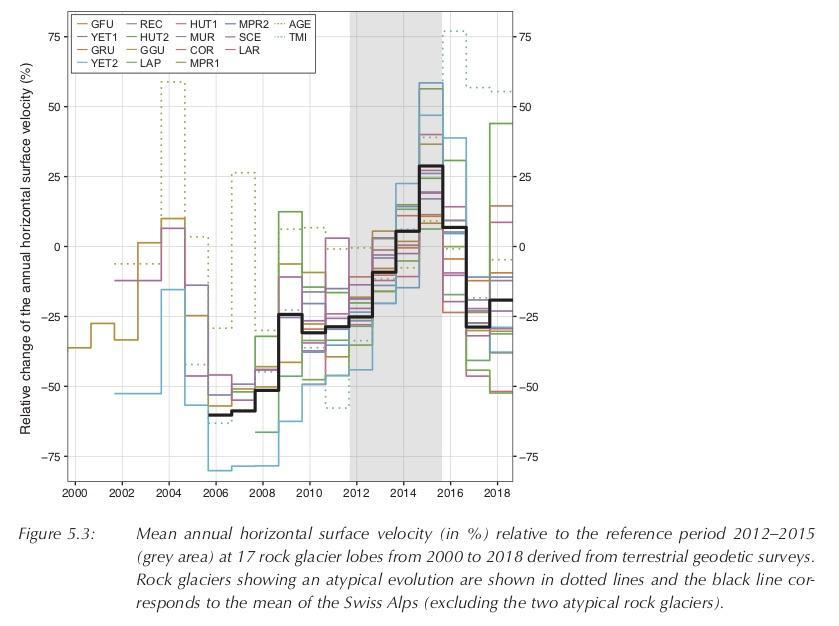
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## ECV Product: Rock Glacier Kinematics (RGK)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Rock Glacier Kinematics (RGK) | | | | |
| **Definition** | The kinematics of rock glaciers depends on the temperature profile between the surface and the main shearing horizon at depth: the closer to 0°C it is, the faster the rock glacier is moving. Most rock glaciers have a concomitant regional behavior at the (pluri-)annual to (pluri-)decennial time scale. Nevertheless, some rock glaciers may accelerate or decelerate abnormally. Therefore, it is important to use as far as possible a relatively large set of rock glaciers for performing a regional trend analysis. The ECV product consists of regional relative velocity time series, which are synthetizing individual velocity times series acquired by terrestrial or remote sensing survey. | | | | |
| **Unit** | Surface velocities of rock glacier are measured in m/yr.  The relative velocity time series has no unit and is expressed in relative deviation (ratio) to a reference period. | | | | |
| **Note** | There are two sets of approaches for measuring rock glacier surface velocities: in situ terrestrial survey (e.g. repeated GNSS field campaigns, permanent GNSS stations) and remote sensed based approaches (e.g. InSAR, satellite-/air-/UAV-borne photogrammetry). In both cases, the result is an annual velocity value expressed in m/yr, from which is derived the relative velocity time series (acceleration/deceleration).  Only talus-connected rock glaciers and possibly debris-mantled slope-connected rock glaciers are of concern, whereas glacier-connected and glacier forefield-connected rock glacier are not or must be considered separately.  The selection of rock glaciers for RGK monitoring is strongly dependent on site accessibility and safety for in situ measurements and on favorable configuration for investigation with remote sensing methods, so that an ideal spatial distribution is not always reachable. | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** |  | Spatial distribution of selected rock glaciers | G | Representative sites in a defined regional context | At least 30% of the active talus-connected rock glaciers should be selected in a region, which is a part of a mountain range, in order to represent its climatic context. Only possible with remote sensing approaches. |
| B | Sufficient sites in a defined regional context | Allows the definition of a regional trend. |
| T | Time series on individual rock glaciers | Concerns mainly in situ measurements providing continuous time series at annual resolution (or max 2-3 yrs interval). |
| **Vertical Resolution** | m/yr | Horizontal surface velocity values per selected rock glacier. Movement is supposed to be downwards along the slope when methodologies do not allow the distinction  between horizontal and vertical flow. | G | Velocity range | The velocity value is computed as the average over the entire moving part of the rock glacier. Mean, min, max and std are provided. |
| B | Velocity field | The velocity value is computed as the average over the targeted moving part of the rock glacier. Mean, min, max and std are provided. |
| T | Velocity value at a point | Velocity is measured on a selected point of the rock glacier. The location should be consistent over time.    For annual in situ measurements, the value is corrected for a 365 day interval.  For remote sensing data obtained for a shorter period, values are extrapolated to annual values. |
| **Temporal Resolution** |  | Individual time series  Average over a specified period | G | seasonal | Allows to assess the influence of snow melt and summer heat on velocity. |
| B | 1 yr | Annual value measured near the end of glaciological year. Allows an interpretation of interannual variations. |
| T | 2-3 yrs | Maximal interval allowing an interpretation of the impact of interannual climate variability. Can be completed by back analysis based on historical images at lower temporal resolution. |
| **Timeliness** |  | Regional time series  Average over a specified period | G | Yearly | Velocity is computed as an average over a time period of 1 year (glaciological year) |
| B | 2-3 years | Velocity is computed as an average over a time period of 2-3 years (glaciological year) |
| T | 3-6 years | Velocity is computed as an average over a time period of 4-6 years (glaciological year). Depends on the periodicity of images for regional surveys (aerial photographs or satellites images). The value corresponds to a common periodicity for aerial image coverages, and can be adapted to regional/national specificities. |
| **Required Measurement Uncertainty** |  |  | G | 3 months | Minimum time needed for data processing. |
| B |  |  |
| T | 1 years |  |
| **Stability** | % | Sensor/algorithm uncertainty  (Relative) | G | 5 | A finer uncertainty allows a finer quantification of trend in velocity over the selected region |
| B |  |  |
| T | 10 | Relative minimal measurement uncertainty allowing to analyze velocity trend over time. |
| **Standards and References** | IPA Action Group Rock glaciers inventories and kinematics (<https://ipa.arcticportal.org/activities/action-groups>) | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Rock glacier acceleration, due to permafrost degradation, may induce emerging hazards in high mountain ranges. Knowing the regional velocity trend allows discriminating rock glaciers that move away from it. | | |
| **Extremes[3]** | Yes | Yes? | Interannual variations of rock glacier dynamics appear to be primarily related to external climatic factors rather than to the internal characteristics of the rock glaciers. They are mostly well related to shifts in mean annual ground surface temperature with a time lag reflecting the delay in propagation of corresponding anomalies deeper into permafrost. Seasonal factors may also play an important role. A lower intensity of winter ground freezing and/or a larger amount of winter snowfall facilitate a higher rate of annual rock glaciers surface motion. | | |



Example 1 - Long time series of an individual rock glacier (Laurichard rock glacier, from Bodin et al. 2018). Are represented: the mean velocity of 5 points, and the velocity of each point. Absolute scale in m/yr. Measurement interval 2-3 yr before 2000, annual after 2000.



Example 2:

Regional time series from the Swiss Alps (from PERMOS Report 2015-2018). Are represented: the mean velocity change, calculated from 23 individual time series, and each series. Relative scale in % of change. Measurement and calculation interval 1 yr.

[1]Goal (G); Breakthrough (B)(not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

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| --- | --- |
| Author: Rock glacier - IPA Action Grou | Email cbarboux@gmail.com |
| See below Comment and Table | |

The IPA (International Permafrost Association) Action Group Rock glacier inventories and kinematics (2018-2022) is an international initiative gathering more than one hundred members, which aims to define standards for the set-up of consistent and comparable rock glacier inventories and for the development of a climate-oriented rock glacier kinematics monitoring strategy. Resulting of the Action Group Workshop II (February 2020), the following proposition related to the ECV Permafrost product Rock Glacier Kinematics has been formulated.

ECV: Permafrost

ECV Product: **Rock Glacier Kinematics**

General introduction

Rock glaciers are the best geomorphological expression of the creep of mountain permafrost and constitute a prevalent heritage of the mountain periglacial landscape. Observing changes in rock glacier kinematics provides information about climate impact on mountain permafrost and has the potential to become a key parameter of cryosphere monitoring in mountain regions. The temporal evolution of rock glacier kinematics depends, amongst others, on the altering of the temperature profile between the permafrost table and the main shearing horizon at depth: the closer to 0°C it is rising, the faster the rock glacier tends to become. By comparing existing surface velocity time series, it appears that many rock glaciers have a concomitant regional behavior at the (pluri-)annual to (pluri-)decennial time scale. The main objective of the ECV product Rock Glacier Kinematics (RGK) is the setting up of a global dataset of rock glacier surface velocity time series, which would permit to assess the regional/global reaction of mountain permafrost creep to climate change.

Preliminary remarks

See standards and definitions from the [*IPA Action Group Rock glacier inventories and kinematics*](https://www3.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier/workshop-ii.html):

-> Technical definition and standardized attributes of rock glaciers ([link to the current version](https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_Baseline_Concepts_Inventorying_Rock_Glaciers.pdf))

-> Rock glacier kinematics ([link to the current version](https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_RockGlacierKinematics.pdf))

The following required items have to be specified for the ECV product Rock Glacier Kinematics:

**Horizontal resolution**

This item may have different meaning according to the type of variable (e.g. : pixel size for remote sensing coverage, mesh size for modelling, sampling interval, spacing of measurement stations, …). Regarding RGK, it consists of surface velocity time series measured/computed on single rock glaciers. The spatial resolution can be expressed into two horizontal dimensions:

-          the spatial distribution of selected rock glaciers that has to be considered for the setting up of a regional/global overview,

-          the resolution of the surface velocity value measured/computed on a single rock glacier unit that is dependent on the methodology/procedure used.

In order to clarify each of these two dimensions, the item “spatial resolution” is replicated twice. See also comments for the derivation of this item after the table.

**Vertical resolution**

This item is not relevant for surface velocity.

**Temporal resolution**

In the present version of IP and fact sheets, the item “temporal resolution” refers to the “frequency” (i.e. the periodicity of measurements). However, in the case of RGK, an additional temporal dimension should be taken into consideration: the time observation window (dates/period of measurement), that is constrained by the methodology used for measurement.

The field “temporal resolution” is duplicated, but standards for the time observation window are added for each standardized frequency. See also comments for the derivation of this item after the table.

**Measurement uncertainty**

The objective of RGK is to combine individual time series in order to observe relative regional/global interannual changes in rock glacier behavior. For this purpose, a low relative measurement uncertainty must be ensured for allowing a reliable analysis of the temporal velocity changes for each individual time series. Thus, this item is expressed in % of the observed velocity and is specific to each value or time series. See also comments for the derivation of this item after the table.

**Stability**

The problem of sensor drift is not relevant for RGK except for permanent GNSS. In that specific case, the sensor drift can be considered as the instability of the ground on which it is installed (e.g. rotation of the boulder). This instability cannot be estimated precisely as the causes could be diverse.

Moreover, the velocity value is an annualized displacement rate derived from methodologies allowing either for displacement measurement (i.e. from permanent location, point or area with always the same coordinates, e.g. photogrammetry) or for position measurements (i.e. from moving position, e.g. GNSS). On the long term, the stability is not ensured in the case of displacement measurement, as the location of this measurement is constant over time whereas the creeping mass is moving (the observed surface of the rock glacier will change). Likewise, in the case of position measurement, the stability is not ensured on the long term since the location is moving over time and the creeping mass is subject to change of topography for instance. This stability cannot be estimated but if major change is detected, time series must be stopped or adjusted accordingly.

The only stability that has to be ensured is related to a change of methodology or procedure used to measure and compute velocity value, as well as the required parameters that need to be consistent over time (time observation window and horizontal resolution of the velocity value). If one of these elements is changing, two times series must be derived for the selected rock glacier unit. The merging of these two time series can only be performed in the case of existing temporal overlap. Requirements for this overlapping are described for the item “Stability”.

Proposed requirements

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Rock Glacier Kinematics (RGK) | | | | |
| **Definition** | Global dataset of surface velocity time series measured/computed on single rock glacier units | | | | |
| **Unit** | m/yr | | | | |
| **Note** | RGK can be measured/computed from terrestrial survey (e.g. repeated GNSS field campaigns, permanent GNSS stations) or remote sensing based approaches (e.g. InSAR, satellite-/air-/UAV-borne photogrammetry). The velocity values can be derived either from an annualized displacement measurement or from an annualized displacement computed from position measurements.  RGK is defined for a single rock glacier unit that is expressed geomorphologically according to standards. Time series must be measured/computed distinguished if they come from different units, even in a unique rock glacier system. Several time series can be measured/computed on the same rock glacier unit when derived from different methodologies.  The spatial connection of the rock glacier to its upslope unit has to be described for each time series accordingly to standards. RGK focuses primarily on talus-connected rock glaciers and debris-mantled slope-connected rock glaciers, whereas glacier-connected and glacier forefield-connected rock glaciers, whose surface displacement rates can be significantly affected by other processes than permafrost creep, must be considered aside. | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | [1] | **Value** | **Derivation and References and Standards** |
| Horizontal Resolution |  | Spatial distribution of selected rock glaciers | G | Regional coverage | At least 30% of the active talus-connected and/or debris-mantled slope-connected rock glaciers should be selected in a region, which is a part of a mountain range, in order to represent its climatic context. Only possible with remote sensing approaches. |
| B | Multiple sites in a defined regional context | Allows the definition of a regional trend. |
| T | Isolated site | Continuous time series produced either from in situ measurements or remotely sensed measurements. |
| Horizontal Resolution (2) | m/yr | Surface velocity valuea  One value per selected rock glacier unit | G | Flow field | Velocity is computed/measured by aggregation over a target area on a rock glacier unit. The aggregation procedure and the target area should be consistent over time. Allows the best representation of the effective movement over the rock glacier unit. |
| B | Few discrete points | Velocity is computed/measured as an aggregation of few measurement points over a target area on a rock glacier unit. The aggregation procedure and the target area should be consistent over time. Allows a better representation of the effective movement over the rock glacier unit. |
| T | Velocity value at a point | Velocity is computed/measured on a single point. The location should be consistent over time and be spatially representative of the rock glacier unit it is taking part (i.e. located within a recognized  moving area). |
| Vertical resolution |  | Not relevant | G |  |  |
| B |  |  |
| T |  |  |
| Temporal Resolution | yr | Frequency  and  Time observation windowb | G | Frequency = 1 yr  Time observation window = 1 yr | Measured/computed once a year. The time observation window is 1 year and consistent over time. |
| B | Frequency = 1 yr  Time observation window < 1 yr | Measured/computed once a year. The time observation window is shorter than 1 year (e.g. observation on summer period only).. It should not be shorter than 1 month and must be consistent over time. Allows a better representation of the annual behavior. |
| T | Frequency = 2-5 yrs  Time observation window > 1 yr | Frequency limited by a time observation window of 2-5 yrs. This time period corresponds to the common periodicity for aerial image coverages, and can be adapted according to regional/national specificities. Longer intervals are admissible for optical images, as well as for reconstructions from archives. |
| Timeliness |  |  | G | 3 months | Minimum time needed for data processing. |
| B |  |  |
| T | 1 year |  |
| Required Measurement Uncertainty | % | Sensor/algorithm uncertaintyc | G | 5% | Relative velocity uncertainty allowing for the reliable analysis of velocity trend over time (relative change of the RGK). Appropriate and higher precision measurement technique may be required depending on the observed velocity range. |
| B | 10% |  |
| T | 20% | Relative minimal velocity uncertainty allowing for the reliable analysis of trend over time (relative change of the RGK). Appropriate measurement technique is required depending on the observed velocity range. |
| Stability |  | Overlapping | G | With overlap several yrs | Time observation window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of these elements is changing, two times series must be derived for the selected rock glacier unit. If these two time series have an overlap of several years ensuring consistency, they can be merged into a single time series. The merging procedure must be documented. |
| B | With overlap 1 yr | Time observation window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of these elements is changing, two time series must be derived for the selected rock glacier unit. If these two time series have an overlap of 1 year ensuring consistency, they can be merged into a single time series. The merging procedure must be documented. |
| T | Without overlap | Time observation window, horizontal resolution of the velocity value and methodologies/procedures used to measure/compute velocity value for a single time series must be consistent over time. If one of this element is changing without overlap, two time series must be derived for the selected rock glacier unit. |
| Standards and References | IPA Action Group Rock glaciers inventories and kinematics (<https://ipa.arcticportal.org/activities/action-groups>)  Standards and definitions :  - Technical definition and standardized attributes of rock glacier ([link to the current version](https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_Baseline_Concepts_Inventorying_Rock_Glaciers.pdf))  - Rock glacier kinematics ([link to the current version](https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/CurrentVersion/Current_RockGlacierKinematics.pdf)) | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation** | Yes | Yes | Rock glacier acceleration, due to permafrost degradation, may induce emerging hazards in high mountain ranges. Knowing the regional velocity trend allows discriminating rock glaciers that move away from it. | | |
| **Extremes** | Yes | Yes? | Interannual variations of rock glacier dynamics appear to be primarily related to external climatic factors rather than to the internal characteristics of the rock glacier. They are mostly well related to shifts in mean annual ground surface temperature with a time lag reflecting the delay in propagation of corresponding anomalies deeper into permafrost. Seasonal factors may also play an important role. A lower intensity of winter ground freezing and/or a larger amount of winter snowfall facilitate a higher rate of annual rock glaciers surface motion. | | |

Examples of results

See attached

Comments – Derivation of values

In all cases, the methodology/procedure used to provide time series on a single rock glacier unit has to be consistent over time and must be documented in the metadata.

**a** – **Horizontal resolution (2) / Surface velocity value**.

Depending on the methodology/procedure, the measured/computed velocity value can be expressed in 3D (e.g. displacements from GNSS), 2.5D (e.g. displacement from terrestrial laser scanning), 2D (horizontal velocity, e.g. from orthoimages), or 1D (vector in the line of sight, e.g. from InSAR). Since the main interest is to compute time series in order to observe the interannual variability and changes, no conversion to a standard dimensionality is requested. However, the data type must be consistent over time and indicated in the metadata.

Velocity can be derived from point measurements (e.g. continuous GNSS), from few discrete point measurements (e.g. multi-point GNSS surveys) or from flow field (e.g. airborne photogrammetry). In order to produce consistent time series, the measured/computed surface velocity value must be representative for the selected rock glacier unit:

-          When the velocity rate is measured on a single selected point, the location should be consistent over time, and be spatially representative of the landform, i.e. located within a recognized moving area.

-          When the velocity value is computed over a targeted moving part, the procedure for computing the value (aggregation) must be consistent over the time. The targeted moving part should be spatially representative of the landform, i.e. located within a recognized moving area.

G/B – Velocity is computed/measured by aggregation that must be documented in the metadata. Individual series used to derive the provided surface velocity values must be, as far as possible, provided.

**b** – **Temporal resolution**.

The value is always expressed as an annual value in m/yr. In case of a measurement interval > to 1 yr, the obtained value is reported for the different years.

B – Some methods are computed on shorter time observation windows (e.g. 6 days for Sentinel InSAR data). In order to avoid the reporting of single infra-annual variation, the period covered by the measurement should be at least one month. It can be obtained by an aggregation of several shorter time observation windows.

**c –** **Measurement uncertainty**.

The measurement uncertainty is dependent on the methodology and the procedure to measure/compute the velocity value. For instance, uncertainty for geodetic position measurement by total station are <1 cm, uncertainty for position measurement using GNSS are 2-3 cm and uncertainty for displacement measurement using photogrammetric processing are a few dm. The measurement uncertainty can reach up to several meters for displacement measurement using photogrammetric processing from low resolution optical satellite images.

The order of magnitude of rock glacier velocities is ranging generally from some cm/yr to several m/yr. This is for instance two order of magnitudes lower than that of glaciers, several orders of magnitude lower than that of ice-sheets. In the typical case of rock glacier, the measurement uncertainty allow for the selection of the better suited methodologies/procedures depending on the rate of velocity to observe. Setting a relative value as a threshold means that very slow rock glaciers for instance are excluded from the dataset if not monitored by an appropriate and high precision measurement technique. This would also mean that a rock glacier that is not moving and starts to accelerate enters the dataset only after onset of measurable movements.

Finally, the measurement uncertainty depends on the measurement methodology (uncertainty of position or displacement measurement), on the procedure (for instance aggregation) as well as on the time observation window used to measure and compute the annual velocity value for the selected rock glacier unit. Depending on the observed order of magnitude of velocity, some methodologies could be better suited than others. The measurement uncertainty is estimated in m/yr. The ratio between this uncertainty and the considered annual velocity value has to be lower than thresholds defined for T, B or G. If the ratio is lower than the threshold, significant values can be obtained by increasing the observation time window to a multiannual interval.

[1]         Goal (G); Breakthrough (B)(not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

### Comment 2

|  |  |
| --- | --- |
| Author: Annett Bartsch | Email: Annett.Bartsch@polarresearch.at |
| Requirements for GCOS parameters related to permafrost have been recently reviewed within the framework of the user requirements discussion of the ESA CCI+ Permafrost project (http://cci.esa.int/Permafrost). Specifically, rock glacier kinematics as an associated parameter of the ECV permafrost has been considered. The requirements have been jointly reviewed with the IPA action group (User requirements survey in 2019 and Action Group Workshop II (February 2020)). The above response by the working group therefore reflects the CCI+ Permafrost project recommendations. | |

### Comment 3

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| Author: Click here to enter text. | Email: Click here to enter text. |
| Click here to enter text. | |

### Comment 4

|  |  |
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| Author: Click here to enter text. | Email: Click here to enter text. |
| Click here to enter text. | |

## ECV Product: Active Layer Thickness (ALT)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Active Layer Thickness (ALT) | | | | |
| **Definition** | The surface layer of the ground, subject to annual thawing and freezing in areas underlain by permafrost. Thickness of seasonally thawed soils measured in (cm), surface displacements measured in (cm). surface subsidence. | | | | |
| **Unit** | cm | | | | |
| **Note** | There are three methods for measuring ALT: mechanical probing, frost tubes and temperature interpolation (with the assumption that 0°C = freeze point). In all three cases, the result is a depth/thickness value expressed in cm. | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** |  | Spatial distribution of sites | G |  |  |
| B |  |  |
| T | sufficient sites to characterize each bioclimate zone |  |
| **Vertical Resolution** |  |  | G |  |  |
| B |  |  |
| T | ~15 cm | Only one value. It can be a mean value for CALM protocol. For temperature interpolation, sensor spacing should be not more than 15 cm around ALT depth. |
| **Temporal Resolution** |  |  | G | 1 year, at end of thawing period | ALT is an annual value, which is measured once a year at the end of the thawing period. In case of continuous measurement (borehole data), ALT is defined at time of maximal penetration of above 0°C temperature. |
| B |  |  |
| T | 1 year, at end of thawing period | ALT is an annual value, which is measured once a year at the end of the thawing period. In case of continuous measurement (borehole data), ALT is defined at time of maximal penetration of above 0°C temperature. |
| **Timeliness** |  |  | G | 1 year | The active layer thickness is measured and provided once a year. |
| B |  |  |
| T | 1 year | The active layer thickness is measured and provided once a year. |
| **Required Measurement Uncertainty** | cm | mechanical probing penetration uncertainty / sensor uncertainty | G | 1 | Goal value for CALM protocol (mechanical probing and frost tubes), other values for temperature interpolation. |
| B | 5 |  |
| T | 10 |  |
| **Stability** | cm | Stability = bias due to surface subsidence in case of ice loss in ice-rich permafrost. Needs to be corrected in order to get the true thaw depth.  Thaw depth = active layer thickness + surface subsidence since previous year | G | 1 |  |
| B | 5 |  |
| T | 10 |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. The active layer is a particularly critical issue. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |

[1]Goal (G); Breakthrough (B)(not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
| --- | --- |
| Author: Annett Bartsch | Email: Annett.Bartsch@polarresearch.at |
| Requirements for GCOS parameters related to permafrost have been recently reviewed within the framework of the user requirements discussion of the ESA CCI+ Permafrost project. This comment summarizes the outcome with respect to 'active layer thickness'. The related project reports are available under <http://cci.esa.int/Permafrost>  GCOS currently confines requirements to in situ observations, as direct measurements of the target parameters are not available from satellites. Remote sensing of permafrost is indeed challenging. The physical subsurface variables which characterize its thermal state – ground temperature, ice content and thaw depth – are not directly measurable through current remote sensing technologies. In order to gain spatially continuous information models are key. Numerical permafrost models based on satellite derived information such as landsurface temperature and snow properties can indirectly provide remote sensing driven information on the by GCOS listed parameters. This is for example addressed within the framework of the European Space Agency Climate Change Initiative project on Permafrost. The Permafrost\_cci project gathered existing user requirements from international consensus references, such as GCOS-200, the IGOS Cryosphere theme report (WMO, 2007) and the WMO RRR database, as well as from the climate modelling community through the Modelling Working Group of the Permafrost Carbon network (PCN). The requirements review further covered user survey results from ESA DUE GlobPermafrost, a white paper in the framework of the WMO Polar Space Task Group (Bartsch et al. 2014), workshop reports (e.g. NRC 2014) and discussions with representatives of the International Permafrost Association (IPA) and the IPA Action Group ‘Specification of a Permafrost Reference Product in Succession of the IPA Map’. Views from climate researchers associated with the project (AWI, University of Fribourg, West University of Timisoara) were also taken into account. The requirements review is documented in Bartsch et al. (2019).  Users demand a combination of extensive geographical coverage (global permafrost extent 20-30 Mio km²), high spatial resolution (target grid cell resolution 1km), monthly temporal resolution and long temporal coverage (one to several decades back in time). An expert survey documented in NRC (2014) also considered Radar techniques for active layer thickness estimation and suggests 30 m horizontal resolution based on such techniques. In general, thaw depth in better than annual temporal resolution is required, in addition to active layer thickness (maximum thaw depth). See also Table 2.  The horizontal resolution definition in the current GCOS listing (spatial distribution of boreholes) is not applicable for satellite data derived information. **It is therefore suggested to introduce products which can be represented in grid cells (based on satellite observations) of the ECV permafrost in addition to the in situ parameters, specifically thaw depth.**See Table 1.  **Table 1: Suggestions for a new permafrost associated product: Thaw depth**   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | **Name** | Thaw depth within active layer | | | | | | **Definition** | The active layer is the surface layer of the ground, subject to annual thawing and freezing in areas underlain by permafrost. Thaw depth of seasonally thawed soils measured in (cm). | | | | | | **Unit** | cm | | | | | | **Note** | The requirements for thaw depth reflect the determination through models which use relevant satellite observations as input or radar techniques. | | | | | | **Requirements** | | | | | | | **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** | | **Horizontal Resolution** | m | Size of grid cell | G | 30 | Expert survey result documented in NRC (2014) | | B | 1000 | User survey result documented in Bartsch et al. (2019) | | T | 10000 | User survey result documented in Bartsch et al. (2019) | | **Vertical Resolution** |  |  | G |  |  | | B |  |  | | T | 5 cm | Expert survey result documented in NRC (2014) | | **Temporal Resolution** |  |  | G | biweekly | Expert survey result documented in NRC (2014) | | B | monthly | User survey result documented in Bartsch et al. (2019) | | T | annually | User survey result documented in Bartsch et al. (2019)  Active layer thickness (ALT) as an annual value, which is measured once a year at the end of the thawing period. In case of continuous measurement, ALT is defined at time of maximal penetration of above 0°C temperature. | | **Timeliness** |  |  | G |  |  | | B |  |  | | T | 1 year | The active layer thickness is measured and provided once a year. | | **Required Measurement Uncertainty** | cm | RMSE | G | 10 | User survey result documented in Bartsch et al. (2019) | | B |  |  | | T | 25 | User survey result documented in Bartsch et al. (2019 | | **Stability** | cm | Stability = bias due to surface subsidence in case of ice loss in ice-rich permafrost. Needs to be corrected in order to get the true thaw depth.  Thaw depth = active layer thickness + surface subsidence since previous year | G |  |  | | B |  |  | | T |  |  | | **Standards and References** |  | | | | | | **Adaptation and Extremes** | | | | | | |  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | | | **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. The active layer is a particularly critical issue. | | | | **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |     **Table 2:** Threshold (minimum) and Goal (optimal) requirements identified for Active layer thickness/Thaw Depth following items defined in CCI projects and suggestions documented in NRC (2014)   |  |  |  |  | | --- | --- | --- | --- | |  | **CCI (2019)** | | **NRC (2014)** | |  | **Threshold** | **Target** | **Target** | | **Geographical coverage** | Pan-Arctic | Global with regional specific products | - | | **Temporal sampling** | < yearly | < monthly | biweekly | | **Temporal extent** | Last decade | 1979 - present | - | | **Horizontal resolution** | 10 km | 1km | 30 m | | **Subgrid variability** | - | - | - | | **Vertical resolution** | - | - | 5 cm | | **Vertical extent** | - | - | - | | **Precision** | 10 cm | 1 cm | - | | **Accuracy** | RMSE < 25 cm | RMSE < 10 cm | - | | **Stability** | Accuracy needs to be temporally homogeneous | Accuracy needs to be temporally homogeneous | - | | **Error characteristics** | Independent multi-date validation | Independent multi-date validation | - |   ***References in addition to GCOS documents***  Bartsch, Annett; Allard, Michel; Biskaborn, Boris Kolumban; Burba, George; Christiansen, Hanne H; Duguay, Claude R; Grosse, Guido; Günther, Frank; Heim, Birgit; Högström, Elin; Kääb, Andreas; Keuper, Frida; Lanckman, Jean-Pierre; Lantuit, Hugues; Lauknes, Tom Rune; Leibman, Marina O; Liu, Lin; Morgenstern, Anne; Necsoiu, Marius; Overduin, Pier Paul; Pope, Allen; Sachs, Torsten; Séjourné, Antoine; Streletskiy, Dmitry A; Strozzi, Tazio; Ullmann, Tobias; Ullrich, Matthias S; Vieira, Goncalo; Widhalm, Barbara (2014):  Requirements for monitoring of permafrost in polar regions - A community white paper in response to the WMO Polar Space Task Group (PSTG), Version 4, 2014-10-09., 20 pp,  <https://doi.pangaea.de/10013/epic.45648.d001>  Bartsch, A., Matthes, H., Westermann, S., Heim, B., Pellet, C., Onacu, A., Kroisleitner, C., Strozzi, T. (2019): ESA CCI+ Permafrost User Requirements Document, v1.1 <http://cci.esa.int/sites/default/files/CCI+_PERMA_URD_v1.1.pdf>  Duchossois G., P. Strobl, V. Toumazou, S. Antunes, A. Bartsch, T. Diehl, F. Dinessen, P. Eriksson, G. Garric, M-N. Houssais, M. Jindrova, J. Muñoz-Sabater, T. Nagler, O. Nordbeck, User Requirements for a Copernicus Polar Mission - Phase 1 Report, EUR , Publications Office of the European Union, 29144 ENLuxembourg, 2018, ISBN 978-92-79-80961-3, doi:10.2760/22832, JRC111067 <https://publications.jrc.ec.europa.eu/repository/handle/JRC111067>  National Research Council (2014). Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18711>. | |

## ECV Product: Thermal State of Permafrost

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Thermal State of Permafrost | | | | |
| **Definition** | Permafrost is subsurface earth material that remain continuously at or below 0°C throughout at least two consecutive years, usually for extended time periods up to many millennia.  Product definition: Ground temperatures measured at specified depths along profiles. | | | | |
| **Unit** | °C | | | | |
| **Note** | Measurements made in boreholes, and usually presented as temperature profiles. Active layer = surface layer that thaws/freezes every year  ZAA = Zero annual amplitude, maximum penetration depth of seasonal variations | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | N/A | Spatial distribution of boreholes | G | Regular spacing | Especially in Arctic areas, it is necessary to fill the gaps in order to calibrate/compare with remote sensing products and climate modeling results. |
| B | Transects | In Arctic areas, longitudinal transects allow the assessment of gradients.  In mountain ranges, longitudinal or latitudinal transects for assessment of climatic zones and of continentality gradients. |
| B | Various settings | In Arctic areas, various terrain with different thermal conductivity and topo-climatic conditions: ice-rich, ice-poor, ...  In mountain permafrost, various geomorphological and topo-climatic settings: rock-glaciers, rock walls, in various aspects.  Allows for comparison of different reaction to climate change. |
| T | Sufficient sites to characterize each bioclimate zone | Boreholes in continuous, discontinuous, and sporadic permafrost areas. In discontinuous/sporadic permafrost, boreholes must be located in permafrost affected zones. Some boreholes in non-permafrost areas can be useful for comparison.  Location of boreholes is strongly dependent on accessibility of borehole sites. |
| **Vertical Resolution** | N/A | Borehole depth, defined according to characteristic permafrost layers | G | Below ZAA | Allows assessment of mid- to long term trends, and extrapolation of the total permafrost thickness if sufficiently deep. |
| B | Down to ZAA | Allows measurement of the full seasonal variations, and assessment of interannual trend. |
| T | Down to permafrost table | Allows calculation of active layer depth and measurement of the temperature of the uppermost permafrost at the permafrost table |
| m | Sensor spacing along borehole for continuous monitoring / measuring interval for manual measurement | G | Down to ZAA: 0.2 | Currently accepted values. Actual spacing has to be adapted to thickness of the different layers and should be higher on boundary values (active layer/permafrost, ZAA), in order to allow an accurate interpolation. |
| B | Down to ZAA: 0.5 |
| T | Down to ZAA: 1 |
| G | Below ZAA: 1 |
| B | Below ZAA: 5 |
| T | Below ZAA: 10 |
| **Temporal Resolution** |  | Sampling interval for continuous monitoring / periodicity for manual measurement.  Depends on depth, must be more frequent in active layer than below ZAA | G | Active layer: 1h | Only useful in topmost layers, affected by diurnal variations. |
| B | Active layer: 1d | Assessment of rapid changes due for instance to melt water infiltration or air convection. |
| T | Active layer: 1y | Sites with manual measurement are measured only once a year. |
| G | Down to ZAA: 1d | Assessment of rapid variations in terrain with high thermal conductivity. |
| B | Down to ZAA: 1 month | Assessment of seasonal variations. |
| T | Down to ZAA: 1 year | Sites with manual measurement are measured only once a year. |
| G | Below ZAA: 1 month | Allows detection of extreme seasonal variations. |
| B | Below ZAA: 1 year | Sites with manual measurement are measured only once a year. |
| T | Below ZAA: 5 years | Sufficient for mid- to long-term trend. |
| **Timeliness** |  |  | G | Weekly /real time | Only useful for hazard issues, for instance for high mountain rock walls (rock fall hazard). |
| B |  |  |
| T | Yearly | Most site measurements are retrieved only once a year |
| **Required Measurement Uncertainty** | °C | Sensor uncertainty | G | 0.01 | Useful for finer definition of freeze/thaw dates |
| B | 0.05 | Mean annual trends are often less than 0.1 °C. Reachable with high resolution sensors. |
| T | 0.1 | Reachable with most standard sensors. |
| **Stability** | °C | Sensor drift over reference period. Assumed drift value of commonly used sensors. Sensor drift correction needs recalibration of sensors | G | 0.01 | Not realistic ? |
| B | 0.05 | Should be reached in order to maintain drift below trend. |
| T | 0.1 | Commonly accepted value based on experience. Calibration of sensor probe is possible in case of manual measurement. It is often impossible for fixed sensor chains. Drift can be minimized by 3 or 4 wire mounting. In situ calibration/correction is possible for sub-surface sensors using “zero curtain”. |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. The direct link between summer heat waves and rock fall frequency is well established. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |

[1]Goal (G); Breakthrough (B)(not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 1

|  |  |
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| Author: Andrea Merlone | Email: Click here to enter text. |
| From Andrea Merlone: Standards and references are needed in terms of measuring procedures and instrument maintenance. The requirements in terms of drift (sensors stability) is of the same order of the total uncertainty. This requires periodic recalibration of the sensors which must therefore be accessible. Methods to avoid convection in boreholes also need to be standardizes as well as the sensors chains features. Minimum requirements on logging systems also need prescriptions. CGW can address such issues in the specific chapter of the contribution to the new guide n. 8. | |

### Comment 2

|  |  |
| --- | --- |
| Author: Jeannett Nötzli | Email: schanett@gmail.com |
| See Below comment and table | |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Thermal State of Permafrost | | | | |
| **Definition** | Permafrost is subsurface earth material that remain continuously at or below 0°C throughout at least two consecutive years, usually for extended time periods up to many millennia.  Product definition: Ground temperatures measured at specified depths along profiles. | | | | |
| **Unit** | °C | | | | |
| **Note** | Measurements made in boreholes, and usually presented as temperature profiles or temperature time series. Active layer = surface layer that thaws/freezes every year  ZAA = Zero annual amplitude, maximum penetration depth of seasonal variations | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | N/A | Spatial distribution of boreholes | G | Regular spacing | Especially in Arctic areas, it is necessary to fill the gaps in order to calibrate/compare with remote sensing products and climate modeling results. *Use polar region instead of Arctic region throughout to not exclude permafrost in Antarctica* |
| B | Transects | In Arctic areas, longitudinal transects allow the assessment of gradients.  In mountain ranges, longitudinal or latitudinal transects for assessment of climatic zones and of continentality gradients. *Elevational gradients are also important in mountain regions* |
| B | Various settings | In Arctic areas, various terrain with different thermal conductivity and topo-climatic conditions: ice-rich, ice-poor, ...  In mountain permafrost, various geomorphological (various landforms: rock-glaciers, debris slopes, rock walls) and topo-climatic settings (aspect, elevation)  Allows for comparison of different reaction to climate change. |
| T | Sufficient sites to characterize each bioclimate zone | Boreholes in continuous, discontinuous, and sporadic permafrost areas. In discontinuous/sporadic permafrost, boreholes must be located in permafrost  zones. Some boreholes in non-permafrost areas can be useful for comparison and model validation.  Location of boreholes is strongly dependent on accessibility of borehole sites. |
| **Vertical Resolution** | N/A | Borehole depth, defined according to characteristic permafrost layers | G | Below ZAA | Allows assessment of mid- to long term trends, and extrapolation of the total permafrost thickness if sufficiently deep. |
| B | Down to ZAA | Allows measurement of the full seasonal variations, and assessment of interannual trend. |
| T | Down to permafrost table | Allows calculation of active layer depth and measurement of the temperature of the uppermost permafrost at the permafrost table |
| m | Sensor spacing along borehole for continuous monitoring / measuring interval for manual measurement | G | Down to ZAA: 0.2 | Currently accepted values. Actual spacing has to be adapted to thickness of the diffe  rent layers and should be higher on boundary values (active layer/permafrost, ZAA), in order to allow an accurate interpolation. *What is meant by accepted values? There are no available standards and the spacing of the sensors strongly depends on the purpose of the measurements, site specific characteristics and available instrumentation (and funds).* |
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| B | Down to ZAA: 0.5 |
| T | Down to ZAA: 1 |
| G | Below ZAA: 1 |
| B | Below ZAA: 5 |
| T | Below ZAA: 10 |
| **Temporal Resolution** |  | Sampling interval for continuous monitoring / periodicity for manual measurement.  Depends on depth, must be more frequent in active layer than below ZAA  *Typically all sensors are on the same string and is does not make sense to distinguish the sampling intervals for different depths with continuous automatic logging. Storage capacity is no longer a limitation. Further, larger sampling intervals at greater depth imply that there is not other heat transport by conduction, especially in mountain regions this is often not the case.* | G | Active layer: 1h | Only useful in topmost layers, affected by diurnal variations. |
| B | Active layer: 1d | Assessment of rapid changes due for instance to melt water infiltration or air convection. |
| T | Active layer: 1y | Sites with manual measurement are measured only once a year. |
| G | Down to ZAA: 1d | Assessment of rapid variations in terrain with high thermal conductivity. |
| B | Down to ZAA: 1 month | Assessment of seasonal variations. |
| T | Down to ZAA: 1 year | Sites with manual measurement are measured only once a year. |
| G | Below ZAA: 1 month | Allows detection of extreme seasonal variations. |
| B | Below ZAA: 1 year | Sites with manual measurement are measured only once a year. |
| T | Below ZAA: 5 years | Sufficient for mid- to long-term trend. |
| **Timeliness** |  |  | G | Weekly /real time | Only useful for hazard issues, for instance for high mountain rock walls (rock fall hazard). *This is not possible today. Real time data is important as baseline and for timely reporting.* |
| B |  |  |
| T | Yearly | Most site measurements are retrieved only once a yea*r It is strongly advised to have real time access, data retrieval once a year implies a significant risk of large data gaps (up to one year)* |
| **Required Measurement Uncertainty** | °C | Sensor uncertainty *Refering to the sensor alone or the entire measurement setup including calibration???* | G | 0.01 | Useful for finer definition of freeze/thaw dates |
| B | 0.05 | Mean annual trends are often less than 0.1 °C. Reachable with high resolution sensors. |
| T | 0.1 | Reachable with most standard sensors. |
| **Stability** | °C | Sensor drift over reference period. Assumed drift value of commonly used sensors. Sensor drift correction needs recalibration of sensors | G | 0.01 | Not realistic ? |
| B | 0.05 | Should be reached in order to maintain drift below trend. |
| T | 0.1 | Commonly accepted value based on experience. Calibration of sensor probe is possible in case of manual measurement. It is often impossible for fixed sensor chains. Drift can be minimized by 3 or 4 wire mounting. In situ calibration/correction is possible for sub-surface sensors using “zero curtain”.  *Sensor calibration is not always possible (because of temperature chains blocked in the borehole) and there is a risk that the chain cannot be inserted at the exact same location. Zero curtain calibration is only possible in the active layer. Reduncancy with overlapping thermistor chains or dual measurements is crucial here! See PERMOS guidelines!!!* |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and decreasing infrastructure and slope stability in high mountain ranges. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. A direct link between summer heat waves and rock fall frequency is  assumed. Timeliness of temperature reporting must be improved for sites of interest. | | |

[1]Goal (G); Breakthrough (B)(not mandatory, more as one possible); Threshold (T), for definitions see [Guidelines](http://tiny.cc/ecv-review)

[2] Is the ECV Product directly relevant to support Climate Adaptation?

[3] Can the ECV Product be used to monitor climate extremes or aspects of extremes?

### Comment 3

|  |  |
| --- | --- |
| Author: Jeannett Nötzli | Email: schanett@gmail.com |
| The Swiss Permafrost Monitoring Network PERMOS is about to consolidate and publish its best practice recommendations for long-term borehole temperature measurements in mountain permafrost. The paper will be submitted in spring 2020. | |

### Comment 4

|  |  |
| --- | --- |
| Author: Annett Bartsch | Email: Annett.Bartsch@polarresearch.at |
| See below Table and Comments | |

Requirements for GCOS parameters related to permafrost have been recently reviewed within the framework of the user requirements discussion of the ESA CCI+ Permafrost project. This comment summarizes the Outcome with respect to 'thermal state of permafrost'. The related project reports are available under <http://cci.esa.int/Permafrost>

GCOS currently confines requirements to in situ observations, as direct measurements of the target parameters are not available from satellites. Remote sensing of permafrost is indeed challenging. The physical subsurface variables which characterize its thermal state – ground temperature, ice content and thaw depth – are not directly measurable through current remote sensing technologies. In order to gain spatially continuous information models are key. Numerical permafrost models based on satellite derived information such as landsurface temperature and snow properties can indirectly provide remote sensing driven information on the by GCOS listed parameters. This is for example addressed within the framework of the European Space Agency Climate Change Initiative project on Permafrost. The Permafrost\_cci project gathered existing user requirements from international consensus references, such as GCOS-200, the IGOS Cryosphere theme report (WMO, 2007) and the WMO RRR database, as well as from the climate modelling community through the Modelling Working Group of the Permafrost Carbon network (PCN). The requirements review further covered user survey results from ESA DUE GlobPermafrost, a white paper in the framework of the WMO Polar Space Task Group (Bartsch et al. 2014), workshop reports (e.g. NRC 2014) and discussions with representatives of the International Permafrost Association (IPA) and the IPA Action Group ‘Specification of a Permafrost Reference Product in Succession of the IPA Map’. Views from climate researchers associated with the project (AWI, University of Fribourg, West University of Timisoara) were also taken into account. The requirements review is documented in Bartsch et al. (2019).

Users demand a combination of extensive geographical coverage (global permafrost extent 20-30 Mio km²), high spatial resolution (target grid cell resolution 1km) including representation of subgrid variability, high temporal resolution (monthly data) and long temporal coverage (one to several decades back in time). See also Table 1.

**Table 1:**Threshold (minimum) and Goal (optimal) requirements identified for ground temperature following items defined in CCI projects

|  |  |  |
| --- | --- | --- |
|  | **Ground temperature** | |
|  | **Threshold** | **Goal** |
| **Geographical coverage** | Pan-Arctic | Global with regional specific products |
| **Temporal sampling** | annually | monthly |
| **Temporal extent** | Last decade | 1979 - present |
| **Horizontal resolution** | 10 km | 1km |
| **Subgrid variability** | no | yes |
| **Vertical resolution** | 50 cm exponential | 5 cm exponential |
| **Vertical extent** | 15 m | 30 m |
| **Precision** | 0.5 K | 0.1 K |
| **Accuracy** | RMSE < 2.5°C | RMSE < 0.5°C |
| **Stability** | Higher stability than existing  datasets | Accuracy needs to be temporally homogeneous |
| **Error characteristics** | Independent multi-date validation | Independent multi-date validation |

Accuracy requirements stated by the users are strongly complicated by the fact that permafrost ECV physical variables (ground temperature and active layer thickness) often feature significant variations at spatial scales below the target requirement of 1km, which in the few documented cases exceed even the threshold requirement of an RMSE of 2.5K (e.g. Fig. 2 in Gisnås et al., 2014). Therefore, even comparison of “perfect” 1km average temperatures to point temperature measurements in boreholes will feature a significant RMSE which in this case rather reflects the spread of temperatures in space than the accuracy of the method (assuming that boreholes are placed at random locations within a pixel). In real-world permafrost ECV assessment, a bias introduced by the method/model and the input data will overlap with this effect, which significantly complicates the evaluation of accuracies. The very high accuracy requested in GCOS-200 from in situ measurements is therefore not achievable in case of modelling based on satellite data records.

**It is suggested to introduce products which can be represented in grid cells (based on satellite observations) of the ECV permafrost in addition to the in situ parameters, specifically ground temperature.**See table 2.

Table 2: Suggestions for a new Permafrost associated product: Ground temperature

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Ground temperature | | | | |
| **Definition** | Ground temperature is the bulk temperature of the ground below the surface, not the surface (skin) temperature, independent from presence of soil. | | | | |
| **Unit** | °C | | | | |
| **Note** | The requirements for ground temperature reflect the determination through models which use relevant satellite observations as input in the context of permafrost monitoring. Permafrost is subsurface earth material that remain continuously at or below 0°C throughout at least two consecutive years, usually for extended time periods up to many millennia. | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | km | Size of grid cell | G | 1 | User survey result documented in Bartsch et al. (2019) |
| B |  |  |
| T | 10 | User survey result documented in Bartsch et al. (2019) |
| **Vertical Resolution** | cm |  | G | 5 | User survey result documented in Bartsch et al. (2019) |
| B |  |  |
| T | 50 | Vertical extent 15m, User survey result documented in Bartsch et al. (2019) |
| **Temporal Resolution** |  |  | G | monthly | User survey result documented in Bartsch et al. (2019) |
| B |  |  |
| T | annually | User survey result documented in Bartsch et al. (2019) |
| **Timeliness** |  |  | G | Weekly /real time | as for thermal state definition |
| B |  |  |
| T | Yearly | as for thermal state definition |
| **Required Measurement Uncertainty** | °C | RMSE | G | 0.5 | User survey result documented in Bartsch et al. (2019) |
| B |  |  |
| T | 2.5 | User survey result documented in Bartsch et al. (2019) |
| **Stability** | °C |  | G |  |  |
| B |  |  |
| T |  |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. The direct link between summer heat waves and rock fall frequency is well established. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |

***Inconsistencies of parameters with WMO RRR (OSCAR) and further requirements collections***

In addition to the parameters listed in GCOS-200, GCOS-107 mentions permafrost extent. It corresponds to the aerial fraction within an area at which the definition for the existence of permafrost (ground temperature < 0 ºC for two consecutive years) is fulfilled. The characterization of the permafrost extent in terms of aerial coverage has been employed for decades in the permafrost community, e.g. in the classic IPA permafrost map displaying classes of continuous, discontinuous, sporadic and isolated permafrost. No specific requirements for permafrost extent are available through GCOS to date. Permafrost extent is, however, the sole target parameter listed in the WMO RRR database (<https://www.wmo-sat.info/oscar/variables/view/124>), where differing requirements are listed for the application areas Hydrology and Climate-TOPC. Temporal resolution requirements are very high (target 6 hours), reflecting the velocity of atmospheric processes and so the drivers in modelling or the dynamics of seasonally frozen soil (e.g., to account for the number of freezing and thawing days). However, permafrost is a sub-surface property and the relationships between the frozen ground and the relevant climatic elements, are complex. The source of the WMO RRR requirements is unknown and they have been so far not confirmed in published user surveys regarding permafrost.

Permafrost extent has been further identified as a target parameter for a potential future satellite mission within the framework of Copernicus (Duchossois et al. 2018). Horizontal resolution requirements have been defined with threshold 10 m and goal 1 m. Temporal resolution has been defined with 10 years as threshold and 1 year as target. Accuracy should be 85% and 95% respectively. Permafrost extent has been also included as required parameter in the report with 1m - 10m (local) and 100m (circumpolar) required horizontal resolution and annual temporal resolution.

It is therefore suggested to also **include permafrost extent as additional product** (see table 3) and to further reconcile relevant existing user requirement collection activities.

**Table 3:**Suggestions for new Permafrost associated product: Permafrost extent

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | Permafrost extent | | | | |
| **Definition** | Fraction of permafrost-underlain area within a grid cell's horizontal area. Permafrost is subsurface earth material that remains continuously at or below 0°C throughout at least two consecutive years, usually for extended time periods up to many millennia. | | | | |
| **Unit** | fraction | | | | |
| **Note** | The requirements for permafrost extent reflect the determination through models which use relevant satellite observations as input in the context of permafrost monitoring | | | | |
| **Requirements** | | | | | |
| **Item needed** | **Unit** | **Metric** | **[1]** | **Value** | **Derivation and References and Standards** |
| **Horizontal Resolution** | m | Size of grid cell | G | 1 | Expert survey results documented in Duchossois et al.( 2018) and in NRC (2014) |
| B | 10 | Expert survey results documented in NRC (2014) |
| T | 100 | Expert survey results documented in NRC (2014) |
| **Vertical Resolution** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Temporal Resolution** | years |  | G | 1 | Expert survey results documented in Duchossois et al. (2018) |
| B |  |  |
| T | 10 | Expert survey results documented in Duchossois et al. (2018) |
| **Timeliness** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Required Measurement Uncertainty** | % | Accuracy | G | 95 | Expert survey results documented in Duchossois et al. (2018) |
| B |  |  |
| T | 85 | Expert survey results documented in Duchossois et al. (2018) |
| **Stability** |  |  | G |  |  |
| B |  |  |
| T |  |  |
| **Standards and References** |  | | | | |
| **Adaptation and Extremes** | | | | | |
|  | Relevant? (Yes/No) | Sugg. Req. sufficient? (Yes/No) | Explanation | | |
| **Adaptation[2]** | Yes | Yes | Permafrost degradation, due to thawing and ice-loss, induces drastic changes in Arctic environment, and emerging hazards in high mountain ranges. | | |
| **Extremes[3]** | Yes | No | Summer heat waves induce enhanced deepening of the active layer, and possible ice-loss in the upper permafrost. The direct link between summer heat waves and rock fall frequency is well established. Timeliness of temperature reporting must be improved for sites of interest for hazard monitoring. | | |

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