Climate Modelling User Group

Deliverable 2.3

Suitability of CCI ECVs for Climate Science and Services

Centres providing input: Met Office, MPI-M, ECMWF, MétéoFrance,
IPSL, SMHI, DLR, BSC

Also contributions from Vrije Universiteit Brussel

Version	Date	Status
0.1	30 July 2019	First CMUG assessment of CCI+ ECV product documents
0.5	9 August 2019	Input from Met Office; ECMWF, MPI-M, MétéoFrance, BSC, IPSL, DLR, SMHI
1.0	30 August 2019	Submission to ESA
1.1	11 December 2020	Update by MO, ECMWF, MPI-M, MétéoFrance, BSC, IPSL, DLR, SMHI
1.2	15 December 2020	Submission to ESA
1.3	15 December 2020	Resubmission of clean document to ESA
1.4	21 January 2021	Typo corrected
1.5	05 July 2021	Contribution on Ice Sheets from VUB
2.0	11 Aug 2021	First draft of v2 submitted to ESA
2.0_RID	10 Sep 2021	RIDs received from ESA
2.1	10 Sep 2021	RIDs addressed, resubmitted to ESA

CMUG CCI+ Deliverable 2.3

Suitability of CCI ECVs for Climate Science and Services

Table of Contents

1. Purpose and scope of the Technical Report

The purpose of this report is to review the documentation of each ESA CCI+ project and provide feedback on both the products and documentation to ESA and the CCI teams. This feedback is provided from the point of view of users working in climate research and climate services who are represented by the ESA CCI+ Climate Modelling User Group (CMUG).

A previous version of this report from CMUG Phase 2 was entitled the Technical Note on Product Assessment[1] this provides comments and technical advice on the "Product Validation and Inter-comparison Report", "Climate Assessment Report" and "Uncertainty Characterisation Report" for 11 of the Phase 2 CCI ECVs. The versions of these documents reviewed then were the most recent at the date of the report (February 2017). Other CCI project reports were also assessed where found to be relevant.

This current report, the second for CMUG in CCI+ Phase 1, will focus on the User Requirements Document (URD), the Product Specification Document (PSD), the Product User Guide (PUG) and either the Product Validation Plan (PVP) or the Product Intercomparison and Validation Report (PVIR) for each CCI project, with other documents reviews on an *ad hoc* basis. The URD is reviewed for 20 of the current CCI projects, the PSD is reviewed for the 9 ECVs new in Phase 1 of CCI+, the PUG is reviewed for 17 of the CCI projects, the PVP for 4 and the PVIR for 11. The CCI project on Glaciers is not considered in this document due to lack of expertise available at the time of writing but will be included in version 3 due in January 2022.

This report will cover

- The extent to which the URD captures requirements, from the perspective of the climate modellers and climate service users represented by CMUG
- Omissions from the ECV product described in the PSD
- Assessment of the utility of the PSD; does it contain all relevant information needed to start using the data?
- Usefulness of the PUG to a new user
- Opinions on the validation methods laid out in the PVP or PVIR
- Feedback on the format and readability of all documents
- Ideas and recommendations for CCI+ Phase 2

The aim is to produce a concise report which will be useful when shared with the CCI+ projects.

The report starts with a table listing which version of the documentation has been reviewed, this is followed by a section on each ECV within which there are sub-sections for each

[1] https://climate.esa.int/documents/644/CMUG_PHASE_2_D2.3_Product_Assessment_v3.1.pdf

document considered. The document reviews are then summarized with some overall recommendations from CMUG for the CCI+ projects and Phase 2 of the CCI+ given. Finally an acronym list and references are given.

2. Versions of Documents Reviewed

The comments in this report refer to the relevant documents available to CMUG as of 16th November 2020 when the CCI projects were contacted for latest versions. For the 14 CCI ECVs from Phases 1 and 2, the PSD was reviewed in the previous D2.3[1] so is not considered here, for the new ECVs established in the CCI+, both URD, PVIR/PVP, PUG and PSD are discussed. Other documents are reviewed in cases where the reviewer has used them in the course of their work, but the focus of this version of the report is the PSD, PUG, PVIR/PVP and URD. The documents reviewed are listed in Table 1. Where the documents are available online, the URL is given in Table 1, if there is no URL then the documents were provided directly to CMUG by the ECV teams or ESA and the relevant contact is named.

CMUG recommends that the most up to date documentation should be made available on ESA's new CCI web pages and that naming conventions and document structure should be consistent between the CCI projects.

Table 1. Version of documents reviewed.

ECV	URD	PSD (for ECVs new at CCI+ only)	PUG	PVP	PVIR	Others	CMUG lead / last update
Aerosols	V4.5 (28/08/2020): Pers comm Thomas Popp	N/A	V1.1 (22/04/2020) https://climate.esa.int/documents/81/Aerosol_cci_PUG_v1.1.doc	V2.1 28/08/2020 https://climate.esa.int/documents/619/Aerosol_cci_PVP_v2.1_final.pdf	N/A		Angela Benedetti (ECMWF)/ May 2021
Biomass	V1 (15/11/2018): http://cci.esa.int/sites/default/files/Biomass%20D1.1%20User%20Requirement%20Document%20V1.0.pdf	V2 (20/03/2020): http://cci.esa.int/sites/default/files/Biomass_D1.2_%20Product_Specification_Document_v2.pdf	V2.0 (07/10/2020) https://climate.esa.int/documents/617/Biomass_D4.3_CCI_PUG_V2.0.pdf	V1.1 (03/03/2019) http://cci.esa.int/sites/default/files/biomass%20D2.5%20Product%20Validation%20Plan%20%28PVP%29%20V1.0.pdf	V2.0 (17/12/2020) https://climate.esa.int/documents/616/Biomass_D4.1_Product_Validation_Intercomparison_Report_V2.0.pdf		Debbie Hemming (Met Office) / May 2021
Cloud	V3.0 (14/07/2017): Pers. Comm. Simon Pinnock	N/A	V5.1 (16/01/2020) https://climate.esa.int/media/documents/Cloud_Product-User-Guide-PUG_v5.1.pdf	N/A	V6 (03/02/2020) https://climate.esa.int/media/documents/Cloud_Product-Validation-and-Intercomparison-Report-PVIR_v6.0.pdf	CECR v4.1 (03/04/2018): https://climate.esa.int/media/documents/Cloud_Comprehensive-Error-Characterisation-Report-CECR_v4.1.pdf CAR v3.1 (18/09/2017): https://climate.esa.int/media/documents/Cloud_Climate-Assessment-Report-CAR_v3.1.pdf	Ulrika Willen (SMHI) Aug 2019 Axel Lauer (DLR) Apr 2021
Fire	V7 (27/11/2019): https://climate.esa.int/documents/224/Fire_cci_D1.1_URD_v7.0.pdf	N/A	FireCCI51 - MODIS (v1.0; 21 April 2020), FireCCISFD11 Sentinel-2 Sub-Saharan Africa (v1.2, 12 February 2019), FireCCILT11 - AVHRR-LTDR (v1.0, 7 December 2020) FireCCIS1SA10 - Sentinel-1 South America (v1.0, 12, July 2019)		v1.1 (15/10/20): https://climate.esa.int/documents/623/Fire_cci_D4.1_PVIR_v1.1.pdf		Pablo Ortega (BSC) Apr 2021

Green House Gasses (GHG)	**V3 (17/02/2020):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/URD/URDv3.0_GHG-CCIp_Final.pdf	**N/A**	**CO2_OC2_FOCA v3.0 (26/01/2021):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PUGv3_GHG-CCI_CO2_OC2_FOCA_v09_20210126.pdf **CH4_S5P_WFMD v3.0 (8/01/2021):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PUGv3_GHG-CCI_CH4_S5P_WFMD.pdf **CO3_TAN_OCFP v2.0 (10/02/2021):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PUGv2.1_GHG-CCI_CO2_Tan_OCFP_v1.pdf **CO2_GO2_SRFP & CH4_GO2_SRFP v1.1 (4/02/2021):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PUGv1.1_GHG-CCI_CO2_GO2_SRFP_v2.pdf **CH4_GO2_SRPR v1.2 (3/12/2020):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PUGv1.1_GHG-CCI_CH4_GO2_SRPR_v2.pdf	**v2.1 (19/03/21):** https://www.iup.uni-bremen.de/carbon_ghg/docs/GHG-CCIplus/CRDP6/PVIR_GHG-CCIp_v2p1.pdf	**Angela Benedetti (ECMWF) May 2021**
HRLC	**V2.0 (03/01/2020):** https://climate.esa.int/media/documents/CCI_HRLC_Ph1-D1.1_URD_v2.0.pdf	**V2.0 (03/01/2020):** https://climate.esa.int/media/documents/CCI_HRLC_Ph1-D1.2_PSD_v2.0.pdf	**v1.1 (4/05/2020):** https://climate.esa.int/media/documents/CCI_HRLC_Ph1-D4.3_PUG_v1.1.pdf	**v1.4 (4/02/2021):** pers comm Francesca Bovolo	**Enza di Tomaso (BSC) Apr 2021**

Ice Sheets (Greenland and Antarctic)	Antarctic V1.0 (10/12/2019): https://climate.esa.int/media/documents/ST-UL-ESA-AISCCI-URD_v1.0.0.pdf Greenland v2.1 (15/01/2021): https://climate.esa.int/documents/637/ST-DTU-ESA-GISCCI-URD-001_v2.1.pdf	N/A	Antarctic v1.0 (03/06/2021): https://climate.esa.int/documents/1243/ST-UL-ESA-AISCCI-PUG-0001.pdf Greenland v1.0 (14/10/2020): https://climate.esa.int/documents/276/ST-DTU-ESA-GISCCI-PUG-001_v1.0_6Z3mTw8.pdf	N/A	Antarctic v1.3 (04/05/2018): https://climate.esa.int/media/documents/ST-UL-ESA-AISCCI-PVIR-001_v1.3a.pdf Greenland v1 (14/10/2018): https://climate.esa.int/documents/1250/ST-DTU-ESA-GISCCI-PVIR-001_v1.0_9S3FM3F.pdf	Philippe Huybrechts and colleagues (VUB) / July 2021
Lakes	V1.1 (05/09/2019): https://climate.esa.int/sites/default/files/filedepot/incoming/CCI-LAKES-0019-URD-1.1.pdf	V1.2 (15/05/2020): https://climate.esa.int/sites/default/files/filedepot/incoming/CCI-LAKES-0016-PSD_V1.2_signed_CA.pdf	V1.1 (15/05/21): https://climate.esa.int/documents/360/CCI-LAKES-0029-PUG_v1.1_signed_CA.pdf	V1.0 (24/04/21): https://climate.esa.int/documents/988/CCI-LAKES-0030-PVP_V1.2.pdf		Grace Redmond (Met Office) / Nov 2020 Erasmo Buonomo (Met Office) May 2021
Land Cover	V1.0 (16/09/2019): https://transvol.sgsi.ucl.ac.be/download.php?id=afff326017409fd6	N/A			PUGS v1.3 (31/08/2020): https://datastore.copernicus-climate.eu/documents/satellite-land-cover/D3.3.12-v1.3_PUGS_ICDR_LC_v2.1.x_PRODUCTS_v1.3.pdf	Enza di Tomaso (BSC) Apr 2021
Land Surface Temperature (LST)	V1.1 (21/02/2019): pers. Comm. Simon Pinnock	V1.11 (17 June 2020): pers comm. Simon Pinnock	v1.2 (22/10/2020): https://admin.climate.esa.int/media/documents/LST-CCI-D4.3-PUG_-_i1r2_-_Product_User_Guide.pdf		v1.2 (23/09/2020): https://admin.climate.esa.int/media/documents/LST-CCI-D4.1-PVIR_-_i1r2_-_Product_Validation_and_Intercomparison_Report.pdf	Jean-Christophe Calvet (Météo France) Nov 2020 Rob King (Met Office) Apr 2021

Ocean Colour	**V1.0 (31/07/2019): https://docs.pml.space/share/s/lg8js7hFSOaaZrtbtFGbmQ**	**N/A**	**V1.0 (12/10/2020): https://docs.pml.space/share/s/okB2fOuPT7Cj2r4C5sppDg**			**PVASR v3.0 (Pt1 23.12.15; Pt 2 15.01.16)[2]** **CAR v2.0 (04.02.16): https://docs.pml.space/share/s/wZZzAxTJQkuC7wwdt3kJRQ**	**David Ford (Met Office) / Apr 2021**
Ozone	**V3.1 (01/09/2020): pers. Comm. Michel Van Roozendael**	**N/A**		**v2.1(06/12/2020): https://climate.esa.int/documents/409/Ozone_cci_PVP_2.1_20201206.pdf**		**CECR v2 (22.12.16): http://cci.esa.int/sites/default/files/filedepot/incoming/Ozone_cci_KIT_CECR_02_01_02.pdf**	**Angela Benedetti (ECMWF) May 2021**
Permafrost	**V1.1 (12/02/2019): https://climate.esa.int/documents/101/CCI_PERMA_URD_v1.1.pdf**	**V2.0 (30/11/2019): http://cci.esa.int/sites/default/files/CCI%2B_PERMA_PSD_v2.0.pdf**	**v2.2 (03/03/2021): https://climate.esa.int/documents/596/CCI_PERMA_PUG_v2.2.pdf**		**V2.1 (14/01/2021): https://climate.esa.int/documents/627/CCI_PERMA_PVIR_v2.1.pdf**		**Jean-Christophe Calvet (Météo France) Apr 2021**
Sea Ice	**V2.0 (20/03/2020): https://climate.esa.int/documents/78/Sea_Ice_User_Requirements_Document_2.0.pdf**	**N/A**	**SIT v1 (10/02/2017): https://climate.esa.int/documents/75/Sea_Ice_Thickness_Product_User_Guide_1.0.pdf** **SIC v1.1 (20/09/2017): https://climate.esa.int/documents/70/Sea_Ice_Concentration_Product_User_Guide_1.1.pdf**		**SIT v1.1 (23/07/2018): https://climate.esa.int/documents/76/Sea_Ice_Thickness_Product_Validation_and_Intercomparison_Report_1.1.pdf** **SIC v1.1 (23/07/2018): https://climate.esa.int/documents/71/Sea_Ice_Concentration_Product_Validation_and_Intercomparison_Report_1.1.pdf**		**Andreas Wernecke (MPI-M) May 2021**
Sea Level	**G l**	**V1.6 (22/10/2014):**	**N/A**	**v2.2 (13/12/2016): https://climate.esa.int/docu**		**V2.0 (09/12/2016):**		**Pablo Ortega**

[2] Reviews of these PVASR documents were included in an earlier draft of this report compiled by the previous CMUG management team, the documents referenced are not available to the current reviewer, but they are later versions than those currently linked from the CCI Ocean colour web pages, so the discussion is left in as it may be relevant

(previously Sea Surface Height)	global	http://www.esa-sealevel-cci.org/webfm_send/235		ments/477/SLCCI-PUG-029-2-2.pdf		https://climate.esa.int/documents/478/SLCCI-PVIR-073_SL_cciV2-1-1.pdf	(BSC) Apr 2021
	coastal	V1.2 (16/06/2020): http://www.esa-sealevel-cci.org/webfm_send/640	N/A	v1.3 (11/06/2020): https://climate.esa.int/documents/605/SLCCI_PVP006_ProductValidationPlan_v1.3.pdf		V1.0 (05/10/2020): https://climate.esa.int/documents/606/SLCCI_PVIR_018_ProductValidation_v1.0.pdf	David Ford (Met Office) Apr 2021
Sea State		V1.0 (06/02/2019): http://cci.esa.int/sites/default/files/Sea_State_cci_URD_v1.0-signed.pdf	V1.0 (05/02/2019): http://cci.esa.int/sites/default/files/Sea_State_cci_PSD_v1.0-signed.pdf	v1.0 (17/01/2020): https://climate.esa.int/documents/884/Sea_State_cci_PUG_v1.0-signed.pdf		V1.0 (22/06/2020): pers comm David Cotton	David Ford (Met Office) / Apr 2021
Sea Surface Salinity (SSS)		V1.4 (03/01/2019): http://cci.esa.int/sites/default/files/SSS_cci-D1.1-URD-v1r4_signed-accepted.pdf	V1.6 (28/01/2019): http://cci.esa.int/sites/default/files/SSS_cci-D1.2-PSD-v1r6_signed-signed.pdf	v1.2 (5/03/2020): http://cci.esa.int/sites/default/files/SSS_cci-D4.3-PUG-v1.2-signed_0.pdf	V1.1 (04/12/19): http://cci.esa.int/sites/default/files/filedepot/SSS_cci-D2.5-PVP-v1.1-signed.pdf		Andreas Wernecke (MPI-M)/ Nov 2020 Pablo Ortega (BSC)/April 2021
Sea Surface Temperature (SST)		V2.1 (13/01/2017): https://climate.esa.int/documents/280/SST_CCI-URD-UKMO-201-Issue_2.1-signed.pdf	N/A	v2 (8/04/2019): https://climate.esa.int/documents/267/SST_cci_PUG_v2.pdf		Product Quality Assessment Report (PQAR) v4.1 (27/10/2020): https://datastore.copernicus-climate.eu/documents/satellite-sea-surface-temperature/v2.0/D2.SST.2-v2.2_PQAR_of_v2SST_products_v4.1_APPROVED_Ver1.pdf	Andreas Wernecke (MPI-M) May 2021
Snow		v2.0 (17/12/2019): http://snow-cci.enveo.at/documents/Snow_cci_D1.1_URD_v2.0.pdf	V2.0 (19/12/2019): http://snow-cci.enveo.at/documents/Snow_cci_D1.2_PSD_v2.0.pdf	v2.0 (09/11/2020): https://climate.esa.int/documents/287/Snow_cci_D4.3_PUG_v2.0_r2MH0hU.pdf		V2.0 (25/11/2020): pers comm Gabriele Schwaizer	Jean-Christophe Calvet (Meteo France) Apr 2021

Soil Moisture (SM)	**V2.1 (19/11/2020): pers comm. Richard Kidd**	**N/A**	**v2 (16/04/2021): https://admin.climate.esa.int/media/documents/ESA_CCI_SM_D4.2_v2_Product_Users_Guide_v06.1_i1.0.pdf**	**V2 (16/04/2021): https://admin.climate.esa.int/media/documents/ESA_CCI_SM_D4.1_v2_PVIR_v6.1_issue_1.0.pdf**	**Frederique Cheruy (IPSL) & Amen Al-yaari (Sorbonne University) May 2021**
Water Vapour	**V2.0 (18/11/2019): http://cci.esa.int/sites/default/files/Water_Vapour_cci_D1.1_URD_v2.0-trackchanges_ms_tvuk.pdf**	**V2.1 (27/11/2019): http://cci.esa.int/sites/default/files/Water_Vapour_cci_D1.1_URD_v2.0-trackchanges_ms_tvuk.pdf**	**V1.1 (13/10/2020): pers. Comm. Pauline Cocevar**	**V1 (24/02/2021): Pers. Comm. Pauline Cocevar**	**Axel Lauer (DLR) May 2021**

3. Comments on CCI project documentation

The CCI ECV projects for which the documentation has been reviewed (22 of the 23 ECV projects, with Glaciers outstanding and to be included in the next version of the document) are considered here in alphabetical order. The comments and recommendations of the reviewers are split so that it is clear which comments refer to which document and which refer to the ECV product and documentation set overall.

2.1 Aerosols

Version 2.0 of the URD for the Aerosols_cci project, dated 28 August 2020, the Product Validation Plan version 2.1 dated 28 August 2020 and the Product User Guide version 1.1 dated 22 April 2020 were reveiwed.

User Requirement Document

This document has undergone several revisions and is now in a very mature form. However, there are now new aerosol variables proposed for climate monitoring and assimilation and user requirements for these should be covered by the new version of the document for CCI+ Phase 2. Profiles of backscatter and extinction (at several wavelengths) such those provided by lidar systems are good examples. Vertical profiles are mentioned throughout the document but no explicit requirement is set. In view of the current ESA operational and planned missions (Aeolus and EarthCARE) with lidar sensing capabilities, CMUG would like to see discussion of these variables in future versions of the document. Also, other variables are being considered by GCOS for inclusion as ECVs and these should be discussed. In particular surface (speciated) emissions have been flagged as extremely important.

In summary CMUG recommends for future versions of this document:

- New aerosol products such as profiles of backscatter and extinction should be mentioned, including any plans to include these in the ECV product in future
- New variables being considered for inclusion as ECVs should be mentioned, e.g. surface (speciated) emissions
- Requirements for vertical profiles should be outlined in detail

Product Validation Plan (PVP)

This is a solid validation plan, set out in a concise and effective manner. No improvements can be recommended.

Product User Guide (PUG)

This is a well written document. As a user, I know that the CCI+ AER products are easy to download and use. I would suggest expanding the section related to the product limitations and strengths in connection to SLSTR. It is now known from the verification that SLSTR performs less satisfactorily that AATSR due to the specific viewing geometry. I think the users should know more about this. At the moment, to the best of my knowledge, the SLSTR

dataset cannot be considered to be continuing the AATSR climate data record, is this correct? Please add a comment specifically to address this in the document.

2.2 Biomass

The following documents are reviewed below:
- Version 1.0 of the User Requirements document (URD) dated 15 November 2018,
- Version 2.0 of the Product Specification document (PSD) dated 20 March 2020,
- Version 1.1 of the Product Validation Plan (PVP) dated 03 March 2019,
- Version 2.0 of the Product User Guide (PUG) version 2.0 dated 07 October 2020,
- Version 2.0 of the Product Validation and Intercomparison Report (PVIR) version 2.0 dated 17 December 2020.

User Requirement Document (URD)

User requirements defined in the URD reflect the needs of the two major communities that use AGB data: i) climate / carbon modelling, and ii) REDD+. While there is some overlap in requirements of these users, there are significant differences relating to scale. Climate / carbon modelling requires gridded data typically at 500 m or coarser resolution, whereas REDD+ requires country based data at 1 ha or finer resolution. The requirements of these two communities are well defined in the URD.

Product Specification Document (PSD)

The PSD introduces a suitable range of products that meet the broad user requirements in the URD. Details on the uncertainties relating to spatial resolution and the accuracy are not currently defined, but will become clear as the product develops, which should not affect user applications at this stage. There are questions over how to calculate the AGB change product, CMUG recommends further discussion with users of the product to resolve this.

Product Validation Plan (PVP)

The PVP provides a clear and comprehensive plan for the validation of AGB, and links to further relevant literature and datasets, CMUG would ask that it is made clearer if information on the seasonality (intra-annual timing) of AGB is available from the proposed datasets and analyses?

Product User Guide (PUG)

The PUG provides a very useful and comprehensive summary of the algorithms, thematic content, limitations, and technical specifications (format, file names and metadata) of the Biomass_cci data products available at the end of the second year of the project. This is supported by appendices of information on the datasets that are helpful for interpreting the AGB map and map data format. To help understand the extremes in the datasets CMUG would find it useful if extreme categories could be included in the figure scales where relevant, e.g. for figure 3-1 it would be helpful to include a discrete category for the highest AGB estimates 350-?? Mg ha^{-1}. The visual comparison of AGB with Google Earth maps is useful for communicating the detail available from the AGB estimates to wider audiences.

Further, the comparison with higher resolution airborne laser scanning (ALS) data for selected regions (figure 3-6 to 3-11) is helpful for demonstrating very high-resolution model-observation based assessments.

Product Validation and Intercomparison Report (PVIR)

The PVIR assesses the quality of the three Biomass_cci products (global AGB for epochs 2017, 2018 and a refined 20210 product) and their uncertainty measures, relative to plot observations and LiDAR campaign data. The potential errors in all datasets and harmonisation steps are well explained and it is useful that both observation-based and model-based uncertainties are considered. The spatial and ecoregion assessments are helpful for comparing with comparable model output, although variations in biome / ecoregion categories may provide a limitation on this. CMUG would welcome the use of additional datasets to extend the error associated with using small plot data for AGB map assessment.

Suggestions for CCI+ Phase 2

If the details on uncertainties, and questions over how to calculate AGB change are not resolved by the end of Phase 1 then CMUG recommends that these are prioritised in Phase 2.

2.3 Cloud

The documents reviewed in this section for the Cloud_cci project are:

- User Requirements Document (URD) version 3.0, 14/07/17
- Product User Guide (PUG) version 5.1,16/01/20
- Comprehensive Error Characterisation Report (CECR) version 4.1, 04/18
- Climate Assessment Report (CAR) Version 3.1, 09/17
- Product Validation and Intercomparison Report (PVIR) Version 6.0, 03/02/20

The documents are nicely structured and well written. The product user guide is particularly nicely done. The URD could be further improved by providing tables grouped by application rather than by source as this would allow the reader to quickly find the required information. In the product user guide, an extension of Annex C on how to use the uncertainty information provided with the datasets would be very welcome. This could include information on error correlation lengths in space and time and possibly recommendations for best practices when averaging, regridding, etc. the uncertainty estimates for applications such as model evaluation. This could be an aim for CCI+ Phase 2.

User Requirements Document (URD)

Specific Recommendations

- Section 2.2.6: ERA-Interim is available from 1979-2019, so there is probably no need to use ERA40. ERA-Interim has now been replaced by ERA5, which is planned to cover 1950 to present.
- Section 2.2.1 (GCOS requirements on cloud radiative properties) could be transformed into a table.
- Table 4 summarizes the user requirements for climate monitoring. If possible, also other user requirements could be grouped by application (NWP, climate modelling, model evaluation, etc.) rather than by source (WMO, GCOS, CMUG, etc.). This would make the document easier to read.
- If possible, provide one “overarching” summary table for user requirements from different sources.

Product User Guide (PUG)

Specific comments

- Uncertainty information and known limitations for each group of variables is great, the bullet list format makes it easy to get a quick overview.
- An overview table on recommended applications or examples of existing applications for the different datasets would be welcome.
- The section on data access, citation, etc. is very helpful.

Suggestions for the PUG in CCI+ Phase 2

Propagation of Level-3 uncertainties into higher level products (Annex C) is a great addition and an excellent starting point for further analyses. Providing guidelines or best practice to

help users take advantage of the uncertainty information could be a possible improvement. This could include guidelines on:

- error correlation lengths in space and time
- best practice for averaging, regridding
- how to compare with model data

Comprehensive Error Characterisation Report (CECR)

Suggested changes and additions to the CECR that would help the reader and user of the data:

- Add a specific description and validation of the CFC uncertainty
- Add which CALIOP time periods were used for the training and validation of CFC in CECR Table 5-1.

Climate Assessment Report (CAR)

- Cloud_cci data compares well with the GEWEX Cloud assessment data base, except for an underestimation of high level clouds especially during the day. This might be improved by using the nighttime methods also at daytime in CC4CL.
- The Cloud_cci pixel based uncertainties show the user which areas should be carefully treated, e.g. polar and high altitude snow covered regions. However, the uncertainties were larger than the spread between the AVHRR datasets especially for the polar regions. According to the PVIR these uncertainties should not be used. That should be stated clearly at the site where the data can be downloaded.
- To improve the usability of Cloud_cci CFC in climate studies, a simple statistical method was developed for correcting CFC by bias correcting or "debiasing" the AVHRR-PM CFC data using synoptic observations. The corrected (debiased) dataset significantly outperforms the original one in terms of accuracy and precision, and standardizes performance among NOAA satellites. Therefore, debiasing can implicitly remove the inhomogeneity in CFC time series due to changing overpass times and unresolved diurnal cycle. The correction decreases the magnitude of trends but keeps their signs unchanged. This debiased dataset should be made available to users.

Product Validation and Intercomparison Report (PVIR)

General comments / ideas

- Using a wider than single-spaced line spacing would improve readability of such an extensive document.
- The tables are very useful, enabling quick search of the document.
- As an idea for future versions of this document: where available, the per-pixel uncertainties might possibly be used to check how much of the deviations found between the Cloud_cci data and the reference datasets in section 4 can be explained within these uncertainty estimates and possibly also to distinguish between systematic and random differences.
- Usage of ERA-Interim data could be replaced with ERA5.

- Evaluation of seasonal differences is not part of the evaluation (and that's fine). But whenever striking differences are found in particular seasons, this could be mentioned as a precaution for users of the data.

Specific Comments

- ***Section 2:***
  - Other key documents mentioned in introduction (e.g. ATBDv5, etc.) might not be straight-forward to find for the inexperienced user. Giving a reference or a website could help with this. Maybe simply insert hyperlinks into the document.
- Section 3.3:
  - SIS and SDL are not defined in the text / figure captions but only in the list of acronyms.
  - Do numbers given for standard deviation include both, temporal and spatial (different stations) variation?
- Section 4:
  - I like the "general findings" summarized as bullet points
  - From a user's point of view, I would find it more convenient to have the evaluation results sorted by variable instead of separating into morning/afternoon, i.e. I would prefer going through all variables and read about morning/afternoon results in sections directly following each other or maybe even side-by-side in the same section.
  - Figures showing climatological means (e.g. figure 4-1): it would be a bit easier to gauge the differences between the different satellite products when showing the absolute values of the reference dataset only and difference plots for all other datasets instead.
  - Discussions: whenever possible, a more quantitative language would be helpful, e.g. providing a measure/number/estimate (or a reference to a table) for statements such as "has worsened", "slightly decreased trend", "a bit lower", etc. (examples taken from the section on total cloud cover, but this applies to other discussion sections as well).
  - Captions of figures showing standard deviation ("…standard deviation of […] averaged…"): not sure I understand the term "averaged" as I thought this would be simply the temporal standard deviation calculated from a time series of monthly means for the given time period.
  - Tables: I would rather speak of e.g. "evaluation metrics" than "evaluation scores" as the quantities given here are (in my opinion) not really "skill scores" in the sense of combined metrics but rather simply individual metrics.
  - Page 31, second bullet point ("with all datasets being with approx."): being with → being within?
  - The footnotes on pages 38/74/101 are repeated on the following pages. Not sure that's needed. Probably enough to only put the footnotes on pages where they are actually referenced.
  - Page 44, third line from bottom: "relative" → "relatively"
  - Page 57, line 2: "tropic" → "tropics"

- Section 5:
  - Page 100: not sure the term “blacklisted” is the best option, maybe rather something like “masked as missing”?
- Section 6:
  - The introductory parts for the individual variable are a bit repetitive. The common parts such as the formulas and explanation of the terms could be summarized in the beginning of section 6.
  - Uncertainty estimates for the reference datasets could be summarized in a table as this would help to quickly find the key information.
- Section 7:
  - A table summarizing the numbers for the different variables would be great.
  - The tables “Recommendation on the usage” are great and could be put in a more prominent position (e.g. a separate subsection) so they are easier to find when looking through the table of contents.
  - Page 131: “heavy aerosol” → e.g. “high aerosol concentrations”
  - Caption of table 7-2: not sure what is meant by “tractability” in this context.

2.4 Fire

This section reviews the following documents:
1) The PUGs of the 4 ongoing (not deprecated) datasets:
- FireCCI51 - MODIS (v1.0; 21 April 2020),
- FireCCISFD11 Sentinel-2 Sub-Saharan Africa (v1.2, 12 February 2019),
- FireCCILT11 - AVHRR-LTDR (v1.0, 7 December 2020) and
- FireCCIS1SA10 - Sentinel-1 South America (v1.0, 12 July 2019);

2) The PVIR of all datasets (v1.1, 15 October 2020); and
3) the User Requirement Document version 7.0 dated 27 November 2019.

MODIS / AVHRR-LTDR / Sentinel-2 Sub-Saharan Africa (SFD) / Sentinel-1 South America (S1SA) - PUG

The four documents provide a very detailed up-to-date account and relevant information for the users for the four datasets that are currently supported by the Fire_cci. The format is consistent and very well structured in all the documents, which are at the same time tailored to the particularities of each of the products. We value the level of detail in each of the sections, which include clear and concise explanations and high-quality figures that nicely illustrate the information provided in each of the product layers and attributes. The first three documents also include a clear description of how uncertainty is characterised in the corresponding products and provide recommendations on product use, both of which are of great value. Neither the description of uncertainty nor the recommendations on product use have been included in the last document (Sentinel-1 South America), which would be desirable. The first two documents also have a section of known issues, not present in the other two (S1SA and S2SA). For coherence across documents, we suggest including it in all of them, as it is not clear if no issues are known for the last two, or if they are simply not reported. Another section that is only included in two of the documents and we recommend adding to the other two (S1SA and SFD) is product validation. We also note that for the last one there is a mismatch between the name of the database used in the document (Small Fire Database), and the one reported in the Fire_cci key document section (Sentinel-2 Sub-Saharan Africa).

D4.1 product - PVIR

This document assesses the quality of the burned area global and regional products, describing the methods and some preliminary results. The validation protocol is thoroughly detailed and its implementation is well supported with a nice selection of very illustrative figures. However, we have noted that some of the figures, especially some of the first ones (2 to 9), are blurred and would benefit from improved definition. Considering several accuracy metrics to evaluate the products is also valuable, as is the inclusion of the equations used to derive them. However, as not all readers of the document will be familiar with these metrics, we recommend providing some short explanation on how to interpret them and the nuances between them. We have also noted that this document does not cover all the burned area Fire_cci products (e.g. Sentinel-2 Sub-Saharan Africa or the Small Fire Database are not included). It would be good to acknowledge that some datasets are not included, justify why, and refer to other documents (if available) describing how they have been evaluated.

User Requirements Document (URD)

The latest Fire_cci User Requirements Document gives an exhaustive account of the current burnt area products, their characteristics and identified limitations, their suitability for different uses, the ongoing initiatives and projects in which they are used and/or for which are relevant. More importantly, it explains how they meet (or will meet) the user requirements identified through different surveys and by different institutions. The document is also frequently revisited and updated with new inputs from different sources to keep it as relevant as possible to all users.

The document is very detailed and, in some sections, would benefit from some synthesis tables distilling the key information for the readers. For example, the main user requirements for each of the different applications, indicating if there are products that already meet them. Or the most important recommendations for each of the characteristics listed in Section 7.

Another suggestion for future versions of the document is to specify potential requirements that have been taken into account to meet the needs of other CCI+ projects, like RECCAP-2, in which fires (and their respective carbon emissions) play an important role.

2.5 Greenhouse gases (GHG)

The documents reviewed for the GHG_cci project are:

- User Requirement Document (URD) version 3.0 dated 17 February 2020
- the Product Validation and Intercomparison Report (PVIR) version 2.1 dated 19 March 2021
- the Product User Guides (PUGs) for the 5 latest products:
  - *CO2_OC2_FOCA version 3.0 dated 26 Jan 2021*
  - *CH4_S5P_WFMD version 3.0 dated 8 Jan 2021*
  - *CO3_TAN_OCFP version 2.0 dated 10 Feb 2021*
  - *CO2_GO2_SRFP & CH4_GO2_SRFP version 1.1 dated 4 Feb 2021*
  - *CH4_GO2_SRPR version 1.2 dated 3 Dec 2020*

User Requirement Document (URD)

This document is quite exhaustive in many aspects related to column observations of GHG. The only element not sufficiently treated was the vertical resolution which is only briefly mentioned in section 5.3. It is undoubtedly true that the utility of column-average retrievals without any vertical resolution has been clearly demonstrated. However, with advances in modelling and assimilation of GHG it will be more important in the future to have also vertically resolved measurements, and requirements for those will have to be provided. CMUG suggests that for the next update of the URD document, experts are asked specifically about this aspect. The same comment applies to observing cycle (section 5.4). While this aspect is not relevant for regional flux inversions it might be relevant for assimilation of GHG concentrations.

As a general comment, the document is more geared toward the requirements for flux inversions at the regional level. In future revisions of the document this could perhaps be expanded to include also other applications such as data assimilation of GHG atmospheric concentrations.

Product Validation and Intercomparison Report (PVIR)

This document is an excellent and detailed validation document with impressive results, particularly for CO2. Please expand the executive summary with some key points that go together with the three tables presented, referring to the page numbers of the document in which more detailed information can be found. It's hard for the reader to go through 100 pages of report, so signposting to the most relevant information would be welcome.

Product User Guides (PUGs)

Designed to provide information for each individual CO2 or CH4 retrieval/dataset and brief enough to be readable, I found them useful. In particular, it was useful that all documents had a similar structure (although some were missing a brief introductory summary, which is always welcome), including a section on known issues and recommended data usage. I would recommend including a short executing summary for all retrievals in future versions of the PUG documents.

2.6 High Resolution Land Cover (HRLC)

The documents reviewed for the HRLC_cci project are

- User Requirement Document (URD) version 2.0 dated 3 January 2020
- the Product Specification Document (PSD) version 2.0 dated 3 January 2020
- the Product User Guide (PUG) version 1.1 dated 4 May 2020
- the Product Validation Plan (PVIR) version 1.4 dated 4 February 2021

The URD and PSD are found to be useful with clear explanations and sufficient detail. However, the PUG would benefit from some editing and clarification and the PVIR was less easy to read with many figures and little explanation. Below are some recommendations for improving the documents. Recommendations for CCI+ Phase 2 specific to HRLC_cci are also given.

User Requirement Document (URD)

CMUG would like to see more information on aggregation tools, the report states "*Visualization and aggregation tools like the ones developed within the ECV MRLC project as the HRLC products are expected to be quite large and should be easily aggregate at the model cell scale while compiling the distribution of the PFT within this cell. These tools will facilitate the use of HRLC data by climate and vegetation models usually working at lower spatial resolutions.*" Details should be provided of how this aggregation will be done. Will users benefit from high resolution information even after aggregation (since the HRLC should be consistent with the MRLC)?

Product Specification Document (PSD)

Users have been consulted on the desired format of data and metadata. Two preferences have been expressed by the users and potential users: GeoTIFF and NetCDF files with metadata included in the file. However, this has been translated in the PSD only in supporting GeoTIFF specifications with separate metadata in XML format. The product specifications in terms of data format do not seem to satisfy a considerable number of users preferring NetCDF format as standard, with metadata included within the product file, nor to satisfy the CCI Data Standards (ref. CCI-PRGM-EOPS-TN-13-0009, version 2.1).

Furthermore, there seems not to have been user-consultation about the plan of providing data in Universal Transverse Mercator projection. It could well be that users might prefer a regular grid or Gaussian projection. It might be advisable to consult users further on this point.

In several places in the PSD it says "*The static map will refer to the year 2018*." but in one place it says "*year 2019 chosen for the static map*". The year chosen should be clarified.

Minor details: some references or explanation is needed for the abbreviations GlobCover, SIGMA, RR in "*in the context of the GlobCover*", "*the recent SIGMA validation experiment*" "*HRLC mapping activities: RR, static maps and change detection.*", for readers who don't know what they are.

Product User Guide (PUG)

This document provides information on the products that are currently being developed for the HRLC new Essential Climate Variable (ECV) including a general description of the products, the planned format, naming convention for the product files, delivery methods, the availability of quality flags and plans for an independent validation. Four products are envisaged: a static HRLC map for a specific year (2019), historical HRLC maps every 5 years, historical HRLC change detection maps every year, NDVI/EVI indexes every 4 months. The latter three products will cover the period from 1990 to 2015.

With HRLC being a new ECV, certain aspects of the products are yet to be determined in the current version of the document (for example, it is stated that "*delivery projection and data organisation [...] will be discussed at the time of the first delivery*", or that "*ERS-1, ERS-2, ENVISAT-ASAR will also be considered*", or that "*The change map will be produced on the basis of Landsat acquisitions of 1 year*" - which year?). If updated information is available at this stage into the project, those aspects could be revised.

Additionally, here are some suggestions are for aspects to be expanded in the document.

- It would be useful to add information for the users about the tile schemes, either the Sentinel 2 MGRS tiling scheme or the Landsat Path/Row tiling scheme that will be used by the HRLC products.
- There is no explanation on how the pixel-wise uncertainty will be characterized.
- Some explanation of the field "probability" would be useful as it is not clear what it represents, and also the definition of the six status used to characterize a pixel in the pre-processing phase ("Filled" status?).
- Some products are declared Level 4, another L3P, and another L3, it would be good to clarify it.
- Three products are named "MERGED". It would be useful to explain briefly the reason.
- There is a mention of a delivery of a product, called VRT file, consisting of the merge of all the tiles. It would be useful to have more details about this format and it should be included in the table in section "2.1 Products summary" (the table has no title or number) where currently only the delivery of multiple files is present.
- Regarding the NDVI/EVI index product, the statement that "*there is no confidence information, since it is a simple mathematical product that does not depend on any further process from our side*" does not encourage its use. It would be good to provide more explanation for it.
- Section 8 on User Tool does not introduce the user tool that is mentioned in other documents (a user tool similar to the LC_cci user tool to do re-sampling, re-projections, …). Are there still plans to create one?
- In general, the document will benefit greatly of some re-editing, in particular Section 1 and 2: different typos are present and some sentences do not read well.

Product Validation and Intercomparison Report (PVIR)

This document provides quality and quantitative assessment on Round Robin prototypes of the HRLC new ECV products. It also inter-compares the products with reference data.

We list here some suggestions to improve the document:

- Section 3.1 should briefly explain the validated products.
- Table 2 is not useful without some explanation of all the acronyms used and briefly of the algorithms behind them. The SAR maps are not in the table.
- The visual assessment highlights only issues with the products without providing examples of good performance that are listed in Table 3.
- In the quantitative assessment section suddenly the name "processing chain" is used to identify the different products/algorithms, this might be confusing for the user as it was not used before.
- The two assessment methods (per stratum and unbiased) are not easy to follow, it would be useful to have a clear explanation of what they calculate.
- Given the many plots, the sections on quantitative assessment would benefit from more extensive conclusion sections explaining the findings obtained in the various assessments, also with the use of summary tables.

Recommendations for CCI+ Phase 2

CMUG would like to see engagement extended to more groups of users who would benefit from the impressive high resolution. Most climate modellers will aggregate at a coarser resolution, but there might be more applications/users that can benefit from sub-grid information. Some effort should be made to identify these.

2.7 Ice Sheets – Antarctic and Greenland

The documents reviewed in this section are

- Antarctic Ice Sheets User Requirements document version 1 dated 10/12/2019
- Greenland Ice Sheets User Requirements document version 2.1 15/01/2021
- Antarctic Ice Sheets Product User Guide version 1 dated 03/06/2021
- Greenland Ice Sheets Product User Guide version 1 dated 14/10/2020
- Antarctic Ice Sheets Product Validation and Intercomparison Report version 1.3 dated 04/05/2018
- Greenland Ice Sheets Product Validation and Intercomparison Report version 1 dated 14/10/2018

User Requirement Documents

The URD (User Requirements Document) for the GrIS (Greenland Ice Sheet) and AIS (Antarctic Ice Sheet) appear as comprehensive and useful documents. They are publicly available for download from the ESA-CCI website and contain contact information. The documents have a reference ID and a time of release, indicating that the report history is documented. A list of acronyms and abbreviations is also included.

The documents are a useful addition to the datasets, as they sketch the background, the need and the usefulness of the ECVs that are provided by ESA-CCI. The documents state that feedback is acquired and integrated into the datasets and their guidance documents, which significantly improves the data quality. The summary of the GCOS (Global Climate Observing System) and user requirements hereby enable the user to draw conclusions with respect to the quality assessment of the datasets. Furthermore, future plans are also included, from which the users can derive expected products.

Product User Guides

The PUG (Product User Guide) for the GrIS (Greenland Ice Sheet) and AIS (Antarctic Ice Sheet) appear as mature, user-friendly, extensive and comprehensive documents that are publicly available from the ESA-CCI website. Both reports contain contact information of the authors and project leaders, and also references to scientific publications are included in case the user requires more in-depth information. The documents have a reference ID and a time of release, indicating that the report history is documented. As such, users can make sure that the latest version has been selected. The documents are an added value to the datasets and guide the users towards correct usage and interpretation of the datasets. It must be said, however, that jargon is regularly used, which may not always be understandable for non-expert users. A list of acronyms and abbreviations is included in both documents and aids the comprehensibility of the text.

In the documents, each ECV (Essential Climate Variable) is treated in separate paragraphs. For both the AIS and GrIS these are the surface elevation change, the ice velocity and the gravimetric mass balance. For GrIS, also ice discharge and supraglacial lakes are included, while for AIS, the grounding line location is discussed additionally. All paragraphs include

information about the product data content, the data format, file naming convention, the grid projection, the known limitations and a suggestion for software tools to visualize the data. An additional open software GIS (Geographic Information System) tool, QGIS, may be added as a suggestion, as it allows for easy visualization. It may be useful to add some specific applications for each ECV (e.g. ice discharge calculations from ice velocities, global sea level change contribution from the gravimetric mass balance or surface elevation change, etc.). Below, we furthermore add some suggestions for additional remarks, by using the examples of the 3 different ECVs that are present in both PUGs (ice velocity, surface elevation change and gravimetric mass balances). These can then be integrated in the document for better usage and interpretation of the data.

For the ice velocity ECV, it may be useful to spatially indicate some regions over the ice sheet where relatively lower quality data are generally found. For example, spatially filled data gaps are not flagged in the dataset and hence are not detectable. Furthermore, there is no information given related to the time of the year during which valid pixels for the velocity estimate were acquired. Also, without clipping with an ice mask, non-ice-covered pixels have values that are not NaN. A suggestion for a data-matching ice mask may therefore be useful. Another aspect is that products contain 'stripes' or 'streaks' in slow flow areas due to ionospheric disturbances, which can be seen from visual inspection, and this phenomenon is not mentioned in the document. Next, for AIS, no figure or map is included that shows the velocity data. However, a map of ice sheet-wide AIS velocities is shown on the referred CryoPortal download page (http://cryoportal.enveo.at/), but these data are not available for download (i.e. only data for some individual glaciers are available). In the PUG, also no information is given related to the spatial extent of the AIS IV data.

With respect to the surface elevation change ECV, it can be noted that the variable name of the SEC in the downloaded files is "rate of surface elevation change" with units meter year-1. This choice of words may confuse users in thinking that it is a trend with units meter year-2. The listing of discussed paragraphs is also not always consistent (e.g. for the AIS PUG, no product known limitations are discussed for the SEC ECV).

It may furthermore be useful to state that also other processes than surface melt and accumulation can contribute to surface elevation change, and that SEC does not necessarily equal mass change. From the examples of the metadata that are included in the PUG, it can be deduced that the global attributes and variables in the AIS and GrIS data files are not similar. For example, for AIS, a parameter that quantifies the total number of contributing radar altimeter measurements used to calculate dh/dt is mentioned, while it is absent in the GrIS PUG. This may be useful information for data quality assessment. It may be useful to state that peripheral ice caps and glaciers are not all included in the GrIS file. For AIS, there is no link to download the SEC data is included on the website (https://climate.esa.int/en/projects/ice-sheets-antarctic/data/).

For the gravimetric mass balance ECV, the information with regards to the gravimetric mass balance (GMB) ECV is rather compact in the GrIS PUG. Product known limitations are, for example, not included for this ECV. It may be useful to state, for especially non-expert users, what the definition of the mass balance of an ice sheet is and how users can convert the data to global sea level contributions. From the data, no gridded error and uncertainty characterization can be found.

Product Validation and Intercomparison Reports

As with the PUG, also the PVIR (Product Validation and Intercomparison Reports) for the GrIS (Greenland Ice Sheet) and AIS (Antarctic Ice Sheet) appear as user-friendly documents. They are publicly available for download from the ESA-CCI website. The reports contain contact information and references to scientific publications. The documents have a reference ID and a time of release, indicating that the report history is documented by a change log. Also here, the regular use of expert terminology is noted, which may affect the comprehensibility of the text for non-experts. Although a list of acronyms and abbreviations is also included. It can be said that the documents are an added value to the datasets, as a comprehensive description of validation procedures significantly improves the data quality. As before, each ECV (Essential Climate Variable) is treated separately in the documents, including information about sources of independent validation data (including references), the validation procedure, the validation outcome and recommendations for product improvement.

With respect to velocity, the product is evaluated against multiple publicly available products covering the same area. The overall conclusion shows good results, as the statistics of validation outcome exhibit good agreement between ESA-CCI data and external independent datasets. The discussion of the results is, however, rather compact. In the AIS PVIR, some text is furthermore still shown in red, which gives the document a rather incomplete impression.

For the surface elevation change data, a possible suggestion may be broadening the spatial and temporal extent of the validation procedure and to elaborate more on how the different surface characteristics, data acquisition methods and data processing methods may influence the interpretation and outcome of the validation procedure. As of now, data seem to be validated only to airborne laser altimetry data, which implies low spatial coverage. The discussion and interpretation of the results is also rather compact. Differences between ESA-CCI radar altimetry and other independent datasets may, for example, be allocated to the pronunciation of the slope-related error, differences in subsurface penetration of the signal, and/or the modeling and processing/editing component. Furthermore, differences related to spatial/temporal coverage and sensitivity to weather conditions play a role in explaining the remainder of the observed variance.

Finally, in the section on issues of validation of GMB some text is shown in red, which gives the document a rather incomplete impression.

2.8 Lakes

The documents reviewed for the Lakes_cci project are:

- User Requirement Document (URD) version 1.1 dated 5 September 2019
- the Product Specification Document (PSD) version 1.2 dated 15 May 2020
- the Product User Guide (PUG) version 1.1 dated May 2020
- the Product Validation Plan (PVP) version 1.2 dated 24 April 2020

Some feedback on data quality is also supplied.

User Requirement Document (URD)

The user requirements are well covered by this document. The survey carried out was comprehensive and minimum and target standards were identified which is useful.

One issue which was not addressed is the requirements for data quality, specifically for missing data and data gaps. These can make the data unusable if they are not addressed. Users require high frequency lake data without gaps and a preliminary assessment of what is currently available does not match this criterion. The GCOS climate monitoring principles are listed including regular assessment of data quality, and CMUG wonders if this is being carried out? Given the data gaps that currently exist in the product, there is a need for a tool to fill these in some useful way (see section on data quality below).

Product Specification Document (PSD)

While it is useful to keep the information at the highest granularity of information available there are cases (lake surface temperature) where the data are actually 5 km resolution but have been put on a 1/120 degree grid so that they matched with other products. This unnecessarily bloats the data size and can make it difficult to deal with, particularly when the user is not interested in most of the variables available. It would be useful for variables to be available on their native grid as well as the standard 1/120 degree grid.

Data size is a big issue, the total Lake_cci data set is near 2 Tb in size, it would be much easier to handle if there was an option to download variables individually as well as the full set.

One final point, the table in Section 6.3 in the PSD specifies a valid minimum temperature of -200 K. CMUG suggests that unphysical thresholds should be avoided.

Product User Guide (PUG)

The PUG is useful and clear. Table 1 captures our requirements (basic ones are daily frequency and 10 year length), but it doesn't capture the real life incompleteness (sometimes sparsity) of these datasets, which is an issue for application to climate modelling.

Section 3.3.1 on lake ice cover (LIC) includes a CMUG relevant application in point 4) of the user application list, however, it would probably be useful to include numerical weather prediction studies as a separate item here. NWP could reasonably be done with these datasets as well as climate modelling evaluation studies. For this there will be the same issue with data gaps raised above and from our contribution to this WP, i.e. the need for a spatial and temporal complete dataset at daily frequency (and for at least 10 years), in order to produce reasonable climatological estimates even from a Regional Climate Model (RCM) driven by reanalysis.

LSWT, section 3.4: potential use in NWP and climate modelling is not mentioned, and LSWT is even more relevant to these applications than is LIC.

Product Validation Plan (PVP)

This document is clearly laid out and easy to read. The plan of validation through comparison of the products with in situ data and other products, for case studies based on field work and for combined verification to look at consistency between variables is sound. The sections on constraints of the validation are welcome, although it could perhaps be made clearer how some of the issues described might be addressed.

The statement "*when the climate data records are released for external use, project scientists will be collecting feedback from data users and improving the data production chains accordingly*." is good in theory, and CMUG would encourage pursuing this process fully. We would be interested in being part of the round robin process outlined in Sections 5 and 6.

At a recent Climate Science Working Group (CSWG) meeting it was noted NWP models using data assimilation can supply information useful for gap filling, and such a dataset would also be useful for evaluation. Currently no European Meteorological services assimilate lake data, but as work progresses using the FLake model some data may become available in the near future and making early use of this might be of benefit to Lakes_cci.

An acronyms list would be a useful addition.

Some specific queries and comments are recorded below:

- In section 2.4 both validation method 1 and method 2 rely on in situ data with the limitations described in detail. The statement "*validation only allows providing general overview of errors budget (for in site Calibration / Validation experiment) and comparisons against in situ data give another overview*" seems contradictory as all validation described uses in situ data and it is not clear what the "regular external validations" mentioned are. This section could be made clearer.
- Section 3.1: references for the hypsometric method could be given
- Section 3.2: S1 and S2 are not defined
- Figure 3 needs map reference (lat/lon on axes) and text should be larger
- Figure 7: "Locations of 113 in 43 lakes" → "Locations of 113 observations in 43 lakes"

- Section 4.1: Unfortunate that all observations are in the northern hemisphere
- Section 4.4: "The principal constraint is that the number of remotely-sensible lakes with in situ data, which is limited." → "The principal constraint is the number of remotely-sensible lakes with in situ data, which is limited." Or "The principal constraint is that the number of remotely-sensible lakes with in situ data is limited."
- Section 5.4: It seems unlikely that there are no constraints to the validation of the 250 m LIC product?

Data Quality

CMUG WP3.7 is now underway. The goal was to use Lake Surface Temperature and Lake Ice products as ancillaries to a Regional Atmosphere only Climate model (RCM) in order to assess the impact of accurate lake information on the RCM's ability to represent Land Surface Temperature (using the LST ECV observations for comparison.)

However, the patchy nature of satellite data will make this impossible without a significant amount of post processing and interpolation. The RCM relies on coherent spatial data in time and space with no missing data present. WP3.7 plan to run an RCM over Europe, and during some months, an average grid box only contains 3 days of non-missing data per month. CMUG are instead considering the use of the ARC3 dataset for an RCM experiment to test the effect of prescribed lake temperature on existing temperature biases over Europe. The ARC3 dataset is based on a physical reconstruction of lake data from satellite observations which requires specific scientific expertise for its completion, and which should be considered in projects aimed at producing data for general use, and a successful result from the RCM experiment would support this requirement.

In order for the Lakes_cci data to be of most use to the climate community, reconstruction applying techniques similar to those applied to the ARC3 lake data set would make the data much more useful. Ideally, the reconstruction would go further than the ARC3 dataset and produce a daily spatially gridded data sets.

At the moment the amount of processing and observational expertise needed to use the Lakes_cci datasets is a barrier to their use in the climate community, particularly for modelling. It would be our strong recommendation that observation scientists be given the resource to develop a reconstruction of Lake Ice and Lake Surface Water Temperature.

2.9 Land cover

Version 1.0 of the User Requirement document, dated 16 September 2019, version 1.3 of the Product User Guide and Specification (PUGS), dated 31 August 2020 were reviewed. Feedback on the quality and maturity of the data product was also supplied

User Requirement Document (URD Version 1.0 from September 2019)

A general re-editing/polishing of the document would be useful to make it clearer and avoid any misinterpretation: some paragraphs are hard to follow; some datasets, initiatives, models are mentioned without a reference or link. A detail: the link http://cci.esa.int/content/tablet-app provided in the document is not working.

There is ambiguity about the need for a high-resolution product from the climate community: the document states that "*climate-modelling groups currently aggregate the CCI LC data to coarse resolutions. As such, they find that the current spatial resolution of 300m is a good balance between global coverage and detail*." It should be clarified if the community needs/uses a 300m resolution or only an aggregation to a coarser resolution.

The URD has a section on the “User Tool”. It is not clear if the tool referred to is the CDF application. It is stated that "*The vast majority of users have not used the user tool (64%). Some users were not aware that it existed, or didn’t have need of it. There appear to be some difficulties in installing the tool, or understanding how to use it*." CMUG would be keen to promote the tool to the research community, but more information is required e.g. links to the location of the tool.

A "tutorial to explain the use" of the user tool would useful in some form (it could be a video or a simple document)

Product User Guide and Specification (PUGS version 1.3 from 31 August 2020)

This document provides information on the C3S LC Intermediate Climate Data Record for 2016-2019, a continuation of the LC_cci maps for 1992-2015. Consistency is maintained between the two data sets consisting of global, yearly LC maps at 300m spatial resolution. The document explains the specifications of the products (format, filenames, metadata, content) and how to access them. The document is very clear and a useful reference for users.

We have some suggestions for some aspects that could be improved. A complete validation is not yet presented in this version of the document, it would be useful to know what the plans are for this and where the results will be reported. There is no observational uncertainty characterization associated with the maps, some users may be interested in this. There is no mention in Section 2.1 of the “User Tool” that prepares data for model computation doing conversions, aggregations, subsets and which is available through the LC_cci visualization interface. It would be useful to know if this is still maintained and further developed. Minor comments for Table 5: a green tick should maybe be used for the target requirements in Phase II for the geographic coverage; the meaning of black diamonds is not explained.

Quality

The visual quality assessment of the LC_cci global SR-7day composites performed using SR composites from various satellite data sources (AVHRR, PROBA-V, MERIS FR and RR) show that the overall quality of the SR composite from FR and RR and PROBA-V data is very good and from AVHRR, is sufficient. 4 different issues were identified:

- Issue 1: missing lakes and island
- Issue 2: NoData (NaN value) in the desert over bright areas
- Issue 3: Cloud/snow ice discrimination
- Issue 4: Undetected semi-transparent clouds and clouds

The issues identified do not constitute a critical road block on the path forward, but should be addressed as time allows.

CCI Global Land Cover map V2

The Land Cover map results from a processing chain which uses the MERIS Full Resolution (FR) and Reduced Resolution (RR) multispectral SR 7-day composites as inputs. The map is a Level 4 product according to the CEOS definition. More specifically, the MERIS RR and SPOT-VGT data were used when needed to compensate for the lack of MERIS FR acquisitions.

CCI Global Land Cover Map V2						
Parameters	Sensors	Spatial coverage	Spatial grid	Temporal coverage	Temporal resolution	Total data volume
Land cover	MERIS SPOT-VGT	Global	300m*300m	1992-2015	annual	~350MB

- The quality of the map varies according to the region of interest. Areas with a lower MERIS FR coverage are:
  - Western Amazon basin
  - Chile and southern part of Argentina
  - Western part of the Congo basin
  - Gulf of Guinea
  - Eastern part of Russia
  - Eastern coast of China and Indonesia
- Not all possible changes between the 22 Land Cover classes are captured in the dataset because more emphasis was put on capturing carbon cycle changes. For instance:
  - Conversions between rainfed and irrigated agriculture
  - Conversions between forest classes e.g. broadleaved to mixed.
  - Conversion between sparse vegetation and lichens and mosses
  - Conversion between ‘pure’ class to a mosaic class (e.g. forest degradation characterised by the evolution of a pure forest to a mosaic of natural vegetation).
- Although LC_cci maps are available at 300 m spatial resolution, change detection and therefore land cover changes can only occur at 1 km spatial resolution.

- Changes along the coastlines and of permanent snow and ice class are not included in the LC_cci products.
- Changes occurring in the 2014-2015 period are limited to forest changes (as the methodology needs confirmation of the land cover over the last 2 years).
- Change detection performance is dependent on the input data quality and availability. The generally lower quality of AVHRR SR and georeferencing implies less reliable change detection.
- Occurrences of misclassification of the larger land cover classes exist. Similarly water is sometimes misclassified as another LC class.
- Also, certain small islands appeared to have been classified as water.

CMUG recommends that these issues are prioritised based on user needs and addressed as resource allows.

Suggestions for future development

Future opportunities for exploiting land cover change maps (also applicable to HRLC) could include:

1. **Easy transferability with other LCCS** such as IPCC, Corine, the International Union for Conservation of Nature (IUCN), the US Geological Survey's (USGS) National Land Cover Database (NLCD), International Geosphere-Biosphere Programme (IGBP) and MODIS. This would help a lot to update LC information in models with the use of the ESA product.
2. **Improving coarse resolution climate simulations**. High resolution land cover could inform improvements in understanding PFT fractions within the more detailed land cover classes found in LC_cci Phase 2 300 m products e.g. information about forest degradation (affecting carbon storage), roughness of vegetation canopy (affecting heat and moisture exchange in the atmosphere), and links between topography, land cover and soil (which may affect hydrological models).
3. **Climate impact and mitigation studies.** It is possible to use the output from higher resolution climate models to drive land surface model studies designed to investigate the impact of different land use management strategies on regional carbon budgets. For instance, studies like this could be done at < 5 km for a large continental domain such as Africa for a period of decades. Some recent studies have highlighted the importance of vegetation productivity in tropical grasslands (related to interannual rainfall) as a key driver for interannual changes in atmospheric carbon dioxide.
4. **High resolution weather and climate modelling.** In addition to improving the understanding of PFT fractions, developing a better understanding of physical properties of the land surface such as canopy height, surface roughness and urban morphology. Urban morphology will be covered in the next round of Medium Resolution Land Cover. The availability of other satellite observations such as albedo, FaPAR, fire, and surface soil moisture would also allow better analyses of bias in models. Consistency between land surface parameters input to models is also important e.g. canopy height, LAI, land cover and albedo. Future planned development of weather and climate models on icosahedral grids will allow models to be run efficiently at very high resolutions. This further implies a significant need for high resolution land cover in the weather and climate community.

5. **Locations.** Results from a 2-year uncertainty study have highlighted several locations which could be treated as priority areas for understanding Earth system/climate processes and climate/weather effects:
   a. Europe & North America: Cross-walking uncertainty in bare soil in the agricultural belt (extending into Russia).
   b. SE Asia: Urban mapping (morphology of buildings), tree PFT fraction especially in Southern China. Important for simulating high impact weather impacts on populations
   c. Africa: Shrub vs grass cover in tropical savannahs, to understand LC class uncertainty.
   d. South America: Tropical savannahs are important for carbon fluxes because tropical grasses are very productive and they are very responsive to inter-annual variability in climate.
   e. Northern high latitudes: tree PFT vs bare soil uncertainty seems to contribute most to albedo uncertainty. This may be linked to thermokarst lakes, the northern extent of the tree line, or LC mapping of wetlands.

2.10 Land Surface Temperature (LST)

The documents reviewed for the LST_cci project are:

- User Requirements Document (URD) version 1.1 dated 21 February 2019
- Product Specification Document (PSD) version 1.11 dated 17 June 2020
- Product Validation and Intercomparison Report (PVIR) version 1.2 dated 23 September 2020
- Product User Guide (PUG) version 1.2 dated 22 October 2020

The standard of the LST_cci documentation is very variable, while the format and length of the PUG and PVIR are good, the PSD and URD, however, are disappointing, they are very long (160 pp each) and difficult to read (full of tables). It seems that the authors put all the material they had into these documents without thinking of their readability. The LST team should try to produce more concise new versions following the example of the Permafrost team.

User Requirement Document (URD)

This document provides a detailed insight to the process used to create the LST_cci product specification. A substantial amount of raw data are provided from the requirements gathering process. These data coming from a wide range of user cases means that the LST_cci can be created to be appropriate many applications. The full set of raw data exposes the user to ideas and concepts (given as requirements) that may be new to them. This also means that all users can fully understand why the product has certain specifications. Evidence for this is also given by the treatment of the GlobTemperature product in this document. An understanding of how the process used to generate the similar user requirements for GlobTemperature show how lessons have been learnt and how LST_cci can be produced to give users a noticeable improvement of the existing product.

This thorough treatment of the data allows users to consider new ideas and ways to understand the LST_cci data which has the potential to further improve their scientific work. However, the full set of information could be presented in a more accessible format. A full summary early in the document would allow the reader to decide what raw data is useful for their work without having to search for it or read large sections of the document that might not be appropriate.

The URD states that a validation and user assessment will be carried out independently to data production to ensure that the products meet the requirements of the climate community. No details are specified yet on how such validation will be done. CMUG recommends inclusion of this information (e.g. signposting to relevant documents) within the URD.

Product Specification Document (PSD)

The PSD provides a comprehensive guide to the file formats, metadata and variables contained in the LST_cci files, it specifies LST uncertainty estimates, including information for different uncertainty components on a grid-point level and the total uncertainty derived

from the uncertainty components, which will both be in all LST_cci products. This addresses the user requirements from the URD. Such information is needed to fully exploit the data and create systems that use the data files. The full account of the underlying data in each file (based on platform and processing level) is good because it allows an individual to select the most appropriate subset of the data. This information is complete and presented clearly. Differing levels of processing are clearly split and the user can see how the file attributes, metadata and underpinning raw data vary across such different versions of the product.

The PSD further provides an elaborated overview on the uncertainty components of the retrieval, covering random uncertainty, locally correlated atmospheric uncertainty, locally correlated surface uncertainty, systematic uncertainty, and total uncertainty. It specifically accounts for the important differences in the terms uncertainty, error, accuracy and precision. The aim is to provide the uncertainty information with a clear documentation including descriptions of how to use the data and worked examples. The presented uncertainty characterisation is sophisticated and goes far beyond what other products provide. The URD further summarizes the results collected on the uncertainty information requirements of the users, the current use, and barriers of using uncertainty data. These findings are reflected in the PSD.

The exemplary uncertainty characterisation provides a solid basis for the missing CECR, UCR and UB. Missing information e.g., includes the measures of how the uncertainty should be quantified (standard deviation, root-mean square error, confidence intervals?).

The details of the user requirements and how LST_cci improves on existing products could be moved to a separate document or referred to in the User Requirements Document. This would make the information required to use the product easier to locate in the PSD.

Product User Guide (PUG)

This document begins with a quick start guide to the LST data products. This is a welcome addition so that the user can immediately see what variables and from what sensors data are available and have a short outline to the file format. This helpful format continues through the rest of the documents, with section 3 “How do I use the ESA LST cci data?” chapter being clearly presented and laid out. The use of questions as headings means the user can quickly find and relate to the explanations and information given.

The use of a FAQ style for a makes it simple to find most things the user needs to understand before using the product. There will be some information that is difficult to find as a result but this will be limited to more advanced questions in which the user will be probably be best directly contacting the LST_cci team directly anyway; so this keeps this PUG in a user friendly format.

It is a welcome addition that file headers and contents examples are given in appendices to the document. This gives the user a clear guide to whether they are correctly loading the data and obtaining the correct product. Information and examples on how to use the uncertainty information in the product is missing from the document. That is not necessary a bad thing because the theory and mathematics behind that can get quite involved but references to the documents where this information is recorded is recommended.

Product Validation and Intercomparison Report (PVIR)

This document provides a comprehensive review of the techniques and results from the validation preformed on the LST_cci dataset. Two methods of validation are presented, one using ground station data, the second comparing to existing satellite products. This is useful methodology for the CCI data user because it gives both a measure of the accuracy of the product and allows the user to have confidence in using CCI products over existing products.

For the first method, each ground site is individually presented. The plots for these results are clear and the user can very quickly get an understanding of the performance of each platform in the CCI product across different biomes and climate regions. The report explains how some features plotted arises, from cloud cover issues, vegetation etc… and these can then be investigated by the user if they need to,

The second comparison allows the CCI product to be compared over wide areas at the continental length scale. This is an important result because of the lack of ground weather stations and research sites in some parts of the world, and to show how spatial consistency across the product set. Again the results are clearly presented by the given plots. The text and accompanying tables provide the full details.

The conclusion is the dataset performs well in both tests. The report points to differing performance from different platforms depending on the biome/region the validation is being performed. This is good information to highlight because the user can choose to use LST_cci data from differing platforms depending on their region of interest.

2.11 Ocean Colour (OC)

The documents reviewed for the OC_cci are:

- User Requirements Document (URD) version 1 dated 31 July 2019
- the Product Validation and Algorithm Selection Report (PVASR)[6] version 3.0 dated 23 December 2015 (Pt1) and 15 January 2016 (Pt2)
- the Climate Assessment Report (CAR) version 3.0 dated 29 June 2017
- the Product User Guide (PUG) version 1.0 dated 12 October 2020

User Requirements Document (URD)

The Phase 3 OC_cci URD consists of a draft paper prepared for submission to Nature Scientific Reports, followed by the contents of the Phase 2 URD. The Nature Scientific Reports paper summarises the Phase 1 and Phase 2 user surveys, and so no extra substantive information appears to have been added compared with the Phase 2 URD. The CMUG review of the Phase 3 URD will therefore be kept brief, as the Phase 1[3] and Phase 2[4] URDs have been previously reviewed.

The user surveys conducted by the OC_cci team have been comprehensive, and the discussion in the URD draws out many major points, discusses apparent contradictions, and puts them in context. As well as surveys conducted by OC_cci, both CMUG requirements and those from other projects are drawn on and discussed. This results in a comprehensive piece of work. The format of the Phase 3 URD is perhaps a little unusual, and adds little to the Phase 2 URD, but all the necessary information is present, and the draft Nature Scientific Reports paper provides an accessible and readable overview, with more detailed information provided later on in the report.

One thing that stands out as meriting further discussion is the quote "*Within the free field for this question, there were significant requests for providing primary production and Photosynthetically Active Radiation (PAR) with other requests for inorganic or calcite concentrations and particulate organic carbon. Additional parameters comparable with historical optical measurements were requested, such as Secchi disk depths and the Forel-Ule scale, alongside zooplankton estimates.*" Primary production in particular is widely used by climate modellers, and particulate organic carbon is increasingly used, but these requirements are not currently addressed by OC_cci. That's not to say they necessarily need to be, given the derived nature and large uncertainties of such products, but the issue is an important one which merits further discussion. It is likely that climate modellers will continue to use primary production and other derived products, but go elsewhere to find them.

[3] http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D2.3_TechReportonProducts_v0.6.pdf
[4] http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D2.3_Product_Assessment_v3.1.pdf

Product Validation and Algorithm Selection Report (PVASR)[5]

In the outlook of the v1 Product Validation and Algorithm Selection Report it is stated "*The auxiliary meteorology data should be harmonised. For SeaDAS processing SeaWiFS, MODIS and MERIS data NCEP is applied and but MEGS, POLYMER, Forward NN uses the ECMWF data in the MERIS product".* What should have been made clear, is that the ERA-Interim fields MUST be used for the atmospheric water vapour correction in phase 2 of the CCI for all ocean colour products. This will avoid sudden discontinuities seen in the water vapour field of the operational ECMWF fields. CMUG made this point strongly at the beginning of the CCI project. According to the v2 report it appears that the choice was made to use NCEP instead, which at least is consistent, and the v3 and v4 reports do not appear to state what was used.

- While validation of the products is a continuous process, there are still concerns with regards to the under-sampling of the in-situ datasets particularly in the low and high productive (chlorophyll-a concentration) regions.

The OC_cci team's proposition for periodic comparisons of algorithms when there is a significant change to either in-situ observations or retrieval methods, followed by mission re-processing, is commendable (Ref: URD). However, there should also be a system (perhaps to be considered by ESA) to archive the previous version(s) with corresponding training and validation dataset to maintain backward compatibility and traceability.

Climate Assessment Report (CAR)

The range of applications for the OC_cci data is further expanded in v3 of the CAR, providing a comprehensive overview of the products, their accuracy, and examples of how they can be utilised for climate research. As well as a variety of improvements to the processing chain, and adding VIIRS data when available, two important user requirements are addressed for the first time in the v3 products. Firstly, the products are updated in delayed mode, so are available (at the time the v3 CAR was written, this has since been overtaken by NASA processing changes and the v4 product release) within a month of real time. The CAR rightly notes that the same quality as the initial time series cannot be guaranteed, but with this caveat, having a fully consistent set of products being continually updated should be of great use to a number of users. As long as there continues to be regular reprocessing of the entire time series, based on ongoing new research, CMUG very much encourage this approach.

Secondly, the v3 products begin to merge algorithms for Case 1 and Case 2 waters, in order to create a global product applicable for all water types. This is a major user requirement, which is not addressed by other ocean colour products, and requires substantial new research. The CAR notes that this has "*been addressed to some extent in Phase 2 of OC_cci, but requires sustained additional effort*." CMUG welcome a product release that begins to address this, but echo that sufficient resources need to be put in to addressing what is a novel and demanding, but extremely important requirement.

[5] These PVASR documents were reviewed by the previous CMUG management team, the documents referenced are not available to the current reviewer, but they are later versions than those currently linked from the CCI Ocean colour web pages, so the comments are left in as they may be relevant

Despite the v1 and v2 OC_cci products being specifically developed for Case 1 waters, the data assimilation sections mostly focus on Case 2 water studies using the v2 products. This is an important gap in the analysis. On the other hand, it is encouraging to see the utilisation of the error characteristics of OC_cci data in data assimilation studies. Furthermore, even in Case 2 waters their use appears to be of benefit for reanalyses. For the v3 dataset, which promises greater accuracy for Case 2 waters, it would be interesting to see how their accuracy compares with v2, but this has not been detailed for data assimilation in the v3 CAR.

The OC_cci dataset includes two GCOS variables: chlorophyll-a concentration and water-leaving radiances. The GCOS requirements for these two variables, as stated in the update to the satellite supplement to the GCOS Implementation Report (GCOS, 2016), is for an accuracy of 30% for chlorophyll-a concentration and of 5% for water-leaving radiances. In terms of stability, GCOS set their requirements as 3% for chlorophyll-a concentration and 0.5% for water-leaving radiances. The validation of these two OC_cci v1.0 data products, against *in situ* observations, concluded that the GCOS requirement is met for most of the range in chlorophyll concentrations (except for concentrations lower than 0.1 mg $Chl.m^{-3}$) and for most water leaving radiances (with best results for the shortest wavelength of 412 nm), but slightly missing the GCOS target at longer wavelengths, as the frequency of higher relative errors increases with increasing wavelengths. These conclusions remain true for the v2 and v3 products. It appears that GCOS requirements are now being met for the full range of chlorophyll concentrations, although this does not seem to be explicitly stated. The subtropical gyres, where chlorophyll concentration is typically very low, and the highly productive coastal waters, where chlorophyll tends to be very high, are the geographical regions that exhibit the largest relative errors.

Whilst not GCOS variables, there is a growing user requirement for products such as phytoplankton functional types (PFTs). It is encouraging to see the OC_cci team considering this issue, and presenting an initial demonstration of such an application. These and other novel products required by users should remain a focus.

In the first sentence of section 3.1 of the CAR, it states that SeaWiFS and MODIS are from ESA and that MERIS is from NASA: these affiliations should be reversed. This was noted in the review of v2, and remains uncorrected in v3. The v3 CAR ends by stating that "*A major concern remains the stewardship and curation of the OC_cci products once the present phase of the CCI product comes to an end.*" CMUG echo the sentiments that further sustained research is still required in order to fully address user needs, particularly in relation to accuracy in Case 2 waters. The OC_cci products to date have come a long way towards doing this, but much ground-breaking work still needs to be done before the potential contribution of ocean colour to climate studies is fully realised.

Product User Guide (PUG)

The OC PUG is a helpful document with an appropriate level of detail and provides a good introduction to the products for users. It is a mature document and has evolved well from earlier versions previously reviewed by CMUG. This current review therefore focusses on a few additions and clarifications which might be useful.

Arguably, sections 5 and 6 on the scientific and technical overview of the products would sit more intuitively earlier in the document, perhaps between the current sections 1 and 2. The current structure is also valid though, so this is merely being raised as a thought to consider.

The discussion of uncertainties and detailed instructions on how to use and interpret them are very useful, and necessary for users. Worth adding though is advice on when to unbias the data, and when to use the data values as provided. This is not currently clear and may mean some users are not using the data in the most appropriate way.

Also lacking is any mention of what depth the ocean colour data represent, and to what extent it is appropriate to treat them as purely surface values. This is not straightforward, so definitive guidance is not expected, but some mention and signposting to the literature would be helpful.

The overview of previous versions in section 9 is useful, but omits to mention that v4.2 corrects an issue in the chlorophyll product as well as kd. It would be worthwhile making clearer the differences between v4.0, v4.1, and v4.2.

Figure 6 shows the bias in v5.0 to be near-zero, in contrast to v4.2. The text just reads “The magnitude of the bias has been across most of the global oceans” – presumably the word “reduced” should be added – but it would be interesting to know the reason for this improvement.

Finally, some minor comments:

- Some acronyms, such as QAA and AD4, are used without explanation – a table of acronyms might help.
- The “Where can I get detailed information?” subsection of section 1 references the old-style CCI website.
- The Python code in section 3 should be updated from “print nc.variables[“chlor_a“][:].mean()” to “print nc.variables[“chlor_a“][0,:].mean()” to reflect the time dimension added from v2 onwards.
- The caption to figure 8 states “monthly and 8-day composites” were used, but the figure only appears to use 8-day composites.
- In the “Specific elements of the sinusoidal product” subsection on page 38/39, the alignment of variables in the example NetCDF header could be improved.

2.12 Ozone

The User Requirements Document (URD) version 3.1 dated 01 September 2020, the Comprehensive Error Characterization Report (CECR) version 2 dated 22 December 2016 and the Product Validation Plan (PVP) version 2.1 dated 06 December 2020 are reviewed.

User Requirement Document (URD)

This is a very mature document which reflects the fact that ozone is an "old" ECV and has been considered carefully by the scientific community for climate monitoring and reanalysis/ analysis applications. The authors offer a very detailed overview of the requirements, including comparisons with models. This part could be complemented and expanded with recent reanalysis from CAMS and C3S.

The authors also point out that vertically resolved information (ozone profiles) on longer time scales (decades) is rare and global coverage is weak, particularly in the Southern Hemisphere. This could be addressed in future satellite missions.

Finally they mention that no specific requirements for Level-1 data are set because users are interested in Level-2 and Level-3. While this may be true for climate applications, assimilation users may start using Level-1 data in the future. For the next update of the URD CMUG would recommend also including requirements for Level-1 data.

Comprehensive Error Characterization Report (CECR)

The CECR includes a new section discussing error characterization of the OMPS-LP USask 2D retrieval process, which only accounts for the random error component. Although the smoothing error is not included in the reported error estimate, they included representative averaging kernels in the product as diagnostic quantities, this should be explicitly described in the CECR

Please note that the ECMWF web-site is www.ecmwf.int and not www.ecmwf.eu as written in page 25. In addition, the final sentence of page 31 misses the subject, which I assume refers to the table that follows.

Product Validation Plan (PVP)

This is an excellent and complete document. CMUG would recommend close collaboration with WMO bodies which oversee the ground-based ozone measurement network (GAW) in matters related to requirements. It is also important that ESA CCI groups are involved in WMO panels (for the example the Scientific Advisory Group on Reactive Gases).

2.13 Permafrost

The User Requirement Document (URD) version 1.1 dated 12/02/2019, the Product Specification Document (PSD) version 2.0 dated 30/11/2019, the Product User Guide (PUG) version 2.2 dated March 2021 and the Product Validation and Intercomparison Report (PVIR) version 2.1 dated 14 January 2021 are reviewed here.

User Requirement Document (URD)

The user community is briefly described and a synthesis of past user requirement surveys is presented (e.g. OSCAR, GCOS, GlobPermafrost) together with a new original survey performed by the project. The latter is presented in detail, but the raw data should be included in an Appendix.

User requirements are also briefly described in the ATBD. Reading the ATBD is needed to fully understand the URD because the methods used have limitations that limit the feasibility of user requirements. These limitations are clearly described in the ATBD.

Product Specification Document (PSD)

This document contains a useful glossary giving the definition of 23 terms (e.g. talik) used to describe permafrost conditions. Data used for validation are also listed, which is essential information. Product specifications (temporal and spatial resolution, accuracy, etc.) and format are described. This is a concise and clear document.

Key atmospheric variables such as air temperature, wind speed, and precipitation are used. They are derived from the ERA5 atmospheric reanalysis. Wind speed is corrected for surface roughness and altitude. A simple spin-up procedure is applied and should be improved in the future. Since the considered ground layer is quite thick (100 m), a long spin-up of several decades (or even centuries) is probably needed. This should be clarified.

Product User Guide (PUG)

The permafrost Product User Guide (PUG) document issued in March 2021 describes the general properties of the products (e.g. file format) and defines the permafrost variables that are produced: ground temperature, active layer thickness, and permafrost extent. This is a clear and concise document.

A short chapter lists known limitations of the products. Each variable is illustrated by a map but no time series is shown. This would be helpful and should be considered for future versions of this document. The novelty with respect to previous versions is a more complete description of known issues, which is welcomed by CMUG.

Figure 1 presents a map of the mean annual ground temperature (MAGT) at 1 m depth in 2005. This may lead users to think that MAGT at 1 m is to be considered in priority for some

reason. Is MAGT at 1 m depth really representative of permafrost or should values at deeper soil layers be considered?

More generally, examples of potential applications based on the use of each sub-product could be indicated: since this product is quite new, this would be useful to users not familiar with such variables. For all sub-products, an indication of the statistical distribution of values (e.g. percentiles, or at least min, max, mean and standard deviation) would be useful to complete the figures.

Multi-year time series (1997-2018) could be shown for all variables at one location representative of the permafrost area. In the "known limitations" section, "ground stratigraphies" and "Yedoma" should be defined because all users may not understand these terms.

It is mentioned that the quality of the product is reduced over the Siberian Yedoma permafrost type. Users could be interested in an updated version of the Siberian Yedoma since this permafrost type is particularly vulnerable to climate warming (https://doi.org/10.1016/j.earscirev.2017.07.007). Is this planned?

Product Validation and Intercomparison Report

The permafrost product validation and intercomparison report (PVIR) is an extensive document of 81 pages. A more concise document would be more convenient.

The permafrost variables are defined, together with the independent observations and metrics used to produce validation scores. Two versions of the products corresponding to two projection systems (POL and SIN) are considered. This is surprising because in the PUG, only the POL projection system is described. Why complicate the PVIR with unnecessary material about the SIN products? Focusing on the POL products would clarify the PVIR document. The authors may only show the final result corresponding to the product available to the users. If there is any good reason to show results for the SIN products, it should be explained.

Figure 3.13: it seems that the content of the Figure is different from the caption.

Tables 3.12 and 3.14: units should be consistent (replace cm by m).

Figure 3.14: why is g-score that bad at 0 and 2 m for year 2017?

Overall, this document contains a lot of information. Both executive summary and summary sections are quite long but do not provide the key messages the users need in order to decide whether they can use these products or not.

2.14 Sea Ice

The User Requirements Document (URD) version 2.0 dated 20 March 2020 is reviewed first and the documents for Sea Ice Thickness and Concentration are then reviewed in separate sections. For Sea Ice Thickness (SIT) the Product Validation & Intercomparison Report (PVIR) version 1.1 dated 23 July 2018 and the Product User Guide (PUG) version 1 dated 10 February 2017 are reviewed and for Sea Ice Concentration (SIC) the PVIR version 1.1 dated 23 July 2018 and the PUG version 1.1 dated 20 September 2017 were reviewed.

As part of the Sea Ice (SI) CCI, climate data record of both SIT and SIC have been developed. The former record is only available for the Northern hemisphere during winter, while the latter is available for both hemispheres all year round. Both records have a relatively large number of sources for observational uncertainty that are very coherently addressed.

User Requirements Document (URD)

The CCI+ Sea Ice User Requirements Documents (URD) (Reference: D1.1, Issue: 2.0 from March 20 2020) synthesizes user requirements from previous reports, a survey among users who have experience with previous SI ECV products and detailed discussions with individual researchers. This multi-level approach avoids unnecessary repetitions of broad user surveys and allows insight into user needs at a high level of detail. The assessment of user needs is comprehensively discussed with regard to feasibility (from the product development teams) and bigger picture (from the climate user group). In addition the report identifies two primary types of users (expert and non-expert users) which further helps to take their needs into account. For example: this separation allows the authors to identify the need for a more general, easy to understand and prominently posted note on the uncertainties of L4 sea-ice thickness product, while at the same time less processed data would benefit more for comprehensive quantitative uncertainty estimates, distributed with the data.

The format of the presented document seems well suited to prepare the product specifications. The following comments could be considered for future versions of this (kind of) report.

Section 3 would be easier to follow if you would introduce the format (Requirements, Response by CCI Team, Conclusions by Climate User Group) and authors thereof more clearly in the beginning of Section 3 (in addition to the 'Scope' section)

The discussion of the use of radar freeboard for model applications in Section 3.1 is interesting. To my knowledge the transformation of model results to a radar freeboard is non-trivial since factors like radar snow-penetration depth, local ice/snow thickness distributions and radar re-tracker characteristics can play a role. The SIT product development team has much more expertise with these processes than most users will have, who would therefore benefit largely from any guidance. Would it be possible (though probably not as part of this project) to develop a radar freeboard observations operator? It would attempt to estimate the corresponding radar freeboard for a set of model variables like ice and snow thicknesses and snow temperature/liquid water content and probably other parameters which have a significant impact on the measurements. This operator could then be used by modelers to

calculate radar freeboard based on model parameters in preparation for a comparison with the measured radar freeboard. Even a simple regression and discussion of limitation would be of value for users of the radar freeboard data.

Considering the different needs of expert and non-expert users, it would be useful to provide a full user product handbook and a short/simple version for non-expert users. Maybe even boiling it down to a one-page fact-sheet.

Did any of your discussions identify a need for a specific set of in-situ observations which should not be used as reference for the product development to remain independent? Or is the first priority to improve the data quality, utilizing all available data?

Discussions like those building the basis for Section 3, often do not follow a format which can easily be presented like more general questionnaires. However, any additional information would help the reader to understand the basis of the conclusions and allow for more transparency. This could include a list of questions/topics participants were asked, the number of participants in each group and maybe some overview of summary notes.

Sea Ice Thickness

Product Validation and Intercomparison Report (PVIR-SIT)

PVIR-SIT compiles a very large set of reference data products to thoroughly analyse the SIT quality.

At times in section 3.1 (Product inter-comparison) it is not clear whether statements about lowering the uncertainties are conclusions from figures shown or are based on additional (not shown) analysis (e.g. based on the provided product uncertainty estimates). If there is no additional analysis, I do not understand how an inter-product comparison can identify an uncertainty reduction (since we do not know the real state), in particular since the figure colour bar extents (+/-0.25 m) are most of the time smaller than the claimed uncertainty reduction (~0.5 m, ~0.6 m, ~1 m). For this it might be interesting to repeat the following validation (using in-situ data) for preview1 data and check whether the preview2 is better in reproducing those measurements.

Again, the validation with independent data is fairly advanced and appreciated. I do wonder, however, why the correlations between SI_cci SIT and reference data shown, which are frequently quite small (in about 1/3 of the comparisons the R^2 values are below 0.1) receive comparably little attention. Some SI_cci SIT distributions agree indeed very well with the validation data distributions but show close to no correlation. Could the distributions be right for the wrong reasons?

It is not clear to me how well the reported errors are represented in the product uncertainty estimates. For many applications it is as important to have a reliable uncertainty estimate as it is to have a good SIT estimate, so that we are not over-confident in the SIT values. It would be very helpful to validate the provided uncertainties alongside the SIT values.

Can you comment on the possibility to make the compiled validation data set publicly available?

Specifics:

- You mention the Sea of Okhosk on page 15 and 17 but in the figures show only the very north of that sea, with no more than two or three valid data points in total. Is that correct?

- Similarly, the Lincoln Sea is mentioned on page 16 but is virtually not covered by ENVISATs orbit, please check.

Product User Guide (PUG-SIT)

The Sea Ice Thickness (SIT) Product User Guide gives a good and precise staring point into the use of the SI_cci SIT product. The technical description is well done and product properties are well described.

It should be considered to highlight the existence of biases between missions more clearly, these exist not only in regions with significant surface type mixing (P11) (see e.g. Figure 9c in PVIR). Similarly, it should be mentioned that the data has to be sanitised by the users (e.g. filtering of negative SIT).

Could you clarify what snow data is used for the southern ocean since for the OSI-SAF data: 'coverage is incomplete for the Envisat observation period and non-existent for the ERS-1&2 period' (P12)?

ENVISAT SIT appear to be biased low in the PVIR, is this not a known limitation?

CMUG would like to see more examples of how the data can be used, e.g. the toolboxes/programs/scripts used to create the figures in the guide.

Sea Ice Concentration

Product Validation and Intercomparison Report (PVIR-SIC)

The Sea Ice Concentration (SIC) Product Validation and Intercomparison Report investigates the SI_cci SIC quality predominantly with (less continuous but high quality) MODIS data. This is done for several years, followed by an analysis of the regional quality disparity.

The product evaluation focuses on locations with nearly 100% and 0% SIC. This might be necessary for technical reasons, but I am not sure how representative the resulting findings are for the dataset in general. Considering that dynamic tie-points are found in a comparable way (correct me if I am wrong), most of the validation efforts shown here appear to be tie-point validations only. Should we expect the algorithm errors to be larger for fractional (0<SIC<100) sea ice coverage? If so, how much? CMUG would suggest expanding on the method used here and explaining the reasoning behind using the extreme value points.

Do I remember correctly (from the SI_cci progress meeting) that the reasons for strongly asymmetric distributions for the SICCI3RELF (e.g. figure 4.2.2. lower right panel) have been found? If not, it would be good to investigate why this algorithms behaves so differently.

Since there is the possibility of errors in the validation data (i.e. locations with real SIC<100% being included in the SIC=100% ground truth data, which would explain the increased lower tails in those distributions), the median (in addition or instead of the mean) could be considered to calculate the bias.

It is great that the validation and intercomparison results are published in the scientific literature. Would it be possible to quickly summarize the main results of those papers for this report?

It is not clear how well the reported errors are represented in the product uncertainty estimates. For some applications it is at least as important to have an reliable uncertainty estimate as it is to have a good SIC estimate, so that we are not over-confident in the SIC values. It would be very helpful to validate the provided uncertainties alongside the SIC values.

Can you say anything about the temporal stability of the product?

Can you comment on the possibility to make the compiled validation data set publicly available?

Product User Guide (PUG-SIC)

The PUG gives a good overview of the underlying sensors and algorithms. It also provides a good entry point into the file content and limitations.

CMUG would like to see more examples on how the data can be used, e.g. the toolboxes/programs/scripts used to create the figures in the guide. It could also be useful to have an example how the status flag can be decomposed into its bits or how raw and sanitised data can be combined to gain a complete field of raw data (including locations which have been changed and which have not been changed).

When discussing the influence of melt ponds, it is indicated that the SIC product aims to represent the sea ice fraction excluding melt ponds and open ocean. I understand that melt ponds are virtually impossible to distinguish from ocean with this data, but what is the target of the product? Some further explanation on this point would be welcome.

Advice on which algorithms should be used in which circumstances should be added.

2.15 Sea Level

Sea level products are split into those relating to global sea level and those relating to coastal sea level. The documents for each set of products are addressed separately here.

Global Product

The User Requirements Document (URD_global) version 1.5 dated 22 October 2014, the Product User Guide (PUG_global) version 2.2 dated 13 December 2016 and the Product Validation and Intercomparison Report (PVIR_global) version 2.0 dated 9 December 2016 are reviewed here.

Global Product User Requirements Document (URD_global)

The document gathers input from different sources to provide a comprehensive view of the requirements and needs for a wide spectrum of users and groups, from the observational community to the broad climate research community, including for modeling and operational applications. It is therefore a useful reference document for many different user groups, in particular section 5 that provides a synthesis of the major requirements.

There are, however, a few aspects in the document that could be improved. The first relates to the reference documents used to extract the information. Because the current URD for Global Sea Level is from 2014, many of the documents it refers to are 10 years old and have been superseded. For example, CMUG input was included from its phase-I requirement baseline document v1.2 (from 2010), but there are two newer documents from subsequent CMUG phases that reflect better the current modeling needs for the different ECVs: Deliverable 1.1 of CMUG-II (from 2016) and a first version of Deliverable 1.1 in CMUG-III (finalised in 2020). There is also a newer Implementation Plan with GCOS recommendations from 2016 (GCOS-200), which includes updated specifications for the Sea Level products with respect to those included in Table 2.1 of the current URD document. Similarly, tables 2.2 and 2.4 in the URD documents could also be updated with the latest WMO requirements (OSCAR/Requirements).

The URD could also be improved by including a section on the polar regions, for which remote sensing is crucial. The importance of this region was indeed highlighted in the URD, but no specific recommendations had been identified and therefore listed. Several documents exist now that could help to fill this gap, e.g., the user requirements study from WP1 of the Polar Monitoring project, and the user requirements for the Copernicus Polar Mission.

Likewise, the URD would be more complete if it included some specific information on the requirements for the sea level budget closure project (e.g. from the D1.1 Science Requirements Document), that is one of the most important ESA activities linked to the Sea Level ECV. The other major global research initiative involving sea level is the WCRP Grand Challenge (also a CLIVAR Research Foci) on "Regional Sea Level Change and Coastal Impacts", for which a Science and Implementation Plan exists that provides requirements for

an optimal and integrated sea level observing system. It would therefore be worthwhile to include these requirements on the new URD.

Global Product User Guide (PUG_global)

The document gathers essential information for the users of the global Sea Level_cci products, including an overview of the instruments used, the altimetric standard applied, and other relevant aspects like the nomenclature, format, variable attributes, NetCDF headers and map projections used. It also reports the changes with respect to the earlier version (1.1). The document is therefore useful and fulfils its purpose.

Some suggestions are now listed of aspects in the document that could be improved:

- In Section 5.4 it would be desirable to include a figure illustrating the Cartesian projection and the level of detail provided by the spatial resolution. Sections describing the different variables and their attributes could also benefit from similar figures.
- No information on the observational uncertainties of the different variables is currently provided and would be desirable, as it can be critical for some users. For this, including a reference to relevant documents that describe them in detail would suffice.
- A similar suggestion is made regarding the validation of the different products, which is not addressed nor mentioned in the document.
- Also desirable is information on the continuity (or lack of continuity) of the products. The document mentions that the v2.0 of the global SL product would be extended until December 2015, but 5 years have passed since then and is not clear if this happened or the extension reached more recent years. It would be important to update this information, mentioning also if the product has been extended further, and if there is any plan to do so. If the products are discontinued, it should be mentioned too, explaining the reason (e.g. lack of new satellites to provide continuity, identified issues, priority for the production of new products based on refined techniques/data).
- A final suggestion is to include a section reporting potential problems/caveats in the products that the users should be aware of: e.g., data gaps, specific temporal periods or regions with higher uncertainty or reported problems.

Global Product Validation and Intercomparison Report (PVIR_global)

This document provides a comparison of the two global SL datasets produced by the Sea Level_cci, describing their similarities and also their differences, and providing explanations of the reasons behind some aspects where they disagree. It also includes a comparison of both datasets with two other independent observation-based estimates, and documents which one of the two CCI products is in better agreement with them. As such, the document nicely fits its purpose, and is a useful reference for potential users of the CCI products.

We now provide a list of recommendations of several aspects that can help to improve the usefulness of the document:

- The two CCI datasets compared (v2.0 and v1.1) exhibit identical long-term trends over the whole period addressed in the document (1993-2014) which suggests that this is a robust estimate. However, they also show some significant discrepancies in terms of temporal variability, which are particularly evident in Figure 3. It would be good to

quantify the level of agreement between the two datasets with correlation metrics, not only for the global mean time series but also at the grid point level, to identify regions with important differences (which would attest of higher observational uncertainties). For these correlations, removing the long-term trend would be desirable, to focus on the month-to-month variations. It would also be important to indicate when correlations are significantly different, and where that happens, if it can be explained by methodological differences.

- Another recommendation is to explain, in the annual signal section, how the phase and magnitude are defined, as a proper definition is currently lacking.
- Similarly, it is not clear in Figure 10 how the variance for each temporal step is computed. Does it represent a spatial variance? Or does it represent a temporal variance over a moving window? More details are needed for clarity.
- The final section on validation could be improved by providing some metrics of agreement (e.g. root mean square errors, correlations) between the two ECV products and the two independent datasets from tide gauges and ARGO floats, for global averages and if possible too at the regional level. That information is essential for the users to give preference to one dataset over the other, depending on their final application.

Coastal Product

The User Requirements Document (URD_coastal) version 1.2 dated 16 June 2020, the Product User Guide (PUG_coastal) version 1.3 dated 11 June 2020 and the Product Validation and Intercomparison report (PVIR_coastal) version 1.0 dated 5 October 2020 are reviewed here.

Coastal Product User Requirements Document (URD_coastal)

The Sea Level in Coastal Areas URD provides a concise and useful summary of what will be done in the project to address various aspects of user requirements. Included is valuable discussion of the advantages and disadvantages of certain approaches, and potential limitations given both the satellite and in situ data records. All the main points appear to be covered with no obvious omissions, though some aspects could use clarifying.

It is not clear how closely tied the proposed work is to surveyed user requirements, rather than simply what can be done with the available data. The general context is provided satisfactorily, but specific reference to user consultation is largely limited to a link to the global Sea Level URD. This does contain sections specifically addressing requirements for coastal products, but it would be useful to briefly synthesise these in the coastal URD. The proposed work can then be further discussed in this context. For instance, in the coastal URD it is unclear what the highest resolution near the coast will be, and within what distance of the coast this will be, as different numbers are mentioned in different places. Being clearer about this, and tying it to the needs of different applications, could be informative.

For the global merging, it is unclear whether open ocean and other coastal regions will use the standard SL_cci algorithms, or ones designed for coastal areas. Would this product become a replacement for the existing global SL_cci product, or always just be tailored to users interested in coastal regions?

The proposed validation against high-resolution ocean models will use a mixture of hindcasts and reanalyses, though the distinction that some runs include data assimilation and others do not is not made in the URD. For the hindcasts, the ensemble of 1/4° resolution simulations considered by Sérazin et al. (2015) will be used. Sérazin et al. (2015) also present two corresponding 1/12° simulations, it is not clear if these will also be used. For the reanalyses, a table is given describing available products, but this seems incomplete. For instance it does not include the CMEMS IBI simulation mentioned further down in the text. Nor is there mention of the CMEMS Northwest European Shelf (NWS) products, which cover almost all of the defined North East Atlantic region, include tides, and are available at 1.5 km resolution for near-real-time products and 7 km resolution for reanalysis. Furthermore, there is no discussion of the inclusion of data assimilation in these products and the ORAS5 reanalysis. Data assimilation will make these products more accurate, but the fact that they assimilate altimetry data means they are not independent of the Sea Level product being validated. This merits discussion.

It is also not clear if the validation against models and in situ observations will be the only error characterisation performed, or if other methods such as those suggested by Merchant *et al*. (2017) will also be employed. Again, this should be discussed in the context of specific user requirements.

Coastal Sea Level Product User Guide (PUG_coastal)

The coastal sea level PUG provides a concise technical introduction to the products. It contains useful information, but could be expanded to be more helpful to users from a range of backgrounds.

It seems to be written for an audience already familiar with using SLA products in NetCDF format. Inexperienced users, who arguably are most in need of a PUG, would benefit from the PUG being expanded to include a simple introduction to the variables in SLA products, and more detail on how to interpret them and common applications. For instance, exactly what sea level anomaly, mean sea surface, and mean dynamic topography represent, and how to use them for different applications. Comparison to tide gauge data may be a common one, as would validation of and assimilation into ocean models. The examples provided are a good start, particularly the inclusion of sample code in section 3.6.

Missing is any discussion of uncertainty information, and appropriate ways to calculate uncertainties. Also useful would be a brief overview of how the coastal products compare to the global product.

Coastal Sea Level Product Validation and Intercomparison Report (PVIR_coastal)

The coastal sea level PVIR is a well-written and accessible document, providing plenty of information of interest to users. The methods are well explained, as are uncertainties and caveats with the approaches taken, particularly for section 4 on the comparison with tide gauge data.

Section 5 on characterisation of uncertainties at regional scales is comparatively brief, and more detail on the methods and results could be usefully included. The document states that a manuscript is in preparation, so presumably further results will become available in the future.

Very intriguing are the results shown in figure 5, suggesting little significant difference in coastal and open ocean trends. It will be interesting to see the community explore this further in future.

2.16 Sea State

The documents reviewed for the Sea State _cci are:

- User Requirements Document (URD) version 1.0 dated 06 February 2019
- the Product Specification Document (PSD) version 1.0 dated 05 February 2019
- the Product User Guide (PUG) version 1.0 dated 17 January 2020
- the Product Validation and Intercomparison Report (PVIR) version 1.0 dated 22 June 2020

User Requirements Document (URD)

With regards to the User Requirements Document, it is satisfactory, but it is suggested that more explicit further information is provided on how the authors see the timetable for the planned roll out of key improvements to the dataset that they have indicated. Specifically:

• Addition of variables representing period and direction (the text seems to imply these for Phase 1, but they are not presently described as alternatives in the PSD and are likely to need some substantial R&D to be completed)

• Is the proposed target coastal zone resolution for a later phase? (CMUG suggests that the coastal zone is defined in the main body of text in addition to the caption for Table 2.3)

Product Specification Document (PSD)

The Sea State_cci Product Specification Document (PSD) describes a data product where the quality of the Phase 1 SWH product will be as good as, or better than, the now discontinued GlobWave long term dataset. As such it will be useful for climate modelling (at different temporal and spatial scales), reanalyses and NWP assimilation. With regards to the PSD as it stands the main comments are:

- it would be good to definitively state the temporal processing applied to the data (I assume from 20 Hz to 1 Hz, but I couldn't see this explicitly) both in the documentation text and also in the netCDF file metadata
- it would also be useful to users to contrast these data to the CMEMS NRT product where there are overlaps

Product User Guide (PUG)

The sea state PUG is a useful combination of accessible overview and technical information. It is important to have an easily readable introduction for new users, and that has largely been achieved.

Something which could usefully be added, perhaps in section 3, is a high-level overview of the difference between swh, swh_adjusted, and swh_denoised. This would help new users to determine which variable(s) more quickly and accurately they should be using for their specific applications.

Similarly, some discussion of best practice in using the uncertainty information, and any pitfalls in doing so. For instance, how to calculate the uncertainties over an aggregated region or global time series, particularly for cases where a simple averaging of uncertainties is not the correct approach.

While it is unlikely to be necessary for users experienced with NetCDF data, the PUG for some other ECVs contains instructions on how to work with the products in different applications or languages, sometimes with sample code. This is something that could be considered, or at least link to tutorials elsewhere.

Product Validation and Intercomparison Report (PVIR)

The Sea State_cci PVIR provides a good initial validation and intercomparison, including many worthwhile plots and comparisons. It feels like just a starting point though, and given the list of future work in section 5, the authors evidently agree. CMUG look forward to seeing how the document evolves accordingly over the course of the project.

In the results shown, further comment on some of the most interesting features would be appreciated. For instance, section 2.3.2 shows the CCI climatology to be consistently higher than that of ERA5 or RY2019, but makes no comments on possible reasons why or potential consequences. This would be extremely interesting to know more about. There is some discussion of this in the published paper of Timmermans *et al*. (2020), that could be usefully included in the PVIR. Similarly for other results and discussion in Timmermans *et al*. (2020) and Dodet *et al*. (2020), particularly as this work has already been performed.

Validation of L2 and L3 products will be very important, and this is included under future work. A detailed validation and comparison to other products will definitely be of interest to users.

2.17 Sea Surface Salinity (SSS)

The documents reviewed for the SSS_cci project are:

- User Requirements document (URD) version 1.4 dated 03/01/2019
- the Product Specificaiton document (PSD) version 1.6 dated 24/04/2019
- the Product User Guide (PUG) version 1.2 dated 5 March 2020
- the Product Validation Plan (PVP) version V1.1 dated 4 December 2019

User Requirements Document (URD)

The Sea Surface Salinity (SSS) User Requirement Document version v1r4 (Ref.: ESA-CCI-PRGM-EOPS-SW-17-0032, Filename: SSS_cci-D1.1-URD-v1r4.docx) presents a set of user requirements for satellite SSS products in a clear and structured way. The document first gives a good overview of relevant applications for SSS data, followed by summarizing previous user requirement assessments as well as results of a new survey. These results are well summarized in a concise manner in the final section. We have nevertheless a few ideas for consideration of future versions of this document. These are listed below, followed by some minor specific comments.

The requirements from previous assessments (Section 2) and the new user survey (Section 3) are presented and discussed independently and are only compared and synthesized to a very limited extent (stating that they are not substantially different). If possible, it would be very interesting to discuss to what extent the new user survey supports previous findings and if they show differences, whether they can be interpreted as a change of user requirements. Can the two sources be synthesized into a single updated set of requirements?

This document does not discuss which requirements are possible to meet. While this might not be within the scope of this work, it could be worth to state this explicitly in Section 1.1 ('Scope') and/or to discuss e.g. the trade-off between resolution and accuracy in a bit more detail. For example, do 78% of users ask for global mean accuracy of 0.2 or better (implying that for only 22% of users an accuracy of 0.3 or worse would be acceptable), but when given realistic (I assume) scenarios, the most popular option has a low accuracy of >0.3 (Figure 14). What are the implications of this? Should future surveys have more questions which visualize the expected retrieval trade-off between desirable properties? Would it be useful (and feasible) to develop a simple tool for users to select the optimal combination spatio-temporal resolution and accuracy? Only five participants (10%) in the presented survey are from outside Europe and North America. Am I correct that this number is too small to see whether these users have distinct requirements? The whole continent of Africa is not represented at all, neither is India despite its EO space program. How could future assessments be improved to be more representative? Considering the large range of applications and the fact that participants had no preference for any one of 37 products (Page 17) it becomes clear that there is no single product to fit all requirements/applications. Different levels of processing are one approach to this problem, different averaging periods/bin sizes another. A comment on the (perceived) need for any further differentiations (if there are any) could be very valuable. Did you consider asking for the interest in satellite products which are fully independent from (specific) in-situ observations? Or should all available data be used to prioritize product quality?

Specific comments:

- Page 15: 'All respondents were asked about their general research interests and have cited mainly ocean circulation, freshwater fluxes and air-sea interaction (Figure 4)'. According to Figure 4, interest in 'Trend and variability analysis' was larger than in Air-sea interaction.
- 'CATDS', 'BEC', 'RSS' and 'JPL' have not been specified.
- The Revision Date is 03/01/2019 (Cover page) which is nearly four months before the Revision following ESA comments (for v1r4, this issue, Page ii)
- Section 1.6 SISS: missing 'Salinity'?
- Page 28 last sentence: '(has been chosen 36 times in total, which is 32% of the answers)'. Did you consider using the number of participants as reference here (instead of number of answers) since this question allows multiple selections?

Product Specification Document (PSD)

The Sea Surface Salinity (SSS) Product Specification Document (PSD) (Ref.: ESA-CCI-PRGM-EOPS-SW-17-0032, Filename: SSS_cci-D1.2-PSD-v1r6.docx) establishes the link between user requirements and SSS product specifications. It is convincingly showing how the user input has informed the product development and the structure of the developed product. Some minor comments can be found below.

While it is clear how the URD informed the product specifications for the first phase of the CCI+, this document could be improved by highlighting which requirements are not fully met and where further product developments should focus. It is for example mentioned that bias corrected L2 and L3 are planned to be developed in the second phase of the project but the link of these to the URD could be made clearer.

The flow of the document might benefit from moving Section 2 past sections 3, 4 and 5. This would introduce the product variables before quoting the exact attributes which come with them.

The difference between spatial smoothing scales and grid size could be better explained. I assume this is based on the need for reduced uncertainty and required higher resolution for some applications. In this context I think that the attribute spatial_resolution (which I believe refers to the sensor footprint size, not the product grid resolution) would benefit from further explanation.

Specifics:
I compared the attributes given in the PSD with those of a data file I happened to have at hand. This file is version 1.8, instead of version 1.6 for which I have the PSD, that means that there is no need for those to agree on all cases. Below is a list of attributes which might have changed (with no aspiration to be complete) and should be kept in mind for updated versions of the PSD:

- ‘conventions’ in the PSD is called ‘standard_name_vocabulary’ in the v1.8 file
- ‘naming authority’ in the PSD is called ‘naming_authority’ in the v1.8 file
- The file contains a ‘creation_time’ attribute which is not the same as ‘date_created’.
- The attributes ‘spatial_grid’, ‘geospatial_vertical_min’ and ‘geospatial_vertical_max’ are provided in the file but not in the PSD

- The SSS variable does not have the following attributes: 'coordinates', 'units', 'valid_range', 'scale_factor', 'add_offset' (lines 211, 212, 216, 217, 218 in the PSD)
- AD01 is the User Requirement (instead of 'Reference') Document (URD)

Product User Guide (PUG)

The document summarises indispensable information for the users of the two first Level-4 SSS datasets produced in the first-year exercise of the CCI+: a monthly mean product and a 7-day running mean product. It also includes a full list of references to other key documents expanding on some aspects of the dataset production and their evaluation. The document is therefore a useful reference in which potential users of the SSS products can resolve their concerns or be redirected to other documents where they can be clarified.

An important caveat conveniently stated in the document is that both products are preliminary versions that have not been fully validated, thus warning the users of potential problems that could be encountered, flagging also already identified issues, and providing in addition an appropriate channel to communicate them and/or provide feedback to the product producers (Mngt_CCI-Salinity@argans.co.uk). Also important for potential users is the information that is provided on how the errors and biases are computed in each product. For the weekly dataset, it is, however, unclear what the term "variability" represents in the equation (section 2.3.2.3). Is it the variance? Or the standard deviation? Similarly, it should be clarified what the term error_L2OS stands for. We also note that not all the acronyms in section 1.6 are used in the document (e.g. UCR/CECR, SRAL), and thus recommend the list to be revised.

Another aspect of potential interest to users, that is currently not addressed in the document and could lead some users to prefer the SSS_cci products over other datasets, is the mid-term/long-term sustainability of the dataset. We thus recommend providing information on the current plans to extend the datasets further in time (how long are the current missions expected to continue? will there be other missions providing continuity to the datasets?), and also on the additional improvements that are being considered for future product versions.

Product Validation Plan (PVP)

This document describes the validation protocol for the Sea Surface Salinity (SSS) products obtained in the course of ESA SSS_cci project, including a list of the independent SSS datasets that will be used as ground truth measurements. The protocol is well explained, providing a detailed account of the different types of underlying uncertainties (accuracy vs representativity) that need to be addressed during the validation, which ones have been estimated and how, and which ones haven't and why (e.g. vertical representativity errors). It also provides clear unambiguous definitions of key concepts, like traceability or uncertainty, as well as of the quality metrics that are considered to perform the validation, explaining the different relevant information that can be derived from each of them. To complement the final list of products that will be used as ground truth measurements provided in section 4, we suggest specifying which other observational products have been considered to calibrate/generate the SSS_cci datasets, and to clarify as well if they are completely independent from the ground truth references, and if not, to explain the potential impact on the validation results.

2.18 Sea Surface Temperature

The User Requirements Document (URD) version 2.1 dated 2.1 13 January 2017, the Product Quality Assessment Report (PQAR) version 4.1 dated 27 October 2020[6] and the Product User Guide (PUG) version 2 dated 8 April 2019 are reviewed. Some comments are also included on the maturity of the data.

User Requirements Document (URD)

The SST_cci Phase-II User Requirement Document (URD) (Document Ref : SST_CCI-URD-UKMO-201, Issue 2.1) constitutes a comprehensive collection of user requirements from a thorough assessment of the literature (including from earlier CCI phases), lessons learned documents/discussions, an extensive questionnaire and discussions from a user workshop on uncertainties. The results are presented in a structured and clear way and are well analyzed where appropriate (e.g. the questionnaire). Some points follow suggesting minor improvements to the document.

Of particular interest is the fact that the very long list of requirements from the thorough assessment of user needs are synthesized into 64 key requirements in preparation for the product specifications. Some of them seem to be impossible or cumbersome to be considered in a single product (e.g. SST_CCI-REQ-32 and SST_CCI-REQ-33; representation of uncertainties by covariance matrix vs. ensemble representation). A discussion of prioritization might be included in the URD as is the case for some other ECVs (e.g. Sea Ice_cci) although this may be intended to be covered by the PSD.

The questionnaire is well analyzed (which also means that it is not a big problem that the questions are not listed; Annex A is empty) and includes conditional examinations (i.e. how do requirements depend on type of user group/application). In addition, it might be interesting to investigate the relationships between requested spatial resolutions, temporal resolution and accuracy. This could potentially reveal clusters in this three-dimensional space which could provide more information for product candidates than analyzing requirements individually. For example: it could be imagined that one set of applications require high spatial resolution but is less stringent on the temporal resolution while most other applications require dense temporal sampling with more flexibility on the spatial resolution. In this hypothetical case an SST product which attempts to satisfy high spatial and temporal resolutions at the same time would lead to unnecessarily high uncertainties.

Considering the great turnout of the survey, would it be possible to check the results of the survey for differences in user requirements by place of origin? It is shown (and I am sure it is difficult to avoid) that the majority of responses is from the US and Europe but it is not clear whether scientific interests are homogeneous or whether this predominantly western inquiry leads to a distortion of the focus of the product development.

If applicable, would it be of interest to check in future with users if there are in-situ datasets which should remain independent from the satellite product and its uncertainty estimates?

[6] https://datastore.copernicus-climate.eu/documents/satellite-sea-surface-temperature/v2.0/D2.SST.2-v2.2_PQAR_of_v2SST_products_v4.1_APPROVED_Ver1.pdf

In section 2.2 accuracy and precision are defined, in 2.3 it is stated: 'The “Accuracy” target here is thought to represent the SST standard uncertainty at the stated spatial scale, rather than bias.' These appear to be conflicting definitions which should be clarified.

The executive summary is repeated in the introduction, which I do not think is necessary.

Product Quality Assessment Report (PQAR)

The SST Product Quality Assessment Report provides an in-depth evaluation of the SST product. The thorough comparison with in-situ measurements is well structured and covers an assessment of the provided product uncertainties, latitudinal aspects and the temporal development of data quality, which renders it a very useful resource.

Below are some minor points which might or might not be helpful to the team.

- I am not clear what the differences between this document and a Product Validation and Inter-comparison Report would be.
- I am not sure about one aspect of the validation plots (which I like in general very much). They always show the discrepancy RSTD centered at 0 (instead of mean/median). This might or might not be the standard way to produce this kind of plots. In any case, users will assume that the provided uncertainty (green dashed lines) incorporates biases and (unbiased) signal noise. In one case (Figure 2.2.2.1, AVHRR-M02) the median is outside of the discrepancy RSTD. So in the rare case of large biases, would it not be more appropriate to center the RSTD on the median to see how large the overlap of the two distributions would be?
- The Figures in Section 2.2 also do not follow the same numbering system as those in the previous sections.
- Regarding the target of 0.1 K and limited availability of in-situ data with this precision: I think you do a better job in evaluating whether the product reaches this target than you state. For example, the two leftmost bins in Figure 2.2.5.2 top row (and 2.2.6.1) show discrepancies towards drifter measurements below 0.2 K, which indicates that (1) the drifter uncertainty might be overestimated, and (2) that the satellite products add close to no additional discrepancy to this. In other words, even if drifter uncertainty is 0.2 K, if the satellite to drifter discrepancy is not significantly larger you have shown that the satellite uncertainty is <0.2 K.
- Can you comment on the possibility to make the compiled validation data set publicly available?
- P44 (2.2.2 Level 2 against GTMBA): ' ATSR and daytime AVHRR are well estimated.' I think you mean nighttime here.
- P46 (2.2.3 Level 3U against drifters) 'The uncertainties of daytime ATSR-1 (2 channel data) are slightly over-estimated' I think you mean under-estimated here
- P52: '2.2.7 Level 4 against GTMBA' I think this section is about Level 3C data instead of Level 4?

Product User Guide (PUG)

The SST Product User Guide provides a good entry point to the SST product. The 'which product could I use' section (3.1.3) is a great addition to point the user to the most appropriate

datasets. Also, the PUG puts a focus on technical guidance for the users (the use of toolboxes etc.) which is very helpful.

At times it might be possible to condense the content (e.g. I am not sure section 4.2.4 is necessary) and be a little more specific. For example, L3C data files are introduced several times but it has initially not been clear to me whether the data from all orbits is provided as different variable layers or combined to a single field. That is in part because it is not explicitly stated how data is combined if measurements from different orbits for the same location are available. In Table 14 it does say that the file contains the 'best available skin SST', however, the exact same words are used in Table 12 with regards to L3U files. CMUG would request that these definitions are rewritten to be clearer.

It should be checked whether a restructuring of some parts of the guide could help the reader to find the relevant information more easily and quickly. For example,
- the important 'Limitations' (section 3.5.6.2) is a subsection of 'Why use ESA SST CCI data (and why not)?' which is in turn a subsection of the 'Frequently asked questions'. 'Limitations' could be placed more prominently.
- similar considerations apply to section 3.5.6.1. (Key features of ESA SST CCI data)

Regarding the highlighted periods of increased noise in AVHRR data (1982 and 1983), it is not clear to me whether this is represented in the provided uncertainties (flag)?

The different levels of spatially correlated uncertainties (including section 7.5) are great, it would be even more beneficial to propagate those uncertainties (ideally also accounting for uncertainty due to interpolation) to L4 data.

Side note: The x-axis label in the figures in Table 4 is a little confusing, are these values of the RSTD or the discrepancy which is shown here?

Maturity of data

A section on feedback from users was given with an issue of data download speeds being highlighted by several users following the v1 release. Also several minor issues with reading the data and treatment of associated flags. CMUG in D3.1v2 have highlighted problems with the time associated with the data which is different according to which depth of the data you are interested in. These issues are not mentioned in the corresponding section of the v2 CAR, so presumably have been improved, but this is not explicitly stated. Feedback from users seems generally positive, with some requesting extra products such as climatologies and monthly files to be available alongside the daily data.

Validation methods approved by the GHRSST science team and conforming to the guidelines under the QA4EO framework under the CEOS-WGCV were adopted. This international oversight of the validation plans is to be encouraged by all CCI teams. The GCOS stability requirement is met in the tropical Pacific and comparable to that of the pre-cursor ARC data. However, in general for regions of 100 km scale an accuracy of 0.1 K with the CCI data is not quite achieved being closer to 0.15 K. Areas with persistent cloud cover are particularly challenging in terms of achieving accuracy requirements.

2.19 Snow

The User Requirements Document (URD) version 2.0 dated 17/12/2019, the Product Specification Document (PSD) version 2.0 dated 19/12/2019, the Product User Guide (PUG) version 2.0 dated November 2020 and the Product Validation and Intercomparison Report (PVIR) version 2.0 dated November 2020 were reviewed.

A general comment is that this project is in its early phases and only the Snow Water Equivalent (SWE) product is available to the users at this stage. The ATBD was made available to the CMUG, but this document has not yet been published because the authors want to publish the algorithms once they are final. We suppose that the authors are aware of the upcoming special issue in Remote Sensing entitled "Remote sensing of global snow water equivalent" (https://www.mdpi.com/journal/remotesensing/special_issues/snow_water_equivalent). This journal is known for publishing well written papers in about one month (from the day of submission to the actual open-access publication) and so would make a good vehicle for publicizing the final data set.

User Requirements Document (URD)

The user community is briefly described. A synthesis of past user requirement surveys is presented (e.g. IGOS, GCOS, OSCAR) together with a new original survey performed by the project. The latter is presented in detail.

Reading the ATBD is useful to understand the URD because the methods used have limitations that limit the feasibility of user requirements.

Product Specification Document (PSD)

A rather old reference for SWE (Takala et al. 2011) is given in the PSD together with a very brief description of the algorithm's upgrades, more detail would be useful. Product specifications (temporal and spatial resolution, accuracy, etc.) and format are described adequately. This is a concise and clear document.

Product User Guide (PUG)

The snow Product User Guide (PUG) document issued in November 2020 describes the general properties of the products (e.g. file format) and defines the snow variables that are produced: snow cover fraction (SCF, several options) and snow water equivalent (SWE). This is a clear and concise document.

For each variable, a short chapter lists strengths and known limitations of the products. Each variable is illustrated by a map but no time series is shown. Multi-year time series could be shown for all variables at one location to be defined. This location should be representative of an area with seasonal snow cover and with a significant seasonal and interannual variability of snow cover and snow water equivalent (e.g. in northern Germany). This would be particularly useful for the AVHRR SCF time series because AVHRR sensors had no onboard calibration. The users need to figure out to what extent time series are homogeneous in time.

Product Validation and Intercomparison Report (PVIR)

The snow product validation and intercomparison report (PVIR) is a document of 53 pages issued in November 2020. Landsat satellite images are used together with in situ snow depth observations for performing the validation.

Information seems to be duplicated in Tables 3.13 and 3.14 (exactly the same figures in (a) and (b)). Presentation of these Tables could probably be simplified.

Figures 3.5, 3.6, 3.9, 3.10: to which subfigures are Dozier, Klein and Salomonson related? Could score changes in time be explained? This validation exercise is quite convincing. However, indirect validation through a comparison with the NOAA IMS SCF product would have been interesting since SCF users are familiar with the IMS product.

2.20 Soil moisture

The User Requirements Document (URD) version 2.0 dated 19 November 2020, the Product User Guide (PUG) version 2 dated 16 April 2021 and the Product Validation and Intercomparison Report (PVIR) version 2 dated 16 April 2021 are reviewed here.

It would be useful if the SM_cci key document web pages (https://climate.esa.int/en/projects/soil-moisture/key-documents/) followed the same format as the other CCI projects, especially as the number of documents increases as the project matures.

User Requirements Document (URD)

This document is very well written and structured. It helps better understand the SM_cci product and leads to better use by the final users. Latest updates and a state-of-the-art of the three datasets: the ACTIVE dataset from scatterometers, the PASSIVE product from radiometers and the COMBINED (scatterometers + radiometers) are well described going from algorithm development to product validation. This helps the user community to be updated along the ongoing development of the ESA CCI soil moisture product. However, the evaluation against ERA-5 could be misleading as it is still model dependent and this should be clearly stated.

While in some disciplines, the use of SM_cci products is already widespread, in others, the soil depth mismatch between CCI and models' simulations is a problem and might limit the usefulness of the ESA CCI product for the evaluation of climate model simulations. As an example, while the soil depth of the CCI soil moisture product is (2-5) cm, the surface layer of CMIP models is 10 cm. Soil moisture at 10 cm starts to behave differently. It would be valuable to continue to explore the possibility to produce a root zone soil moisture.

Product User Guide (PUG)

This document is well prepared and structured as well as very helpful for final users.

In section 2: Soil Moisture within the environment an update to references would be encouraged, the most recent reference is from 2011. Since then much work on the role of soil moisture in the climate has been done for instance

- on the coupling between soil moisture and convection (e.g. Taylor *et al*., 2012 DOI: 10.1038/nature11377 , Guillod *et al*., 2015 DOI: 10.1038/ncomms7443),
- on the impact on the nocturnal cooling and the amplitude of the diurnal cycle (Cheruy *et al*., 2017, https://doi.org/10.1002/2017MS001036),
- on the temperature biases in climate model (e.g. Al-Yaari *et al*., 2019, https://doi.org/10.1038/s41598-018-38309-5),

Some specific comments are listed below:

- There is a problem with the citations: "Error! Reference source not found."
- Al-Yaari et al., 2019, could have been referred in "ESA CCI-SM in Earth system applications".

Product Validation and Intercomparison Report (PVIR)

This document is also well prepared and structured.

The authors focus mainly on the comparison between products/CCI versions but very rarely interpret the origin of the differences. The comparison is mostly limited to the diagnostics of agreement or disagreement. It seems essential to us that the scientists who know the data best suggest possible cause of disagreement. For instance, there are opposite trends between the CCI passive, active, and combined products, which is quite surprising. The authors should help the end-user to decide which dataset is trustworthy for different applications and what the pros and cons are.

Minor points:

- p 18 "Error! Reference source not found"
- p 22 that that
- p 22: ERA5 observation. As far as I know ERA5 SM is a model product not an observation.
- A few words on the meaning of "break adjusted" might help the end-users, does the change go in the expected direction?
- Concerning the in-situ measurement, are the values of the soil moisture assimilated in ERA product?
- p. 32 Comment on Fig. 22: The increase in correlation is mostly for the absolute value.
- p.41 (in particular, its temporal dynamics), could the authors be more specific, as for instance they show that there is not agreement in the tendencies between the various sets.

Recommendations for CCI+ Phase 2

GLDAS Noah (v2.1) is used for scaling the datasets to each other. We think that the used model outputs (or any other intermediate information) should be explicitly included in the final SM_cci product files. This could be useful for a detailed evaluation of some LSM.

Spatial and temporal gaps over densely vegetated regions is a well-known shortcoming of the SM_cci product and this hampers the full use of CCI soil moisture over these regions. The SM_cci team decided to flag data over these regions. We recommend providing this information and let final users decide whether they are useful or not.

2.21 Water Vapour (WV)

The documents reviewed for the WV_cci project are:

- User Requirement Document (URD) version 2.0 dated 18 November 2019
- the Product Specification Document (PSD) version 2.1 dated 27 November 2019
- the Product User Guide (PUG) Version 1.1 dated 13 October 2020
- the Product Validation Plan (PVP) version 1 dated 24 February 2021 are reviewed and

Some suggestions are also provided for CCI+ Phase 2.

The documents are nicely structured and well written. The URD could be improved by providing tables grouped by application as this would allow the reader to find the information needed more quickly. In the product specification document, information on how to use the uncertainty information provided with the datasets would be very welcome. This could include information on error correlation lengths in space and time and possibly recommendations for best practices when averaging, regridding, etc. the uncertainty estimates for applications such as model evaluation. This could be an aim for CCI+ phase 2.

User Requirements Document (version 2.0 from 18 November 2019)

- Figure 2-2: units above panels indicate “gm/kg” but should probably be “g/kg”
- Many acronyms are not explained, e.g. GEWEX, SPARC, GAW, EE7, etc.
- If possible, group user requirements by application (NWP, climate monitoring, climate modelling, model evaluation, etc.) as this would make the document easier to read
- If possible, provide one “overarching” summary table for user requirements from different sources

Product Specification Document (version 2.1 from 27 November 2019)

- Some acronyms are not explained, e.g. PVP
- Page 15: paragraph starting “Unphysical values are declared as […]” appears twice
- Product format and metadata: maybe mention that datasets will also be prepared for obs4MIPs

Product User Guide (PUG) (version 1.1 from 13 October 2020)

General comments

- The use of many acronyms makes the text difficult to read for anyone not very familiar with the topic. Defining the ones in the text that are used repeatedly would make reading the text easier as going back and forth between the text and the glossary is somewhat breaking the flow.
- The numbering of the subsections is sometimes a bit too detailed (e.g. 3.2.2.2.1.1). At least for me this makes it rather more difficult to remember the main context than it helps to structure the document. After a while I start feeling a bit “lost” in the document.

- In many cases, no details are given but only references to other documents. This is of course fine but I would find it helpful to have wherever possible at least a few keywords or a 1-2 sentences summary so it would be possible to get the basic idea without having to go through a number of external documents.
- I like the "fact sheets" (e.g. tables 3-4, 3-5, 3-6) as this allows for a quick overview. I find this very helpful.
- It would be nice to have some context (e.g. an introductory paragraph in the beginning of the section) for the software tools presented in section 5. E.g. who is the target group (scientists, students, interested public, etc.)? What are the main applications of the tools (visualization, analysis, website, etc.)? What is the context within ESA CCI? What is the motivation for choosing the tools shown?
- Not sure there is a large added value from the listings in section 11 as people will have to check the actual content of the files they downloaded anyway as any printed table might be outdated.

Specific Comments

- Caption of figure 2-2: not sure what is meant by "Symmetric system". Maybe add brief explanation.
- The processing chain (section 3.1.2) could be outlined in a few sentences instead of only referring to other documents. Without any further explanation, I find figure 3-1 difficult to understand.
- Input products (section 3.1.3.1.1): it would be nice and helpful to have the products used explicitly listed here.
- Page 16: there are several empty subsections "3.1.3.1.2" on the page
- Page 17: empty subsection "3.1.3.1.2.3"
- Section 3.1.3.1.2.4: what is meant by "24 NetCDF products per year"? 24 netCDF files per year, i.e. one file per month and product?
- Page 18: empty subsections "3.1.3.2.1", "3.1.3.2.2" and "3.1.3.3"
- Section 3.1.3.2.1: there are empty parenthesis at the end of the first paragraph. Is there anything missing?
- Section 3.1.3.3.1.1: I am not familiar with the term "final flag bands". Maybe add a brief explanation.
- Table 3-1: given the content of the table, I guess the caption should rather read something like "variables and coordinates in Level-3 TCWV land product"?
- Table 3-1: the variables time, lat, lon are usually not called "bands" as suggested in the caption of the table but rather "coordinates". Variables ending in "_bnds" are usually (in climate modelling at least) referred to as "bounds" and not "bands".
- Table 3-1, time_bnds: maybe rather simply speak of "time bounds"?
- Page 21, last line: "merge products" → "merged products"?
- What is the difference between figure 3-5 and figure 3-6? Both look the same to me.
- The caption of figure 3-5 says "CDR-3" but the figure says "CDR-4".
- Section 3.2.2.2.1.1, "The missing values are set to NaN": while there is technically nothing wrong with this approach, it makes it more difficult to process the data with some programming languages. It would be more common to define a "missing value" (e.g. netCDF attribute "_FillValue") and use this value instead of setting data points to

NaN as this is approach widely used and therefore supported by most programming / scripting languages.

Product Validation Plan (issue 3.0 from 24 February 2021)

General comments

- The use of many acronyms makes the text difficult to read for anyone not very familiar with the topic. Defining the ones in the text that are used repeatedly would make reading the text easier as I find going back and forth between the text and the glossary is somewhat disruptive.
- A summary of the different processing / validation steps e.g. as schematics would be helpful and make it easier for those not familiar with the process to get an overview more quickly and more easily.
- Colocation criteria are given (e.g. $\Delta t \leq 24h$, $\Delta r \leq 1000\ km$) but not explained. What is the rational for these criteria?
- I am missing a section on how the results of the evaluation will be put into context / rated, e.g. in terms of fitness for purpose, recommended applications, meeting the goals of ESA CCI, etc.

Specific Comments

- I am not sure I fully understand the purpose of the list of references in the beginning of section 1.2 without any further explanation. I would either give one or two keywords per reference to make it clearer which reference is addressing which definition or remove the list and add the references (as needed) to the list in Appendix 1.
- The first paragraph about the lack of interactions between tropospheric and stratospheric communities in section 1.3 seems a bit out of place. Maybe connect with CDR requirements or remove?
- Section 2 (p. 15), 3rd paragraph: "references" → "reference datasets"
- Section 2.2 (p. 16): for the sake of completeness, it would be nice to have a 1-2 sentence summary of the CDR-2 dataset (similar to the ones for CDR-1 on p. 15 and for CDR-3 on p. 17)
- Schematic of the workflow shown in fig. 4-2 is great and really helpful; similar schematics for the other steps would be great.

Suggestions for CCI+ Phase 2

Provide guidelines on how to use uncertainty estimate of gridpoint values:

- error correlation lengths in space and time
- best practice for averaging, regridding
- how to compare with model data

4. Summary

Overall, CMUG recommendations are for concise documents with clear contents. Large tables and data should be included in annexes, as the information they contain is relevant and useful to the user, but inclusion in the main body of the report can often detract from readability. The LST_cci URD and PSD are examples where document length is excessive and reorganization would be helpful, although the LST_cci PUG is much better structured. The Permafrost_cci project also provides a number of examples of well-organized documents.

While at times it is useful to summarise key points and conclusions from other project documents, detailed descriptions and text should not be duplicated, e.g. a short summary and a reference to the URD from within the PSD is sufficient, without wholesale duplication. This will allow the reader to grasp the main point being made without finding the referenced document but at the same time allow them to follow up for more detail if necessary.

Some specific feedback on document length and usability specific to individual projects is provided within the sections above, but it is in general requested that documents are written with an eye to both readability and usability, rather than including all available information without consideration for what might be of use. More stringent guidance from ESA on expected content and length for each document would be welcome, as well as a more coherent review process across CCI projects.

CMUG recommends that all products, datasets and documents are citable with a DOI. This is available for many of the CCI ECVs already and should be rolled out to cover them all. CMUG understands that the provision of a DOI is available through CEDA and all projects should take advantage of this service if they have not already.

The CCI projects should also prioritise access to the most recent versions of documents through the new CCI web site and the layout of the “key documents” page for each project could be standardised. Is there some central system in place to ensure these pages are kept up to date?

The format and content of the URDs varies considerably between the CCI projects, some merely collect requirements while others provide detailed discussion of their feasibility. This second approach is useful information for climate modelers and CMUG would encourage all projects to include a section covering physical limitations of the observations. A wider and more representative range of contributors to the URDs is encouraged, in terms of application, but also in terms of geography. CMUG would be keen to work closely with each CCI ECV project when the next round of requirements gathering begins.

For the PVIR CMUG would like to encourage a more standardised approach to uncertainty analysis. A lot of work has been done to assess the datasets, but assigning uncertainties to the data provided to users has not always followed through (e.g. SI_cci SIT).

The PUGs are generally clear and well formatted. However, as for the PVIR, the amount of uncertainty information included varies greatly from one product to another. Guidance could be provided by ESA on what information to include in each document, so that this can be standardised. CMUG would suggest that the process for calculating uncertainty is included in the PVIR together with the results, these results can then be summarized in the PUG and the PVIR referenced. The PUG can then go on to give recommendations about what these results mean in practice for the user. Some projects do this well already Cloud_cci, Fire_cci and Ocean Colour_cci are good examples.

It is recommended that the PUG should be aimed at a new user and with this in mind CMUG particularly liked the "FAQ" style layout of the LST_cci PUG. The fact sheets included in the WV_cci PUG for each product were also well received and including these in appendices to the PUG for all projects is recommended.

A succinct list of the information CMUG would like to see in a PUG is given below.

- Descriptions of sensors
- Technical specifications of data (format, filenames metadata)
- Guide to method of access
- Guide to any preprocessing required by user
- Product strengths and limitations/known issues (i.e. regions or time periods where data is poor)
- Uncertainty characterisation and recommendations for use/best practice/guidelines and validation documents referenced (PVP/PVIR)
- Recommended applications for products and examples of existing applications
- Description of code/toolboxes/algorithms for using data and guidance on when to these should be used
- Maps and time series of data to be included
- Information on the continuity of each product (e.g. when moving from one instrument to another)
- Citation information

Overall CMUG recommendations for all documents are given below

Specific recommendations on the document structure:

- All documents to include an executive summary
- Standardized contents and recommended length
- Information to be grouped by application (e.g. when included in tables)
- Table of acronyms, but acronyms also expanded in text on first use (and subsequently if not used for a number of pages)

Specific recommendations on product and document storage and availability

- Links to all documents from the CCI web site
- DOI provided for all output (documents and datasets)
- Process in place to ensure web site and archives are kept up to date

Recommendations for Phase 2

Specific recommendations are given for each ECV in the relevant sections above. Some points which apply to all CCI projects are listed here:

- New instruments providing additional products should be considered in the URDs for future phases. Technology is progressing fast and CCI should take advantage of developments
- Unphysical values should be avoided
- All data products should be provided in CF compliant NetCDF format. Other formats may be useful too, but this should be the minimum
- Some thought could be given in the next versions of CCI project documents as to how to use the uncertainty information provided with the datasets. It would be helpful to include information on error correlation lengths in space and time and possibly recommendations for best practices when averaging, regridding, etc. the uncertainty estimates for applications such as model evaluation

5. Acronym list

AGB	Above Ground Biomass
ATBD	Algorithm Theoretical Baseline Document
BA	Burned Area
CAMS	Copernicus Atmospheric Monitoring Service
CAR	Climate Assessment Report
CCI+	Climate Change Initiative
CECR	Comprehensive Error Characterisation Report
CEDA	Centre for Environmental Data Analysis
CEOS-LPV	Committee on Earth Observation Satellites Land Product Validation Sub-group
CFL	Calving Front Location
CMUG	Climate Modelling User Group
DGVM	Dynamic Global Vegetation Model
DOI	Digital Object Identifier
ESA	European Space Agency
FR	Full Resolution
GLDAS	Global Land Data Assimilation System
GLL	Grounding Line Location
GMB	Gravimetric Mass Balance
IGBP	International Geosphere-Biosphere Programme
IUCN	International Union for Conservation of Nature MODIS
IV	Ice Velocity
JSBACH	The land surface component of the MPI-Earth Surface Model
JULES	Joint UK Land Environment Simulator
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LSCE	Laboratoire des Sciences du Climat et de l'Environment
LSM	Land Surface Model
LPVS	Land Product Validation Subgroup
MCD45A1	MODIS Collection 5 Burned Area Product
MCD64A1	MODIS Collection 6 Burned Area Product
MERIS	MEdium Resolution Imaging Spectrometer Instrument
MODIS	MOderate Resolution Imaging Spectroradiometer
MOHC	Met Office Hadley Centre
MPI-M	Max Planck Institute for Meteorology
NLCD	National Land Cover Database
NVDI	Normalised Difference Vegetation Index
ORCHIDEE	ORganising Carbon and Hydrology in Dynamic EcosystEms
PAR	Photosynthetically Active Radiation
PFT	Plant Functional Types
PSD	Product Specification Document
PVIR	Product Validation Intercomparison Report
PVP	Product Validation Plan
RCM	Regional Climate Model

REDD+	Reducing Emissions from Deforestation and forest Degradation
RR	Reduced Resolution
SEC	Surface Elevation Change
SFD	Small Fire Databases Burn Product
SIC	Sea Ice Thickness
SIT	Sea Ice Concentration
SMAP	Soil Moisture Active Passive
SR	Surface Reflectance
SWE	Snow Water Equivalent
UCR	Uncertainty Characterisation Report
URD	User Requirements Document
URL	Uniform Resource Locator
USGS	United States Geological Survey

6. References

Al-Yaari, A., Ducharne, A., Cheruy, F. et al. Satellite-based soil moisture provides missing link between summertime precipitation and surface temperature biases in CMIP5 simulations over conterminous United States. Sci Rep 9, 1657 (2019). https://doi.org/10.1038/s41598-018-38309-5

Cheruy, F., Dufresne, J. L., Aït Mesbah, S., Grandpeix, J. Y., & Wang, F. (2017). Role of soil thermal inertia in surface temperature and soil moisture-temperature feedback. Journal of Advances in Modeling Earth Systems, 9(8), 2906–2919. https://doi.org/10.1002/2017ms001036

CMUG-PhaseII D1.1 Requirement Baseline Document v0.6 (http://ensembles-eu.metoffice.com/cmug/CMUG_PHASE_2_D1.1_Requirements_v0.6.pdf)

CMUG-PhaseIII D1.1 User Requirement Document (link tbc)

ESA Sea Level Budget Project, Deliverable 1.1, Science Requirements Document (https://climate.esa.int/documents/183/ESA_SLBC_cci_D2.1.2_v1.1.pdf)

Dodet, G. and Piolle, J.-F. and Quilfen, Y. and Abdalla, S. and Accensi, M. and Ardhuin, F. and Ash, E. and Bidlot, J.-R. and Gommenginger, C. and Marechal, G. and Passaro, M. and Quartly, G. and Stopa, J. and Timmermans, B. and Young, I. and Cipollini, P. and Donlon, C. (2020) The Sea State CCI dataset v1: towards a sea state climate data record based on satellite observations. Earth Syst. Sci. Data, **12**, 1929–1951 https://doi.org/10.5194/essd-12-1929-2020

GCOS, 2016: The Global Climate Observing System for Climate: Implementation Plan. *WMO GCOS-200 341 pp. Available at* https://library.wmo.int/doc_num.php?explnum_id=3417

GCOS-200, The Global Observing System for Climate: Implementation Needs, GCOS Implementation Plan 2016 (https://gcos.wmo.int/en/gcos-implementation-plan)

Guillod, B., Orlowsky, B., Miralles, D. et al. Reconciling spatial and temporal soil moisture effects on afternoon rainfall. Nat Commun 6, 6443 (2015). https://doi.org/10.1038/ncomms7443

Merchant, C. J., Paul, F., Popp, T., Ablain, M., Bontemps, S., Defourny, P., Hollmann, R., Lavergne, T., Laeng, A., de Leeuw, G., Mittaz, J., Poulsen, C., Povey, A. C., Reuter, M., Sathyendranath, S., Sandven, S., Sofieva, V. F., and Wagner, W.: Uncertainty information in climate data records from Earth observation, Earth Syst. Sci. Data, 9, 511–527, https://doi.org/10.5194/essd-9-511-2017, 2017.

OSCAR/Requirements, WMO, User requirements for observation (https://www.wmo-sat.info/oscar/requirements)

Polar Monitoring project WP1, User requirements study, Polar Monitoring Mission, Assessment and Consolidation of Requirements and Analysis of Campaign Data, Technical Note (https://www.polarmonitoringproject.org/wp-content/uploads/2020/07/PMM_Task1_Report_TN1_v3.pdf)

Taylor, C., de Jeu, R., Guichard, F. et al. Afternoon rain more likely over drier soils. Nature 489, 423–426 (2012). https://doi.org/10.1038/nature11377

Timmermans, B. W., Gommenginger, C. P., Dodet, G., and Bidlot, J.-R.: Global Wave Height Trends and Variability from New Multimission Satellite Altimeter Products, Reanalyses, and Wave Buoys, Geophys. Res. Lett., 47, e2019GL086880, https://doi.org/10.1029/2019GL086880, 2020.

User Requirements for a Copernicus Polar Mission, Phase 2 Report, High-level mission requirements
(https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111068/2018.1802_src_polar_expert_group_-_phase_2_-_final_report_20180726final2.pdf)

WCRP Grand Challenge on Regional Sea Level Change and Coastal Impacts, Science and Implementation Plan.
(http://www.clivar.org/sites/default/files/documents/GC_SeaLevel_Science_and_Implementation_Plan_V2.1_ds_MS.pdf)