CCI Land Surface Temperature

2022 User Workshop Report

WP5 – DEL-5.3

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Organisation: LST_cci Consortium

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Signatures

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Change log

Version	Date	Changes
1.0		First version

List of Changes

Version	Section	Changes

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Applicable Documents

Identity	Reference
AD-01	LST_cci (2021) User Requirements Document, Reference LST-CCI-D1.1-URD v2.0
AD-02	SST_cci (2017) User Requirements Document Phase II, Reference SST_CCI-URD-UKMO-201 v2.1
AD-03	LST_cci (2023) User Requirements Document, Reference LST-CCI-D1.1-URD v3.0

Acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ARD	Analysis Ready Datasets
ATSR-2	Along-Track Scanning Radiometer - 2
ATSR-3	Along-Track Scanning Radiometer – 3 (also known as AATSR)
AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperatures
C3S	Copernicus Climate Change Service

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CCI	Climate Change Initiative
CDR	Climate Data Record
CMIP	Coupled Model Intercomparison Project
CMUG	Climate Modelling User Group
CORDEX	COordinated Regional Downscaling EXperiment
CRG	Climate Research Group
ECV	Essential Climate Variables
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GOES	Geostationary Operational Environmental Satellites
GSICS	Global Space-based Inter-Calibration System
GDPR	General Data Protection Regulation
HHR	Heat Hazard Risk
IASI	Infrared Atmospheric Sounding Interferometer
IR	InfraRed
IST	Ice Surface Temperature
KNMI	Royal Netherlands Meteorological Institute
L3C	Level 3C satellite product (averaged/reprojected in space)
L4	Level 4 satellite product (averaged across space and time)
LEO	Low Earth Orbiting
LSA SAF	Land Surface Analysis Satellite Application Facility
LST	Land Surface Temperature
LST_cci	LST CCI
MODIS	MODerate resolution Imaging Spectroradiometer
MW	MicroWave
NDVI	Normalised Difference Vegetation Index
NWP	Numerical Weather Prediction
PFT	Plant Functional Type
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SMB	Surface Mass Balance Model
SUHII	Surface Urban Heat Island Intensity
T2m	2m air temperature (e.g. measured at a weather station)
Tair	Near-surface air temperature (typically measured at a weather station at 2m above ground)

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TCI	Temperature Condition Index
TES	Temperature Emissivity Separation
TIR	Thermal InfraRed
UTC	Coordinated Universal Time
URD	User Requirements Document
WMO	World Meteorological Organisation
VCI	Vegetation Condition Index

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1. Executive Summary

The European Space Agency (ESA) Climate Change Initiative (CCI) for Land Surface Temperature (LST), or "LST_cci", 2022 User Workshop was held online 27-29 September 2022. A total of 136 participants registered for the event from all over the world. Twelve 1-hour live sessions were held over the three-day event, comprising oral and poster presentations, demonstrations and practical sessions using LST_cci datasets, discussion sessions with interactive questions for participants to answer online, and a virtual social event.

This report presents full details of the LST_cci 2022 User Workshop, including:

- Motivation for the workshop format and content.
- Full agenda with a summary of the main points from each presentation.
- Results from a workshop feedback survey.
- Outcomes from each discussion session, including the results of the questions posed to the workshop participants.
- A list of recommendations collated during the workshop.

Feedback collected via an online survey after the event was generally very positive. General recommendations regarding the workshop event include:

- The format and content of the LST_cci 2022 User Workshop was well received and should be considered for future virtual events. Eventbrite should be used for the event registration.
- A strategy to increase the number of participants in the live sessions in future online events is required. Holding a combined workshop with another CCI Essential Climate Variable (ECV) project is one potential solution.
- Other types of virtual events could be considered in the future, for example, targeted knowledge-exchange meetings, open question & answer sessions, seminars, etc.
- An LST_cci code repository could be considered for both users and the project team to upload useful computer code to process LST_cci datasets. However, it should be made clear that the repository is maintained on a best-efforts basis and the code in the repository should be used with caution as it is not guaranteed to be free from errors. The repository could also include code made available to users during workshop practical sessions.

In addition, some specific recommendations have also been defined based on the questions posed to workshop delegates during the discussion sessions and other feedback received during the event, which are listed in Table 1. These recommendations will be used to define new requirements for the LST_cci project in an updated version of the User Requirements Document (URD) [AD-03].

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Table 1: List of specific recommendations resulting from the LST_cci 2022 User Workshop. The recommendations are explained and numbered in Section 4 of this report and are indicated in the 'Notes' column of this table, e.g. LST-UWR2022-REC-01 refers to Recommendation #01.

Recommendation	Notes
Data Format and Accessibility	
Provide easy access to LST_cci products and facilities to improve data download.	LST-UWR2022-REC-30. Requested by 1 respondent and combined with R9 "Provide a direct link to download LST_cci data on the LST_cci web pages", a consensus from the discussion.
Provide reprocessed LST_cci datasets at least annually.	LST-UWR2022-REC-04. At least 11 of 12 respondents would like at least annual reprocessing.
Provide LST_cci data within 48 hours of acquisition.	LST-UWR2022-REC-01 and combined with LST-UWR2022-REC-29 "Provide LST_cci products in real-time". 5 of 11 respondents require data within 48 hours of acquisition.
Provide LST data on a Polar EASE grid.	LST-UWR2022-REC-14. Requested by 3 users (1 post-workshop in response to a specific email sent to the LST_cci distribution list).
Ensure LST_cci ARDs are provided with good documentation, in easy-to-access formats with simple quality flags.	LST-UWR2022-REC-19. Each list item was requested by one user.
Provide LST data that are stable over time and free from non-climatic discontinuities.	LST-UWR2022-REC-21. Requested by 2 of 9 respondents.
Provide fill values in files for missing data products and an inventory of files with missing data.	LST-UWR2022-REC-12. Requested by some users during discussion.
Extend LST_cci Regridding Tool to produce temporal means (e.g. weekly, pentads, etc).	LST-UWR2022-REC-15. Requested by 2 of 6 respondents.
Develop a wrapper for the LST_cci Regridding Tool to process multiple files.	LST-UWR2022-REC-16. Requested by 1 of 6 respondents.
Provide detailed information on what satellite-observed LST fields represent and how this relates to climate model parameters.	LST-UWR2022-REC-24. Requested by 1 of 9 respondents. Combined with LST-UWR2022-REC-28 "Provide detailed information on what satellite-observed LST fields represent and how the data can be used most effectively", also requested by 1 respondent.
Maintain a webpage/blog as a permanent resource that can be accessed for historical issues.	LST-UWR2022-REC-05. Consensus during discussion.

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Recommendation	Notes
Provide users with the option to be sent email notifications when new issues are discovered and added to the issues list.	LST-UWR2022-REC-06. Requested by 11 of 12 respondents.
Provide information on data gaps, e.g. due to sensor outages or satellite manoeuvres.	LST-UWR2022-REC-11. Requested by several users during discussion.
Product Types	
Provide LST_cci data as 10-day means.	LST-UWR2022-REC-02. 3 of 12 respondents require 10-day means.
Provide gap-filled LST_cci products.	LST-UWR2022-REC-03 and combined with LST-UWR2022-REC-23 "provide gap-filled LST data". 7 of 12 respondents might use ap-filled data with large uncertainties. E.g. based on model data, heavily interpolated, or a climatology.
Provide LST climatologies.	LST-UWR2022-REC-17. At least one user requested this.
Provide selected properties derived from LST, for example, anomalies, daily minimum and maximum LST, annual means and LST- 2m air temperature differences.	LST-UWR2022-REC-18. Each list item was requested by one user.
Data Specification	
Provide LST_cci products on UTC grids.	LST-UWR2022-REC-25 from UWR 2022. Requested by 1 of 9 respondents. Provide time-consistent fields with time stamp 00:00, 01:00….23:00 UTC e.g. to match model output.
Provide LST data with increased frequency and spatial resolution.	LST-UWR2022-REC-22. Requested by 1 of 9 respondents. For example, to match that of high-resolution climate models.
Priorities	
Prioritise dealing with cloud cover in IR data sets.	LST-UWR2022-REC-13. Requested by 7 of 12 respondents. Improve cloud masking and gap filling.
Error and Uncertainty	
Provide detailed information on uncertainties.	LST-UWR2022-REC-10. Request from a single user during discussion; consider including this information in individual file metadata.
Cloud	

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Recommendation	Notes
Improve IR cloud screening.	LST-UWR2022-REC-07. Requested by 6 of 12 respondents, e.g. incorrect cloud mask.
Provide detailed information on IR cloud screening processes.	LST-UWR2022-REC-08. Consensus during discussion.
Other	
Provide observation time, view angles, total uncertainty and land cover classification in LST_cci ARD products.	LST-UWR2022-REC-20. Combined response from 4 respondents.
Provide observation operators to convert LST to T2m and potentially other variables.	LST-UWR2022-REC-26. Based on information provided by 9 respondents. For example, to soil moisture, below- and within-canopy temperatures and temperatures associated with different PFTs.
Include additional variables in LST_cci products where possible to support climate services using LST.	LST-UWR2022-REC-27. Based on feedback from 10 respondents, include T2m and land cover classification (both high priority); other variable such as surface humidity, modelled surface 'skin' temperature, emissivity, NDVI, fractional vegetation and total column water vapour could also be considered (low priority).

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2. Workshop Overview

2.1. Workshop Details

The LST_cci 2022 User Workshop took place 27-29 September 2022 online. An online format was chosen primarily due to the success of the LST_cci 2020 User Workshop, which was originally planned to be an in-person event but was held online as it was scheduled in June 2020, during the early months of the Covid-19 pandemic.

Given that most aspects of the LST_cci 2020 User Workshop were very successful, the format of the LST_cci 2022 User Workshop was designed to be similar. However, some improvements and additional design elements were included based on feedback from the 2020 User Workshop delegates (primarily through a dedicated feedback survey), the LST_cci Project Team and several project requirements [AD-01], including those formulated during the 2020 workshop event. These are detailed in Table 2.

Table 2: Feedback from the LST_cci 2020 User workshop and project requirements [AD-01] used to design the format of the 2022 User Workshop. Project requirements are referenced by a unique identification string, e.g. LST-URD-ADV-38-U, that can be cross-referenced with the LST_cci User Requirements Document (URD) [AD-01]. The term 'respondents' corresponds to the respondents of the LST_cci 2020 User Workshop Feedback Survey. This table is continued on the next page of the report.

Feedback /Requirement	Source	Workshop design/agenda
The majority of respondents thought that the 1-hour length of the live sessions, the 30-60 minute breaks between live sessions and the number of live sessions was about right.	2020 User Workshop Feedback Survey	Retain overall format of 2020 workshop: 3 days, four 1-hour sessions per day, 30-60 minute breaks.
At least 50 % of respondents reported that they enjoyed the breakout sessions and would like to see similar breakout discussions at future events. No respondents reported not enjoying the breakout sessions. Of the respondents that commented on the breakout session length, 84% felt the length of the breakout sessions was about right.	2020 User Workshop Feedback Survey	Include breakout sessions if/when required. Length of sessions should be ~40 minutes.
Respondents generally felt that Padlet was well organised, a valuable component of the workshop and that something like Padlet would be a good addition to future events.	2020 User Workshop Feedback Survey	Use Padlet (or similar) for the 'offline' component of the workshop. Presenters to upload slides/posters; commenting/discussion enabled for each presentation; upload live session recordings; provide agenda. Ensure there is a clear 'home page' for the Padlets.
Respondents typically felt general networking and the social interaction with other workshop participants was more difficult during the virtual 2020 workshop compared with an 'in person' event.	2020 User Workshop Feedback Survey	Hold a social event online, e.g. 'bring your own drink'. Provide a facility for delegates to meet during workshop breaks.

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Feedback /Requirement	Source	Workshop design/agenda
One of the main weaknesses of the 2020 virtual workshop was the poster session. Posters were not well viewed/commented on and were generally rather overlooked during the workshop event.	2020 User Workshop Feedback Survey	Hold a live poster viewing session following a 'lightning presentation round', where each presenter has 1-2 minutes to present their poster in plenary. Poster viewing session to enable discussion around posters, similar to an in-person event.
LST-URD-ADV-22-I - Provide detailed information on how uncertainties are calculated LST-URD-ADV-23-OI - Provide information on what the uncertainties represent and why they are useful LST-URD-ADV-24-O - Provide information about spatial and temporal structure of the uncertainty components	Existing project requirement [AD-01] and 2020 User Workshop feedback.	Hold a dedicated session on uncertainties in LST_cci products. Include an overview presentation on why they are important, what they represent (including the individual components), examples of when users may need uncertainties. Follow with a practical session for users to explore LST_cci uncertainties.
LST-URD-ADV-38-U - Provide tools to re-grid data and propagate uncertainties	Existing project requirement [AD-01] and 2020 User Workshop feedback.	Hold a dedicated session to present the LST_cci regridding tool. Include an overview/demonstration of the tool. Follow with a practical session for users to explore the tool.
LST-URD-ADV-41-U - Provide hands-on experience for users at dedicated workshops LST-URD-ADV-67-U - Provide information to users in a variety of ways, e.g. traditional documentation, videos, podcasts, etc.	2020 User Workshop Feedback	Hold practical sessions where users can explore the LST_cci data products, including their uncertainties. Provide Python code in a Jupyter Notebook (with lots of documentation) to explore, process and plot LST_cci data in a public area. Include a demonstration of this Python code, which delegates can explore further in a practical session within smaller breakout groups.

As for the 2020 User Workshop, the live sessions were held on Zoom (https://zoom.us/) and offline engagement was primarily through Padlet (https://padlet.com). The Padlets, which are essentially web pages, enabled users to upload their presentations, comment on presentations, download the most recent copy of the workshop information booklet, and navigate the workshop links. New/updated elements for the 2022 User Workshop, compared with the 2020 User Workshop, included:

- Two demonstration/practical sessions giving users 'hands on' experience with the new LST_cci regridding tool, using LST_cci products and exploring uncertainties.
- Using the interactive online survey tool, Slido (www.slido.com), to ask delegates for specific feedback and new recommendations concerning the LST_cci data products during the discussion sessions.

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- A live poster session with an initial lightning round in plenary for presenters to give an overview of their poster, followed by an interactive presentation session using Gather Town (https://www.gather.town), which is a virtual space for users to move around and interact.
- A social event also held in Gather Town.

The full agenda for the 2022 User Workshop is provided in Section 2.3 of this report.

The LST_cci 2022 User Workshop was advertised by email to the complete LST_cci mailing list (~260 people at the time), the Climate Modelling User Group (CMUG), most of the Climate research Group (CRG) leads (via the CMUG lead) and was submitted to Climlist (a moderated international electronic mail distribution list for climatologists and those working in closely-related fields https://lists.osu.edu/mailman/listinfo/climlist). It was also publicised by ESA and the Met Office online, and Tweeted by the LSA SAF (Land Surface Analysis Satellite Application Facility https://landsaf.ipma.pt/en/) and various other private and institutional Twitter accounts. Full details of the workshop, including registration information, were provided on both the LST_cci ESA pages (https://climate.esa.int/en/projects/land-surface-temperature/about/) and an Eventbrite (https://www.eventbrite.com/) registration page. The use of Eventbrite was very successful and enabled delegates to register for the LST_cci mailing list with the appropriate GDPR (General Data Protection Regulation) statement as part of their registration process. Delegates could also request an oral or poster presentation and submit their abstract through Eventbrite.

A total of 136 registrations were received for the 2022 User Workshop, which is almost identical to the number received for the 2020 User Workshop (n=133). Delegates were asked to provide the name of their affiliated institute/company during the registration process. Most of the delegates were from academic or scientific institutions; a complete list of those provided can be found in Appendix A of this report. Despite the similarity in registration numbers, the live sessions were not as well attended with attendance varying between 19 and 42 at the 2022 event compared with 41 and 68 in 2020. However, the pattern of attendance was very similar between the two events, with the highest attendance at the LST_cci project output sessions on day 1 and lowest at the discussion sessions (see the agenda in Section 2.3). The higher interest in the LST_cci project sessions was also reflected in the Zoom recordings download and views, with a larger number of downloads/views for day 1 compared with the other days of the workshop. Overall, there was a large number of Zoom recordings views and downloads suggesting that engagement offline was quite high. (By 4 October 2023, there were 132/57/58 views and 26/12/9 downloads for workshop day 1/day 2/day 3, but note that one view corresponds to one session, such that one person viewing all 12 workshop sessions contributes 12 views.) However, most views were short (≤1 minute) with fewer than 20 views for each day lasting longer than 1 minute. This could be a result of users trying to find a specific presentation, or part of that presentation, that they wanted to watch, for example.

As for the 2020 User Workshop, daily 'digest' emails were issued to all registered delegates during the event, which included updates on the workshop and links to the day's live session recordings and Padlets. A feedback survey was also issued a few days after the workshop, which received 27 responses. The results of this survey are presented in Section 3 of this report.

2.2. Workshop Aims

The primary aims of the LST_cci 2022 User Workshop were to:

- Inform and update users on the LST_cci project and its outputs
  - This was achieved through dedicated presentations focusing on the project outputs delivered by the project team on day 1.

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- Gather feedback from LST data users on both LST_cci and other LST datasets.
  - Workshop delegates and LST users were invited to present either an oral or poster presentation at the workshop in dedicated LST user sessions.
- Define any new requirements for LST from users.
  - A dedicated discussion/feedback session on user requirements was included in the agenda.

Additional objectives of the workshop included:

- Providing users with practical, hands-on experience in using LST_cci products and their uncertainties, which was a requirement identified at the 2020 User Workshop.
- Advertise and demonstrate the new LST_cci regridding tool, which reprojects higher-resolution LST_cci products onto a coarser latitude-longitude grid, including the correct propagation of uncertainties.
- Gather ideas and feedback to help direct future work using LST, including through LST_cci or other follow-on projects. This was achieved through three focused presentation/discussion sessions:
  - User requirements for LST
  - LST and climate modelling
  - Climate services and the future of satellite LST

Finally, the workshop provided a forum for data providers and users of LST to get together and hold fruitful discussions.

2.2.1. Utilising the Outcomes from the Workshop

The User Requirements Document (URD) [AD-01] underpins the LST_cci project and defines the output required from the project through specific requirements. This includes requirements defined from the LST_cci 2020 User Workshop.

The approach taken in this User Workshop Report (UWR) is to list the key outcomes from the workshop as 'recommendations', which are sequentially numbered throughout this report for traceability. These recommendations are translated into official requirements in an updated version of the URD [AD-03], where they are also assigned a unique identification string that can be used for full traceability in other LST_cci documents.

2.3. Workshop Agenda

The workshop agenda is presented over the next few pages. In each case, the name of the presentation is also a link that will download the presentation slides, which are also available via the LST_cci 2022 User Workshop webpage. A summary of the key messages from each presentation is also provided. In order to keep the agenda/key messages tables to a manageable size, please note that not all acronyms are defined here, but a complete list of acronyms used in this report is provided in a glossary near the beginning of this document.

The link to the material used for the two practical sessions is also provided in the agenda, or can be accessed here:

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- Link to Binder and Python code from practical sessions.

A beta version of the regridding tool was utilised during the LST_cci 2022 User Workshop. The regridding tool has now been publicly released and is available to download here:

- Link to LST_cci Regridding Tool on the ESA LST_cci webpages.

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2.3.1. Tuesday

Tuesday 27 September 2022				
Time	**Agenda Item**		**Duration**	**Key messages**
11:15 CEST	Start arriving at workshop		15 mins	
LST_cci Project Chair: Karen Veal				
11:30 CEST	Welcome and general information	Lizzie Good (Met Office, UK)	15 mins	
11:50 CEST	Overview of the LST_cci Project and Products	Darren Ghent (U. Leicester, UK)	25 mins	• LST Essential Climate Variable (ECV) Products are consistent in terms of retrieval algorithms, uncertainty characterisation, and coefficient generation. • Optimisation of best cloud clearing detection across new sensors. • The project is ensuring consistency is maintained with other ECV products where possible. • First climate quality LST at high spatial resolution from Landsat and downscaling developments. • Fully independent and rigorous product validation and intercomparison extended to new sites and external datasets. • Significant increase in maturity levels of all LST ECV Products • Demonstration of climate applications resulting in several journal papers published, accepted, or in review – many led by users in the Climate Research Group.
12:10 CEST	ESA's CCI Programme	Simon Pinnock (ESA)	20 mins	• CCI Project activities: Climate science requirements, algorithm development, data processing, product

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				generation, long-term archiving and outreach, ECV utilisation • CCI Open Data Portal https://climate.esa.int/data • Education resources at https://climate.esa.int/educate • Web-based visualisation tool at https://cfs.climate.esa.int
12:30-13:00	**Break**			
LST_cci Data Set Development and Validation Chair: Claire Bulgin				
13:00 CEST	Details of the LST_cci products (IR LEO) Details of the LST_cci products (IR GEO) Details of the LST_cci products (MW LEO)	Karen Veal, Mike Perry, Sofia Ermida, Carlos Jiménez	40 mins	• Phase 1 products are available on the ESA Open Data Portal • The Calibration Database is an expanded database of surfaces and atmospheres designed to be the principal environment in which algorithms are trained and tested • The CDR is constructed from BTs intercalibrated with IASI using a method with GSICS heritage • Geostationary datasets from SEVIRI, GOES, HIMAWARI: sensors are not intercalibrated. • Unlike IR, MW can penetrate clouds. Time correction improves stability between sensor records.
13:45 CEST	Validation of LST_cci products	Lluis Perez Planells (KIT, Germany)	20 mins	• Validation of LST_cci products is essential to assess product quality and inform users of the data's accuracy and limitations. • LST_cci validation is independent of the data producers • IR LEO products compared to in situ radiometers had biases less than +/- 1 K, RSD was within +/- 2.5 K for most stations.
14:00-15:00	**Break**			

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LST_cci Phase I User Case Studies 1 Chair: Darren Ghent				
15:00 CEST	A new Level 4 multi-sensor ice surface temperature product for the Greenland Ice Sheet	Ioanna Karagali (DMI)	20 mins	• A new, gap-free L4 Ice Surface Temperature (IST) product has been generated over the Greenland Ice Sheet for 2012. • Validation of upstream satellite data and new L4 IST against in situ PROMICE and IceBridge revealed the very high quality and robustness for some of the input datasets and the L4 IST. • L4 IST used to characterise spatial and temporal variability over the Greenland Ice Sheet for 2012 when an extensive melt event occurred. • L4 IST assimilated in a Surface Mass Balance Model (SMB) to assess its potential for improving SMB components. • Significant improvement of model estimates compared to PROMICE and IceBridge, during onset of melt season.
15:20 CEST	Revisiting the Seasonality of Surface Urban Heat Islands	Panagiotis Sismanidis (RUB)	20 mins	• The authors use the LST_cci ATSR-2, ATSR-3, and Terra MODIS data to investigate the seasonal hysteresis of SUHIIs. • Results for wet climate cities confirm the expected concave-up shape. However, for dry climate cities further investigations are required.
15:40 CEST	A country scale assessment of the heat hazard-risk in urban areas	Sorin Cheval (MeteoRomania)	20 mins	• Satellite remote sensing has an excellent potential to support the analysis of the Heat Hazard Risk (HHR) at the urban level and provide results comparable and relevant at the country scale. • The study reveals the influence of the geographical context (i.e. landforms and land cover), climatic factors (i.e. regional climate) and urban characteristics (i.e., city size) on the HHR.
16:00-16:30	**Break**			

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LST_cci Phase I User Case Studies 2 Chair: Darren Ghent				
16:30 CEST	An analysis of the stability and trends in six LST_cci datasets over Europe	Lizzie Good (Met Office)	20 mins	• The stability of six satellite land surface temperature datasets is assessed using homogenized station air temperatures over Europe. • Only two datasets are stable; the other four show non-climatic discontinuities associated with a change in sensor and/or drift over time. • Significant trends in land surface temperature of ~0.65 K/decade over Europe are found for one of the stable datasets between 2002-2018.
16:50 CEST	How indispensable is satellite LST for the statistical modelling of land atmosphere fluxes?	Sophia Walther (MPI)	20 mins	• LST as a predictor variable improves accuracy in data-driven land-atmosphere flux models • LST view zenith angle and overpass time have no effect on model accuracy • Clear-sky bias must be accounted for in these modelling activities otherwise model biases result
17:10 CEST	Insights into the Aerodynamic versus Radiometric Surface Temperature Debate in Thermal-based Evaporation Modelling	Kaniska Mallick (LIST)	20 mins	• The study revealed likelihood possibility of biophysical homeostasis in surface temperature where thermoregulation and self-organization leads to optimum vegetation functioning in water-scarce environments for a given fractional canopy cover. • The homeostasis in surface temperature is evidenced by a coordinated response of the canopy-surface conductance to vapour pressure deficit during high soil water stress and radiative heating of the canopy.
17:30	**End of day 1**			

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2.3.2. Wednesday

Wednesday 28 September 2022				
Time	**Agenda Item**		**Duration**	**Key messages**
11:15 CEST	Start arriving at workshop		15 mins	
LST dataset development (non-LST_cci) Chair: Sofia Ermida				
11:30 CEST	CM SAF LST and applications at MeteoSwiss	Anke Duguay-Tetzlaff (MeteoSwiss)	20 mins	• SUMET Meteosat Surface Radiation CDRs produced by joint retrieval of all components of surface radiation and fluxes. • Long-term record spanning two generations of Meteosat sensors • LST record used as ECV for climate monitoring, drought monitoring and in future for climate indicators, urban heat island mapping
11:50 CEST	Deriving Long-term Dynamics of Land Surface Temperature over Europe: Towards a daytime normalized AVHRR LST Product	Philipp Reiners (DLR)	20 mins	• Orbit Drift Correction for a 36-years AVHRR LST time series • Comparison of corrected LST anomalies with air temperature anomalies • The correction increases the correlation between LST anomalies and air temperature anomalies
12:10 CEST	Ground-based experimental study into directionality of surface temperatures over different crops	Mary Langsdale (King's College London)	20 mins	• Crop growing stage and row structure are key drivers of directionality • Surface heterogeneity can be an unpredictable driver of apparent directionality • Multi-angular adaptation of OWL hyperspectral imager will allow assessment at airborne (and satellite) scale.
12:30-13:00	**Break**			

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Re-gridding tool demonstration and practical Chair: Lizzie Good				
13:00 CEST	Demonstration of regridding tool	Hillel Naberik (ACRI-ST)	20 mins	
13:15 CEST	Demonstration of Binder & Python Code	Mike Perry (U. Leicester)	5 mins	Link to Binder and Python code
13:20 CEST	Practical session in break-out groups		35 mins	
14:00-15:00	**Break**			
Uncertainties demonstration and practical Chair: Lizzie Good				
15:00 CEST	Why are uncertainties important for users of LST data?	Claire Bulgin (U. Reading)	20 mins	• Uncertainties inform users of the degree to which the data are in doubt. • Uncertainties are relevant for all applications – scientific conclusions drawn from data require an understanding of uncertainty to ensure that they are robust.
15:15 CEST	Demonstration of Binder & Python Code	Mike Perry (U. Leicester)	5 mins	Link to Binder and Python code
15:20 CEST	Practical session in break-out groups		35 mins	
16:00-16:30	**Break**			
Poster presentations Chair: Karen Veal				
16:30 CEST	Instructions for poster session	Lizzie Good	5 mins	
16:35 CEST	Lightening round of poster presentations	Poster presenters, 1-2 minutes per poster	20 mins	
16:55 CEST	Poster viewing on Gather Town		60 mins	
	Social event & bring your own drink!			
19:00	**End of day 2**			

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2.3.3. Thursday

Thursday 29 September 2022				
Time	**Agenda Item**		**Duration**	**Key messages**
11:15 CEST	Start arriving at workshop		15 mins	
Validation and application of LST data (non-LST_cci) Chair: Lluis Perez				
11:30 CEST	Evaluation of LST_cci MODIS products with ground data measured along transects at the Valencia Test Site (slides are not publicly available)	Raquel Niclòs (U. Valencia)	20 mins	• LST_cci MODIS products are evaluated using ground data measured along transects at a rice paddy site (with three different land covers across the year) near the city of Valencia. • The results show v2 and v3 LST_cci MODIS L3C product overestimates (2 K) both for EOS-Aqua and EOS-Terra at the site, but the results are much better than those for v1 products (4 K). • Using the same ground dataset as reference, lower systematic uncertainties are shown for the operational products (negligible in the case of MYD/MOD11_L2 products). • The LST_cci evaluation will be extended (larger ground database, longer periods, and other satellite sensors).
11:50 CEST	Land Surface Temperature and NDVI for Assessing Vegetation Stress in the data-scarce Sudano-Sahelian Region of Nigeria	Olapeju Ekundayo (U. Fort Hare)	20 mins	• Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) were calculated from MODIS LST and NDVI datasets using ArcGIS software and computed into yearly maps from 2000-2010. • VCI was below normal between 2000-2002, however TCI below normal for all years. • Stress on vegetation in the region is primarily a result of soil dryness and high land surface temperature.

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12:10 CEST	Detecting geothermal anomalies from space	Agnieszka Soszynska (ITC, U. of Twente)	20 mins	• ECOSTRESS thermal imagery is used with kernel-based thresholding to detect geothermal anomalies • Validation performed using in situ temperature loggers and heat flux plates • Overall accuracy is 78.4%. Further work is needed to investigate false positive and false negative errors
12:30-13:00	**Break**			
User requirements Chair: Lizzie Good & Karen Veal				
13:00 CEST	Session introduction	Lizzie Good (Met Office)	10 mins	
13:10 CEST	Interactive user requirements survey and discussion	Lizzie Good & Karen Veal	50 mins	
14:00-15:00	**Break**			
LST and Climate Modelling Chair: Mike Perry				
15:00 CEST	Use of LST-minus-T2m as a metric to measure moisture stress in vegetation	Rob King (Met Office/CMUG)	20 mins	• The difference between LST and 2m air temperature (T2m) can be used as measure of vegetation moisture stress • LST-T2m relationship matches soil moisture variability, although the two signals are completely are out of phase with each other • The 2003 European heatwave was shown using LST-T2m, derived from LST_cci data • Different satellites give different results when evaluating climate models
15:20 CEST	An overview of CMIP and CORDEX and a potential role for satellite LST	Eleanor O'Rourke (CMIP)	20 mins	• An overview of the CMIP and CORDEX projects of the World Climate Research Programme. • How can LST support CMIP/CORDEX model evaluation and validation.

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				• Example activities at the interface of modelling and observations.
15:40 CEST	Discussion	Lizzie Good & Karen Veal	20 mins	
16:00-16:30	**Break**			
Climate Services and the Future of Satellite LST Chair: Carlos Jiménez				
16:30 CEST	Science into climate services	Emily Wallace (Met Office)	20 mins	• Providing a climate service is a multi-discipline question – marketing is an art/science of its own • Think about the whole package – how will people find it? Will they know how to use it? • How can it be funded in the long term?
16:50 CEST	Discussion	Lizzie Good & Karen Veal	30 mins	
17:20 CEST	Final remarks	Lizzie Good & Darren Ghent	10 mins	
17:30	End of day 3			

2.3.4. Poster Presentations

Posters		
Presenter	**Title**	**Key Points**
José A. Sobrino (U. Valencia)	Temperature and Emissivity Separation from MODIS multispectral TIR (Thermal InfraRed) data	• Application of Temperature Emissivity Separation (TES) algorithm to MODIS database in the framework of ESA LST_cci • Generation of LST and Land Surface Emissivity (LSE) global maps for climate applications

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Jasdeep Anand (U. Leicester)	Validation of Sentinel-3 Land Surface Temperature datasets against ground-based measurements	• The LAW project validates Sentinel-3 LST data via comparison with in situ measurements and has established five new in-situ stations in order to improve coverage of specific biomes
		• The metrics calculated for day/night matched observations for both Sentinel-3A and 3B were:
		  ○ accuracy (median difference between Sentinel-3 and in-situ),
		  ○ precision (robust standard deviation of the difference between Sentinel-3 and in situ),
		  ○ uncertainties validated by comparison of the standard deviation of the satellite - in-situ difference with the total satellite in situ matchup uncertainty.
		• Sentinel-3A/B appear to meet the accuracy criterion for all LAW sites. Total uncertainty has good agreement at the KIT (Karlsruhe Institute of Technology) forest site. However, a minority of matchups overestimate the uncertainty.

Claire Bulgin (U. Reading)	Cloud detection stability of Land Surface Temperature Climate Data Records	• Land Surface Temperature (LST) Climate Data Records (CDRs) often use data from multiple satellite instruments. • To use these data to analyse climate signal, stability over time is essential. • In addition to instrument stability, algorithm stability is also important and this includes cloud detection methods. Changes in cloud detection methods between sensors can lead to discontinuities in performance.
Cheolhee Yoo (Hong Kong Polytechnic University)	Downscaling MODIS nighttime land surface temperatures in urban areas using ASTER thermal data through local linear forest	• Although nighttime LST is an important indicator in urban thermal research, few fine-resolution LST downscaling studies have been conducted. A novel method for downscaling 1 km MODIS nighttime LSTs to 250 m using local linear forest (LLF) is demonstrated over Rome, Madrid and Seoul. • When compared with bias-corrected Aster LSTs, the LLF-based scheme has higher accuracy than a control scheme, while retaining the original LST's dynamic range at the finer resolution and depicted the nocturnal thermal spatial pattern more accurately. The LFF-based downscaled LST (DLST) also had a relatively high spatial correlation with in-city nighttime air temperature.

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		• When compared to the original 1 km LST, LLF-based DLST revealed a greater surface urban heat island intensity for urban-type surfaces as well as a stronger temporal correlation with nighttime air temperature.

Jennifer Adams (U. Zurich)	TRISHNA T-SEC PROJECT – Thermal infrared remote sensing of complex ecosystems	• Project focuses on using TIR remote sensing to understand and measure the water status and stress of continental ecosystems over mountainous and tundra regions.
		• Preliminary results are shown.
		  ○ Thermal Airborne Spectrographic Imager acquisitions over the Laegeren forest site are used to extract component temperatures, validate 3D models and examine spatial scaling.
		  ○ UAV (unmanned aerial vehicle) RGB and TIR radiometer acquisitions over the Murtèl rock glacier and TIR radiometer measurements taken during summer 2022. These data will be combined with other TIR data to investigate spatial scaling and surface energy budget.
		  ○ Analyses of TOMST microloggermeasurements at the Kytalyk site to investigate responses of Siberian tundra vegetation thermoregulation to ecosystem variables.

Julia Stoyanova (National Institute of meteorology and Hydrology of Bulgaria)	LST as a biophysical driving parameter of drought and fire activity in Mediterranean climate environment	• This study characterises the spatial-temporal patterns of fire activity using long term satellite data from SEVIRI (2004-2019). • The statistical relationship between LST, the LST anomaly, and LST-T2m and the occurrence of wildfires on a short-term climatic basis is assessed. • The wildfire vulnerability of the main vegetation types (forest, shrublands, cultivated) in response to LST and Soil Moisture Availability warm and dry anomalies is characterised.
Sebastian Westermann (U. of Oslo, Norway)	Using LST_CCI data in the Permafrost_cci project	• The Permafrost_cci processing chain uses time series of remotely sensed LST to force the ground thermal model CryoGrid, which computes time-resolved ground temperature profiles. • In phase II, NASA MODIS L3 LST will be replaced with ESA CCI global LST_cci 0.01º products: the Aqua and Terra MODIS products, as well as the Sea and Land Surface Temperature Radiometer (SLSTR) products from Sentinel-3A and -3B.

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		• Consistency over (multi-)decadal time periods is a critical prerequisite for use in Permafrost_cci. In the light of the planned decommissioning of MODIS Terra/Aqua, it is important to ensure consistency between MODIS and Sentinel-3 LST data.
Abigail Waring (U. Leicester/NCEO)	Improving temperature observations from Space to close the energy budget of the Earth in support of UNFCCC objectives and the Paris Agreement	• The ESA CCI Aqua MODIS data are used to calculate time series of monthly mean, regional LST anomalies for the Amazon, Greenland, Western Europe, Siberia, China, and Australia for 2002-2018. • Linear trends are calculated for each region.
Mike Perry (U. Leicester)	Using LST data to explore Birmingham's UHI. (Author Charlotte Paton)	• Rural background defined using Normalised Difference Vegetation Index and Normalised Built Area Index. • Sentinel 3 LSTs downscaled using Sentinel 2 data are used to investigate the Urban Heat Island (UHI). • The temperature difference between the UHI and rural background for daytime and nighttime are calculated for several days during July 2021.

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3. Workshop Feedback

This section presents the results of the workshop feedback survey, issued just after the 2022 workshop, which received 27 responses. However, all questions were optional so not all questions are answered by all respondents. The primary purpose of this survey is to help improve future events, rather than to gather requirements for the LST_cci project. It is included here for completeness and future reference.

Question 1 (Figure 3-1) asks how the respondents participated in the workshop. All respondents answered this question. The results show that most of the respondents (n=23) attended one or more live sessions. Just over half the number of respondents (n=16) used the Padlets and attended one or more discussion sessions (n=14). Over a third of the respondents (n=11) participated in at least one practical/demonstration session. Some respondents accessed the recorded presentations (n=8), attended the poster 'lightning round' (n=6) and poster/social event (n=6), and used Gather Town (n=2) to meet with colleagues during the workshop breaks.

***Q1: Please select which options most closely match your participation in the LST_cci 2022 User Workshop (multiple options can be selected)*:**

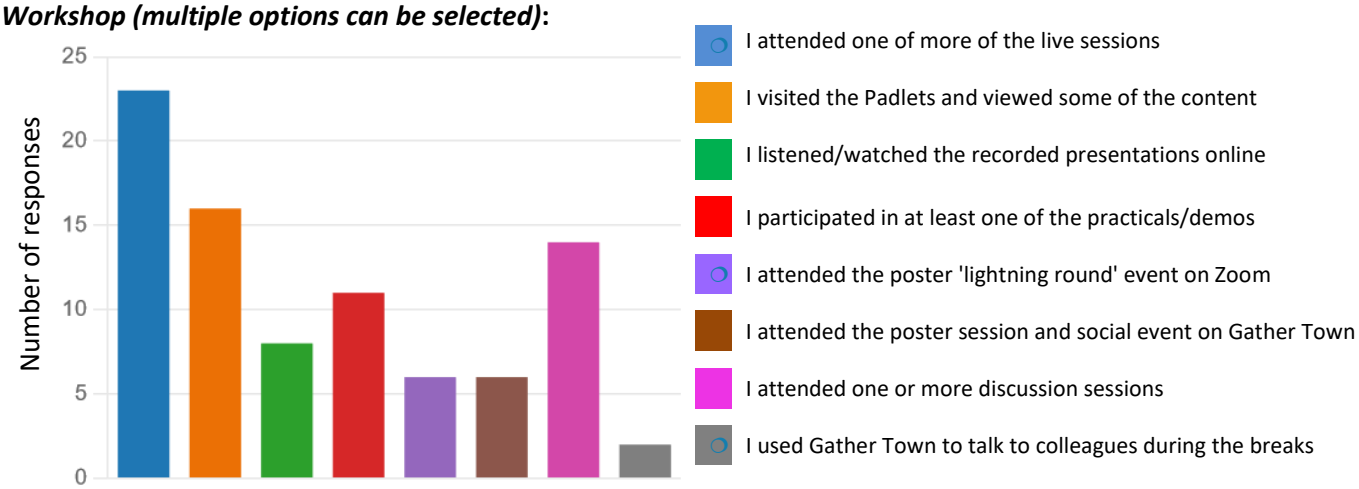

Figure 3-1: Results from Question 1 of the workshop feedback survey. (Note that the order in the legend shown on the right matches the order of the bars in the graph.)

Q2: The LST_cci user workshop utilised a variety of software - did you have any issues with this software?

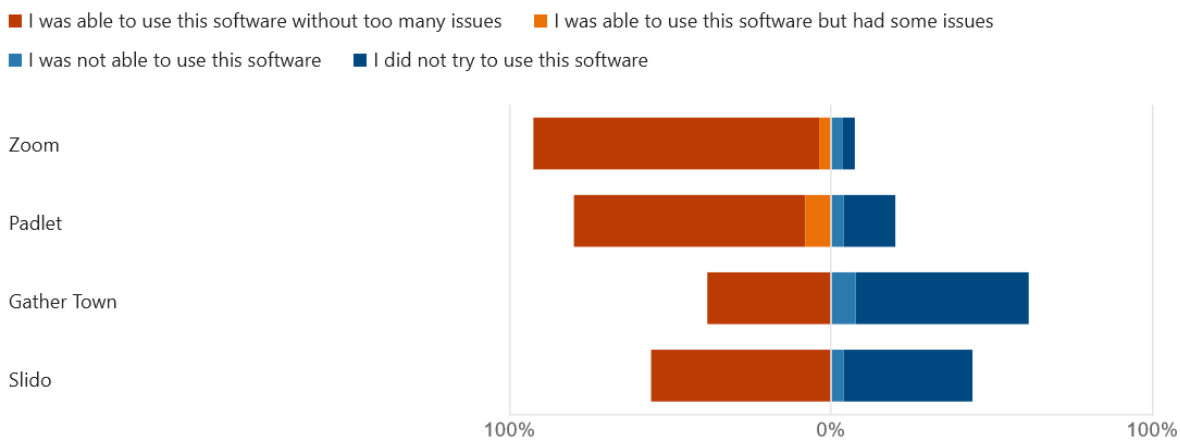

Figure 3-2: Results from Question 2 of the workshop feedback survey.

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The response to question 2 (Figure 3-2) suggests that respondents had very few issues in using the software utilised during the workshop. All respondents answered this question, although two respondents did not provide an answer for all software options. A few respondents had some issues in using Zoom (n=1) and Padlet (n=2). No respondents reported experiencing issues in using Gather Town and Slido, although 2 respondents and 1 respondent, respectively, were unable to use these software applications at all. There was one respondent – a different individual in each case – who was also unable to use Zoom / Padlet.

Question 3 (Figure 3-3) asked the respondents how useful they found the new elements of the workshop. Only 25 respondents answered this question, although one only provided an answer to the first option (demonstrations/practical sessions). In general, respondents were positive about the events in which they participated. Most respondents who participated felt the demonstrations/practical sessions were useful (strongly agreed n=7, agreed n=8, neutral n=1, disagree n=1). Most respondents that participated in the poster event on Zoom and Gather Town also thought the event worked well (strongly agreed n=7, agreed n=4, neutral n=3, did not attend n=10). Fewer respondents attended the social event (n=10), but those that did attend were generally positive about the experience (strongly agree n=2, agree n=5, neutral n=3). More respondents participated in the Slido discussions and again, most were positive about the experience (strongly agreed n=5, agreed n=8, neutral n=4, did not participate n=7).

Q3: Please indicate your agreement with the following statements regarding the new elements of the 2022 workshop (not included in the 2020 workshop):

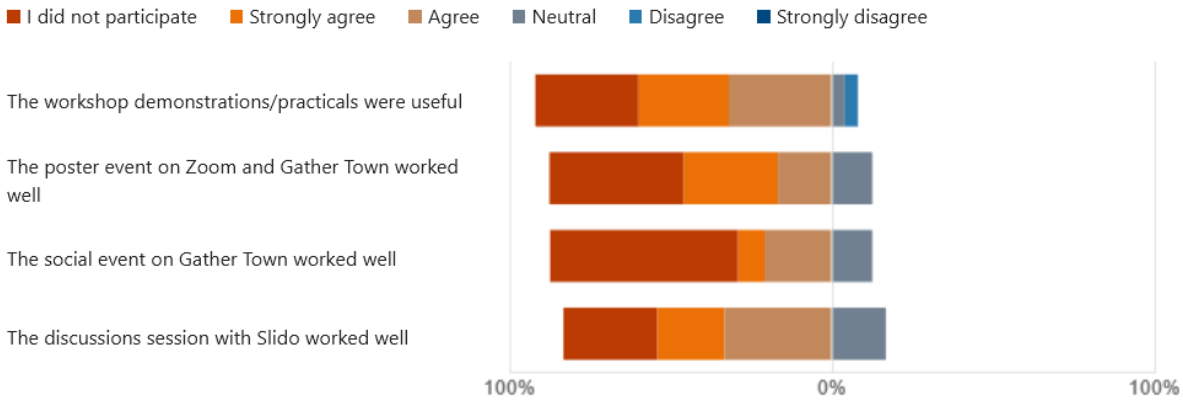

Figure 3-3: Results from Question 3 of the workshop feedback survey.

Five respondents left further comments regarding the new elements of the workshop (Figure 3-4). One respondent commented that the Padlets were somewhat confusing. This feedback was also given in response to the 2020 User Workshop; however, in response, more effort was made during the 2022 Workshop to make the Padlet 'Landing Page' more visible in the workshop information booklet. This comment was only made by one respondent, so may perhaps be an isolated view. However, ways to improve this further will still be considered for the next workshop. One respondent commented that perhaps there was too much use of Slido during the discussions. As it was the first time Slido had been used in an LST_cci workshop, this was a learning experience for all. Fewer questions will be considered for the next workshop anyway, as it was a challenge to get through all questions during the discussion sessions. There was one request to retain the data and code from the practical sessions on GitHub after the workshop, and a general request from some workshop participants during the event to make the Binder permanently available.

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Q4: Please use this box to make any further comments you would like to make to give insight into your answers above about the new elements of the LST_cci User Workshop that we tried this year.

I found the Padlets a bit confusing. This may have been because I was just joining for one session so didn't have the week to get familiar with what was possible.
It could be good to democratise the availability of data (to make available the processed data either in GitHub or other media in GitHub or other means).
Perhaps a little too much use of Slido, having a question or two and then discussion might have been better.
What is the LST EASE grid?
Workshop was very fruitful and informative.

Figure 3-4: Results from Question 4 of the workshop feedback survey. The text has been edited for readability.

Q5: If you attended one or both of the practical sessions, please indicate your agreement with the following statements:

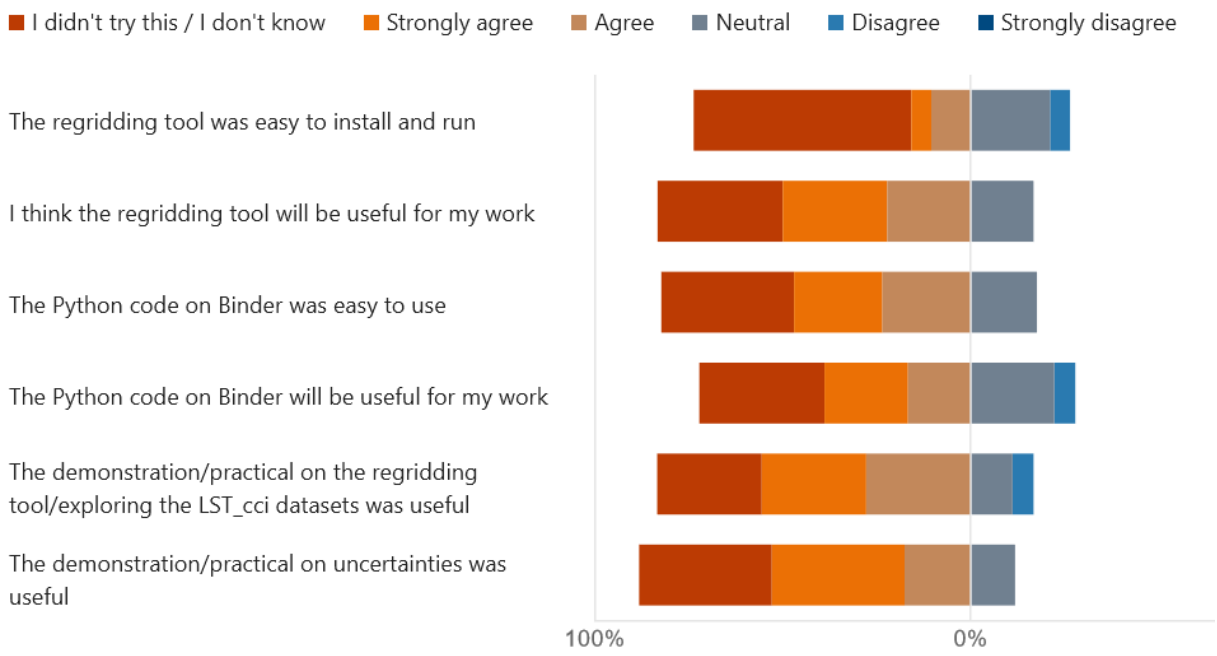

Figure 3-5: Results from Question 5 of the workshop feedback survey.

Question 5 asked the survey respondents for detailed feedback on the demonstration/practical sessions (Figure 3-5). Only 19 responses were received, and not all respondents provided responses for each part of the question. In general, the feedback was positive from those that participated in the practical sessions. Unfortunately, most respondents (n=11) did not try or didn't know whether the regridding tool was easy to install and run and one disagreed that it was easy to install/run. The remaining respondents were more positive about the tool (strongly agreed n=1, agreed n=2, neutral n=4). Respondents were more positive about the tool being useful for their work (strongly agreed n=5, agreed n=4, neutral n=4, don't know n=6). Most respondents that tried the Python code on Binder felt that this was easy to use (strongly agree n=4; agree n = 4; neutral n=3, did not know/didn't try n=6). The results were similar when respondents were asked whether they felt the Python code on Binder would be useful for their work (strongly agree n=4; agree n=3; neutral n=4, disagree n=1, did not know n=6). Respondents felt similar about the overall usefulness of the practical/demonstration on the regridding tool/exploring LST_cci

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datasets (strongly agree n=4, agree n=3, neutral n=4, disagree n=1, did not try/don't know n=6). The respondents were slightly more positive about the usefulness of the uncertainty demonstration/practical (strongly agree n=6, agree n=3, neutral n=2, did not try/don't know n=6).

Question 6 was a free-text question for the respondents to provide more details concerning their experience during the practical sessions. One respondent felt that the practical didn't explore the regridding tool enough. Another respondent felt more time was needed for the practical sessions. These responses will be considered when formulating the next LST_cci user workshop.

Q6: Please use this box to make any further comments you would like to make to give insight into your answers above regarding the practical sessions:

The practical session used code to look at things already done with the regridding tool not the tool itself.
Thank you for organising such type of informative session.
More time for practical session.
Not able to attend practical sessions so no comments on this, thank you.
We will discuss with my colleagues the regridding tool and will come back for some discussion if we decide to apply it in our work.

Figure 3-6: Results from Question 6 of the workshop feedback survey. The text has been edited for readability.

Q7: Is there anything else you would like us to include in the next LST_cci User Workshop, which is expected in 2024? For example, a specific session topic or other 'hands on experience'?

I would enjoy a session about climate applications (although not sure how many climate researchers in the remote sensing community).
LST data fusion.
It could be more interaction. If there is an opportunity to make at least 5 persons in one group in a breakout room and run different mini projects.
LST calculation methods and their differences.
More issues about climate change and urban climate.
Floods and droughts topics.
I would like to hear more application work using LST, such as model revision, data assimilation, and would like to hear the LST future from experts. Thanks, it is a really good workshop.
On LULC [land use / land cover] and its impact on LST.

Figure 3-7: Results from Question 7 of the workshop feedback survey. The text has been edited for readability.

Question 7 asked respondents what they would like to include in the next LST_cci user workshop. Two respondents said they would like to hear more about LST applications. Other respondents requested sessions on LST data fusion, LST calculation methods, climate change & urban climate, floods and droughts and land cover and its impact on LST. All these will be considered for future LST_cci workshops, and in particular, if the project joins with another CCI project for a joint workshop; for example, a combined LST and Land Cover workshop. A joint workshop could also be beneficial in encouraging more people to attend and facilitate more cross-ECV discussions and ideas. The project team have also discussed producing online seminars on more technical matters associated with LST, for example LST retrieval methodology. Finally, one respondent suggested a more interactive approach, for example gathering in small teams to outline small projects involving LST (that could be proposed for funding in the future).

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Q8: Please use this space to provide any further comments on the LST_cci 2022 User Workshop:

The discussion sessions were particularly well conducted and interesting.
It is well organised.
It could be nicer to increase the number of workshops at least once per 6 month or 2 times per year.
Thank you for great organization!
It is an interesting experience for to attend this workshop online. The practical session is useful.
Very informative workshop.
I think that more practical applications will be useful; unfortunately, not many people are familiar with the utility of LST.

Figure 3-8: Results from Question 8 of the workshop feedback survey. The text has been edited for readability.

Question 8 provided a free-text box to provide any other feedback on the workshop. Several respondents provided very positive feedback on the workshop and its organisation. One respondent suggested covering more practical applications for LST. Another respondent suggested holding more frequent workshops. Although holding more frequent workshops may be beyond the scope of the LST_cci project given the level of effort required to hold this type of workshop, other types of events could be considered, for example, open question & answer sessions where members of the project team are available online for a specific window where users can join to 'speak to an expert'.

3.1. Key feedback points

The following list summarises the main feedback points from the LST_cci 2022 User Workshop:

- Very few issues were experienced with the software utilised during the workshop, so Zoom, Padlet, Gather Town and Slido could all be considered for use at future LST_cci workshops/events.
- The poster event on Gather Town with a prior Zoom session with lightning round worked well and could be considered for future events. However, it was not as well attended as expected, so additional effort is needed to encourage delegates to attend.
- Padlet worked well but the workshop committee should consider how the Padlets can be made clearer for future events.
- Slido worked very well during the discussion sessions, but it was challenging to get through all the questions in each session; over the ~105 minutes of question/discussion time during the meeting, 31 questions were posed, averaging ~3.4 minutes per question. For future events, a smaller number of questions would be better, perhaps aiming for ~4-5 minutes per question.
- The demonstration/practical sessions worked well. The format and type of material developed specifically for these sessions could be considered for future events. However, using the Regridding Tool during the practical session did not work so well as not all participants could download or use the tool as it required a Linux system. Although the practical sessions were designed with this in mind (everyone could use the Binders, for example) it would be better to avoid this in future as it created some confusion during the session.
- Longer practical sessions could be considered for future events.
- As the use of uncertainties is not yet widespread and there is evidence to suggest that many users still do not fully understand them, sessions dedicated to the use and understanding of uncertainties should be included in future events.
- The following topics should be considered for future events:

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- Methods for retrieving LST
- Climate applications
- LST data fusion
- Climate change
- Urban climate
- Floods and droughts
- Modelling and data assimilation
- Impact of land cover/land use on LST
- Future plans for satellite LST (e.g. instruments, retrieval, datasets, etc)

- A session (or multiple sessions) to enable participants to 'brainstorm' new project ideas that could subsequently be developed and submitted for funding opportunities could also be considered for future events.
- There was a request for more frequent LST_cci workshops. Whilst this may not be practical given the level of organisation required for such an event, the project could consider holding more frequent smaller or more targeted events, e.g. informal knowledge exchange meetings, seminars, open question & answer sessions, etc.
- Future workshops could be held in conjunction with other CCI ECV projects relevant to LST to encourage more people to attend, reach a wider audience and foster collaboration. For example a combined workshop with SoilMoisture_cci or LandCover_cci could be very fruitful.

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4. Workshop Outcomes

4.1. Summary of Discussion and Feedback Sessions

As noted in the preceding sections of this report, three discussion sessions were held during the workshop on 1) User requirements, 2) LST and climate modelling and 3) climate services and the future of satellite LST. Each of these sessions began with one or two talks, followed by discussion using the 'Slido' online tool (https://www.slido.com/) to pose questions and gather responses from the participants of the workshop. The questions were discussed and agreed by the workshop committee in advance of the workshop and were designed to gather insight into the use of LST and any new requirements for the LST_cci project. As noted in Section **Error! Reference source not found.**, recommendations resulting from u ser feedback are listed in this document and will be used to define new user requirements for the LST_cci project in the URD [AD-03].

4.1.1. User Requirements:

4.1.1.1. Slido Results and Related Discussion

The first two questions of this session were designed to provide context for the later questions and focused on the respondent's main application and their use of LST_cci datasets.

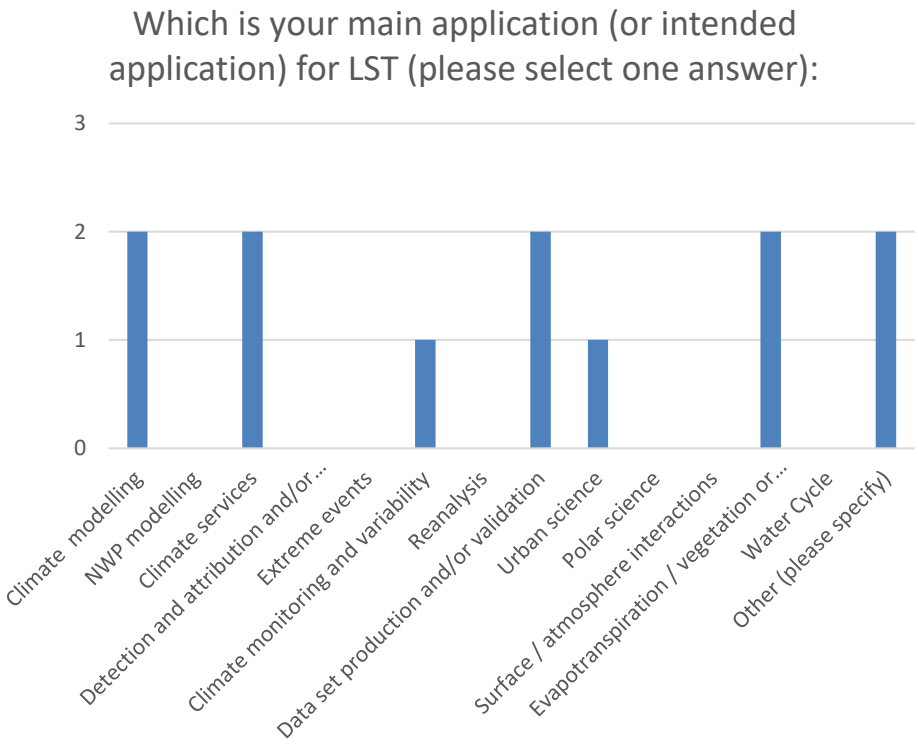

Figure 4-1: Slido result – 'Which is your main application for LST?' Number of respondents = 12. The two applications that are not labelled completely in the figure above are "Detection and attribution and/or climate impacts" and "Evapotranspiration / vegetation or crop monitoring".

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Figure 4-1 shows the main application for LST of the workshop participants present for this discussion session. Of the twelve users who answered this question, six gave climate-based applications (modelling, services, monitoring/variability, dynamics). None of the users who answered had main applications in NWP modelling, reanalysis, Polar science, extreme events, surface/energy interactions, or the water cycle. Of those who answered "Other", one specified energy transition and one stated climate dynamics. The LST_cci project could consider targeting these communities to encourage them to attend future events.

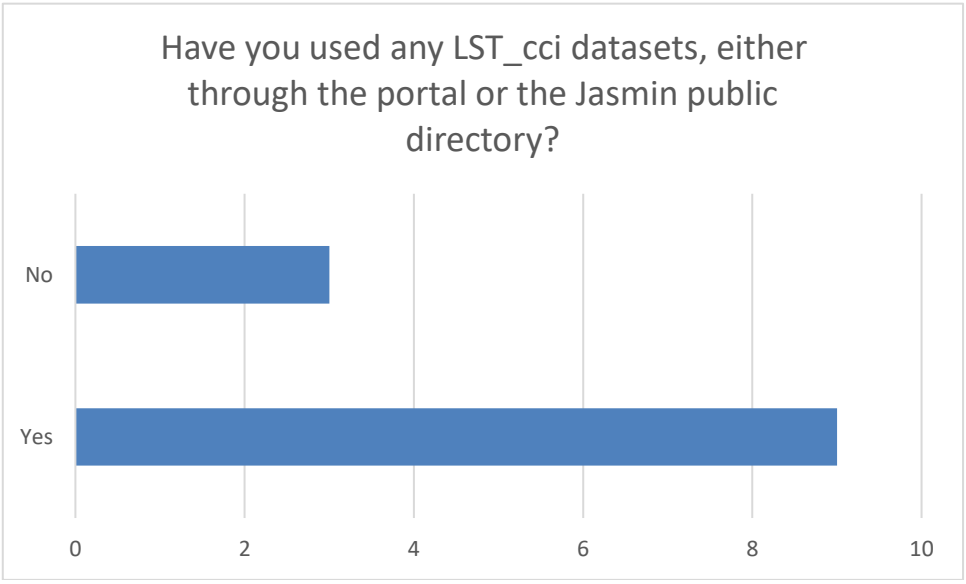

Figure 4-2: Slido results – 'Have you used any LST_cci datasets, either through the portal or the Jasmin public directory? (Yes/No)'. Number of respondents = 12.

Figure 4-2 shows the participants use of LST_cci data. Three quarters of respondents had experience of using LST_cci datasets.

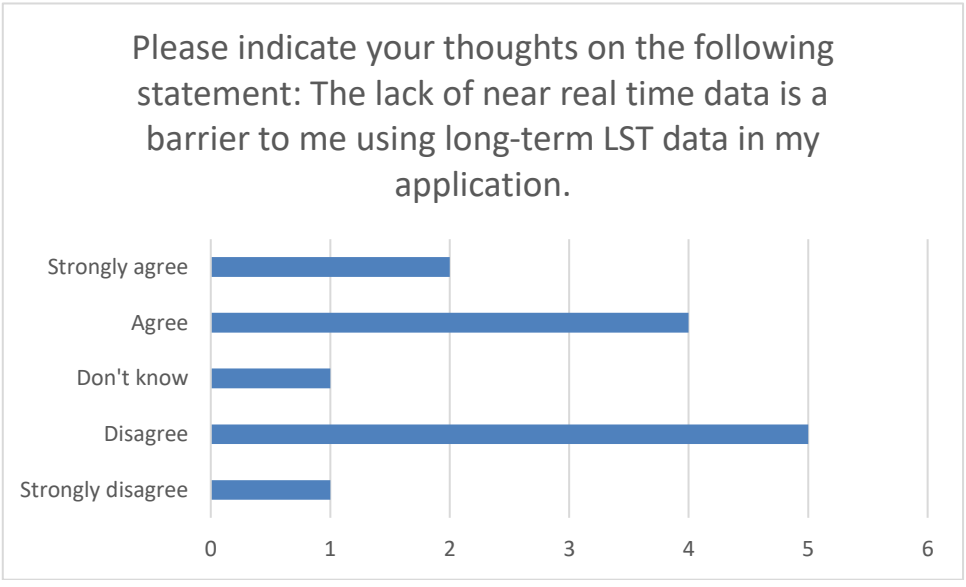

Figure 4-3: Slido results – 'Please indicate your thoughts on the following statement: The lack of near real time data is a barrier to me using long-term LST data in my application)'. Number of respondents = 13.

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Figure 4-3 concerns the availability of near-real time data. Almost half the respondents to this question indicated that lack of real time data was a barrier to their use of LST data.

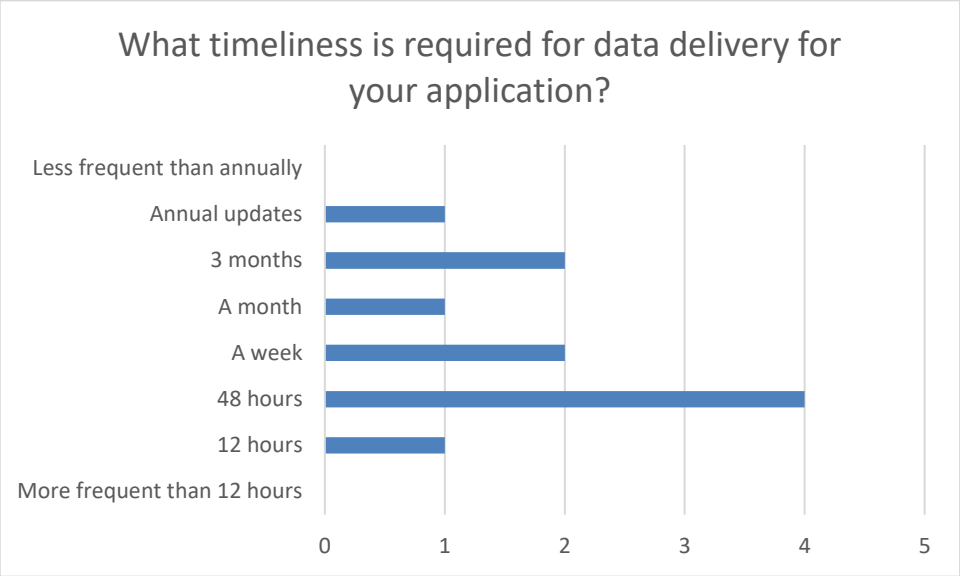

Figure 4-4: Slido results – 'What timeliness is required for data delivery for your application?' Number of respondents: 11.

Figure 4-4 shows the timeliness required for data delivery. The required timeliness varied amongst respondents: no-one required data delivery within 12 hours, however, nearly half required data timeliness to be within 48 hours.

- **Recommendation 1: Provide LST_cci data within 48 hours of acquisition.**

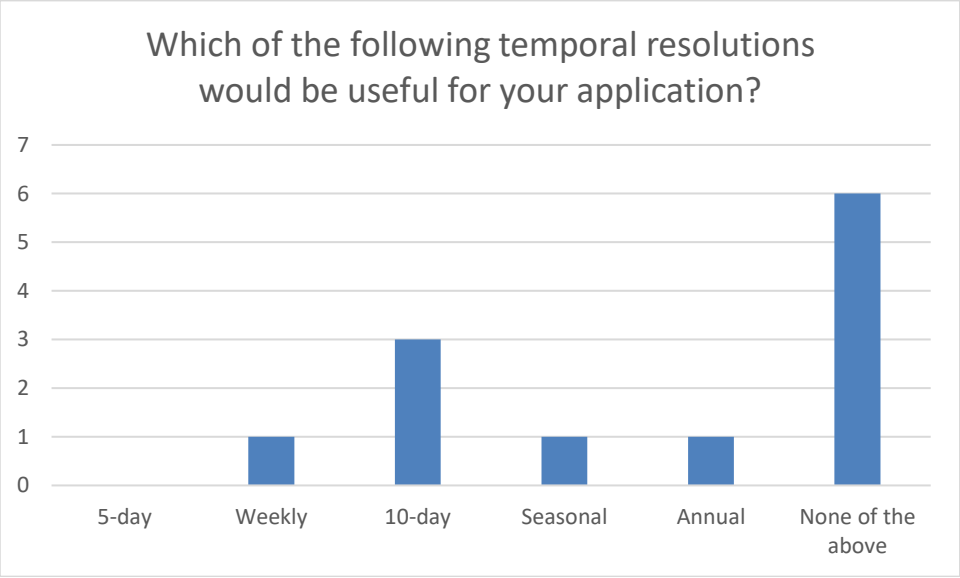

Figure 4-5: Slido results – 'Which of the following temporal resolutions would be useful for your application?' Number of respondents: 12.

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Figure 4-5 is concerned with the temporal resolution of the data that users require. Only a selection of options were provided for this question as users have been asked previously for their requirements for data on several different timescales previously. Half of the replies indicated none of the resolution choices were useful. These users may be using the daily or monthly resolutions LST_cci already provides. Of the resolutions given, 10 daily was most popular with three people indicating this resolution would be useful in their applications.

One user noted that monthly resolutions at a particular time of day would be useful - the merged GEO/LEO IR products provide monthly averages at 3 hourly intervals in Universal Time. Seasonal means were stated to be useful for some climate applications, e.g. LST variations during glacial melt seasons.

- **Recommendation 2: Provide LST_cci data as 10-day means.**

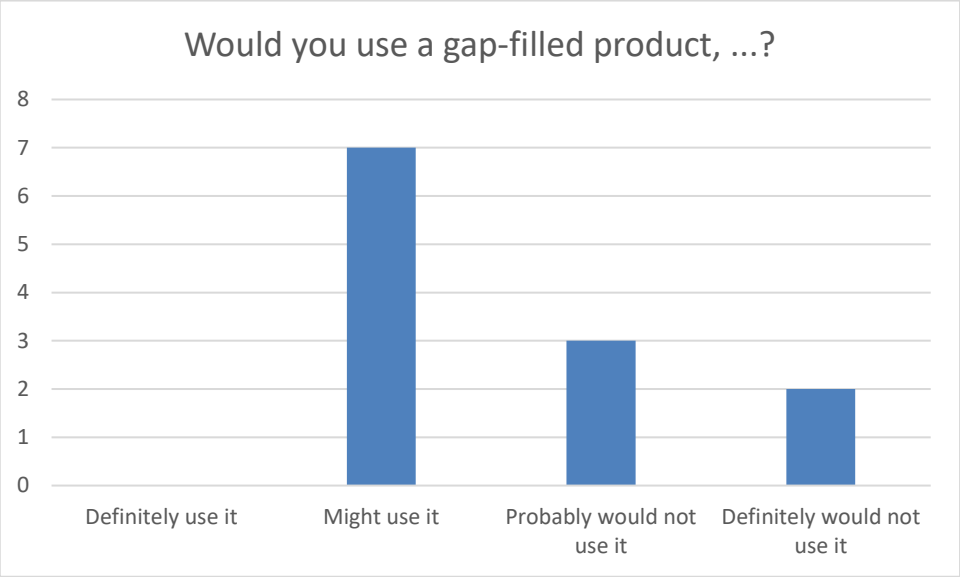

Figure 4-6: Slido results: - 'Would you use a gap-filled product, even if the gaps were filled with a "best guess", e.g. based on model data, heavily interpolated, or a climatology, even if these data have very large uncertainties (e.g. >5 K)?' Number of respondents: 12

Figure 4-6 demonstrates that many respondents might be interested in gap-filled products. However, almost half the respondents either probably or definitely would not use these types of data.

- **Recommendation 3: Provide gap-filled LST_cci products.**

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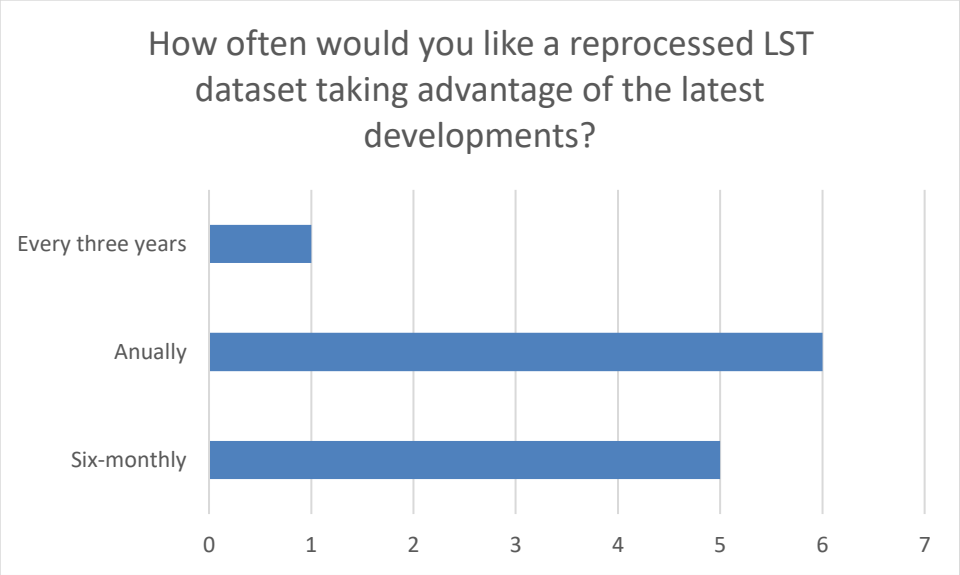

Figure 4-7: Slido results – 'How often would you like a reprocessed LST dataset taking advantage of the latest developments?' Number of respondents: 12

Figure 4-7 shows how often the respondents would like reprocessed datasets. Nearly all users would like at least annual reprocessing, nearly half would like updated datasets at six-monthly intervals.

- **Recommendation 4: Provide reprocessed LST_cci datasets at least annually.**

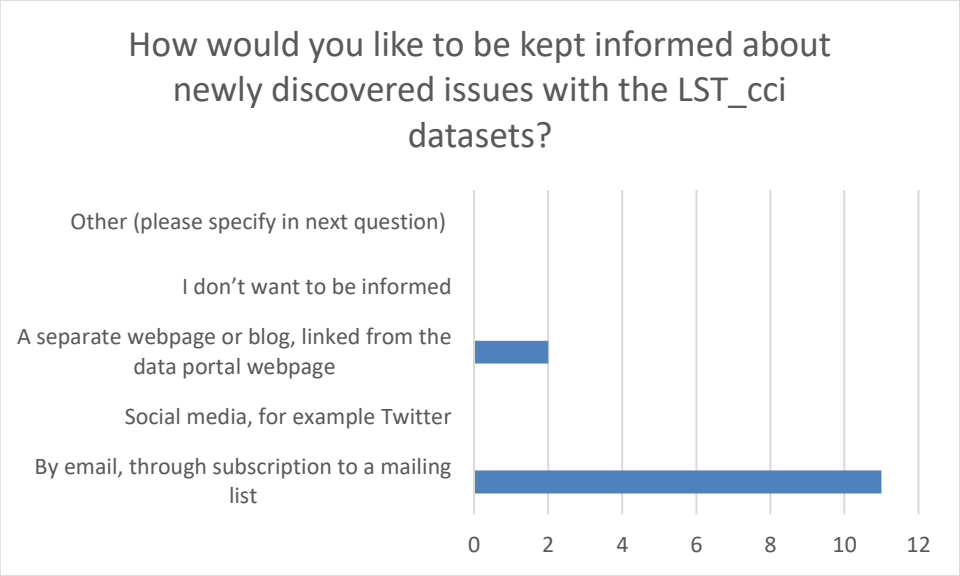

Figure 4-8: Slido results – 'How would you like to be kept informed about newly discovered issues with the LST_cci datasets?' Number of respondents: 13

Figure 4-8 indicates the methods by which participants would like to be informed about new issues found within the datasets. All users wanted to be kept informed of newly discovered dataset issues: most (11/13) through an email subscription and the rest via a webpage linked to the data portal. In discussion, the consensus was to have a webpage/blog as a permanent resource that can be accessed

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for historical issues, but users would have an option to be sent email notifications when new issues were added.

In discussion, some users requested more detailed information on data issues, potentially including a mathematical description if appropriate, so that they could gauge how a data issue might impact their application.

- **Recommendation 5: Maintain a webpage/blog as a permanent resource that can be accessed for historical issues.**
- **Recommendation 6: Provide users with the option to be sent email notifications when new issues are discovered and added to the issues list.**

Question 9 of this session asked about issues experienced with LST_cci data products; the results, which were in 'free text' format are shown in Table 3.

Table 3: Free text entries provided in response to the question: 'If you have used LST_cci data products, have you experienced any issues in using the data and if so, what are the main problems you have experienced so far?' Number of respondents: 12

Cloud covering.
Cloud contamination.
Cloud masking.
Using Meteosat based LST, the main problem is cloudiness.
The cloud flagging is not perfectly clear i.e. what is provided, what has been applied.
Cloud masking in IR data - still missing some cloud!
Missing data files for certain days (can't always be helped if sensor is offline or failed) but maybe address gaps in data?
Latency to most recent periods.
Use of uncertainty info not fully clear.
Bad data issue in 2014.
It is hard to find the link to Jasmine to download the data, buried in a pdf currently. A big red download button in the ESA CCI webpage will facilitate the use/downloading of the data!
Not LST_CCI: georeferencing accuracy.

This question generated much discussion which is summarised below.

- Half of the problems encountered involved cloud and IR data: inaccuracies in the cloud clearing, lack of information on what cloud clearing had been applied, and the difficulty in using data products with gaps due to presence of cloud.
- Data access was highlighted: a direct link to data download on the ESA LST_cci webpage is needed.
- The bad data issue in 2014 was in an early version of the MODIS/Aqua data and has been rectified in later versions.

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- A request was made for more information on the uncertainties as metadata in individual products.
- One user noted that the lack of data for the more recent period was an issue. Phase 1 datasets extended up to 2018-2020 depending on datasets and will be extended to end of 2021 in the first Phase 2 release but this may not be enough for some users.
- Several users requested information on which products were missing when satellite data are not available due to outages for maintenance, manoeuvres etc. Some asked that LST_cci provide the missing products as files with fill values and some would like an inventory of missing files.

As a recommendation for the provision of gap-filled LST data has already been identified earlier in this report, no new recommendation is specified here. Similarly, the recommendation for more up-to-date data provision is also not repeated here as this was also identified earlier in this report.

- **Recommendation 7: Improve IR cloud screening.**
- **Recommendation 8: Provide detailed information on IR cloud screening processes.**
- **Recommendation 9: Provide a direct link to download LST_cci data on the LST_cci web pages.**
- **Recommendation 10: Provide detailed information on uncertainties (consider including this in individual file metadata).**
- **Recommendation 11: Provide information on data gaps, e.g. due to sensor outages or satellite manoeuvres.**
- **Recommendation 12: Provide fill values in files for missing data products and an inventory of files with missing data.**

Figure 4-9: Slido results – 'What do you consider to be the most important issues to resolve with LST datasets in general?' Number of respondents: 12

Figure 4-9 displays a word-cloud regarding the issues considered most important to resolve in the LST datasets. Over half (7/12) of respondents indicated cloud cover as being the most important issue to resolve with two of the respondents indicating high resolution.

- **Recommendation 13: Prioritise dealing with cloud cover in IR data sets (both improved masking and gap filling).**

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Table 4: Free text entries provided in response to the question: 'Thinking about the LST_cci regridding tool that was presented yesterday, what additional map projections would be useful as output, for example, an equal-area grid? Currently the tool can only produce a regular latitude-longitude grid.' Number of respondents: 10

MODIS reprojection tool.
Maybe we can use regrid for other projections.
I'm not sure what CMIP7 grids will look like but if different to regular lat/lon then having those grids available in the regridding tool would be good.
A pre-set regrid? I.e. for certain biomes maybe
lat lon is great!
Work with shape files?
Polar EASE grid.
Some existing plotting software would allow reprojection from lat/lon grid.
Regular lat long grid is fine for me.
Polar EASE grid.

Table 4 shows the free text entries that were provided in answer to the question about other map projections that could be considered for the regridding tool. Two people responded that the current tool is adequate for their needs. One respondent suggested a reprojection matching the CMIP7 grids, although it is not yet known what these will be. There were two requests for the Polar EASE grid, although it should be noted that no respondents cited Polar science as their main application. Following the workshop, an email was sent to all members of the LST_cci mailing list asking whether it would be useful for the LST_cci project to provide LST data on a Polar EASE grid. One positive response was received in reply to this enquiry, suggesting that there may be a need for data provision on a Polar EASE grid, but this is not widespread.

- **Recommendation 14: Provide LST data on a Polar EASE grid**

Table 5 shows the free text responses in answer to a question about other useful tools that would help users to use LST_cci data products. The ESMValTool and Climate Data Operators are existing tools that can already be used with LST_cci data products. Two respondents highlighted the need to extend the Regridding Tool to produce temporal means as the current tool only averages and propagates uncertainties in space. One respondent noted that it would be useful to develop a wrapper for the existing Regridding Tool that would allow multiple files to be processed as the current tool only processes one file at a time.

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- **Recommendation 15: Extend LST_cci Regridding Tool to produce temporal means (e.g. weekly, pentads, etc).**
- **Recommendation 16: Develop a wrapper for the LST_cci Regridding Tool to process multiple files.**

Table 5: Free text entries provided in response to the question: 'In addition to the regridding tool presented yesterday, are there any other tools that would help you to use LST_cci data products? Number of respondents: 6

Regridding over days, 10-days, month.
Climate Data Operators.
Wrapper for the regridding tool.
Would be good if a tool could process multiple files, e.g. a date range, rather than a single day.
Uncertainty tool.
ESMValTool.

Table 6: Free text entries in response to the question: 'What additional processing do you apply to LST data in order to use these data in your application? For example, regridding, additional cloud screening, outlier filtering, etc.' Number of respondents: 6

Regridding, daily averages.
Provide climatology for comparison.
Anomaly calculations.
Combining with other data to create useful indices.
Merging into one file (monthly data).
Additional cloud screening - not all cloudy data are screened in the operational data.

Table 6 provides the free-text responses in answer to a question about any addition processing that users apply to LST data. The aim of this question was to ascertain whether there was any additional processing that users are routinely applying to LST products that the project could support, e.g. by adapting the Regridding Tool to perform some of this processing. Additional processing included spatial regridding, temporal averaging, additional cloud screening, and calculation of climatology and anomalies. Provision of LST_cci climatology products was discussed, noting that some climate data records (CDR) now had the temporal coverage of 20-30 years required for an accurate climatology. However, calculation of an accurate climatology from 'gappy' data, in the case of IR datasets in particular, is not straightforward. Furthermore, there are many aspects to consider when making climatologies, for example, how closely to adhere to the World Meteorological Organisation's (WMO) requirements for climatological normal. Therefore, the provision of climatologies is an area that the LST_cci project could consider for future work.

- **Recommendation 17: Provide LST climatologies.**

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Table 7: Free text responses to the question: 'Are there any derived properties of LST that would be useful in your application? For example, minimum and maximum LST, amplitude of annual cycle, a location-based variance parameter? Number of respondents: 5

Climatologies and anomalies.
Monthly means.
Min/max daily/monthly/annual LST.
Climatology.
LST-T2m.

Table 7 provides the free text responses to a question concerning the calculation of useful properties of LST. The aim of this question was to ascertain what additional products the LST_cci project could provide in the future that would be useful for users. In addition to calculating climatologies, which was already highlighted in the previous question, respondents identified daily minimum and maximum LST, the LST-air temperature difference (LST-T2m), and anomalies. Monthly means are already provided as standard by the LST_cci project so are not identified here as an additional recommendation.

- **Recommendation 18: Provide selected properties derived from LST, for example, anomalies, daily minimum and maximum LST, annual means and LST-2m air temperature differences.**

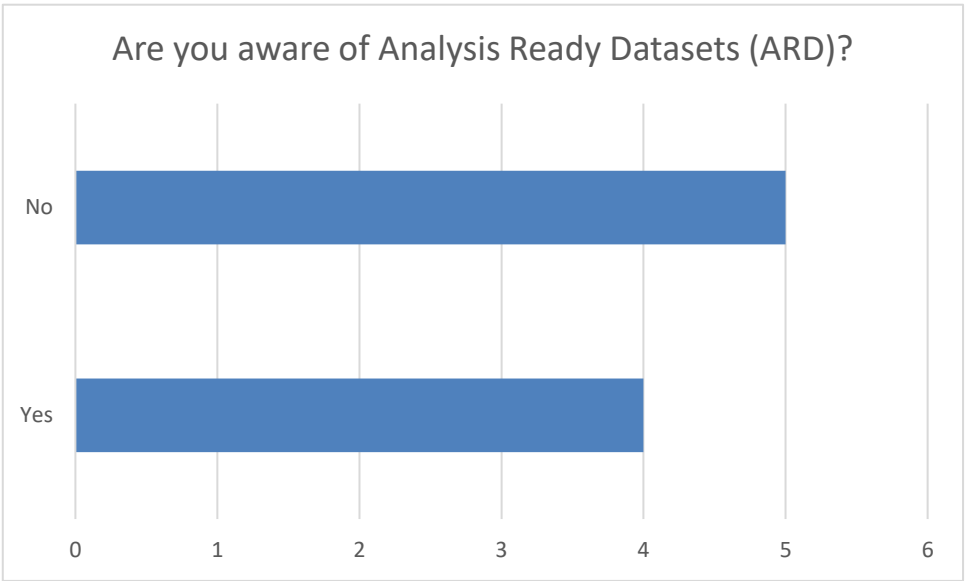

Figure 4-10: Slido results – 'Are you aware of Analysis Ready Datasets (ARD)?' Number of respondents: 9

Figure 4-10 shows how many participants are aware of Analysis Ready Datasets (ARD). Just under half the respondents were aware of ARDs. The aim of this question was to ascertain whether the respondents knew what ARDs were, providing context for the following questions that ask about additional requirements for ARDs.

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Table 8 provides the free text responses to a question asking about further requirements for LST ARDs. Good documentation, easy access formats and a simple quality flag were highlighted. Three of the seven respondents did not know what would be needed.

Table 8: Free text responses in answer to the question: 'What more is needed from the LST_cci project to provide an ARD-type product? Number of respondents: 7

Good documentation.
Easy to access data formats.
Format into GeoTIFF for instance.
Don't know.
Simple Quality flag.
Not know.
Not sure.

- **Recommendation 19: Ensure LST_cci ARDs are provided with good documentation, in easy-to-access formats with simple quality flags.**

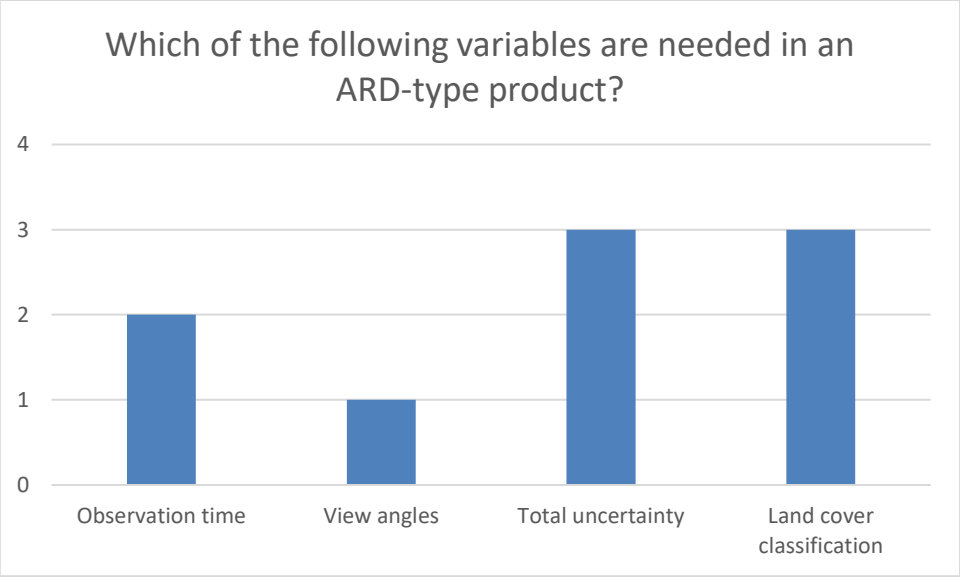

Figure 4-11: Slido results – 'Which of the following variables are needed in an ARD-type product? This is just for an ARD-type product, the core LST_cci products will still contain these variables'. Number of respondents: 4

Figure 4-11 shows what variables respondents consider necessary in an ARD-type product. Only four people responded: three considered total uncertainty and land cover classification necessary for an ARD product, two thought observation time should be included, and one thought the view angles should be in an ARD product.

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- **Recommendation 20: Provide observation time, view angles, total uncertainty and land cover classification in LST_cci ARD products.**

4.1.1.2. Summary of Recommendations

- Provide LST_cci data within 48 hours of acquisition.
- Provide LST_cci data as 10-day means.
- Provide gap-filled LST_cci products.
- Provide reprocessed LST_cci datasets at least annually.
- Maintain a webpage/blog as a permanent resource that can be accessed for historical issues.
- Provide users with the option to be sent email notifications when new issues are discovered and added to the issues list.
- Improve IR cloud screening.
- Provide detailed information on IR cloud screening processes.
- Provide a direct link to download LST_cci data on the LST_cci web pages.
- Provide detailed information on uncertainties (consider including this in individual file metadata).
- Provide information on data gaps, e.g. due to sensor outages or satellite manoeuvres.
- Provide fill values in files for missing data products and an inventory of files with missing data.
- Prioritise dealing with cloud cover in IR data sets (both improved masking and gap filling).
- Provide LST data on a Polar EASE grid.
- Extended LST_cci Regridding Tool to produce temporal means (e.g. weekly, pentads, etc).
- Develop a wrapper for the LST_cci Regridding Tool to process multiple files.
- Provide LST climatologies.
- Provide selected properties derived from LST, for example, anomalies, daily minimum and maximum LST, annual means and LST-2m air temperature differences.
- Ensure LST_cci ARDs are provided with good documentation, in easy-to-access formats with simple quality flags.
- Provide observation time, view angles, total uncertainty and land cover classification in LST_cci ARD products.
- Consider targeting the NWP modelling, reanalysis, Polar science, extreme events, surface/energy interactions, and the water cycle communities to encourage them to attend future LST_cci events.

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4.1.2. LST and Climate Modelling

4.1.2.1. Slido Results and Related Discussion

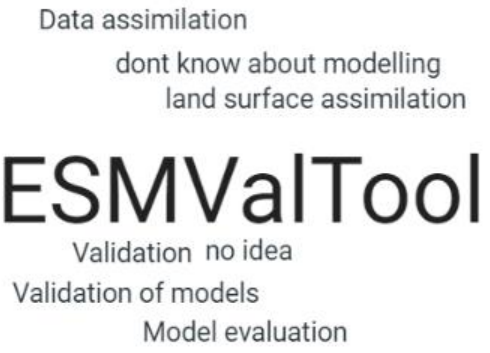

Figure 4-12: Slido results – 'Which climate modelling-based applications are you aware of that currently benefit from LST data?' Number of respondents: 12

Figure 4-12 illustrates which climate modelling-based applications participants are aware of that benefit from LST data. Five of the twelve respondents were aware of model evaluation applications using LST (ESMValTool (n=3), non-specific (n=2)). Two respondents mentioned data assimilation and one mentioned validation. Four respondents indicated they did not know of any modelling-based applications using LST. This question mainly provides context for the following questions in this discussion session.

Figure 4-13: Slido results – 'What other climate modelling-based applications do you think could benefit from LST data?' Number of respondents: 10

Figure 4-13 highlights what additional climate modelling-based applications respondents think could benefit from using LST data. Four of the ten respondents thought NWP could benefit from LST data, although this is not usually considered to be a climate application. However, seasonal-to-decadal forecasting and climate projections are related to NWP and may have been the intention here. Other climate modelling-based applications that were noted include climate services, high-resolution modelling, urban and regional modelling and sub-seasonal-to-seasonal forecasting. In addition, the more general area of improving surface temperature fields in models was also highlighted. The LST_cci project could seek to engage with these modelling communities more closely, particularly at future events. The reanalysis community, not mentioned here explicitly, is another community that could be considered.

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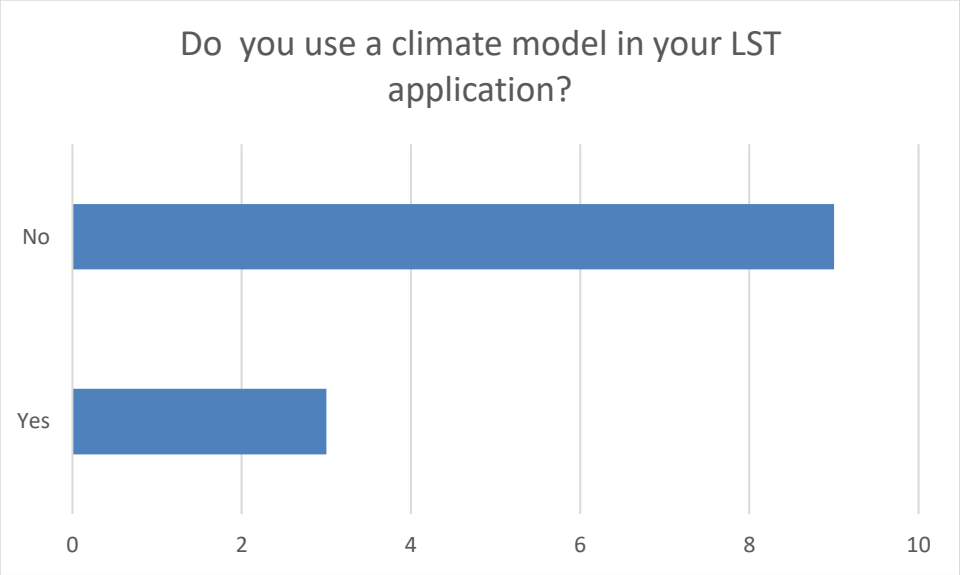

Figure 4-14: Slido results – 'Do you use a climate model in your LST application?' Number of respondents: 12

Figure 4-14 shows how many respondents use a climate model in their LST application. Only three (25%) respondents responded positively to this question, which provides context for the following questions in this discussion session. The results also suggest that there is still scope for improved engagement with the modelling community and to encourage them to come to future LST_cci events.

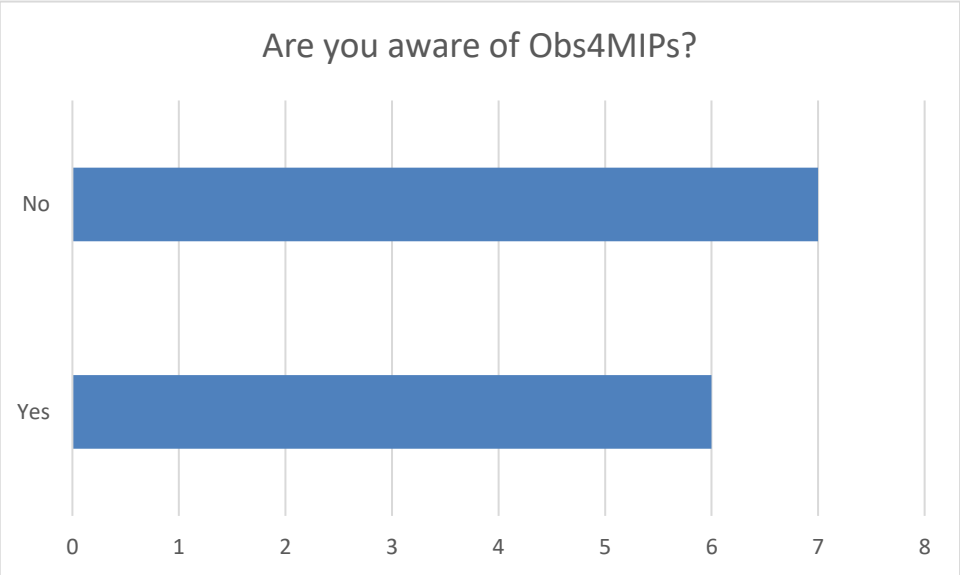

Figure 4-15: Slido results – 'Are you aware of Obs4MIPs?' Number of respondents: 13

Figure 4-15 indicates how many participants are aware of Obs4MIPs. Slightly under half of respondents responded positively to this question, which was to provide context for subsequent questions in this session.

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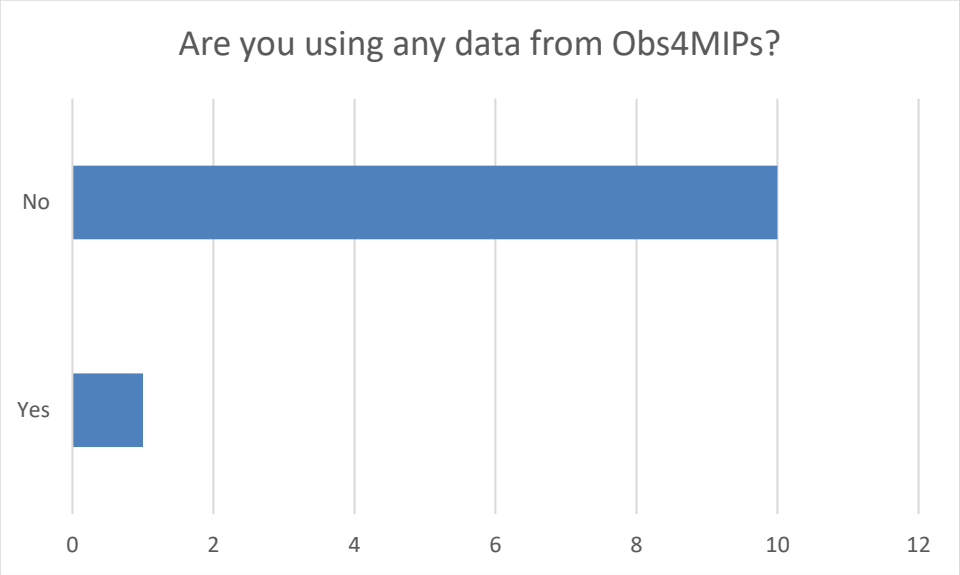

Figure 4-16: Slido results – 'Are you using any data from Obs4MIPs?' Number of respondents: 11

Figure 4-16 indicates how many respondents utilise data from Obs4MIPs. Only one respondent is using data from this project. The results from this question suggest that the LST_cci project could consider engaging more proactively with Obs4MIPs.

Table 9: Free text responses to the question 'What more is needed from the LST_cci project to provide products that are more useful for climate modelling?' Number of respondents: 9

Understanding jumps between sensors to get a longer time series.
Not familiar with modelling either.
Increased frequency and spatial resolution.
Need to specify clearly the observation time for the data points.
LST fields on Universal Time grid.
Not familiar with modelling as a whole.
Long term LST series, at least at monthly resolution, and without step changes.
Gap filled data.
Perhaps more information on what LST represents and how close it is to the parameters output by models?

Table 9 provides the free-text responses to the question asking what more is needed from the LST_cci project to provide useful products for climate modelling. The responses indicate the importance of stability or understanding of instabilities across sensors. In addition, the needs for data with increased frequency and spatial resolution, gap-filled data and a clear understanding of what the satellite LST data represent and how close this is to model parameters were highlighted. Some of the respondents were not familiar with modelling. One respondent also suggested that provision of LST data on a Coordinated Universal Time (UTC) grid would be useful. LST data are already provided with UTC time stamps, but the data could also be provided on e.g. hourly grids with UTC (e.g. 00:00 UTC, 01:00 UTC…23:00 UTC), which

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would better match the output from climate models. This would facilitate an easier comparison between model and satellite LST fields.

- **Recommendation 21: Provide LST data that are stable over time and free from non-climatic discontinuities.**
- **Recommendation 22: Provide LST data with increased frequency and spatial resolution (to match that of high-resolution climate models, for example).**
- **Recommendation 23: Provide gap-filled LST data.**
- **Recommendation 24: Provide detailed information on what satellite-observed LST fields represent and how this relates to climate model parameters.**
- **Recommendation 25: Provide LST_cci products on UTC grids (e.g. time-consistent fields with time stamp 00:00, 01:00….23:00 UTC to match model output).**

Table 10: Free text responses to the question 'Are there any existing tools used in climate modelling where it would be useful to add LST data? For example, LST_cci products have recently been added into the ESMValTool.' Number respondents: 8 (7 respondents indicated they could not answer this question)

Model benchmark tools other than ESMValTool.

Table 10 shows the single response (other than "don't know") to the question asking which other climate modelling tools that might benefit from LST data. The responses to this question emphasise the need to further engage with modelling groups to ascertain the LST needs of this community.

Table 11: Free text responses to the question 'Are there any observation operators that could be developed or applied to LST to make it more directly useful in your application?' Number of respondents: 9

Add info to help with understanding diurnal cycle .
In canopy as opposed to top of canopy would be nice, but that might turn the product into an 'obs constrained model' rather than an observation.
Convert to solid surface temperature (ground surface, not canopy).
LST to surface air temperature.
Disaggregation into LST per PFT.
Convert to T2m.
Convert to 2m air temperature.
LST to soil moisture.
LST collocated to T2m.

Table 11 provides the free text responses to the question asking about observation operators that would help users to ingest LST_cci data in their application. Three respondents suggested an observation operator to convert LST to the equivalent T2m would be useful, whilst a fourth suggested a conversion to soil moisture. Understanding relationships and trends between T2m (and potentially soil moisture) and

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LST in anomaly space might help get LST more widely recognised/used and aid further understanding of differences in trends between biomes, climates, types of surfaces and locations. One respondent suggested converting LST to 'solid surface' temperature (i.e. beneath the canopy), whilst another indicated that a within-canopy temperature would also be useful. Other suggestions included providing information to help understand the diurnal cycle and disaggregating LST to provide the temperatures corresponding to different plant functional types (PFTs).

- **Recommendation 26: Provide observation operators to convert LST to T2m and potentially other variables (e.g. soil moisture, below- and within-canopy temperatures and temperatures associated with different PFTs).**

4.1.2.2. Summary of Recommendations

- Stability or understanding of instabilities across sensors is important for LST use by climate modellers.
- Provide LST data that are stable over time and free from non-climatic discontinuities.
- Provide LST data with increased frequency and spatial resolution (to match that of high-resolution climate models, for example).
- Provide gap-filled LST data.
- Provide detailed information on what satellite-observed LST fields represent and how this relates to climate model parameters.
- Provide LST_cci products on UTC grids (e.g. time-consistent fields with time stamp 00:00, 01:00….23:00 UTC to match model output).
- Provide observation operators to convert LST to T2m and potentially other variables (e.g. soil moisture, below- and within-canopy temperatures and temperatures associated with different PFTs).
- Engage with the modelling community and encourage them to attend future LST_cci events, e.g. climate services, high-resolution modelling, urban and regional modelling, sub-seasonal-to-seasonal forecasting and reanalysis communities, as well as those working with Obs4MIPs.

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4.1.3. Climate Services and the Future of Satellite LST

4.1.3.1. Slido Results and Related Discussion

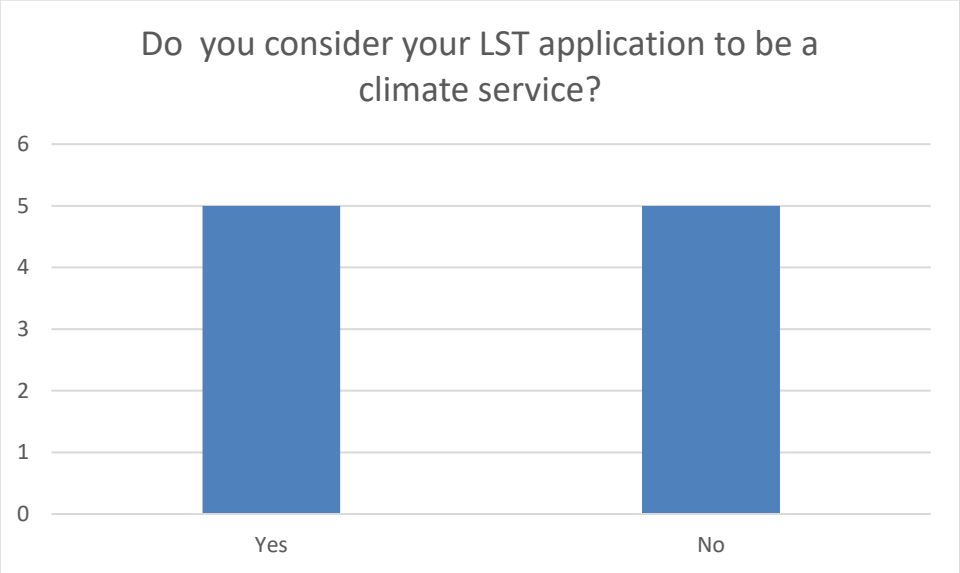

Figure 4-17: Slido results - 'Do you consider your LST application to be a climate service?' Number of respondents: 10

Figure 4-17 indicates how many respondents believe their LST application is a climate service. Half of the participants responded positively to this question, which provides context for the remaining questions within the session.

Figure 4-18: Slido results – 'Which climate services are you aware of that currently benefit from LST data?' Number of respondents: 9

Figure 4-18 illustrates climate services known to the session participants that already benefit from LST. Drought monitoring services and Urban Heat Island (UHI) services were each suggested by two respondents. Other services (each mentioned by one responder) included cryosphere research, fire risk, heatwave monitoring, and tomato growing. The purpose of this question was primarily for information gathering purposes, but also to provide context for the following questions.

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Figure 4-19: Slido results – 'What other climate services do you think would benefit from LST data?' Number of respondents: 8

Figure 4-19 is a word-cloud displaying other climate services that respondents believe would benefit from LST data. These include epidemiology, urban planning, ecosystem monitoring, pest emergence, insurance, forest disease, cryosphere, and energy balance. The LST_cci project could consider how to engage more widely with these communities to encourage uptake of LST_cci data.

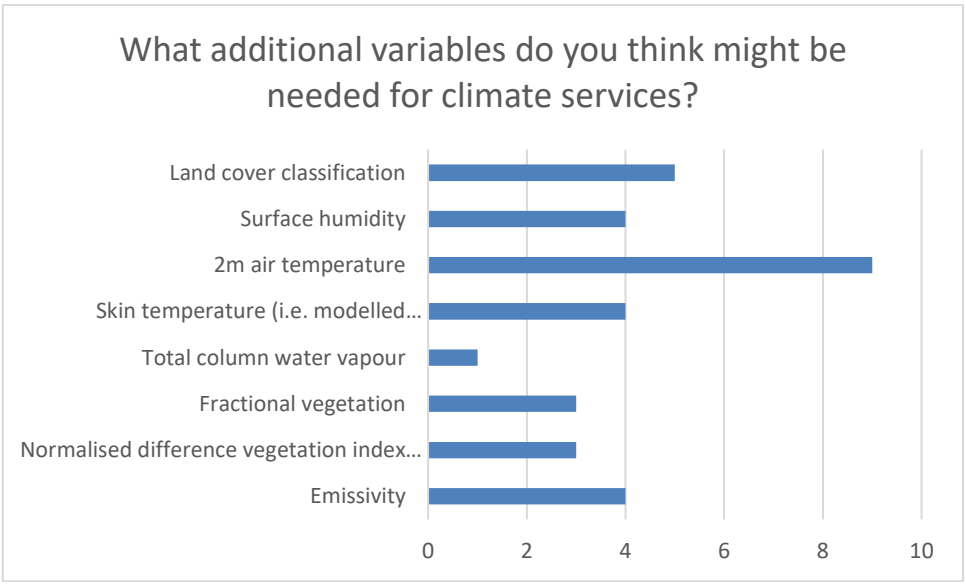

Figure 4-20: Slido results – 'What additional variables do you think might be needed for climate services?' Number of respondents: 10

Figure 4-20 is concerned with additional variables needed by those working in climate services. Two-metre air temperature and land cover classification were the most popular options selected, with 9 and 5 respondents respectively. Total column water vapour was considered the least important variable to be included with only one participant selecting this option.

- **Recommendation 27: Include additional variables in LST_cci products where possible to support climate services using LST, including T2m and land cover classification (both high priority); other variable such as surface humidity, modelled surface 'skin' temperature, emissivity, NDVI, fractional vegetation and total column water vapour could also be considered (low priority).**

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Table 12: Free text responses to the question 'Please specify any existing climate service tools that you are aware of where it would be useful to add LST data?' Number of respondents: 8

CropWatch.
Drought & Vegetation Data Cube, EUMETSAT.
C3S toolbox.
Climate explorer. Not CCI but is good.
Don't know (n=4).

Table 12 provides the free text responses to the question concerning existing climate services tools where it would be beneficial to include LST data. Most respondents were not aware of any such tools, but four suggestions included CropWatch, the EUMETSAT Drought & Vegetation data cube, C3S toolbox and Climate Explorer (KNMI). The LST_cci project could consider engaging with the providers of these tools to assess the potential for including LST_cci products.

Table 13: Free text responses to the question 'What do you think are the main barriers that are preventing LST from being used in climate services?' Number of respondents: 7

The fact that its definition is so variable in one sense (soil temp, building roof temperature, canopy temperature) etc makes it quite difficult to know exactly how to integrate it into a global climate service - regional services may be easier in this respect.
To know what benefits LST could bring and to whom? What does it offer above other options?
Difficult to find and download.
Lack of understanding of LST in a certain field.
Systems tend to stick to using what they know.
Timeliness of climate LST data.
Knowledge of what can be done with LST.

Table 13 provides the free text responses for the question concerning barriers preventing uptake of LST in climate services. Respondents to this question consider that the main barrier is a lack of knowledge and understanding of what LST represents and therefore how it can be used. The timeliness of the data availability was also identified as a barrier by one respondent. Another respondent suggested that LST data are currently difficult to find and download.

- **Recommendation 28: Provide detailed information on what satellite-observed LST fields represent and how the data can be used most effectively.**
- **Recommendation 29: Provide LST_cci products in real-time.**
- **Recommendation 30: Provide easy access to LST_cci products and facilities to improve data download.**

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4.1.3.2. Summary of Recommendations

- Include additional variables in LST_cci products where possible to support climate services using LST, including T2m and land cover classification (both high priority); other variable such as surface humidity, modelled surface 'skin' temperature, emissivity, NDVI, fractional vegetation and total column water vapour could also be considered (low priority).
- Provide detailed information on what satellite-observed LST fields represent and how the data can be used most effectively.
- Provide LST_cci products in real-time.
- Provide easy access to LST_cci products and facilities to improve data download.
- Engage with those working in climate services to encourage uptake of LST, including fields known to use LST (heatwave and drought monitoring, urban heat management, cryosphere research, fire risk and tomato growing) and fields where LST may not currently be used but where it may be beneficial (e.g. epidemiology, urban planning, ecosystem monitoring, pest emergence, insurance, and forest disease).
- The LST_cci project could engage with the providers of the following climate service tools to assess the potential for including LST_cci products: CropWatch, the EUMETSAT Drought & Vegetation data cube, C3S toolbox and Climate Explorer (KNMI).

4.2. Additional recommendations

In addition to the main outcomes of the workshop that resulted from the Slido questions and associated discussions, some additional recommendations are listed below.

- The online format of the workshop has many advantages and is preferred by some people. In particular, the benefits are that it is free to attend, requires no travel and therefore has no financial or environmental cost for participants, and incurs minimal costs for the project. However, this 2022 User Workshop was not as well attended as the 2020 event, despite having nearly the same number of registered delegates. If the next User Workshop is also held online, as currently planned, a strategy to increase attendance is required. A possible approach is to hold a joint workshop with another CCI ECV project, for example, SoilMoisture_cci or LandCover_cci to increase the number of potential delegates and presenters. Alternatively, an in-person event could be held, although there is no budget in the current project to cover this.
- The Eventbrite web facility used for workshop registration worked extremely well and should be considered for future events. In particular, it allowed workshop delegates to register for the LST_cci email distribution list with the appropriate GDPR statement.
- Several workshop participants commented that the Python code and Binder (https://mybinder.org/) facility provided by the project for the demonstrations/practical sessions were very useful and requested that these could be made available longer term.
- The potential for an LST_cci code repository where both users and project team could upload code was also discussed. It was agreed that such a repository would be useful, but that this should be unofficially maintained, and all code should come with a clear 'health warning' that the quality cannot be guaranteed and that it should be used with caution.

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5. Summary

The LST_cci 2022 User Workshop was a 3-day virtual event that took place 27-29 September 2022. In addition to providing a forum for the international LST community to meet and exchange knowledge and ideas, the primary aims of the workshop were to inform users about the LST_cci project and recent progress, and to collect feedback to define new or updated user requirements for the project.

Following the success of the LST_cci 2020 User Workshop, a very similar format and content was adopted for this 2022 event with both 'live' and 'offline' workshop components to enable delegates from different time zones to participate in the event. As for the 2020 User Workshop, the live sessions were held on Zoom (https://zoom.us/) and offline engagement was primarily through Padlet (https://padlet.com). The Padlets, which are essentially web pages, enabled users to upload their presentations, comment on presentations, download the most recent copy of the workshop information booklet, and navigate the workshop links.

In response to delegate and project team feedback from the 2020 User Workshop, and some specific LST_cci requirements defined in Phase I of the project (AD-01), the following new/updated workshop elements were adopted for the 2022 event:

- Two demonstration/practical sessions giving users 'hands on' experience with the new LST_cci regridding tool, using LST_cci products and exploring uncertainties. These sessions were formulated to address several requirements defined in the LST_cci User Requirements Document (URD) [AD-01].
- Using the interactive online survey tool, Slido (www.slido.com), to ask delegates for specific feedback and new recommendations for LST_cci data products during the discussion sessions. The expectation was that the Slido results would enable new requirements to be defined quantitatively, in a similar way to those resulting from the online LST user survey issued in Phase I of the LST_cci project.
- A live poster session with an initial lightning round in plenary for presenters to give an overview of their poster, followed by an interactive presentation session using Gather Town (https://www.gather.town), which is a virtual space for users to move around and interact. This session was designed to encourage delegates to view the posters, which were not widely read during the LST_cci 2020 User Workshop.
- A social event also held in Gather Town. This was a new event for the 2022 User Workshop and was designed to encourage scientific interaction and discussion and between delegates.

A total of 136 registrations were received for the 2022 User Workshop, which is almost identical to the number received for the 2020 User Workshop (n=133). The live Zoom sessions were not as well attended with the number of delegates varying between 19 and 42 at the 2022 event compared with 41 and 68 in 2020. However, the access logs for the live sessions' recordings suggest that many delegates engaged offline, either watching or downloading the recordings in their own time. As for the 2020 workshop, the LST_cci project live sessions on day 1 were the most widely attended/viewed. The reason for the comparatively smaller number of delegates attending the live sessions is unknown, but it is notable that the 2020 event took place in the very early stages of the Covid-19 pandemic, when attending online meetings was still a novel experience. Nevertheless, responses to the delegate feedback survey issued after the event were generally very complimentary and confirmed that the event was well run, and the content was of interest to members of the LST user community.

User feedback and recommendations were collected throughout the workshop event, and in particular from the discussion sessions. Some general outcomes from the workshop event are that:

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- The format and content of the LST_cci 2022 User Workshop was well received and should be considered for future virtual events. Eventbrite should be used for the event registration.
- A strategy to increase the number of participants in the live sessions in future online events is required. Holding a combined workshop with another CCI Essential Climate Variable (ECV) project is one potential solution.
- Other types of virtual events could be considered in the future, for example, targeted knowledge-exchange meetings, open question & answer sessions, seminars, etc.
- An LST_cci code repository could be considered for both users and the project team to upload useful computer code to process LST_cci datasets. However, it should be made clear that the repository is maintained on a best-efforts basis and the code in the repository should be used with caution as it is not guaranteed to be free from errors. The repository could also include code made available to users during workshop practical sessions.

In addition to these general outcomes, some specific recommendations were also defined by the workshop delegates, largely based on the results from the Slido questions posed during the discussion sessions. These are listed in Table 14. These recommendations comprise the main outcomes from the workshop and represent a snapshot of some current LST user requirements and priorities at the time of the workshop. They will be used to define new and updated requirements for the LST_cci project in version 3 of its User Requirements Document (URD) [AD-03]. The 30 specific recommendations identified in this User Workshop Report (UWR) are numbered sequentially to enable traceability between this report and the URD. These are indicated in the 'Notes' section of Table 14.

Table 14: List of specific recommendations resulting from the LST_cci 2022 User Workshop. The recommendations are explained and numbered in Section 4 of this report and are indicated in the 'Notes' column of this table, e.g. LST-UWR2022-REC-01 refers to Recommendation #01.

Recommendation	Notes
Data Format and Accessibility	
Provide easy access to LST_cci products and facilities to improve data download.	LST-UWR2022-REC-30. Requested by 1 respondent and combined with R9 "Provide a direct link to download LST_cci data on the LST_cci web pages", a consensus from the discussion.
Provide reprocessed LST_cci datasets at least annually.	LST-UWR2022-REC-04. At least 11 of 12 respondents would like at least annual reprocessing.
Provide LST_cci data within 48 hours of acquisition.	LST-UWR2022-REC-01 and combined with LST-UWR2022-REC-29 "Provide LST_cci products in real-time". 5 of 11 respondents require data within 48 hours of acquisition.
Provide LST data on a Polar EASE grid.	LST-UWR2022-REC-14. Requested by 3 users (1 post-workshop in response to a specific email sent to the LST_cci distribution list).
Ensure LST_cci ARDs are provided with good documentation, in easy-to-access formats with simple quality flags.	LST-UWR2022-REC-19. Each list item was requested by one user.

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Recommendation	Notes
Provide LST data that are stable over time and free from non-climatic discontinuities.	LST-UWR2022-REC-21. Requested by 2 of 9 respondents.
Provide fill values in files for missing data products and an inventory of files with missing data.	LST-UWR2022-REC-12. Requested by some users during discussion.
Extend LST_cci Regridding Tool to produce temporal means (e.g. weekly, pentads, etc).	LST-UWR2022-REC-15. Requested by 2 of 6 respondents.
Develop a wrapper for the LST_cci Regridding Tool to process multiple files.	LST-UWR2022-REC-16. Requested by 1 of 6 respondents.
Provide detailed information on what satellite-observed LST fields represent and how this relates to climate model parameters.	LST-UWR2022-REC-24. Requested by 1 of 9 respondents. Combined with LST-UWR2022-REC-28 "Provide detailed information on what satellite-observed LST fields represent and how the data can be used most effectively", also requested by 1 respondent.
Maintain a webpage/blog as a permanent resource that can be accessed for historical issues.	LST-UWR2022-REC-05. Consensus during discussion.
Provide users with the option to be sent email notifications when new issues are discovered and added to the issues list.	LST-UWR2022-REC-06. Requested by 11 of 12 respondents.
Provide information on data gaps, e.g. due to sensor outages or satellite manoeuvres.	LST-UWR2022-REC-11. Requested by several users during discussion.
Product Types	
Provide LST_cci data as 10-day means.	LST-UWR2022-REC-02. 3 of 12 respondents require 10-day means.
Provide gap-filled LST_cci products.	LST-UWR2022-REC-03 and combined with LST-UWR2022-REC-23 "provide gap-filled LST data". 7 of 12 respondents might use ap-filled data with large uncertainties. E.g. based on model data, heavily interpolated, or a climatology.
Provide LST climatologies.	LST-UWR2022-REC-17. At least one user requested this.
Provide selected properties derived from LST, for example, anomalies, daily minimum and maximum LST, annual means and LST- 2m air temperature differences.	LST-UWR2022-REC-18. Each list item was requested by one user.
Data Specification	
Provide LST_cci products on UTC grids.	LST-UWR2022-REC-25 from UWR 2022. Requested by 1 of 9 respondents. Provide time-consistent fields with time stamp

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Recommendation	Notes
	00:00, 01:00….23:00 UTC e.g. to match model output.
Provide LST data with increased frequency and spatial resolution.	LST-UWR2022-REC-22. Requested by 1 of 9 respondents. For example, to match that of high-resolution climate models.
Priorities	
Prioritise dealing with cloud cover in IR data sets.	LST-UWR2022-REC-13. Requested by 7 of 12 respondents. Improve cloud masking and gap filling.
Error and Uncertainty	
Provide detailed information on uncertainties.	LST-UWR2022-REC-10. Request from a single user during discussion; consider including this information in individual file metadata.
Cloud	
Improve IR cloud screening.	LST-UWR2022-REC-07. Requested by 6 of 12 respondents, e.g. incorrect cloud mask.
Provide detailed information on IR cloud screening processes.	LST-UWR2022-REC-08. Consensus during discussion.
Other	
Provide observation time, view angles, total uncertainty and land cover classification in LST_cci ARD products.	LST-UWR2022-REC-20. Combined response from 4 respondents.
Provide observation operators to convert LST to T2m and potentially other variables.	LST-UWR2022-REC-26. Based on information provided by 9 respondents. For example, to soil moisture, below- and within-canopy temperatures and temperatures associated with different PFTs.
Include additional variables in LST_cci products where possible to support climate services using LST.	LST-UWR2022-REC-27. Based on feedback from 10 respondents, include T2m and land cover classification (both high priority); other variable such as surface humidity, modelled surface ‘skin’ temperature, emissivity, NDVI, fractional vegetation and total column water vapour could also be considered (low priority).

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6. Appendix A: List of Institutes/Companies

University of Reading
NCEO-Leicester
University of Leicester
MeteoSwiss
University of Chinese Academy of Sciences
Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing
Met Office
ESA Climate Office
esa
National Observatory of Athens
Geografiska Informationsbyrån
Luxembourg Institute of Science and Technology
University of Bern
U.K. Centre for Ecology and Hydrology
ACRI-ST
GIB
BAS
University of Leicester
Met Office
uNIVERSITY OF cAGLIARI
Met Office
European Space Agency (ESA)
Indian Institute of Technology Bombay
Nigerian Meteorological Agency
Institute of Meteorology and Water Management (IMGW-PIB)
Ruhr University Bochum
BMKG Indonesia
Estellus
Karlsruhe Intitute of Technology
Luxembourg Institute of Science and Technology (LIST)
Alfred Wegener Institute for Polar and Marine Research
Hong Kong Polytechnic University
TEERTHANKER MAHAVEER UNIVERSITY, MORADABAD
IPMA
K. N. Toosi University of Technology
IMGW-PIB
WASCAL/ FUTMINNA
Met Éireann
University of Valencia
National Weather Service Argentina
UFRN

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National Institute of Meteorology-Tunisia
Chittagong University
University of Zurich
University of Zurich
SRM Institute of Science and Technology
German Remote Sensing Data Center (DFD), German Aerospace Center (DLR)
University of Zurich
ITC, University of Twente
North Carolina State University
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
University of Fort Hare
University of Leicester / NCEO
NOAA
King's College London
University of Oslo, Norway
University of Leicester
University of Lagos, Lagos, Nigeria
University of Leicester/NCEO
Max-Planck-Institute for Biogeochemistry
Air Force Institute of Technology
Imperial College of London - Visiting Researcher at ESA Phi-Lab
University of Maryland, College Park
University of Valencia
eLEAF
Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing
WCRP CMIP International Project Office
National Meteorological Administration, Romania
University of Valencia
SSAI
CNES
University of Valencia
University of Glasgow
CESBIO (CNRS)
CNR
Soil Conservation and Watershed Management Research Institute (SCWMRI)
NASA
IPN
Unibe
University of the Punjab
Ludwig-Maximilians University of Munich (LMU)
NASA
National Oceanic and Atmospheric Administration (NOAA)
Oregon Department of Forestry

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Hawassa University
GIB
INTA
Air Force Institute of Technology
Institute of Urban Meteorology, China Meteorological Administration
UK Centre for Ecology & Hydrology
CNR
UFZ
FUB
CNES
university of maryland
University of Punjab
University of the Punjab, Lahore, Pakistan
University Punjab
Punjab University
Any
Punjab university new campus
University of the punjab
Center for integrated mountain research university of the Punjab
Student
Centre for Integrated Mountain Research, University of the Punjab
03316292137
none
University of the punjab
World Food Program
UN WFP
GFZ Potsdam
UN World Food Programme
Istanbul Technical University
Itu
hdr
Multimedia Academy (MAC)
National Meteorological Administration of Romania
National Institute of meteorology and Hydrology of Bulgaria
CNRM
Teerthanker Mahaveer University
European Space Agency - Climate Office
Acri-ST
Karlsruhe Institute of Technology
SINCAI HIGHSCHOOL CLUJ
Freelance climate scientist and EO/GIS expert
Danish Meteorological Institute
Null

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European Commission, Joint Research Centre Ispra
Addis Ababa University
University of Maryland
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