SnowPEx –

The Satellite Snow Product Intercomparison and Evaluation Exercise

Snow Extent Validation Protocol

Deliverable D7
Snow Extent

Appendix

Prepared by

Gabriele Bippus, Elisabeth Ripper, Thomas Nagler, ENVEO, Austria

Richard Fernandes, Natural Resources Canada, Canada

Sari Metsämäki, Finnish Environment Institute, Finland

Issue / Revision: 1 / 0

Date: 06.11.2015

Document controlled by: Gabriele Bippus

SnowPEx Report

SUBJECT:	**PROJECT COORDINATOR:**
Snow Extent Validation Protocol	ENVEO

ISSUE / REVISION:	CONTRACTOR'S REF:
1 / 0	Deliverable D7 – APPENDIX

Abstract:

This document includes Appendices related to D7 - Methods and Protocols for Intercomparing and Validating SE and SWE products – FINAL (Snow Extent).

This project was funded by the European Space Agency. Responsibility for the contents resides in the author or organisation that prepared it.

AUTHORS: GABRIELE BIPPUS, ELISABETH RIPPER, THOMAS NAGLER, RICHARD FERNANDES, SARI METSÄMÄKI

This page is intentionally left blank.

TABLE OF CONTENTS

This page is intentionally left blank.

A. DEFINITIONS

A.1 Snow Extent

GCOS does not define snow extent. The WMO Global Cryosphere Watch (GCW) glossary cites three definitions of snow cover:

Table A.1:
WMO Definitions of Snow Cover (http://globalcryospherewatch.org/reference/glossary.php).

NSIDC	(1) in general, the accumulation of snow on the ground surface (2) the areal extent of snow-covered ground, usually expressed as percent of total area in a given region.
UNESCO	In general, the accumulation of snow on the ground surface, and in particular, the areal extent of snow-covered ground (NSIDC, 2008); term to be preferably used in conjunction with the climatologic relevance of snow on the ground. See also snowpack.
METEOTERM	Covering of the ground, either completely or partially, by snow.

These definitions are relevant to a specific user community but are ambiguous for the purpose of validation exercises. In this respect we refine these definitions of snow extent as:

Snow extent (SE) is defined as the unique area of snow covered surfaces projected on the local horizontal datum within a spatial mapping unit at a specified time. Here unique implies that the projected area from two vertically superimposed snow covered surfaces is only counted once. The units of snow extent correspond to SI units for area (m^2).

Some qualifications for this definition are required:

i. For mapping units with pre-defined area, SE may be reported as a proportion (as a fraction or percentage) of the mapping unit area.

ii. SE is often reported using a generalized temporal interval (daily). In this case it should correspond to the average SE over that time period unless specified otherwise to reflect observing conditions (e.g. it could be the maximum or minimum SE if specified).

iii. The definition includes snow on canopies as well as in the understory. As such, a region with completely covered understory but no snow on canopies will formally have a SE less than 100% since the area occupied by trunks are snow free. Conversely, a region where both canopies and understory are completely snow covered will have a SE of 100% since the unique projected area of snow covered surfaces cannot exceed the total surface area of the mapping unit.

SE does not distinguish the surface covered by snow. Hence it could correspond to snow over soil, vegetation, structures, ice or water. Therefore it is required that the data provider specifies any deviations from this definition in terms of underlying surface type holding snow; particularly for forest areas it has to be known to if under-canopy snow is considered snow-covered (**snow on ground**) or not (**viewable snow**).

A.2 Associated Quantities

A.2.1 Snow Depth

Snow depth (SD) is the average vertical depth of the snowpack above the ground surface within a mapping unit. SI units for depth are metres (m) but convention is to report SD in centimetres (cm).

A.2.2 Snow Cover Fraction

Snow cover fraction (SCF) is the ratio of SE to the ground area of the mapping unit. Units are dimensionless with 0<=SCF<=1, but sometimes also percentage number is used (range 0-100%). SCF is sometimes reported using irregular intervals.

A.2.3 Binary Snow Extent (Presence/Absence)

Binary snow extent presence/absence (also termed using the more general acronym SE) indicates the occurrence of snow cover (SE>threshold T) or snow free (SE < threshold T) conditions in a mapping unit. SE is usually reported as a Boolean flag (True = snow cover; False=snow free) although a third condition corresponding to no definitive status or a trace amount is sometimes reported.

A.3 Other Key Terms

A.3.1 Elementary Sampling Unit

An Elementary Sampling Unit (ESU) is a contiguous spatial region over which the expected value of SE can be estimated through in situ measurement. The ESU corresponds to the finest spatial scale of SE estimates used for reference SE estimates. The ESU size is at least as large as one measurement footprint of the in situ instrument and typically includes a number of instrument measurements. The maximum ESU size is determined by the level of within ESU SE variability that can be tolerated by the validation protocol and the effort available to conduct measurements. The size of each ESU within a reference region also varies with surface condition, instrument field of view, and spatial sampling design.

A.3.2 Local Horizontal Datum

The local horizontal datum is the plane containing the tangent to the local geoid corresponding to the centre of an ESU or mapping unit. Theoretically, a correction for variability in topography or canopy cover within an ESU should be performed to ensure SE corrects for vertically overlapping snow covered surfaces.

A.3.3 Measurement Geolocation Uncertainty

Geolocation uncertainty, for SE validation, corresponds to the planimetric uncertainty of a satellite or airborne measurements located on the same projection and datum as the ESU or study site reference SE estimates. Geolocation uncertainty is often reported in nominal terms and based on a normal distribution of errors. Acquisition specific biases are often possible so that geolocation uncertainty should be visually assessed in comparison to reference vector layers whenever possible.

A.3.4 Mapping Unit

A mapping unit is the spatial region on the Earth's surface corresponding to a reference or product map value for a specified temporal extent. Reference mapping units often correspond to single ESUs but could in theory correspond to some region based on an aggregate of ESUs. The majority of satellite based SE products use mapping units corresponding to pixels within rasters in a specified map projection. As such, these products include a spatial generalisation corresponding to the transformation of the SE estimate derived from a satellite measurement spatial footprint to the SE estimate in the mapping unit. Considering that GCOS requires gridded SE products at a constant spatial resolution, the SE validation protocol assumes uncertainties due to this generalisation or due to temporal aggregation are considered in the total product uncertainty.

A.3.5 Total Measurement Uncertainty, Accuracy

The total measurement uncertainty includes systematic measurement error and random measurement error. Where there is only one product estimate for each mapping unit the total measurement uncertainty corresponds to the accuracy (JCGM-100 2008).

Current metrics for total measurement error include the root mean square difference (RMSD), the median absolute difference (MAD), the relative RMSD (RRMSD), and the relative median absolute difference (RMAD) applied either to the entire validation database or applied to partitions of the database having a given range of reference or product SCF. In the majority of cases, these comparisons include only one product measurement per comparison so they are equivalent to an Accuracy error.

A.3.6 Bias

Bias, is the expected value of the difference between corresponding product and reference estimates. Bias is an estimate of the systematic measurement error. (JCGM-100 2008).

Bias error can been quantified over the entire validation database as the sum or residuals but this can be less informative if the range of SCF in the product or validation dataset is large. Rather, bias can be better quantified as the slope and offset of a linear structural regression between reference and product SCF values in matched mapping units. In most studies ordinary least squares (OLS) regression is applied but this is not correct considering the rather common occurrence of measurement errors in both reference and product values (Fernandes and Leblanc, 2005). Rather Theil-Sen regression should be applied.

A.3.7 Precision

Precision is the dispersion of product estimates around their expected value for the same actual SE. Precision is an estimate of random measurement error. (JCGM-100 2008).

Precision requires evaluation of residuals after removal of bias. This is often quantified by the same statistics as total measurement error applied to bias corrected product estimates. Precision could also be represented by the confidence interval of prediction about the bias correction line although this relies heavily on various regression assumptions (independent errors) that may not always be present with product or reference datasets.

A.3.8 Completeness

Completeness is the proportion of valid retrievals over an observation domain. (JCGM-100 2008).

Completeness has been represented by the proportion of valid retrievals as a function of time and space.

A.3.9 Stability

Stability is defined as the change in accuracy through time (Padilla et al., 2014).

Stability has been given two interpretations. The first is the product value trend over time. This is not stability of performance but of the product. It could be useful if indeed the product trend is not reasonable but this should be evaluated by comparing the trend in total measurement error over time or the trend in differences between matched product and reference values over time.

B. ANCILLARY GEO-SPATIAL LAYERS

The following ancillary geospatial layers are to be used during comparisons: land cover, forest cover fraction, water cover fraction and digital elevation model. Optionally, a snow climate zone map can be additionally used for partitions. These layers are spatially overlaid to produce a global set of unique partitions over which performance assessment statistics are to be summarized and tracked. The intention of the partitioning is to ensure statistics correspond to similar snow state over a region (i.e. melt, onset, accumulation, wet snow conditions) and to similar land cover conditions that could be related to artefacts within products (e.g. sub-pixel water cover, dense forests). In some cases a partition corresponding to a unique combination of the 4 input layers may have either zero or just a few (<20) comparisons. In the case of zero comparisons the partition should be censored. If there are a few comparisons the partition should be combined by aggregating with similar partitions in order of:

i. forest mask,
ii. water mask,
iii. land cover,
iv. terrain complexity,
v. snow climate zones (Sturm et al., 1995).

B.1 Land Cover

Both snow cover dynamics and satellite algorithms are known to exhibit differences as a function of land surface properties. A global land cover map is used to partition comparisons into different spatial units for reporting comparison statistics.

B.2 GlobCover

Two versions of the ESA GlobCover product with each about 300 m pixel size at the equator derived from MERIS data are currently available:

- V2.2 for the year 2005, based on data from December 2004 – June 2006
- V2.3 for the year 2009, based on data from January 2009 – December 2009

Both versions are available globally, and contain 22 surface classes (Table B.1) defined with the United Nations (UN) Land Cover Classification System (LCCS), and is also compatible with the classification of the GLC2000 (Bontemps, Defourny, & Van Bogaert, 2010) available at (http://bioval.jrc.ec.europa.eu/products/glc2000/products.php).

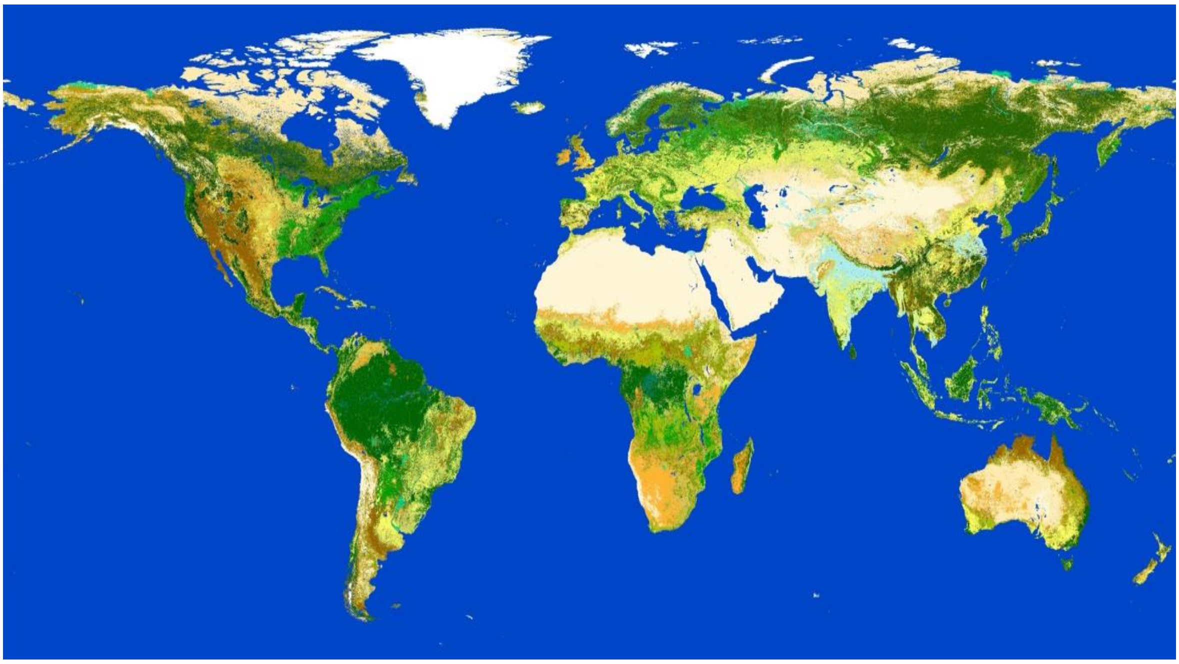

Figure B.1: Preview of the GlobCover V2.3 2009 map published by ESA.

Table B.1:
Coding of GlobCover maps, and associated LCCS labels and entries (from http://dup.esrin.esa.it/globcover/LandCover2009/GLOBCOVER2009_Validation_Report_1.0.pdf).

Value	*Global GlobCover legend (level 1)*	*LCCS Label*	*LCCS Entry*
11	Post-flooding or irrigated croplands (or aquatic)	Irrigated tree crops // Irrigated shrub crops // Irrigated herbaceous crops // Post-flooding cultivation of herbaceous crops	Cultivated Terrestrial Areas and Managed Lands A11
14	Rainfed croplands	Rainfed shrub crops // Rainfed tree crops // Rainfed herbaceous crops	
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	Cultivated and managed terrestrial areas / Natural and semi-natural primarily terrestrial vegetation	

<table>
<tr><th>Value</th><th>Global GlobCover legend (level 1)</th><th>LCCS Label</th><th colspan="3">LCCS Entry</th></tr>
<tr><td>30</td><td>Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)</td><td>Natural and semi-natural primarily terrestrial vegetation / Cultivated and managed terrestrial areas</td><td colspan="3"></td></tr>
<tr><td>40</td><td>Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)</td><td>Broadleaved evergreen closed to open trees // Semi-deciduous closed to open trees</td><td rowspan="9">Woody - Trees</td><td rowspan="11">Natural and Semi-natural Terrestrial Vegetation</td><td rowspan="11">A12</td></tr>
<tr><td>50</td><td>Closed (>40%) broadleaved deciduous forest (>5m)</td><td>Broadleaved deciduous closed to open (100-40%) trees</td></tr>
<tr><td>60</td><td>Open (15-40%) broadleaved deciduous forest/woodland (>5m)</td><td>Broadleaved deciduous (40-(20-10)%) woodland</td></tr>
<tr><td>70</td><td>Closed (>40%) needleleaved evergreen forest (>5m)</td><td>Needleleaved evergreen closed to open (100-40%) trees</td></tr>
<tr><td>90</td><td>Open (15-40%) needleleaved deciduous or evergreen forest (>5m)</td><td>Needleleaved evergreen (40-(20-10)%) woodland // Needleleaved deciduous (40-(20-10)%) woodland</td></tr>
<tr><td>100</td><td>Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)</td><td>Broadleaved closed to open trees / Needleleaved closed to open trees</td></tr>
<tr><td>110</td><td>Mosaic forest or shrubland (50-70%) / grassland (20-50%)</td><td>Closed to open trees / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation</td></tr>
<tr><td>120</td><td>Mosaic grassland (50-70%) / forest or shrubland (20-50%)</td><td>Closed to open shrubland (thicket) // Herbaceous closed to open vegetation / Closed to open trees</td></tr>
<tr><td>130</td><td>Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)</td><td>Broadleaved closed to open shrubland (thicket)</td><td>Shrub</td></tr>
<tr><td>140</td><td>Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)</td><td>Herbaceous closed to very open vegetation // Closed to open lichens/mosses</td><td>Herbaceous</td></tr>
</table>

Value	Global GlobCover legend (level 1)	LCCS Label	LCCS Entry
150	Sparse (<15%) vegetation	Sparse trees // Herbaceous sparse vegetation // Sparse shrubs	
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	Closed to open (100-40%) broadleaved trees on temporarily flooded land, water quality: fresh water // Closed to open (100-40%) broadleaved trees on permanently flooded land, water quality: fresh water	A24 Natural and Seminatural Aquatic Vegetation
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: brackish water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: brackish water	
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	Closed to open shrubs // Closed to open herbaceous vegetation	
190	Artificial surfaces and associated areas (Urban areas >50%)	Artificial surfaces and associated areas	B15 Artificial Surfaces
200	Bare areas	Bare areas	B16 Bare Areas
210	Water bodies	Natural water bodies // Artificial water bodies	B28 Inland Waterbodies, snow and ice
220	Permanent snow and ice	Artificial perennial snow // Artificial perennial ice // Perennial snow // Perennial ice	
230	No data (burnt areas, clouds,…)		

B.3 Forest mask

A binary forest mask for the northern hemisphere is generated from the ESA GLOBCOVER V2.3 data set, using the classes 40, 50, 60, 70, 90, and 100 for identifying forested pixels used for partitioning the intercomparison and validation activities. This binary forest mask is extracted from the GLOBCOVER V2.3 data set using the original map projection (geographic coordinates on WGS84 ellipsoid, EPGS: 4326) and the original pixel size (0.00277777778° x 0. 00277777778°). The retrieved binary forest mask is then reprojected to the map projection WGS84 / NSIDC EASE-GRID 2.0 North (EPSG: 3973), and aggregated to 5 km and 25 km pixel sizes. An aggregated pixel is classified as binary forest pixel if the aggregated fractional forest is ≥ 50 %.

B.4 Water body mask

A global binary water mask is generated from the ESA GLOBCOVER V2.3 data set, using the class 210 for identifying water pixels. This water body mask is used for the product intercomparison and validation activities. This binary water mask is extracted from the GLOBCOVER V2.3 data set using the original map projection (geographic coordinates on WGS84 ellipsoid, EPGS: 4326) and the original pixel size (0.00277777778° x 0. 00277777778°). The retrieved binary water mask is then reprojected to the map projection WGS84 / NSIDC EASE-GRID 2.0 North (EPSG: 3973), and aggregated to 5 km and 25 km pixel sizes. An aggregated pixel is classified as binary water pixel if the aggregated fractional water is ≥ 25 %.

For the generation of reference snow maps from Landsat imagery a high resolution water body mask with 30 m pixel size is derived by combining the water mask of Hansen et al. (2013) with the water body dataset from SRTM DEM V2.1 (http://dds.cr.usgs.gov/srtm/version2_1/SWBD/). The high resolution water masks are reprojected to the original map projection of each product to be validated. All pixels classified as water in at least one of these two layers is considered as water body in the resulting water mask, and in the reference snow maps from Landsat scenes, respectively.

B.5 Land mask

As land mask the inverse of the binary water body mask in map projection EASE-GRID 2.0 derived from ESA GLOBCOVER V2.3 is used.

Additionally, each product has an own land / water body mask used for the product generation. For the product intercomparison exercises only pixels classified in all selected products as snow covered and/or snow free land pixels (cf. Del. 7, Section 3.1 Preparation of SEB and SCF Products) are used.

B.6 Terrain Information

B.6.1 Digital Elevation Model (DEM)

For mapping snow from satellite data over complex terrain a Digital Elevation Model (DEM) is an important auxiliary map, needed for instance for topographic correction. Furthermore, some algorithms are documented as providing invalid or poor retrievals over complex terrain. A DEM is used to specify complex terrain following the approach adopted in the GlobSnow-2 project, described by Bippus et al. (2014).

Several DEMs are currently available on a global or nearly global scale. Table B.2 gives an overview on commonly used DEMs. The GETASSE 3.0 DEM is suggested to be used as standard DEM for product intercomparison with respect to complex terrain.

Table B.2:
Global or nearly global Digital Elevation Models.

DEM	***Version***	***Full Name***	***Pixel Size***	***Spatial Coverage***	***Vertical Accuracy***	***Reference***
GTOPO30	N/A	Global 30 Arc - Second Elevation	0.0083 deg (ca 1 km at equator)	90° N – 90° S	+/- 30 m	http://webgis.wr.usgs.gov/globalgis/gtopo30/gtopo30.htm
ETOPO5	N/A	Global 5 Arc Minute Elevation		90° N – 90° S		http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML
GETASSE	3.0	Global 30 Arc Second Elevation	0.0083 deg (ca 1 km at equator)	90° N – 90° S		http://earth.esa.int/services/amorgos/download/getasse/
SRTM DEM	4.1	Shuttle Radar Topography Mission	0.00083 deg (ca 90 m at equator)	60° N – 56° S	< 16 m	http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1
ASTER GDEM	2	Advanced Spaceborne Thermal Emission	0.000278 deg (ca 30 m at equator)	83° N – 83° S	ca 17 m	Tachikawa et al., 2011

DEM	Version	Full Name	Pixel Size	Spatial Coverage	Vertical Accuracy	Reference
		and Reflection Radiometer Global Digital Elevation Model				

B.6.2 Mountain mask

Following the GlobSnow-2 Validation Protocol (Bippus et al., 2014) all areas with slopes > 2° based on a central difference between three 100m digital terrain model grid cells extents are considered as mountainous terrain. Inter-comparison of products and comparison of products with reference data should be performed for

i) the full area covered by both data sets

ii) only plain areas covered by both data sets

iii) only mountainous areas covered by both data sets

Table B.3:
Terrain classification by slope.

Mountain Class	Description	Slope Condition
1	Plains, Low Slope	Slope <=2% over 100m
2	High Slope	Slope >2% over 100m

The resulting terrain classification is a binary mountain mask extending the northern hemisphere. The mask is reprojected to EASE-GRID 2.0 map projection and resampled to 5 km and 25 km. For aggregated pixels a pixel is classified as mountain if the mountainous fraction of the aggregated pixel is ≥ 50%.

B.7 BIT mask combining the used Ancillary layers

A bit mask including all selected land cover and terrain classes is used for the product intercomparison and validation (Table B.4).

Table B.4:
BIT of selected surface and terrain classes used for intercomparison and validation activities.

BIT	***CLASS***
0	Water
1	Forest
2	Mountain

Based on this BIT mask also multiple combinations of surface and terrain classes are used for partitioning the product intercomparisons and validations (Table B.5)

Table B.5:
Mask values retrieved from BIT-mask, used for partitioning the intercomparison.

VALUE	***CLASS***
0	Non-forested Plains
1	Water
2	Forested Plains
4	Forested Mountains
6	Non-Forested Mountains
2 and 4	Total forested area
0 and 6	Total non-forested area
4 and 6	Total mountains
0 and 2	Total plains
0, 2, 4 and 6	Total land area

B.8 Snow-Climate Zones

The physical properties of snow cover are strongly influenced by the prevailing regional climate. The snow classification scheme of Sturm et al (1995; Figure B.2) can be utilized for the purposes of defining and applying climatology for snow properties such as density, and categorizing and segmenting validation results.

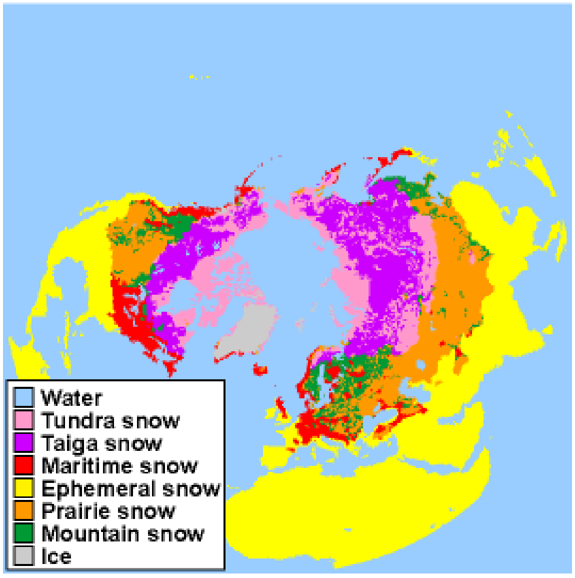

Figure B.2: Climate classification of seasonal snow (from Sturm et al., 1995).

C. SPATIAL AGGREGATION OF PRODUCT GRID CELLS TO ESTIMATE THE PROBABILITY DENSITY FUNCTION OF SNOW COVER FRACTION OVER A VALIDATION GRID CELL

This annex describes using synthetic example the logic for estimating the snow cover faction over a validation grid cell based on an input raster product, as used in the probabilistic approach applied by CCRS. It considers the general case where each product grid cell may include multiple sub-pixel mapped conditions. This case could easily be simplified for products that only consider one possible mapped condition in a product grid cell. The annex includes two separate descriptions: one for binary snow cover extent products and one for snow cover fraction products.

C.1 Binary Snow Cover Extent Products

Figure C.1 provides a synthetic example used to discuss the aggregation of information of binary snow cover extent products within a validation grid cell.

- The grey boxes are product grid cells G.
- Each product grid cell contains a mixture of:
    - Invalid areas (black) – where the product is not to be assessed. This may correspond to water bodies or other land cover conditions (e.g. deserts) where the mapping algorithm is not defined.
    - Unmapped areas (white) – valid areas where the product is not mapped. Most products assume they map entire product grid cells. However, there are products such as the MODIS10C1 where each grid cell is an aggregate of smaller grid cells, some of which may not be mapped. The unmapped areas will have a probability density function assigned to them with mode SCF corresponding to the average SCF of the mapped areas in the validation grid cell S and range spanning a SCF of zero to one. (PDF(SCF|unmapped)
    - Mapped snow areas (blue) – valid areas where the product maps snow. The presence of snow implies an underlying probability density function of snow cover fraction within the mapped snow areas (pdf(SCF|snow))
    - Mapped snow free areas (green) – valid areas where the product maps no snow. The presence of snow implies an underlying probability density function of snow cover fraction within the mapped snow areas (pdf(SCF|snow free)

- The red-star indicates the row, column co-ordinates of the validation grid cell S centre.
- The red-window corresponds to the product window (in #rows and #columns) that area to be used to approximate the product pixels falling within the validation grid cell S. This approximation will be more exact when the validation grid cell S is sufficiently large to include many product grid cells.
- Table C.1 lists the approximate areas for each condition for each product grid cell falling in the validation grid cell. The areas are totalled for the validation grid cell and used to
    - Reduce the range of the triangular pdf(SCF|snow) and pdf(SCF|no snow) to account for increased precision when estimating the central tendency of a distribution.
    - Define the mode of the triangular pdf(SCF|unmapped) as the area weighted average of the mode of the triangular pdf(SCF|snow) and triangular pdf(SCF|no snow).
    - Provide area weights to define the composite probability density function for the validation grid cell: pdf(SCF|S):

Pdf(SCF|S) = [Snow Cover Area * PDF(SCF|snow) + No Snow Area * PDF(SCF|no snow) + 'Unmapped valid' area * PDF(SCF|unmapped valid)] / valid area

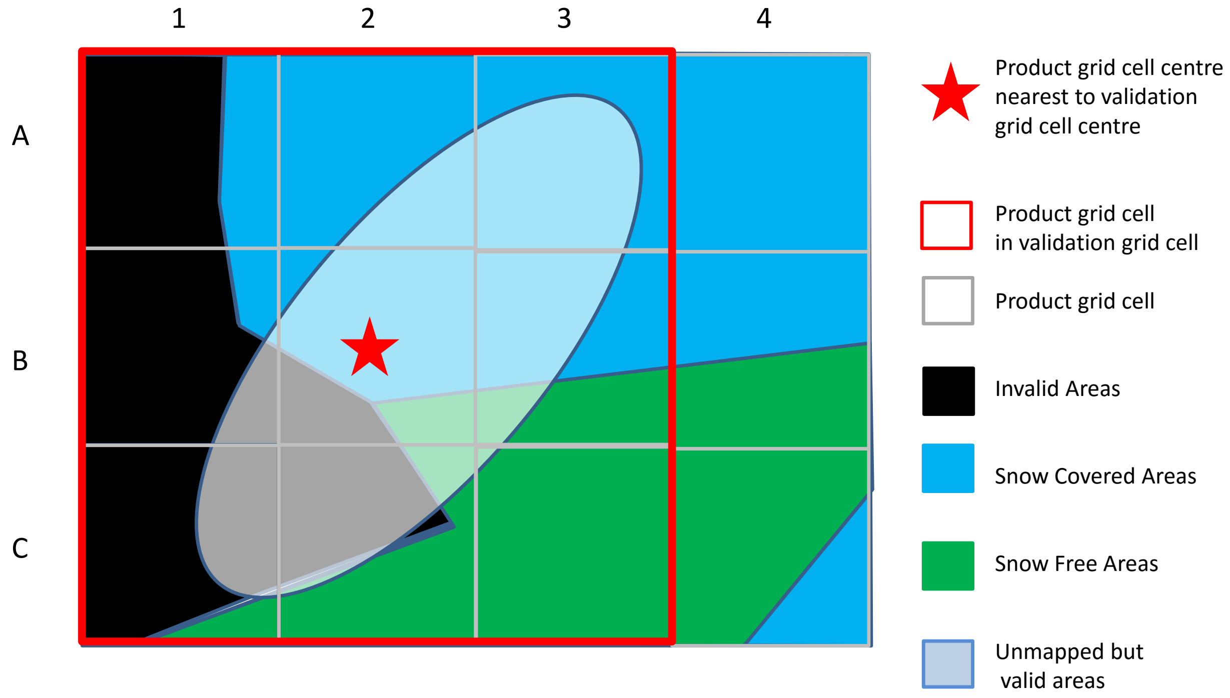

Figure C.1: Synthetic example of a binary snow cover extent product.

Table C.1:
Classified areas for product grid cells falling in a validation grid cell
(assuming each product grid cell area = 1 unit).

Grid Cell	*Valid Area*	*Mapped Area*	*Snow Cover*	*No Snow*	*'Unmapped Valid'*
A1	0.25	0.25	0.25	0.00	0.00
A2	1.00	0.80	0.80	0.00	0.20
A3	1.00	0.20	0.20	0.00	0.80
B1	0.10	0.08	0.08	0.00	0.02
B2	0.80	0.05	0.05	0.00	0.75
B3	1.00	0.60	0.35	0.25	0.40
C1	0.10	0.10	0.00	0.10	0.00
C2	0.70	0.60	0.00	0.60	0.10
C3	1.00	0.95	0.00	0.95	0.05
Total	6.00	3.63	1.73	1.90	2.32

C.2 Snow Cover Fraction Products

Figure C.2 provides a synthetic example used to discuss the aggregation of information of snow cover fraction products within a validation grid cell.

- The grey boxes are product grid cells G.
- Each grey box contains a mixture of:
    - Invalid areas (black) – where the product is not to be assessed. This may correspond to water bodies or other land cover conditions (e.g. deserts) where the mapping algorithm is not defined.
    - Unmapped areas (white) – valid areas where the product is not mapped due to insufficient or noisy surface measurements. Most products assume they map entire product grid cells. However, there are products such as the MODIS10C1 where each grid cell is an aggregate of smaller grid cells, some of which may not be mapped.
    - Mapped areas (blue) – valid areas where the product maps snow cover fraction.
- The red-star indicates the row, column co-ordinates of the validation grid cell S centre.

- The red-window corresponds to the product window (in #rows and #columns) that area to be used to approximate the product pixels falling within the validation grid cell S. This approximation will be more exact when the validation grid cell S is sufficiently large to include many product grid cells.
- Table C.2 lists the approximate areas for each condition for each product grid cell falling in the validation grid cell. The areas are totalled for the validation grid cell and used to
    - Modify the range of the triangular pdf(SCF|snow) to account for increased precision when estimating the mean SCF over multiple product grid cell in the validation grid cell and decreased precision due to the variability between the central tendency (mode in this case) of the SCF mapped over each product grid cell: pdf(SCF|product grid cell).
    - Define the mode of the triangular pdf(SCF|unmapped) as the area weighted average of the mode of the triangular pdf(SCF|snow) and triangular pdf(SCF|no snow).
    - Provide area weights to define the composite probability density function for the validation grid cell: pdf(SCF|S):

Pdf(SCF|S) = [Mapped Area * PDF(SCF|mapped) + 'Unmapped valid' area * PDF(SCF|unmapped valid)] / valid area

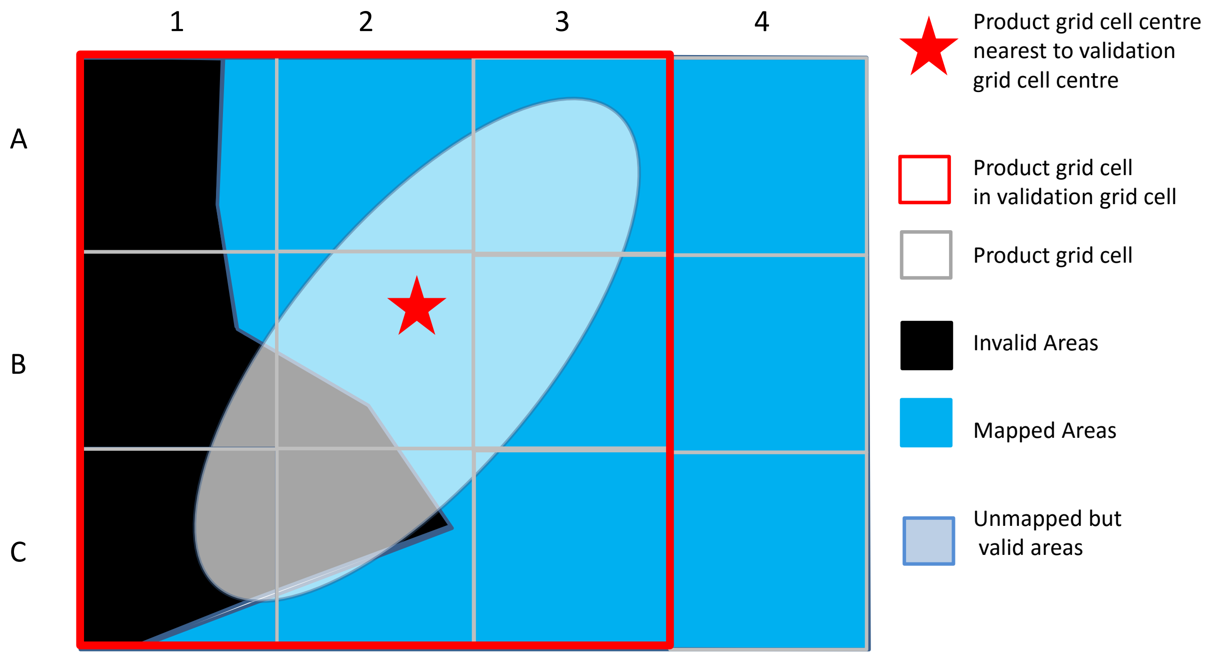

Figure C.2: Synthetic snow cover fraction example.

Table C.2:
Classified areas for product grid cells falling in a validation grid cell
(assuming each product grid cell area = 1 unit).

Grid Cell	***Valid Area***	***Mapped Area***	***'Unmapped Valid'***
A1	0.25	0.25	0.00
A2	1.00	0.80	0.20
A3	1.00	0.20	0.80
B1	0.10	0.08	0.02
B2	0.80	0.05	0.75
B3	1.00	0.60	0.40
C1	0.10	0.10	0.00
C2	0.70	0.60	0.10
C3	1.00	0.95	0.05
Total	6.00	3.63	2.32

D. REFERENCES

Bontemps, S., Defourny, P., & Van Bogaert, E. (2010). GLOBCOVER 2009 Products Description and Validation Report (pp. 1–30).

Fernandes, R, and Leblanc, S.. (2005), Parametric (modified least squares) and non-parametric (Theil–Sen) linear regressions for predicting biophysical parameters in the presence of measurement errors, Remote Sensing of Environment 95 (3): 303-316, doi:10.1016/j.rse.2005.01.005.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., … Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. Science, 342, 850–853. doi:10.1126/science.1244693

Integrated Global Observing Strategy. 2007. Cryosphere Theme Report. http://igos-cryosphere.org/.

JCGM 200:2012(E/F) , (2012). International vocabulary of metrology – Basic and general concepts and associated terms (VIM) 3rd edition, JCGM.

Padilla, M., Stehman, S., Litago, J., and Chuvieco, E., (2014). Assessing the Temporal Stability of the Accuracy of a Time Series of Burned Area Products, Remote Sensing, 6, 2050-2068, doi:10.3390/rs6032050.

Sturm, M., J. Holmgren, and G. Liston. 1995. A seasonal snow cover classification system for local to global applications. Journal of Climate. 8: 1261-1283.

Tachikawa, T., Kaku, M., Iwasaki, A., Gesch, D., Oimoen, M., Zhang, Z., … Carabajal, C. (2011). ASTER Global Digital Elevation Model Version 2 - Summary of Validation Results (p. 27). Retrieved from http://www.jspacesystems.or.jp/ersdac/GDEM/ver2Validation/Summary_GDEM2_validation_report_final.pdf