CCI Land Surface Temperature

2024 User Workshop Report

WP5 – DEL-5.3

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Organisation: LST_cci Consortium

Signatures

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Change log

Version	Date	Changes
1.0		First version

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Version	Section	Changes

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Applicable Documents

Identity	Reference
AD-01	LST_cci (2023) User Requirements Document, Reference LST-CCI-D1.1-URD v3.0
AD-02	LST_cci (2025) User Requirements Document, Reference LST-CCI-D1.1-URD v4.0

Acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ABI	Advanced Baseline Imager
AHI	Advanced Himawari Imager
AR6	(IPCC) Assessment Report #6
ATBD	Algorithm Theoretical Basis Document
ATSR-2	Along-Track Scanning Radiometer - 2
AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperatures
C3S	Copernicus Climate Change Service
CAR	Climate Assessment Report
CCI	Climate Change Initiative
CEDA	Centre for Environmental Data Analysis
CDR	Climate Data Record
CMEMS	Copernicus Marine Service
CMUG	Climate Modelling User Group
DSM	Digital Surface Model
DuAOD	Dust Aerosol Optical Depth
E3UB	End-to-end ECV Uncertainty Budget
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ESMValTool	Earth System Model Validation Tool
EUMECV	Essential Climate Variables
ERA5	ECMWF ReAnalysis v5
EOS-SG	Earth Observing Satellite Second Generation
EOSIS	*Earth Observation Climate Information Service*
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

EVI	Enhanced Vegetation Index
FVC	Fractional Vegetation Cover
GEO	Geostationary (satellite orbit)
GDPR	General Data Protection Regulation
GHCNd	Global Historical Network daily
GOES	Geostationary Operational Environmental Satellites
GSW	Generalised Split Window
HadEX	Hadley Centre EXtremes dataset
HiVE	High-Precision Versatile Ecosphere Monitoring Mission
IASI	Infrared Atmospheric Sounding Interferometer
ICDR	Interim Climate Data Record
IR	InfraRed
IST	Ice Surface Temperature
JAMI	Japanese Advanced Meteorological Imager
KE	Knowledge Exchange
L3C	Level 3C satellite product (averaged/reprojected in space)
L4	Level 4 satellite product (averaged across space and time)
LEO	Low Earth Orbiting
LOS	Length of Season
LSA-SAF	Land Surface Analysis Satellite Application Facility
LSE	Land Surface Emissivity
LST	Land Surface Temperature
LST_cci	LST CCI
LSTM	Land Surface Temperature Monitoring
LWIR	Long Wave Infrared
MAE	Mean Absolute Error
MODIS	MODerate resolution Imaging Spectroradiometer
MTG	Meteosat Third Generation
MTSAT	Multifunction Transport Satellite
MW	MicroWave
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NERC	Natural Environment Research Council

NCEO	NERC Centre for Earth Observation
NOAA	National Oceanic and Atmospheric Administration
NDVI	Normalised Difference Vegetation Index
PSD	Product Specification Document
PUG	Product User Guide
PVIR	Product Validation and Intercomparison Report
RMSE	Root Mean Square Error
RSD	Robust Standard Deviation
S3	Sentinel-3
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
skt	Skin Temperature
SLSTR	Sea and Land Surface Temperature Radiometer
SUHI	Surface Urban Heat Island
SUOMI-NPP	Suomi National Polar-orbiting Partnership
SWIR	Short Wave Infrared
T2m	2m air temperature (e.g. measured at a weather station)
TCWV	Total Column Water Vapour
TES	Temperature Emissivity Separation
TIR	Thermal InfraRed
UCS	User Case Study
UHI	Urban Heat Island
UNET CNN	U-Net convolutional neural network
UTC	Coordinated Universal Time
URD	User Requirements Document
UWR	User Workshop Report
VNIR	Very Near Infrared
VIIRS	Visible Infrared Imager Radiometer Suite
VTS	Valencia Test Site
VZA	View Zenith Angle

1. Executive Summary

The European Space Agency (ESA) Climate Change Initiative (CCI) for Land Surface Temperature (LST), or "LST_cci", 2024 User Workshop was held in person 5-6 December 2024. Attendance at the workshop ranged between 52 on day 2 and 59 on day 1. The workshop comprised 24 oral presentations, including those from the LST_cci project partners, 11 poster presentations, an interactive user-requirements gathering session and a training session.

This User Workshop Report (UWR) presents full details of the LST_cci 2024 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 the interactive user requirements gathering session on day 1, including the results of the questions posed 'live' to the workshop participants during this session.
- A list of key recommendations collated during the workshop.

These key recommendations are explained and numbered here, where LST-UWR2024-REC-01 for example refers to Recommendation 1 in the main body of text:

ID	Recommendation
LST-UWR2024-REC-01	Continue to improve engagement with the climate modelling and climate services communities.
LST-UWR2024-REC-02	Seek opportunities for further outreach activities to publicise LST_cci data.
LST-UWR2024-REC-03	Provide training in how to obtain and use LST_cci data.
LST-UWR2024-REC-04	Project team to consider whether it is worth producing products with few users, noting that there were many users who were not at the workshop who currently use LST_cci products.
LST-UWR2024-REC-05	The product user guide should indicate suitable applications or each product - the characteristics of the product, its suitability for various applications, limitations, etc.
LST-UWR2024-REC-06	Provide information in the PUG on the pros and cons of using VIIRS as a follow-on to Aqua MODIS.
LST-UWR2024-REC-07	The gridding method for VIIRS should choose the pixel nearest the nominal overpass time. This is the method used for all previous IR products and is consistent with the Aqua MODIS products.
LST-UWR2024-REC-08	Consider provision of emissivity data used in the retrieval to be included in LST_cci products. However, a better understanding of why users would like these data would be useful to ascertain before this addition is included. This could be explored at the next user workshop in 2026.
LST-UWR2024-REC-09	Consider providing more information on proximity to cloud, cloud probability and uncertainty in cloud masking.
LST-UWR2024-REC-10	Consider providing digital elevation model output on the spatial resolution of the satellite LST data.
LST-UWR2024-REC-11	Consider providing wind speed information e.g. from ERA5 (which is currently used for T2m).
LST-UWR2024-REC-12	To provide gap-filled LST_cci products.

ID	Recommendation
LST-UWR2024-REC-13	Seek opportunities to provide LST in real time, e.g. through C3S.
LST-UWR2024-REC-14	Include a table of key features based on the table already available to beta users that provides advice to user in helping them to choose the most suitable LST_cci dataset for their application. This could include references to existing studies that use LST data.
LST-UWR2024-REC-15	Provide the means for users to provide feedback on LST_cci datasets, e.g. report issues.
LST-UWR2024-REC-16	The PUG could include code examples for reading and plotting the data.
LST-UWR2024-REC-17	The PUG could include a description of the scope of other relevant documents and signposts to these documents (PSD, ATBD, CAR, PVIR, E3UB).

These recommendations will be considered in the User Requirements Document (URD), either to update existing requirements or to generate new requirements identified by the project.

Feedback collected via an online survey after the event was generally very positive. Notable recommendations for the next workshop event include:

- A 2-day workshop appears to be optimal for the next user workshop, perhaps with some additional event on day 3 (e.g. user training)
- Delegates would like more user presentations at the next workshop.
- The next workshop should include some 'hands on' experience/training but perhaps run in parallel with another type of session as there are a sizeable group of delegates that do not want any training.
- Presentations at the next workshop should be 15-20 minutes duration.
- The next workshop should be either hybrid or in-person with recordings/workshop material made available after the workshop event.
- Water (and perhaps some food) should be available for the duration of the next workshop.
- Communication levels from the 2024 workshop were about right so this approach should be adopted for the next workshop. However, it is noted that the workshop should – including attendees – should be finalised earlier to allow participants to obtain visas in time for the workshop where required.

Based on the success of this in-person event, the LST_cci 2026 User Workshop is also planned as an in-person event and is currently scheduled to take place 12-14 May 2026 at the Met Office in Exeter, UK. Currently, the plan is to hold this workshop in collaboration with the ESMValTool team through the ESA-funded ESO4Clima project, which kicks off in later part of 2025. It is hoped that this initiative will in part address recommendation #1 from this UWR, which is to 'Continue to improve engagement with the climate modelling and climate services communities', a long-standing ambition of the LST_cci project since its conception.

Section 2 of this UWR presents and overview of the workshop, including the workshop design, aims and agenda. Section 3 summarises the feedback from the workshop participants that was collected after the event, whilst Section 4 presents the results from the user requirements gathering session, which has been used to define some recommendations for the project. Finally, Section 5 provides a brief summary of the report.

2. Workshop Overview

2.1. Workshop Details

The LST_cci 2024 User Workshop took place over 1.5 days 5-6 December 2024 in person. An online format was originally planned for this event. However, given the lower attendance at the 2022 online workshop compared to the 2020 online workshop, the project took advantage of an opportunity to hold a joint in-person event with the Thermal Remote Sensing Special Interest Group (https://thermal-rs.earsel.org/) in order to maximise attendance. The Thermal Remote Sensing Special Interest Group workshop was primarily a training and networking event that took place 2-4 December, with the LST_cci workshop following on seamlessly from this prior event.

Based on feedback and session attendance from previous LST_cci workshops, sessions about the LST_cci project and its outputs consistently appear to be one of the most important parts of the workshop for most delegates. With this in mind, the first day of the LST_cci 2024 workshop was dedicated to the LST_cci project, including four user case study (UCS) presentations and a session aimed at gathering user requirements, which was a key objective of the workshop. This one-hour user requirements session was run interactively, using the online survey tool Slido (slido.com) with pre-populated questions that participants could answer in real time. Further details about this session and the results obtained are presented in Section 4 of this user workshop report. The first day of the workshop also included a 'lightning poster presentation session' before the first comfort break to publicise the poster presentations that were on display for the duration of the workshop so that they could viewed during all scheduled breaks. Holding this lightning poster presentation session and emphasising the posters at the beginning of the workshop was a conscious decision as feedback from the previous online workshops was that the posters needed to be more accessible and visible to participants (Table 2-1). The final half day of the workshop was dedicated to other LST user presentations and included an LST_cci data training session that was authored and delivered by the ESA Knowledge Exchange Team with support from the LST_cci project team. This training session and the overall format and content of the workshop was designed specifically to address several requirements identified through previous surveys and workshops (Table 2-1).

Table 2-1: Feedback from the LST_cci 2020 and 2022 User workshops and project requirements [AD-01] used to design the format of the 2024 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 and 2022 User Workshop Feedback Survey. This table is continued on the next page of the report.

Feedback /Requirement	Source	Workshop design/agenda
Respondents typically felt general networking and the social interaction with other workshop participants was more difficult during the virtual workshops compared with an 'in person' event.	2020 and 2022 User Workshop Feedback Survey	Plan in person or hybrid events
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	Ensure posters are advertised clearly and made available to view throughout the workshop. A lightning poster presentation session was included at the 2024 workshop before the first

Feedback /Requirement	Source	Workshop design/agenda
		comfort break to ensure maximum exposure for the posters.
Participants appreciated the strict timekeeping at the 2020 and 2022 LST_cci workshops	Feedback from 2020 and 2022 workshop participants	To inform speakers to keep strictly to time and ensure session chairs keep strictly to time.
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.	Project team feedback	Use Eventbrite for registration for the in-person 2024 workshop and for future workshops. It is current free and easy to set up and enables easy maintenance of delegate lists, including those who have unregistered for the event.
Using Slido worked very well during the discussion sessions in the 2022 workshop, but it was challenging to get through all the questions in each session.	Project team feedback	Ensure there are fewer, more focused questions. Introducing these questions, and the collated responses, 'live' during the session also facilitated insightful discussion (documented by dedicated note takers from the project team).
The demonstration/practical sessions facilitated during the 2022 event worked well and some participants were keen to have similar sessions at future events.	Feedback from 2022 workshop participants	Hold a dedicated LST_cci data usage training session.
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.	Feedback from 2022 workshop participants and the project team	Continue to deliver training, resources and talks/demonstrations on the importance of uncertainty information (also see further requirements below). A dedicated talk on uncertainties was included at the 2024 workshop.
The following topics were suggested in the feedback survey from the 2022 workshop: ○ 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)	Feedback from 2022 workshop participants	Several of these topics were covered by the preceding Thermal Remote Sensing workshop and/or LST_cci 2024 workshop (LST retrieval, Climate applications, urban climate, and future plans for satellite LST). The other topics will continue to be kept in mind for future and could also be considered for future LST_cci User Case Study topics.
A session (or multiple sessions) to enable participants to 'brainstorm' new project ideas that could subsequently be developed and	Feedback from 2022 workshop participants	This was not included in the 2024 user workshop due to the length of the workshop but could be considered for the 2026 user workshop.

Feedback /Requirement	Source	Workshop design/agenda
submitted for funding opportunities could also be considered for future events.		
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.	Project team feedback	LST_cci 2024 workshop combined with Thermal Remote Sensing Workshop. Plans are also underway to combine the LST_cci 2026 workshop with the ESMValTool team.
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 & 2022 User Workshop feedback.	Held a dedicated session on uncertainties in LST_cci products. Include why they are important, what they represent (including the individual components), examples of when users may need uncertainties. Some application of uncertainty information included in practical session at the 2024 User Workshop.
LST-URD-ADV-38-U - Provide tools to re-grid data and propagate uncertainties	Existing project requirement [AD-01] and 2020 User Workshop feedback.	LST_cci regridding tool advertised to users at the LST_cci 2024 user workshop on day 1 during the LST_cci project focus sessions.
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	Held a practical session led by the ESA KE team, who provided Python code during the workshop and continued availability after the workshop.

The LST_cci and Thermal Remote Sensing workshops were advertised as widely as possible, including via the LST_cci project mailing list, the LST_cci webpages, ESA X account, CMUG mailing list, the Thermal Remote Sensing Special Interest Group mailing list and webpages, 'Climlist' and through Met Office social media posts on X and Linkedin. The workshop was well attended with 57 in-person and 2 online attendees on 5 December, and 51 in-person and 1 online attendee on 6 December. Notably, there were a few last-minute cancellations from participants, several of which were due to delays in the provision of visas to attend the event. This is a lesson to be learned for the next workshop to give plenty of notice and confirmation of attendance several months in advance of the workshop to enable delegates to receive their visas on time. Overall, the workshop was a great success with high-quality presentations that kept well to time, a very productive user-requirements gathering session and a useful training session delivered by the ESA KE team.

2.2. Workshop Aims

The primary aims of the LST_cci 2024 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.
- Gather feedback from LST data users on both LST_cci and other LST datasets.
  - Workshop delegates and LST users were invited to submit abstracts for either an oral or poster presentation at the workshop in dedicated LST user sessions.
  - A dedicated user requirements session was held during the workshop that specifically requested feedback on the LST_cci products on day 1 of the workshop.
- Define any new requirements for LST from users.
  - The dedicated discussion/feedback session on user requirements on day 1 also included questions and open discussion on new requirements from users.

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 and 2022 User Workshops.
- Advertise the LST_cci regridding tool, which subsets and/or reprojects higher-resolution LST_cci products onto a coarser latitude-longitude grid, including the correct propagation of uncertainties.

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, 2022 and 2024 User Workshops.

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-02], 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 detailed in Section 2.3.1 (Thursday) and Section 2.3.2 (Friday), which includes key points from each of the oral presentations. Section 2.3.3 summarises the 11 poster presentations. The workshop agenda, together with the oral presentation slides and posters are also freely available to download via the LST_cci webpages at https://climate.esa.int/en/projects/land-surface-temperature/workshops/lst-user-workshop-documents-2025/.

2.3.1. Thursday

Thursday 5th December				
UK time	**Agenda Item**	**Speaker**	**Duration**	**Key Messages**
08:00	Registration		01:00	N/A
09:00	Fire and safety briefing	SPL Staff	00:05	N/A
Introduction to CCI and LST_cci **Chair: Claire Bulgin (U. Reading)**				
09:05	Arrival and welcome	Welcome from U. Leicester & Lizzie Good	00:10	N/A
09:15	Overview of the LST_cci Project	Lizzie Good (Met Office)	00:15	• Presented a summary of the LST_cci project, its aims and the expected products that would be produced. • Highlighted some points for users to consider, e.g. limited coverage due to cloud and swath width, and stability of the LST_cci data. • Advertised the LST_cci Regridding and Sub-setting Tool that is available from the LST_cci webpages.
09:30	LST in ESA's climate programme	Simon Pinnock (ESA)	00:15	• Summarised ESA CCI project overview and aims, and variables included. • How to obtain ESA CCI data products and provided some example applications.
09:45	Poster Lightning Presentations	Poster Presenters	00:30	See Section 2.3.3
10:15	Break & Poster Viewing		00:30	See Section 2.3.3
LST_cci Products (1) Chair: Abigail Waring (U. Leicester)				

10:45	Polar orbiting Infrared LST_cci Products	Karen Veal (U. Leicester)	00:15	• Consistent approach to all IR LEO products: CCI database of atmospheric and surface state used for derivation of coefficients. • Sensors intercalibrated in BT space using IASI as reference. • Multisensor IR CDR includes time correction to account for overpass time differences. • New products from AVHRR/3s on NOAAs and VIIRS on Suomi NPP and NOAA-20.
11:00	Geostationary Infrared LST_cci Products	Sofia Ermida (IPMA)	00:15	• Single sensor independent datasets for GOES/IMAGER, GOES/ABI, MTSAT/JAMI, Himawari/AHI. • Stability analysis done using ERA5 LST as reference. • Bias correction calculated using ESA CCI Aqua MODIS V4.00 (currently no correction for Himawari). • Bias correction cannot completely remove biases between single- and dual-channel datasets.
11:15	High-resolution Infrared LST_cci Products	Charlotte Paton (U. Leicester)	00:15	• High-resolution (100 m) products from (1) Landsat native resolution data and (2) downscaling MODIS 1 km data. • New thermal classification scheme based on thermal properties of observed land as opposed to land use-based classifications. • New classification used as input to optimal estimation retrieval in new 100m LST product from Landsat. • In situ validation results were better than methods using NDVI or CAMEL emissivities.

11:30	UCS#2: Assessment of ESA LST_cci Sea-Ice Surface Temperatures (IST) in the Arctic	Ioanna Karagali (DMI)	00:15	• Uncertainties in the L4 SST/IST product are high in regions where there is no data. The ESA LST_cci IST from SLSTR on S3-A/B and MODIS on Aqua/Terra were assessed for their impact on the L4 product. • An assessment of the single-sensor products against in situ observations show very good results. • Added advantage of the LST_cci data is their contribution to increased data availability. • Overall positive impact of the LST_cci data on the L4 SST/IST product was identified as bias and standard deviation values with respect to in situ observations were reduced. • Future ingestion of ESA LST_cci IST CMEMS Arctic L4 SST/IST Reanalysis & potentially in next version of C3S Global L4 SST/IST CDR/ICDR.
11:45	Microwave LST_cci Products	Carlos Jiménez (Estellus)	00:15	• Overview of MW LST highlighting differences with IR LST. • MW less sensitive to emitting temperature, larger dependence on emissivity, deeper penetration depth, lower spatial resolution, can penetrate clouds so better coverage. • ESA CCI products from sensors on satellites with drifting orbits: time correction available in products. • New work: include more sensors to increase observations to 4 times daily; downscaling to 5 km.
12:00	Lunch Break and Poster Viewing		01:30	
LST_cci Products (2) Chair: Carlos Jiménez (Estellus)				

13:30	Merged Infrared & Microwave product	Abigail Waring (U. Leicester)	00:15	• Building an all-sky merged LST product using machine learning techniques; represents a 'clear-sky' LST equivalent • Implementing a UNET CNN to learn from TIR and MW data, and map MW to refine its resolution to 5 km • The model explores a range of training inputs to best describe the spatio-temporal distribution of LST • The all-sky LST product will cover the globe at a resolution of 5 km • The final product will advance climate & weather applications where observations are scarce, e.g. in the polar regions
13:45	Uncertainties in the LST_cci products	Claire Bulgin (U. Reading)	00:15	• In order to use the data correctly, you must consider the uncertainty in the measurement. • Uncertainty budget built by identifying all possible sources of error. Uncertainty estimates are grouped according to their correlation length scale. With the breakdown of uncertainty components, the uncertainties can be correctly propagated. • A different method is used for the microwave (MW) products. The MW retrieval uses a neural network trained using a calibration database. The regression model is used to estimate the total uncertainty by sampling the neighbouring input-output space. • Information on uncertainties in LST_cci products can be found in the Product User Guide. Detailed information is in the End-to-end ECV Uncertainty Budget (examples for users given in final 3 pages).

14:00	Validation of the LST_cci products	Lluis Pérez-Planells (KIT)	00:15	• LST_cci data products are independently validated to assess their quality and enable users to better understand the data and its limitations. • In situ validation is against measurements from globally distributed stations representing a broad range of land covers and climates. The uncertainty of the in situ validation is also assessed. • In Situ Validation results: most LST_cci products showed a bias better than 2.5 K over most stations; for IR products, with higher spatial resolution than MW and GEO, the bias was better than 1 K for most stations. The RSD was within 2.5 K for most stations, but larger RSDs were observed at some stations and products. The in situ validation uncertainty showed different performance depending on the site. • Satellite-satellite inter-comparisons were done over large areas (continental scale). • Intercomparison results: differences between LST_cci data set pairs were generally better than 1.0 K; larger differences were observed with Operational MODIS and AATSR LST products. • More details can be found the Product Validation and Intercomparison Report (PVIR v3.2).
14:15	User Requirements Discussion Session & Slido Questions	Lizzie Good & Karen Veal	01:00	
15:15	Break & Poster Viewing		00:30	
User Case Studies Chair: Lluis Pérez-Planells (KIT)				

15:45	UCS#1: Moderate extremes indices based on LST	Josh Blannin (Met Office)	00:15	• The aim is to produce an LST indices dataset to compliment HadEX3 (gridded extremes indices based on station data). • Used satellite LST data from ESA LST_cci, and station 2m air-temperature (T2m) from NCEI GHCNd • Distributions of LST and T2m temperatures are similar, but with LST being slightly cooler (example shown: AR6 regions 1 & 16) • Several promising threshold- and value-based indices in AR6 region 16 – these to be investigated further across the other AR6 regions • Percentile-based indices for AR6 region 16 show good correlation and identification of moderate extreme events – also to be investigated in other AR6 regions
16:00	UCS#3: Urban Nighttime Warming Trends derived from LST_cci MODIS Data	Panagiotis Sismanidis (RUB)	00:15	• Calculate the trends in nighttime LST for major cities over the globe. • Globally, the nighttime LST of urban areas increases by 0.06 ± 0.02 K/year. • 5% of these cities exhibit trends higher than 0.1 K / year. • Cities in continental climates, Eastern Europe, China and Middle East warm faster than the rest.
16:15	UCS#5: Analyzing Seasonal Patterns and Temperature Extremes in Urban Areas Using MODIS Data	Irina Ontel (MeteoRomania)	00:15	• Examine the seasonal LST variations across urban, peri-urban and rural areas and investigate the seasonal LST trends, shifts in seasonality, and LST extremes across different cities of Romania.

				• The difference between urban and peri-urban areas is greater in summer and insignificant in winter. Daytime differences are insignificant for most cities, but increase at night. • The trends of daily LST maxima are of significant increase in winter and autumn regardless of the area, and those of minima are significant in winter and summer. • In terms of seasonality, cities in the central and western part of the country have a longer season, due to an earlier start and a later end. In other cities, only the end of the season occurs later, while the start does not show a significant trend. The Length of Season (LOS) ranges between 50 and 140 days, with a mean amplitude of 100 days. • Satellite data have proven to be useful tools in analysing the spatial variation in surface temperature and identifying differences between urban, peri-urban and rural areas.
16:30	Finish			

2.3.2. Friday

Friday 6th December				
UK time	**Agenda Item**	**Speaker**	**Duration**	**Key Messages**
08:00	Registration		01:00	
09:00	Fire and safety briefing	SPL Staff	00:05	
LST Applications (1) Chair: Lizzie Good (Met Office)				
09:05	constellr HiVE, a land surface temperature monitoring mission for better resource accountability	Christophe Lerot (constellr)	00:15	• Mission : Measure temperatures from space to support food security and provide insights for better resource accountability • Agriculture is key to addressing the combined carbon and water challenges • High-Precision Versatile Ecosphere Monitoring Mission (HiVE) will launch in 2025
09:20	A new methodology to generate infrared Land Surface Emissivity including directional effects	Sofia Ermida (IPMA)	00:15	• A new methodology was proposed that combines the empirical VCM that relies on information from the FVC and the direct retrievals provided by the Temperature Emissivity Separation method (TES) to explore the added value of each method. • This new method provides good bare ground estimates thanks to the TES, while providing better estimates over vegetated surfaces thanks to the FVC information, outperforming other available products.

				• The TES was modified to adjust directional effects of emissivity, significantly reducing anisotropy on the LST. • LSE and respective uncertainty are estimated for all the sensors' infrared channels including broadband emissivity. • This new methodology will be implemented for the soon to be released version 2 of the LSA-SAF SEVIRI and AVHRR LSE and LST products. It will also be implemented for the upcoming MTG and EPS-SG. A global 1 km product based on VIIRS is being prepared to be published soon.
09:35	Identification, characterization and correction of directional effects in high-resolution LST	Louis Snyders (VITO)	00:15	• Remote sensing retrieved land surface temperatures (LST) depend, besides on the time of acquisition, on the position of both the thermal sensor and the Sun. The difference in sun-sensor geometry can result in LST differences up to several Kelvin. • A cross-calibration method between numerous pairs of quasi-simultaneous high-resolution LST observations from S3 and the ECOSTRESS allows identification, characterization and correction for directional effects • Applying a directional correction reduces the mean absolute difference between S3 and ECOSTRESS LST from 1.63 K to 1.5 K
09:50	Improving Satellite-based Land Surface Temperature Estimates in Dust-Contaminated Atmospheres: A	Francesco Stante (IPMA)	00:15	• Current operational LST retrieval algorithms do not consider the effect of heavy aerosol loading on the retrievals, and their accuracy is significantly reduced

	Generalized Split-Window Algorithm Dependent on Dust Aerosol Optical Depth			in regions affected by dust aerosols, such as the Sahara Desert and surrounding areas. • A simple solution to improve LST estimations in dust-contaminated atmospheres is to introduce dust aerosol optical depth (DuAOD) as an additional variable on which the coefficients of the Generalized Split-Window (GSW) algorithm are dependent – in addition to total column water vapor (TCWV) and satellite viewing zenith angle (VZA). • To calibrate the DuAOD-dependent GSW we created a dataset containing a wide variety of surface and atmospheric conditions which includes dust aerosol mixing ratio profiles from CAMS' EAC4 atmospheric composition reanalysis. Top-of-atmosphere brightness temperatures used for calibration of the GSW coefficients were simulated using RTTOV. • The DuAOD-dependent GSW has significantly higher accuracy in LST estimation across DuAOD conditions. With synthetic data, a traditional, aerosol-independent GSW has increasing errors with DuAOD, reaching up to 5 K for DuAOD between 0.6 and 0.8 (and low VZA), while a DuAOD-dependent GSW maintains median errors below to 2 K across DuAOD classes. Validation against in situ LST measurements from stations in Dahra (Senegal), Évora (Portugal), Niamey (Niger), and Gobabeb (Namibia) confirm these improvements in LST estimation. • A three-channel variant of the DuAOD-dependent GSW (using SEVIRI channel 8.7 µm, in addition to 10.8

				and 12.0 µm) was also tested, showing similar improvements to the two-channel version. However, due to the large uncertainties of channel 8.7 µm emissivities, the two-channel version is favoured. • The accuracy of the proposed DuAOD-dependent GSW relies heavily on the quality of DuAOD estimates used as input. For MSG-SEVIRI LST estimations the only viable DuAOD product appears to be CAMS' forecasts or reanalysis, as they uniquely provide the necessary spatial coverage and temporal resolution of SEVIRI observations on an operational basis. However, the CAMS DuAOD products have limitations in accuracy that would potentially introduce additional errors in LST estimates.
10:05	LST_cci data training session	ESA Knowledge Exchange Team	01:00	The repository containing the notebook is: https://github.com/esa-cci/ect-training . To set up the necessary environment, you need to either install the notebook on your local machine (as explained here: https://esa-climate-toolbox.readthedocs.io/en/latest/installation_guide.html) or, if you have a github account, run on GitHub Codespace: https://github.com/esa-cci/esa-climate-toolbox/tree/main/.devcontainer .
11:05	Break & Group Photo		00:20	
LST Applications (2) Chair: Sofia Ermida (IPMA)				
11:25	Long-term Trends of LST from a new Daytime-normalized AVHRR Time Series over Central and Southern Europe	Philipp Reiners (DLR, DFD)	00:15	• Harmonized the spectral response curves of the AVHRR instruments on the different NOAA satellites

				• Implemented a correction for emissivity, view angle and water vapour • Implemented an orbit drift correction using LST Annual Cycle parameters derived from SEVIRI data • Created a long-term daily maximum LST time series (1982-2018) as well as 10-daily and monthly products
11:40	Intercomparison of SEVIRI Land Surface Temperature with ERA5 reanalysis over Africa	Riccardo Monfardini (U. Reading)	00:15	• Aim to use high frequency LST retrievals from geostationary satellites to assess diurnal discrepancies with ERA5 skin temperature (skt) • SEVIRI LST and ERA5 skin temperature were compared for the period 2018-2022 • ERA5 skt diurnal range is too limited in clear skies • Small warm bias during nighttime • Large cold bias during daytime hours • This bias is strongly influenced by location/biome • ERA5 Land higher resolution still has bias, shifted by lack of data assimilation
11:55	Use of LST data for producing data for the FAO-WaPOR portal: past, present and future	Henk Pelgrum (eLEAF)	00:15	• Near real time global database using satellite data that allows the monitoring of agricultural water productivity at different scales • LST is integral part of the WaPOR data pipeline • In the past resampled LST caused issues • Currently thermal sharpening is used to provide high resolution LST • Future versions will incorporate next generation high resolution LST open-source data

12:10	Using LST to better understand land atmosphere interactions and improve predictions	Christopher Taylor (CEH)	00:15	• LST allows us to use observations to characterise: surface energy balance changes with soil moisture; atmospheric boundary layer responses to soil moisture; impact of soil moisture on deep convection.
				• The following five applications were explored:
				  ○ LST mapping of E African wetland responses to climate variability
				  ○ Identifying flash drought events
				  ○ Persistence of land memory in Sahel
				  ○ Soil moisture and convective initiation across Sub-Saharan Africa
				  ○ Web portal for nowcasting (to 6 hours) convective storms

12:25	A multi-layer perceptron approach on downscaling land surface temperature for the study of surface urban heat islands	Alexandra Hurduc (IDL)	00:15	• In highly heterogeneous areas with different surface materials and in areas with varying horizontal and vertical structure there is a trade-off between spatial and temporal resolution. The usual approach is to downscale coarse spatial resolution to a finer one, taking advantage of the higher rate of observations of coarser resolution products. • The multi-layer perceptron methodology takes advantage of the spatial resolution provided by sensors onboard polar orbiting satellites and the high observation frequency of one onboard a geostationary satellite. • The method was shown to be capable of reproducing the heterogeneities of surface temperature based on SEVIRI LST, EVI and time of day.

				• Using pixel-wise training it is possible to obtain a model with high accuracy while requiring few input information on the very complex surface of urban areas. • The downscaled LST was also compared to additional polar orbiting sensors, showing a good quality of the model for different surface conditions, and times-of-year and day, with a RMSE of 1.18°C and MAE ranging from 0.94°C to 0.96°C. • This methodology can easily be extended to other regions, given the simplicity of the method and the few input data necessary
12:40	Analysis of urban surface temperature from satellite data with modelled 3D surface temperature	Maria Gkolemi (FORTH)	00:15	• The aim is to use modelling to assess surface temperature in cities from satellite thermal observations. This study compares modelled 3D surface temperature against satellite LST. • The model used is based on TUF-3D (Temperatures of Urban Facets in 3D) and includes a vegetation component using MAESPA (model of forest canopy radiation absorption, photosynthesis and water balance). The model can calculate energy balances and surface temperature in 3D. • The model is in agreement with satellite LST • Model limitations include building types and material properties, model spatial & vertical resolution and temporal resolution, satellite data products registration, forcing data.

				• The model has already been validated against in-situ thermal infrared observations. • Model will be used for assessment of complete temperatures in urban setting
12:55	Wrap up and close	Lizzie Good & Karen Veal	00:05	

2.3.3. Poster Presentations

Posters		
Presenter	**Title**	**Key Messages**
Christian Mollière (OroraTech GmbH)	Towards sub daily Land Surface Temperature	• Developments towards a constellation for frequent and rapid detection of wildfires on a global scale enables exploration of potential LST data products. • The use of uncooled microbolometer arrays allows the scaling of the OroraTech sensor network cost-effectively and fast, due to the reduced system requirements and cost. • The long-wave IR bands allow for the retrieval of LST at a GSD of 200m. • Further additions to the constellation are already being manufactured, with the long-term goal of reaching hourly or even more frequent revisits. • Using a single-band retrieval approach we see early validation results against the SURFRad ground station network of below 5K RMSE. The calibration of our

		sensor array is still in active development and we are working towards achieving even better radiometric performance. • Frequent observations can be used to accurately model the LST time series on the ground, despite the lower radiometric precision when compared to other LST data products. • Additionally, we see an almost two-fold increase in clear observations throughout the year due to very frequent revisits.
Raquel Niclos, presented by Sara Arribas (Department of Earth Physics and Thermodynamics, University of Valencia)	Assessing the accuracy of LST_cci products and analyzing LST trends in the Iberian Peninsula	• LST_cci TERRA-MODIS and AQUA-MODIS, SENTINEL3A_SLSTR_L3C and SENTINEL3B_SLSTR_L3C products were evaluated against ground data at the Valencia Test Site (VTS). MODIS operational LST products (MOD/MYD11_L2 and MOD/MYD21) using the same VTS ground data as reference data. SLSTR operational LST products and an alternative emissivity-dependent, and also viewing-angle dependent, split-window algorithm (E-SWA). • MODIS: V4.00 slightly reduce systematic uncertainties. It still overestimates ground LSTs both for EOS-Aqua and EOS-Terra at the VTS (1-1.5K), but the results for v2-v4.00 are much better than those for v1 products (with 4 K uncertainties). The remaining overestimation is due to differences between emissivities used in the product for the site and ground-measured emissivities. The product

		emissivities are underestimated at the site, still in v4.00. • SLSTR: Similar results were obtained for the LST_cci product and the operational product. Negligible biases were obtained for the alternative E-SWA. In the case of the LST_cci product, emissivities included do not reproduce the site emissivity changes and they are also underestimated for the site. • LST trends over the Iberian Peninsula are analysed using 20 years of the v4 AQUA_MODIS_L3C product series (2002-2021). • LST trends (LST_cci AQUA MODIS L3C 0.01° v4) over the Iberian Peninsula: Significant in the 22% of the area with a mean value of 0.1 K/year at daytime and in the 34% with a mean value of 0.07 K/year at nighttime. Similar trend values were found for the region have been found by other authors.
Helge Daempfling (GFZ Potsdam)	Hyperspectral Soil Property Mapping Using Thermal Infrared (LWIR) Imagery	• For this study we are utilizing thermal hyperspectral sensors to evaluate the properties of topsoils. Our objective is to establish reference databases and validate airborne applications for soil property estimation using these sensors in a laboratory setting. • As part of our study, we combined field measurements of bare soil pixels with lab measurements and chemical analysis of various soil samples. Our main study sites are located in Northern Greece (Western Macedonia) in the intensively

		agricultural used areas around the Amyntaio lignite mine which is around 100 Km west of Thessaloniki. • More than 250 soil samples were collected in several field campaigns from 2018 to 2023 covering the highly variable soils of the region. In 2019 an airborne survey acquired a hyperspectral dataset with a Neo HySpex VNIR and SWIR, and a Telops Hyper-Cam LW (LWIR) sensors covering the study site.
Shaojuan Xu (Research Institute for Regional and Urban Development, Dortmund, Germany)	Emissivity correction of 3D thermal model based on image processing and deep learning	• Using airborne thermal imaging to detect building energy leaks is an essential technique for assessing building energy efficiency. • Deep learning techniques were used for emissivity correction of high-resolution aerial images. • Emissivity-corrected thermal images were used as building textures with existing 3D building models to create a 3D thermal model which enables visualisation of energy leaks and quantitative evaluation of building energy efficiency.
Alexandra Hurduc (Instituto Dom Luiz - IDL)	On the suitability of different satellite land surface temperature products to study surface urban heat islands	• There is a need for understanding the ability of sensors to capture spatial and temporal SUHI patterns. • Results show that caution must be taken when characterizing SUHI based on few observations per day, as these may not fully characterize the range of intensities, translating in different SUHI intensity or signal (positive/negative). Also, as cities and their surroundings are highly heterogeneous surfaces, low

		spatial resolution datasets may dampen the spatial patterns. • Analysis of the diurnal, seasonal and inter-annual variability of the SUHI also suggest low consistency on the variability as given by each product. Therefore, studies focusing on the study of SUHI based on a single product may be significantly affected by the choice of product. We also found significant biases between the products even when considering the same resolution and time of observation. Validation of LST products over urban areas is very difficult due to the high heterogeneity, therefore care must be taken when basing SUHI studies on a single LST product. • Moreover, the low sampling rate joined with observations not matching the hours of extremes for either LST or SUHI, and pixel sizes much larger than surface heterogeneity may lead to discrepancies between SUHI results and consequently, making it difficult to compare studies, even when representing the same climate and degree of urbanization.
Liliia Hebryn Baidy (Scott Polar Research Institute, University of Cambridge)	Downscaling urban Land Surface Temperature variations across different land cover types using high-resolution satellite imagery	• Utilize high-resolution satellite imagery, to downscale LST variations across different land cover types within urban environments in the high latitude urban environment of Tromsø, Norway. • LST modelling is crucial for analysing UHIs, especially in complex urban environments like high-latitude cities.

		• In this research, we applied a methodology to calculate urban LST by integrating a solar radiation model with a DSM derived from LiDAR data in Tromsø, Norway. Utilizing high-resolution satellite imagery allowed us to downscale LST variations across different land cover types within the urban environment. • Limitations of our study include the uncertainty of input variables such as convective heat transfer coefficients, as well as the failure to account for the accumulated heat flux in urban surface materials, which may affect the accuracy of the model.
Tom Snelling (STFC RAL Space)	Performance validation of a commercial radiometer	• The thermal validation of a commercial radiometer against calibration blackbodies used for sea surface temperature is described
Abigail Waring (University of Leicester)	Improving Temperature Observations from Space: Regional Climate Trend Analyses for Aqua MODIS Surface Temperatures Across Earth & Progress Towards a Merged Product	• ESA CCI Aqua MODIS LST anomalies and their propagated uncertainty budgets are used to determine regional climate trends for 2002-2021. • Significant increasing LST trends were found in the Amazon, Siberia, and in Western USA. • Work using a machine-learning method to produce an all-weather LST product merging high-resolution IR and lower resolution MW LST is outlined.
Robert Elliott (Surrey Satellite Technology Ltd)	A low cost, small satellite constellation approach to rapidly monitor Land Surface Temperature for Urban and Agricultural applications over UK and Europe, with optimised cross calibration to ESA and Copernicus missions	• Temperature extremes are a dramatic threat to human health and economy, mounting costs & placing pressure on public services

		• Remote sensing is realistic option for characterisation and measurement of UK Urban Surface Temperature at 100m resolution and multiple times per day. • CLEAR solution has an onboard calibration every scan, and benefits from cross-calibration with LSTM and other missions
Giulia Guerri (Istituto per la BioEconomia (IBE) - Consiglio Nazionale delle Ricerche Institute of BioEconomy (IBE) - National Research Council)	Nationwide surface thermal analysis to detect priority areas for urban mitigation interventions	• Assesses the impact of climate change on cities in Italy using geospatial indicators to describe urban landscape and morphology. landcover and thermal pattern integrating remote sensing data from ASI (Prisma), NASA (Landsat-8 and 9), and Copernicus (Sentinel-1 and 2). • Assessment of mitigation using nature-based solutions and high-albedo pavements showed significant cooling effects with noon day surface temperature and air temperature decreasing by 13°C and 1°C respectively.
Dan Ormsby (Sparkgeo)	Development of a Climate Web Application on the EO Data Hub	• The aim is to develop a web application for the EO Data Hub that combines climate projection and observation data from trusted UK sources including the Met Office, EOCIS and NCEO. • Our approach has been to take the OS Climate workflows that assess the physical risk to assets, adapt them to the hub architecture and data sources and to provide additional capabilities by integrating useful insight from observation data. • The recently released Minimum Viable Product allows users to: view & interrogate hazard indicator

		datasets for Chronic Heat, view & interrogate land surface temperature observations from the U of Leicester at up to 100m resolution, upload asset portfolios of user defined sites of interest or explore results from several sample asset portfolios, run asset assessment workflows, including OS-Climate vulnerability models and land surface temperature observation history at the asset site at 100m resolution in London view metadata to discover the provenance of data included in the solution.

3. Workshop Feedback

3.1. Detailed Feedback

This section presents the results of the workshop feedback survey, issued shortly after the 2024 workshop, which received 25 responses. However, 5 free-text questions were optional so not all these questions were answered by all respondents. The primary purpose of this survey is to help plan for future events, rather than to gather requirements for the LST_cci project. It is included here for completeness and future reference.

Question 1 was concerned with the length of the next LST_cci user workshop, planned for the spring of 2026. Figure 3-1 shows that 40% of respondents suggested a 2-day workshop would be optimal with the remaining respondents split quite evenly (24%, 20% and 16%) between 1.5, 2.5 and 3 days, respectively.

Figure 3-1: Results from Question 1 of the workshop feedback survey: 'We are planning a longer in-person workshop for the next LST_cci event, which will likely be in the spring of 2026 at the Met Office in Exeter, UK. How long do you think this workshop should be?'

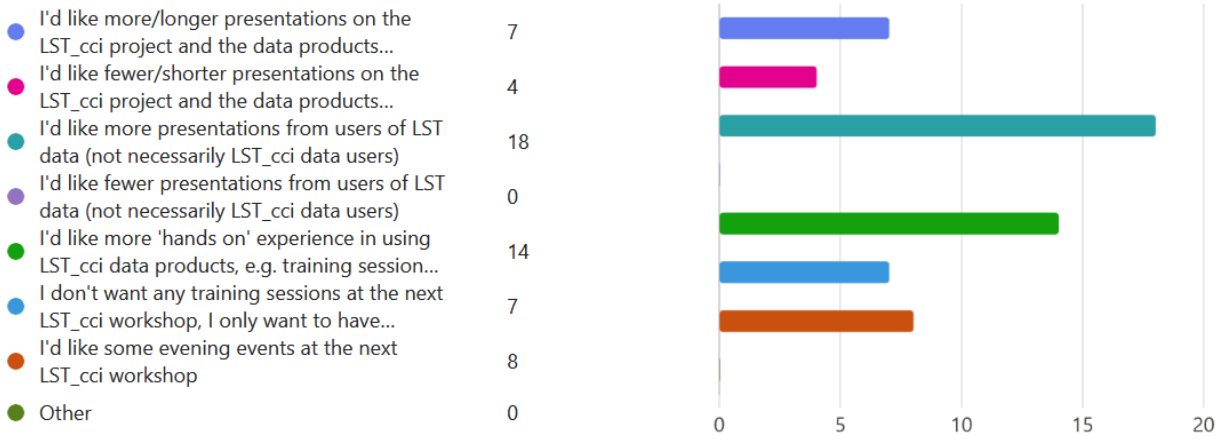

Figure 3-2: Results from Question 2 of the workshop feedback survey: 'We would like to know your thoughts on the content of the next LST_cci workshop. Which statements below best reflect your thoughts? (You can choose multiple options)'

Question 2 asked participants about the content of the next workshop; note that respondents could select multiple options. Figure 3-2 suggests that most (18/25) respondents would like more LST user

presentations and that more than half (14/25) would also like more 'hands on' experience with LST_cci products, e.g. training sessions, 'drop in' sessions, etc. However, some respondents (7/25) indicated they did not want any training sessions. For the next LST_cci user workshop in spring 2026, an ESMValTool training day held either directly before or after the workshop is being considered. An option here could be to run parallel LST_cci data usage support and/or training sessions, which would meet the needs of both these user groups. Several respondents (7/25) indicated that they would like more/longer presentations on the LST_cci project and the data products provided by the project. A number of respondents (8/25) indicated they would like some evening events at the next user workshop; this is being planned for the next workshop already to provide more opportunities for poster viewing and networking.

Figure 3-3 presents the results from question 3, which indicates clearly that users feel that 15-20 minutes duration for presentations, including questions, is the right duration.

Figure 3-3: Results from Question 3 of the workshop feedback survey: What length of presentations do you feel would be optimal at the next LST_cci workshop?

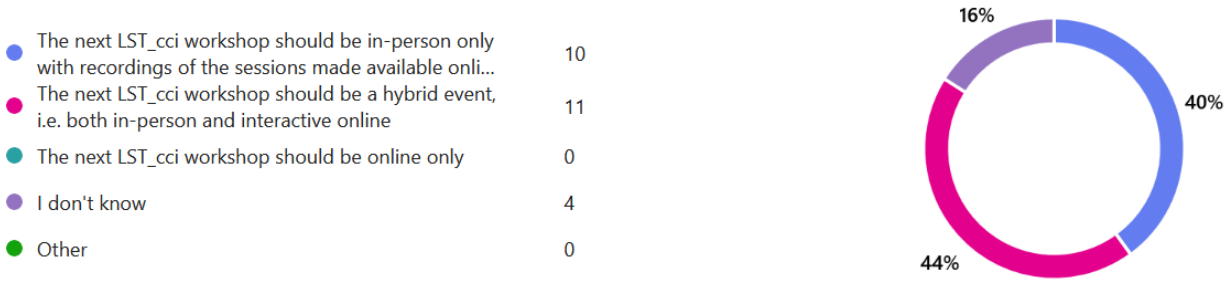

Figure 3-4: Results from Question 4 of the workshop feedback survey: The recent LST_cci workshop was an in-person event, although we plan to make the session recordings publicly available online, e.g. through YouTube. Which statement best matches your thoughts on the format for the next LST_cci workshop?

Question 4 asked participants about the workshop being in person and/or online (Figure 3-4). Four participants indicate they did not have any views here, and the remaining respondents are split almost equally between in-person only with recordings made available online after the event (40%) and hybrid (44%). A hybrid format will be considered for the next event, and this will be discussed with the project team during the planning phase.

Table 3-1: Results from Question 5 of the workshop feedback survey: Do you have any other suggestions for content for the next LST_cci workshop? (OPTIONAL)

Respondents comments
It was very good

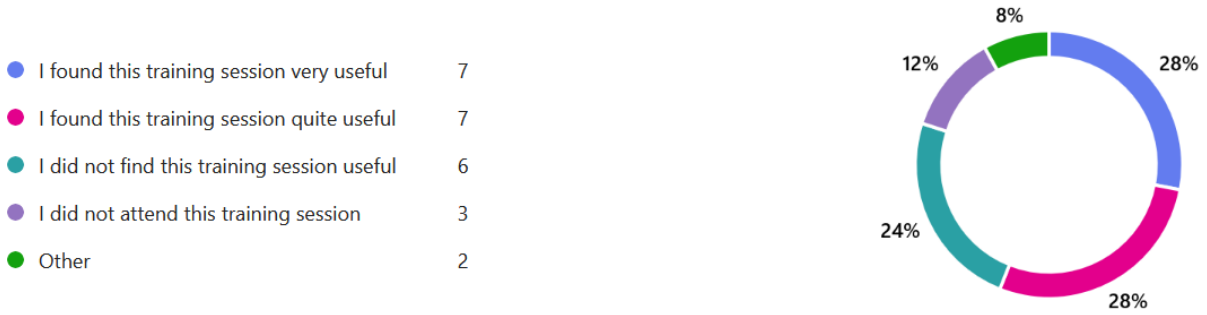

Figure 3-5: Results from Question 6 of the workshop feedback survey: Now thinking about the most recent LST_cci workshop at Space Park Leicester (Thursday 5th - Friday 6th December 2024), which statement most closely represents your feelings about the training session that took place on Friday morning at this workshop?

Question 5 was an optional free-text question asking for any suggestions for the next LST_cci workshop. Only one respondent provided a response that the 2024 workshop was 'very good' (Table 3-1).

Table 3-2: Results from Question 7 of the workshop feedback survey: If we run a training session at the next LST_cci workshop, what would you like to see in this session? (OPTIONAL)

Respondents Comments
Training session focused on how to access LST_cci data and its data format.
I hope there will be more methods and case demonstrations on downscaling analysis and the reconstruction of all-weather high-resolution remote sensing temperature datasets. Many thanks.
Please skip the training sessions. The content can be too basic for participants who are already familiar with programming, and running code cell-by-cell is something everyone can do independently (and the learning effect is limited).
no opinion either way

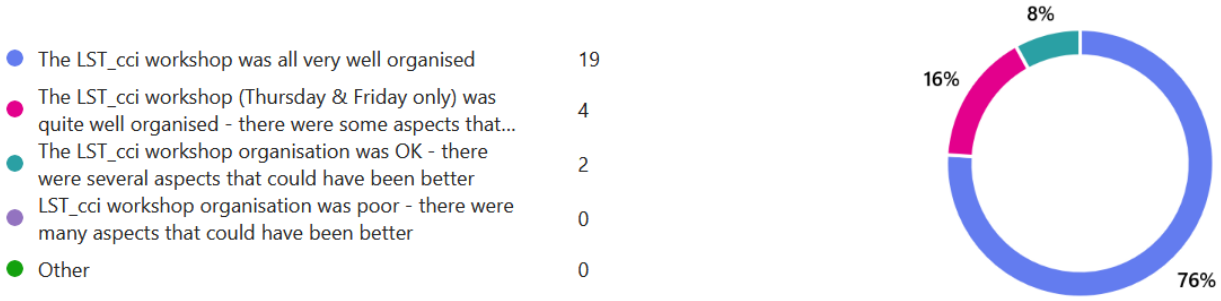

Figure 3-6: Results from Question 8 of the workshop feedback survey: Which statement most closely matches your feelings about the overall organisation of the LST_cci workshop (Thursday 5th & Friday 6th December only)?

Question 8 of the survey was concerned with the organisation of the workshop. The majority of the respondents (76%) thought the workshop was all very well organised. Four respondents (16%) thought the workshop was well organised but there were some aspects that could have been better organised,

while two respondents (8%) thought there were several aspects that could have been better organised. Question 9 was an optional free-text question designed to gather insight into the participants responses to Question 8 (Table 3-3). One respondent requested 'more well-selected short case studies' demonstrating LST applications. Another respondent asked for water and food to be accessible all day. Water will be available at all times from a dispenser at the next workshop and it may be possible to leave the coffee break and lunch food out at all times, and this will be considered for the next event. The final comment provided positive feedback on the event overall.

Table 3-3: Results from Question 9 of the workshop feedback survey: Do you have any comments you would like to make about the organisation of the LST_cci workshop (Thursday 5th and Friday 6th December only), particularly if you felt there were things that could have been done better? (OPTIONAL)

Respondents Comments
More well selected short case studies of applications
It would be nice to have accessible water and food all day
felt like it's a strong community who can help each other to deliver this event, I am not concerned if there are some niggles with technology or the odd presentation is late, it felt accessible and useful to further the research and innovation going into this topic. thanks for organising

Figure 3-7: Results from Question 10 of the workshop feedback survey: Which statement most closely matches your feelings about the emails you received before and during the LST_cci workshop (Thursday 5th and Friday 6th December only)?

Question 10 focused on the communication before and during the workshop (Figure 3-7). The vast majority (84%) of the 25 respondents felt the level and detail of the communications were about right. Three respondents (12%) felt that the number and detail in the emails they received about the LST_cci workshop was about right but wanted more advance notice. This comment is appreciated as unfortunately, the 2024 workshop was planned at rather short notice, taking advantage of the opportunity to join with the Thermal Remote Sensing Special Interest Group event, and it became obvious that organising a workshop with more advance notice is needed to ensure participants had enough notice to attend the event: there were several participants that had to drop out of the 2024 workshop at the last minute due to problems obtaining visas to visit the UK for the workshop.

Table 3-4 shows the optional free-text comments provided in response to question 11 of the survey, which was aimed at providing insight into the responses to question 10 of the survey on the workshop communication. There were only two responses to this question. One respondent commented that they felt everything was very clear. The second respondent commented that they would have liked more information on what was required for the posters. Information was provided well in advance of the workshop to presenters regarding the poster size, orientation and display time. However, the

information provided will be reviewed for the next workshop to see what additional information may be helpful. This comment may be a result of the change of room for the poster presentations at the workshop, which unfortunately had to be changed at the last minute, which did cause some confusion.

Table 3-4: Results from Question 11 of the workshop feedback survey: Do you have any comments you would like to make about the emails/communication you received about the LST_cci workshop (Thursday 5th and Friday 6th December only) both before and during the event, particularly if you felt there were too many or too few emails, or too little or too much detail provided? (OPTIONAL)

Respondents Comments
was all very clear to me tbh
I think I had to request some further info on what was required for the posters so this could've been described better in the original joining instruction

Table 3-5: Results from Question 12 of the workshop feedback survey: Do you have any other comments you would like to make about the recent LST_cci workshop (Thursday 5th and Friday 6th December only) or the next LST_cci workshop? (OPTIONAL)

Respondents Comments
Many thanks. I'm very glad to have the opportunity to participate and look forward to the next time.
As delegates go, I was probably atypical as I work in industry in more of a business development role, rather than working in the field of LST research. It was useful for me to get a general feel of what sort of work is going on in LST but given the event seemed to be mostly post-docs presenting to others, a lot of it went over my head! No problem if that is the format of future events but if so, take my responses here with a pinch of salt!
Thanks for including us it was very useful. I'd probably be interested in hearing more how important LST products are used by operational users (e.g. EUMETSAT, Copernicus) as this helps us improve the business case to develop low cost satellite LST constellations for the LST community.

Question 11 provided the opportunity for participants to provide any other comments about the workshop as an optional free-text entry. Three responses were received, which were positive overall although one respondent suggested it would be useful to hear how important LST products are for operational use in order to develop the business case to develop low-cost satellite LST constellations. Another respondent commented that most of the presentations were technically detailed and perhaps not easy to follow. Both these points will be considered for the next workshop.

3.2. Key Feedback Points

- A 2-day workshop appears to be optimal for the next user workshop, perhaps with some additional event on day 3 (e.g. user training)
- Delegates would like more user presentations at the next workshop.
- The next workshop should include some ‘hands on’ experience/training, but perhaps run in parallel with another type of session as there are a sizeable group of delegates that do not want any training.
- Presentations at the next workshop should be 15-20 minutes duration.

- The next workshop should be either hybrid or in-person with recordings/workshop material made available after the workshop event.
- Water (and perhaps some food) should be available for the duration of the next workshop.
- Communication levels from the 2024 workshop were about right so this approach should be adopted for the next workshop. However, it is noted that the workshop should – including attendees – should be finalised earlier to allow participants to obtain visas in time for the workshop where required.

4. Workshop Outcomes

4.1. Summary of User Requirements Discussion

As noted in the preceding sections of this report, a discussion session on user requirements for LST was held on day 1 of the workshop. In addition to a free discussion in plenary, the 'Slido' online tool (https://www.slido.com/) was utilised to gather user requirements in a quantitative way. 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. The results were displayed during the session in real time in order to prompt discussion to provide insight into participant views. Notes were made during the discussion session and these are included in the interpretation of the Slido results below. As noted in Section **Error! Reference source not found.**, recommendations resulting from user feedback are listed in this document and will be used to define new user requirements for the LST_cci project in the URD [AD-02].

4.1.1. 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 participant's main application and their use of LST_cci datasets.

4.1.1.1. Question 1: Participant's main application

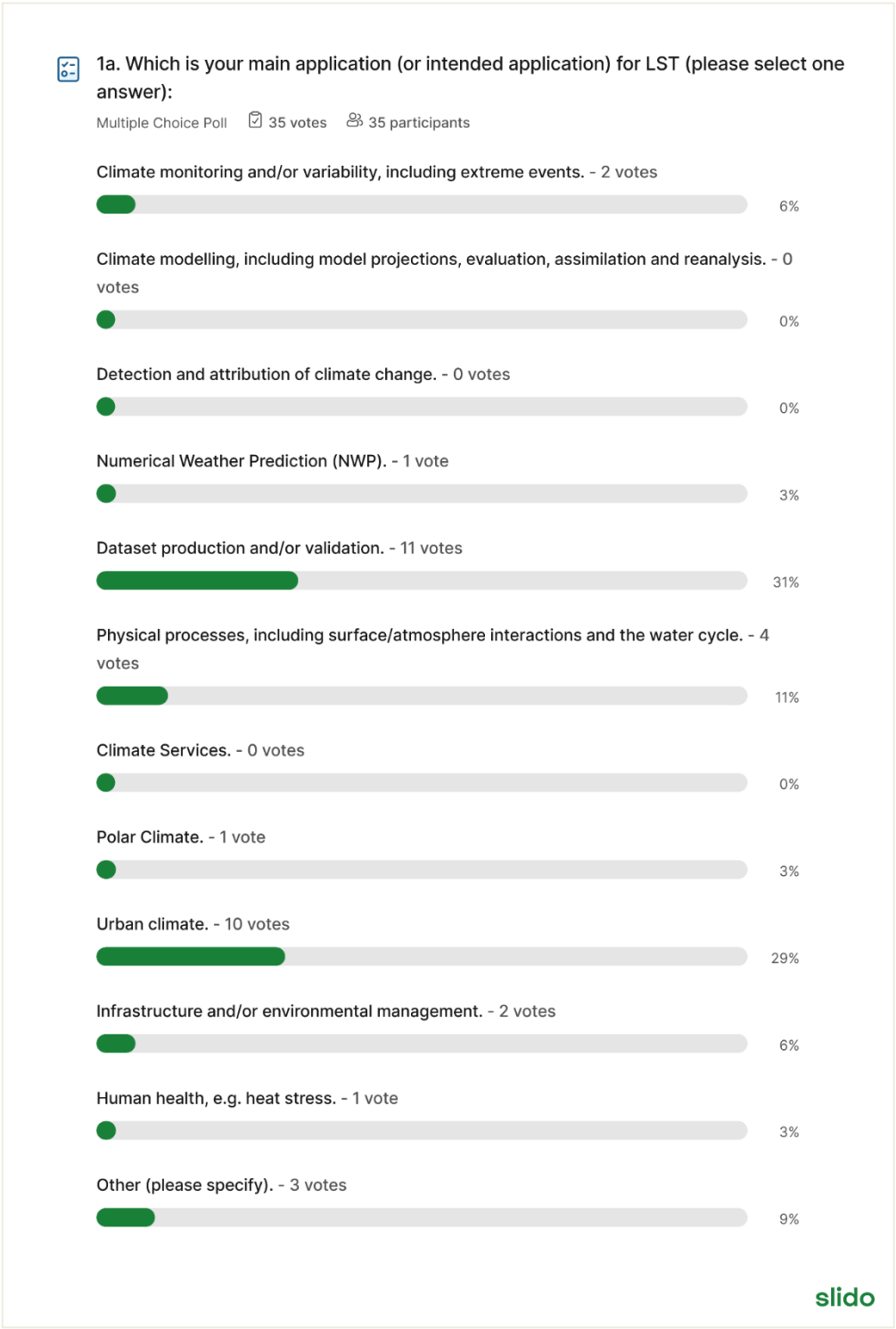

Figure 4-1: Slido result - 1a. 'Which is your main application (or intended application) for LST?' Number of respondents = 35'.

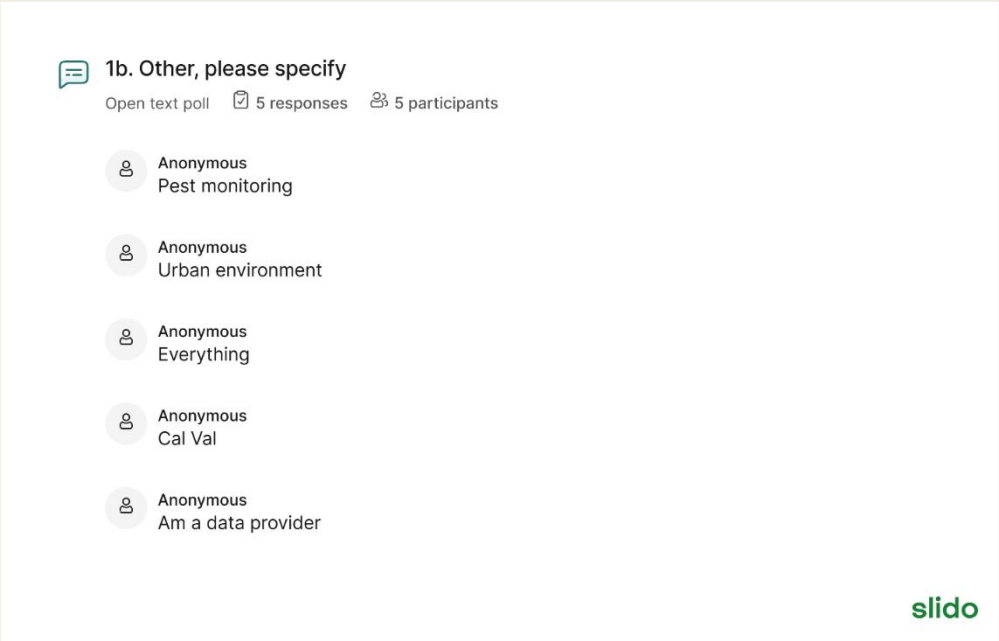

Figure 4-2: Slido result - 1b. Main applications indicated by respondents indicating 'Other' in question 1a. Number of respondents = 5'

Question 1 asked the participants to choose their main application of LST from a list of 11 or indicate 'other' if none of the eleven applied. Those indicating 'other' were asked to supply their main application as free text. There were 35 respondents to the first part of the question and 5 answered the second part of which 3 had answered 'other' in part one, giving a total of 37 respondents. Full results are shown in Figure 4-1 and Figure 4-2. Over 30% of respondents gave their main application as dataset product and/or validation. Nearly 40% of respondents had a main application linked to the human environment (urban climate, infrastructure and/or environmental management, or human health). Only 6% gave climate monitoring as their main application. No respondents gave climate modelling or climate services as their main application. Engaging users in climate modelling and/or climate services has been a focus on the LST_cci projects since the first user workshop in 2020 and this should continue to be an important objective.

- **Recommendation 1: Continue to improve engagement with the climate modelling and climate services communities.**

4.1.1.2. Question 2: Usage of LST_cci datasets

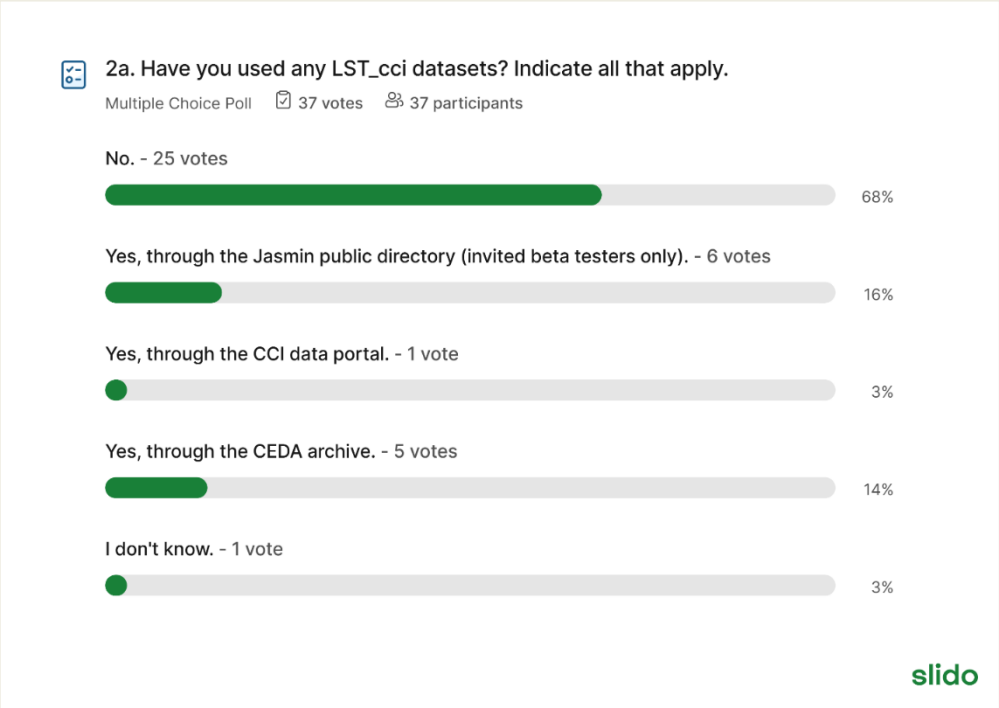

Figure 4-3: Slido result - 2a. 'Have you used any LST_cci datasets?' Number of respondents = 37

Question 2a asked about use of LST_cci datasets. Out of 37 respondents, 25 said they had not used LST_cci datasets and 12 said they had. Of this twelve, 6 were beta testers who had used the data on the Jasmin ESA LST_cci group workspace public directory, 5 had obtained data through the CEDA archive and 1 had obtained data through the ESA CCI data portal. Poll results are shown in Figure 4-3.

Participants were largely from the UK so may be expected to have access to the JASMIN data analysis facility where they can process the data products on CEDA directly instead of needing to first download data from the ESA CCI portal to their own computing facility. The number of users is relatively small indicating a need to further publicise the data, for training to educate in obtaining and using the data, and also to investigate what is stopping people using data.

- **Recommendation 2: Seek opportunities for further outreach activities to publicise LST_cci data.**
- **Recommendation 3: Provide training in how to obtain and use LST_cci data.**

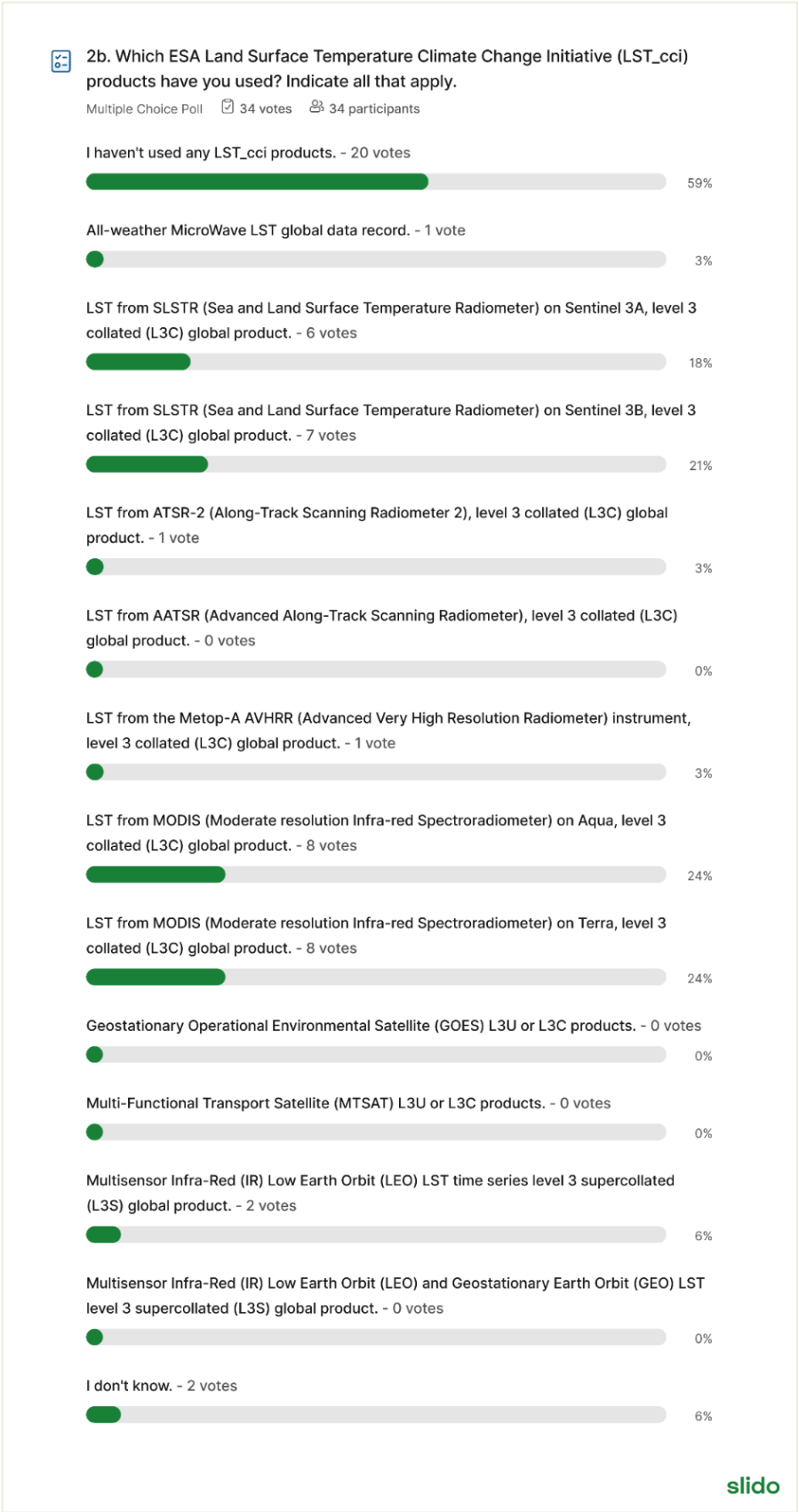

Figure 4-4: Slido result - 2b. 'Which ESA Land Surface Temperature Climate Change Initiative (LST_cci) products have you used?' Number of respondents = 34.

Question 2b asked which LST_cci products participants had used. Of the 34 respondents 20 had not used LST_cci products. The MODIS products were most popular with 8 respondents saying they had used the Aqua MODIS and the Terra MODIS products. Seven respondents said they had used the Sentinel 3B SLSTR product and six said they had used the Sentinel 3A SLSTR product. Two participants indicated they had used the Multisensor IR LEO L3S product. In the cases of the ATSR-2 and the Microwave product, one person had used each product. No-one indicated they had used the AATSR product, the Multi-sensor IR merged LEO GEO product, the GOES products, or the MTSAT products. Two respondents said they didn't know which product they had used. The results are shown in Figure 4-4.

- **Recommendation 4: Project team to consider whether it is worth producing products with few users, noting that there were many users who were not at the workshop who currently use LST_cci products.**
- **Recommendation 5: The product user guide should indicate suitable applications or each product - the characteristics of the product, its suitability for various applications, limitations, etc.**

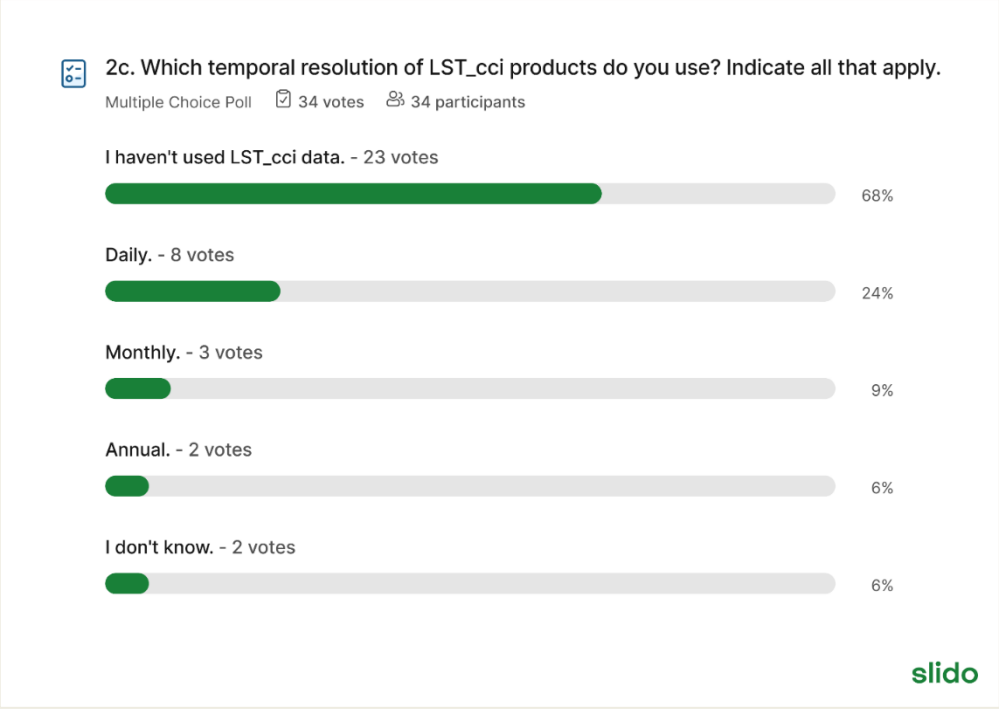

Figure 4-5: Slido result - 2c. 'Which temporal resolution do you use?' Number of respondents = 34.

Question 2c asked about the temporal resolution of LST_cci products used by participants (see Figure 4-5). Fifteen participants responded that they had used LST_cci products: 8 used the daily products, 3 used the monthly products, 2 used the annual products. Two respondents said they didn't know which products they used. As the project already produces both daily and monthly resolution products, no specific recommendations are required here.

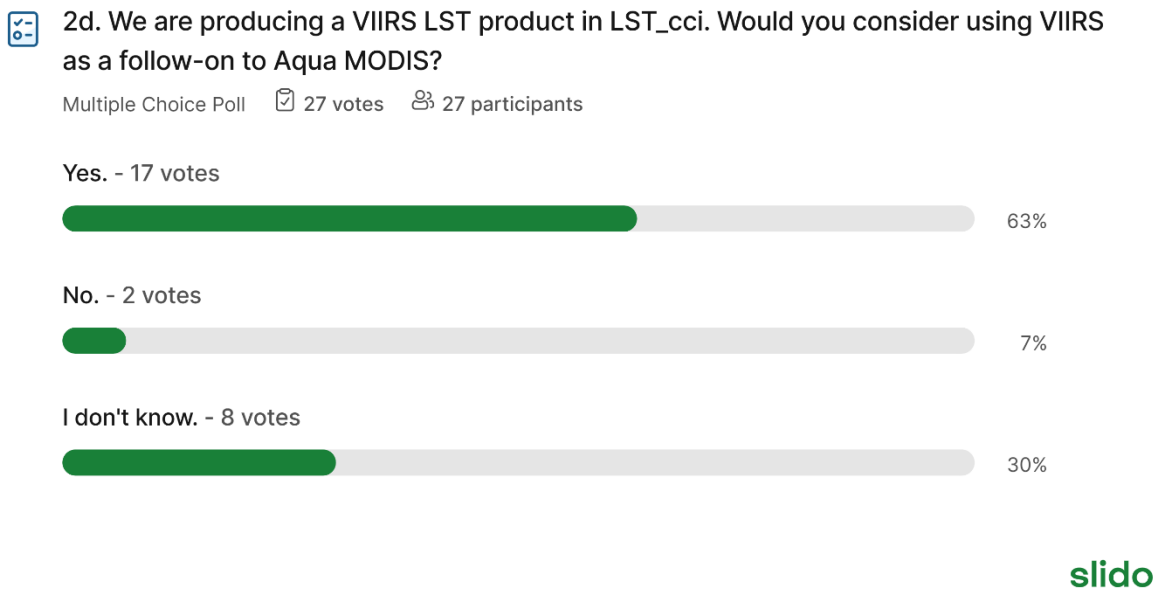

Figure 4-6: Slido result - 2d. 'We are producing a VIIRS LST product in LST_cci. Would you consider using VIIRS as a follow-on to Aqua MODIS?' Number of respondents = 27.

Questions 2d and 2e asked about the new VIIRS LST_cci product. When asked if they would consider using VIIRS as a follow-on to Aqua MODIS 63% said yes, 7% said no, and 30% said they did not know (Figure 4-6).

- **Recommendation 6: Provide information in the PUG on the pros and cons of using VIIRS as a follow-on to Aqua MODIS.**

Before asking Question 2e, information was presented on how the gridding of the VIIRS 750 m L1 products results in gaps in the 0.01° L3C CCI VIIRS products. During gridding of the instrument data in the processing of the L1C products NASA remove overlapping pixels which occur towards the edges of the instrument swath - so-called 'bow-tie deletion'. These gaps are still evident on regridding of the swaths to equal latitude-longitude grids at 0.01° resolution (see Figure 4-7). Different treatment of overlapping pixels produces different amounts of striping: choose pixel by nearest to nominal time (current method for LST_cci IR products): by lowest uncertainty: by lowest zenith angle. The method used in NASA L3 products is to average all the overlapping pixels, which reduces the striping but loses the traceability of the acquisition time and averages pixels that could be over 1 hour apart. Propagating to a 0.05˚ L3C product effectively removes the problem.

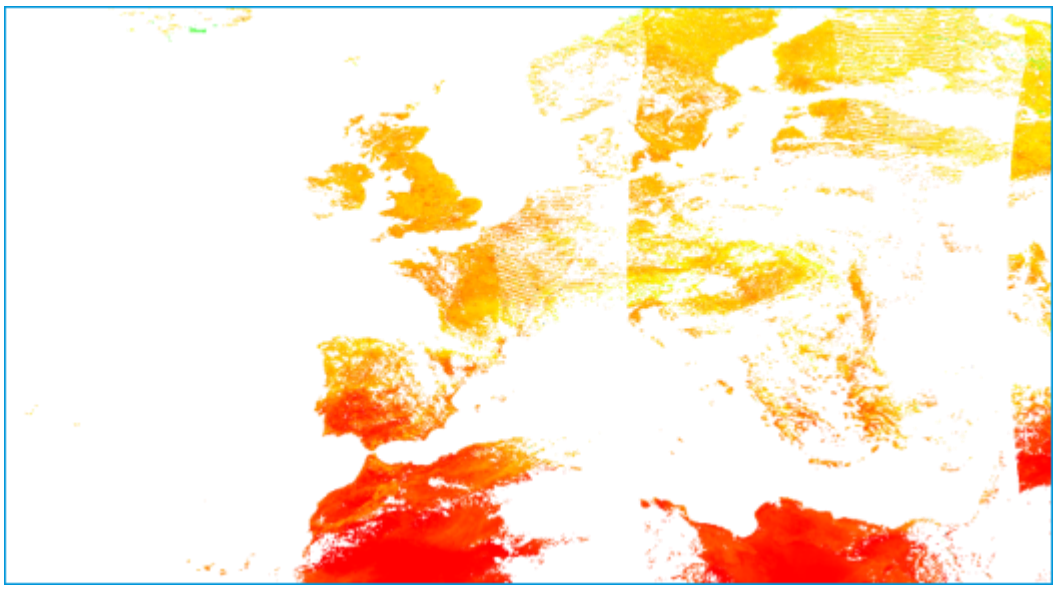

Figure 4-7: Prototype VIIRS 0.01° L3C product: evidence of gaps at edge of swath resulting from the 'bow-tie deletion' in the 750m L1C NASA VIIRS product.

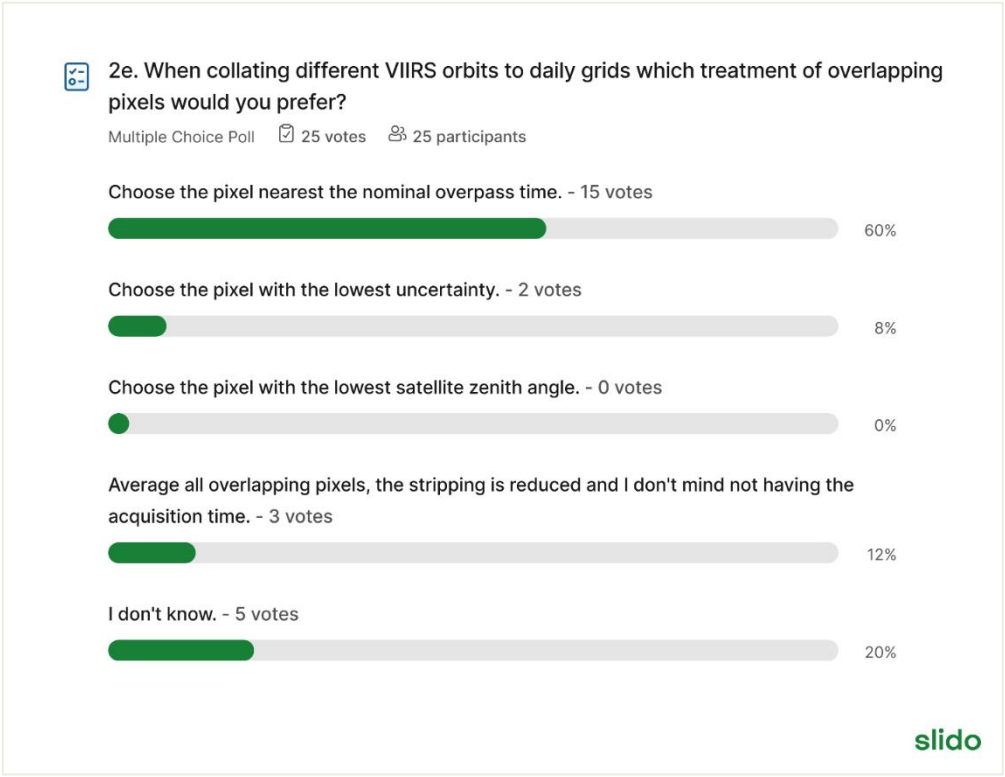

Figure 4-8: Slido result - 2e. 'When collating different VIIRS orbits to daily grids which treatment of overlapping pixels would you prefer?' Number of respondents = 25.

Question 2e asked which method of collation of VIIRS orbits to daily grids would users prefer? Twenty-five participants responded of whom five said they didn't know. Fifteen preferred that the pixel gridded should be the pixel nearest the nominal overpass time, three wanted all overlapping pixels to be

averaged (acquisition time would be lost), and two preferred the pixel gridded to be the pixel with the lowest uncertainty. No one wanted the pixel with the lowest satellite zenith angle as the gridded pixel. Results are shown in Figure 4-8.

In discussion, it was noted that if methods other than 'nearest to nominal' were used then there would be differences in retrieval times in the time series. A bi-resampled product was being used by one participant: it was thought likely this resorted to nearest measurement to fill the gaps. Since VIIRS is being considered as a follow-on to Aqua MODIS the same gridding method should be used for products from these instruments.

- **Recommendation 7: The gridding method for VIIRS should choose the pixel nearest the nominal overpass time. This is the method used for all previous IR products and is consistent with the Aqua MODIS products.**

4.1.1.3. Question 3: Auxiliary variables in product files

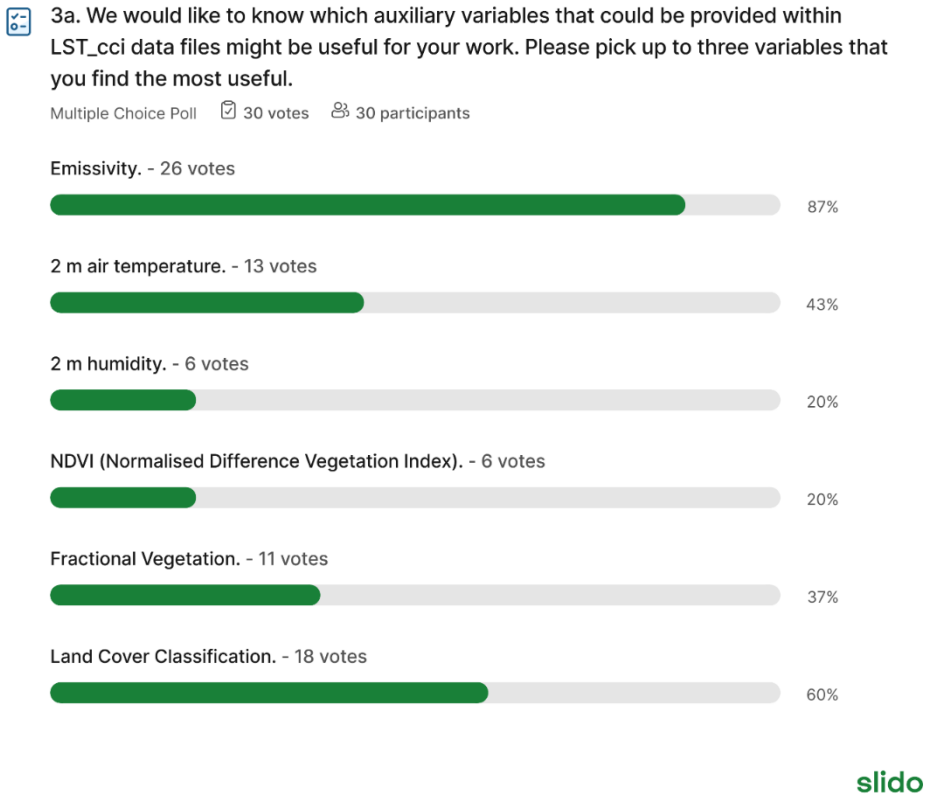

Figure 4-9: Slido result - 3a. ' We would like to know which auxiliary variables that could be provided within LST_cci data files might be useful for your work. Please pick up to three variables that you find the most useful.' Number of Respondents = 30.

Question 3 considers the auxiliary variables which could be provided in the products. Participants were asked to pick from a list of six up to three variables that they would find useful. Thirty participants responded. There were 26 votes for emissivity, 18 for land cover classification, 13 for 2 m air

temperature, 11 for fractional vegetation, and 6 votes for 2 m humidity and for NDVI. Results are shown in Figure 4-9.

There were questions about the source of the auxiliary variable data: meteorological data would likely come from ERA5 (as is the case for T2m); the emissivity would be the data used for the retrieval (currently CAMEL climatology).

- **Recommendation 8: Consider provision of emissivity data used in the retrieval to be included in LST_cci products. However, a better understanding of why users would like these data would be useful to ascertain before this addition is included. This could be explored at the next user workshop in 2026.**

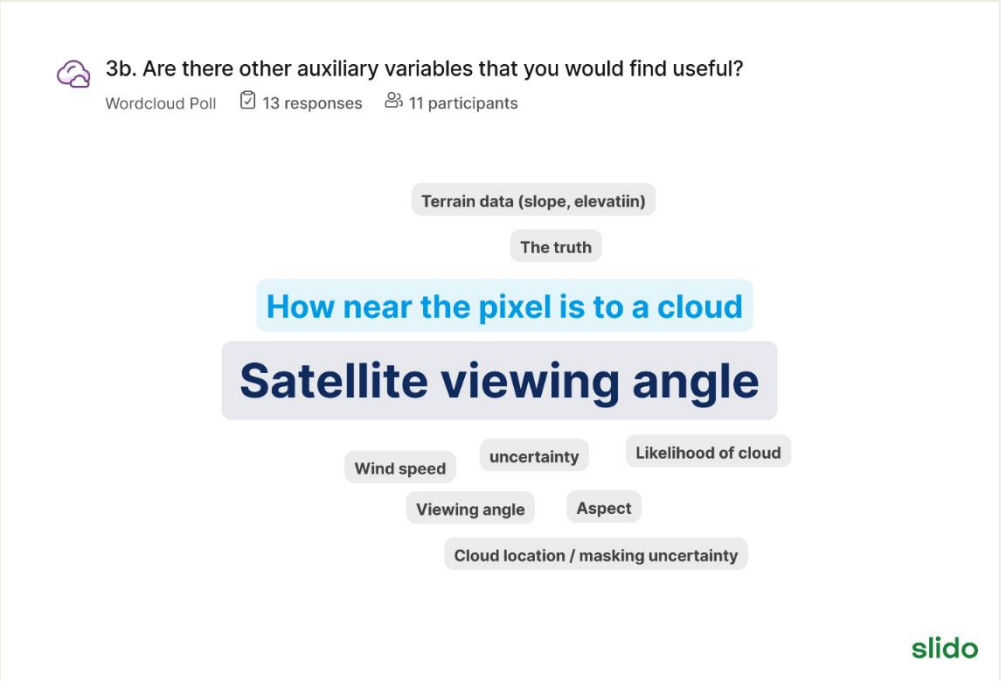

Figure 4-10: Slido result - 3b. 'Are there other auxiliary variables that you would find useful?' Number of respondents = 11.

Participants were then invited to suggest other variables that they would find useful. There were 13 responses by 11 participants. Four participants indicated satellite viewing angle (or view angle); satellite zenith and satellite azimuth angles are already provided in the current LST_cci products. One participant indicated uncertainty; total uncertainty and a breakdown of the uncertainty into components by correlation scales is also already provided. Two participants asked for proximity to cloud. One asked for cloud likelihood and one asked for cloud location / masking uncertainty. Two participants wanted more information about the terrain: one asked for the aspect and one for terrain data (slope, elevation). One participant asked for wind speed. One participant asked for the truth. Results are shown in Figure 4-10.

- **Recommendation 9: Consider providing more information on proximity to cloud, cloud probability and uncertainty in cloud masking.**
- **Recommendation 10: Consider providing digital elevation model output on the spatial resolution of the satellite LST data.**
- **Recommendation 11: Consider providing wind speed information e.g. from ERA5 (which is currently used for T2m)**

4.1.1.4. Question 4: Gap-filling

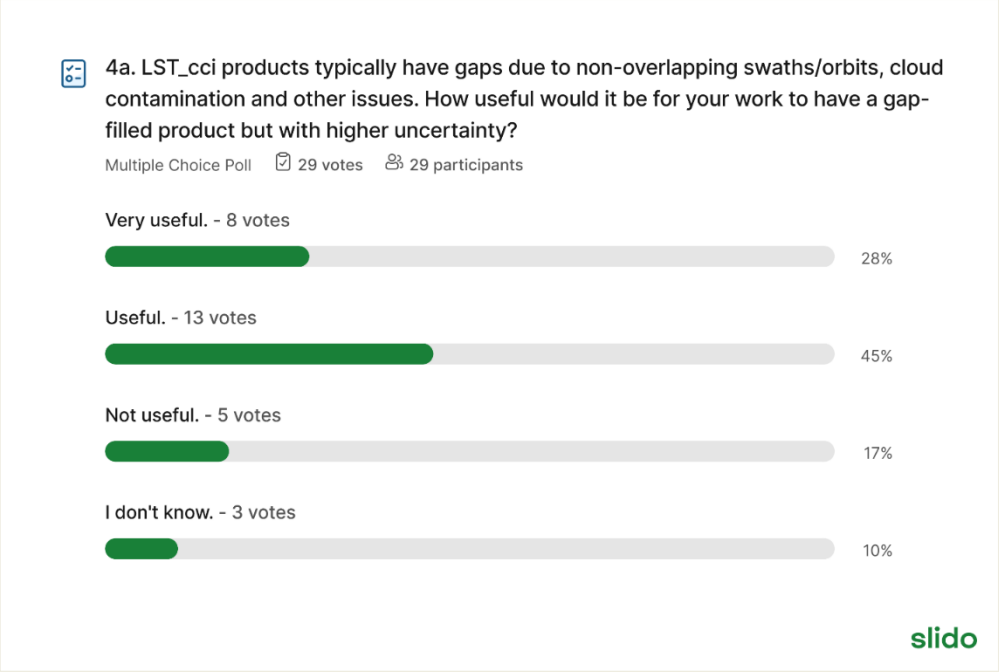

Figure 4-11: Slido result - 4a. 'LST_cci products typically have gaps due to non-overlapping swaths/orbits, cloud contamination and other issues. How useful would it be for your work to have a gap-filled product but with higher uncertainty?' Number of respondents = 29.

An overview of potential spatial gap-filling of IR LST products was presented. It was noted that most gap-filling methods fill with clear-sky estimates of LST even under cloudy conditions and that gap-filled data would have higher uncertainties. Participants were then asked (Question 4): How useful would it be for your work to have a gap-filled product but with higher uncertainty?

Twenty-nine participants responded. Thirteen said they would find a gap-filled product useful, albeit with higher uncertainties, eight said they would find such a product very useful, five said it would not be useful, and three did not know. Results are shown in Figure 4-11.

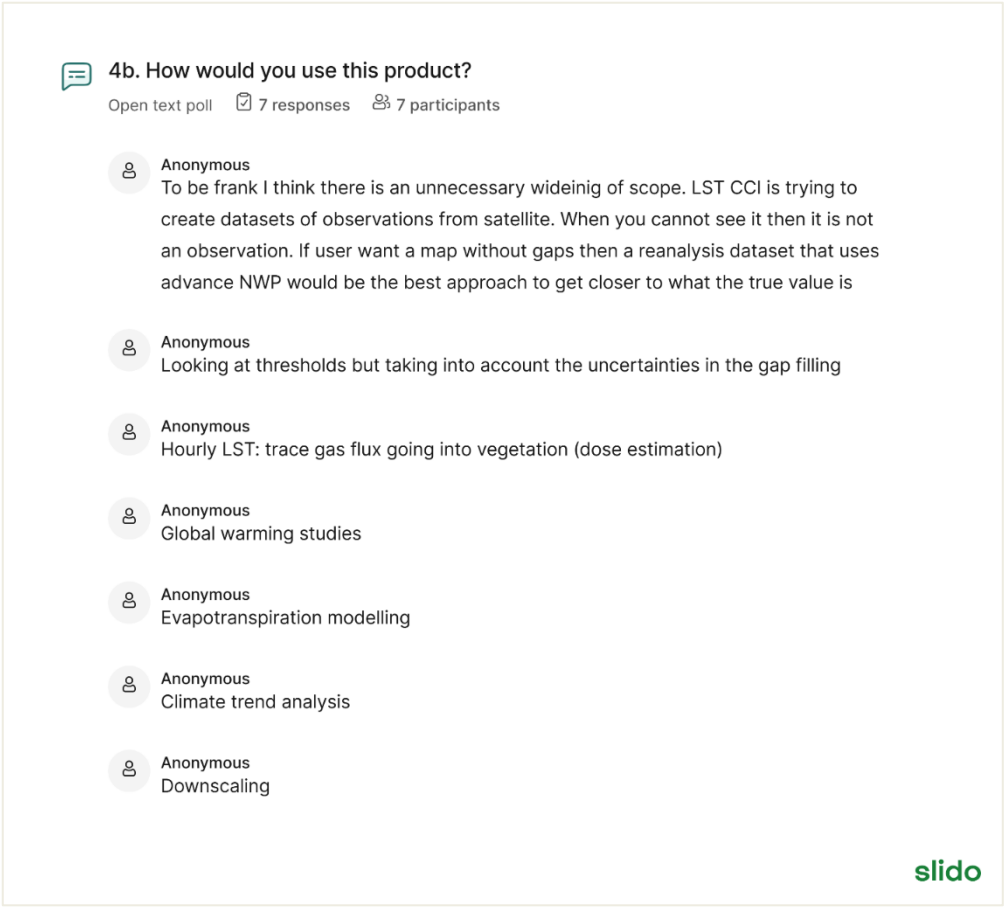

Figure 4-12: Slido result - 4b. 'How would you use this product?' Number of respondents = 7.

When asked how participants would use this product, there were six responses: global warming studies, climate trend analysis, looking at thresholds but taking into account the uncertainties in the gap filling, hourly LST: trace gas flux going into vegetation (dose estimation), evapotranspiration modelling, downscaling. Results are shown in Figure 4-12.

It was noted that CCI would probably not gap-fill standard products, gap-filled products would be separate (Level 4) products. The possibility of interpolating the GEO 3 hourly products to obtain 1 hourly data was discussed. This would require using a diurnal cycle model, these usually require at least 6 data points for fitting which would often not be present. If resorting to a model it may be better to use full reanalysis. Again, interpolation would produce clear-sky estimates when cloud may be present and therefore the meaningfulness/usefulness of these data for many applications is questionable.

- **Recommendation 12: To provide gap-filled LST_cci products.**

4.1.1.5. Question 5: Timeliness

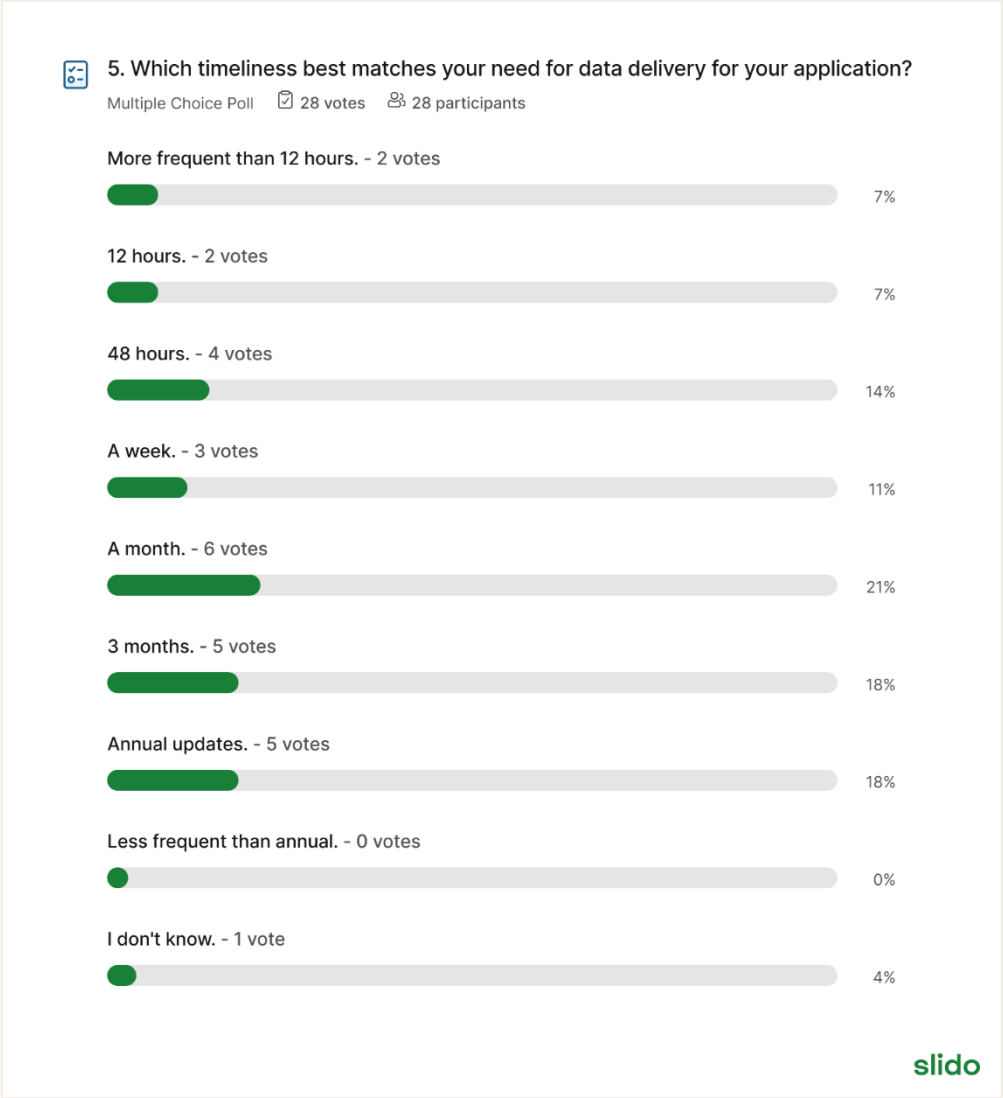

Figure 4-13: Sldio result - 5. 'Which timeliness best matches your need for data delivery for your application?' Number of respondents = 28.

Question 5 asked which timeliness best matches your need for data delivery for your application? 28 participants responded. Six answered 'a month', five said 3 months, five said annual updates, 4 said 48 hours, 2 said 12 hours and 2 said more frequent than 12 hours (see Figure 4-13 for results).

Of the eleven participants who indicated a timeliness of a week or less, seven had also indicated their main application: four said their main application was data production and/or validation and three gave their main application as climate. Therefore, there is a clear demand for product delivery in 'near-real time', i.e. more frequently than is currently provided by LST_cci.

CCI delivers data at the end of each project phase which can be 1-2 years apart. However, Copernicus delivers data operationally, although currently not LST. However, Copernicus could deliver LST in the future. In discussion, it was noted that operational data products may contain inconsistencies and step

changes as processing algorithms are changed so this needs to be considered when providing these real-time products.

- **Recommendation 13: Seek opportunities to provide LST in real time, e.g. through C3S.**

4.1.1.6. Question 6: Product User Guide

Directory/ Product Name (ESACCI-LST-)	Version	Sensor/Satellite	Spatial res.	Temporal resolution	Dataset length	Key features	Good for...	Take care with...
AQUA_MODIS_L3C_0.01/ L3C-LST-MODSA-0.01deg*	4.aa	MODIS/Aqua[1]	0.01° lat-long	Daily Day & night	04/July/2002 – 31/Dec/2021	• 01:30/13:30 local observation time • Cloud free scenes only • ~20 years data • Verified stable over time • Up to two observations per day per grid cell • Includes sea-ice	• Trend analysis • Urban studies • Local/regional/global studies • Long-term studies	• Cloud contamination (causing large negatively-biased LSTs)
TERRA_MODIS_L3C_0.01 L3C-LST-MODST-0.01deg*	4.aa	MODIS/Terra[1]	0.01° lat-long	Daily Day & night	24/Feb/2000 - 31/Dec/2021	• 10:30/22:30 local observation time • Cloud free scenes only • ~22 years LST • Up to two observations per day per grid cell • Includes sea-ice	• Urban studies • Local/regional/global studies • Long-term studies	• Trend/temporal analysis – some inhomogeneities found (see Good et al., 2022) • Cloud contamination (causing large negatively-biased LSTs)
METOPA_AVHRR_L3C_0.01/ L3C-LST-AVHRMA-0.01deg*	1.00	AVHRR/Metop-A[2]	0.01° lat-long	Daily Day & night	01/Mar/2007 – 15/Nov/2021	• 07:50/19:50 local observation time • Global data • Cloud free scenes only • Up to two observations per day per grid cell • Stable orbit but stability of LST data not yet verified. • Includes sea-ice	• Urban studies • Local/regional/global studies	• Trend/temporal analysis – stability not yet verified (although quite likely stable) • Cloud contamination (causing large negatively-biased LSTs)

Figure 4-14: Illustrative lines from a table of key dataset features that it is proposed to include in the PUG.

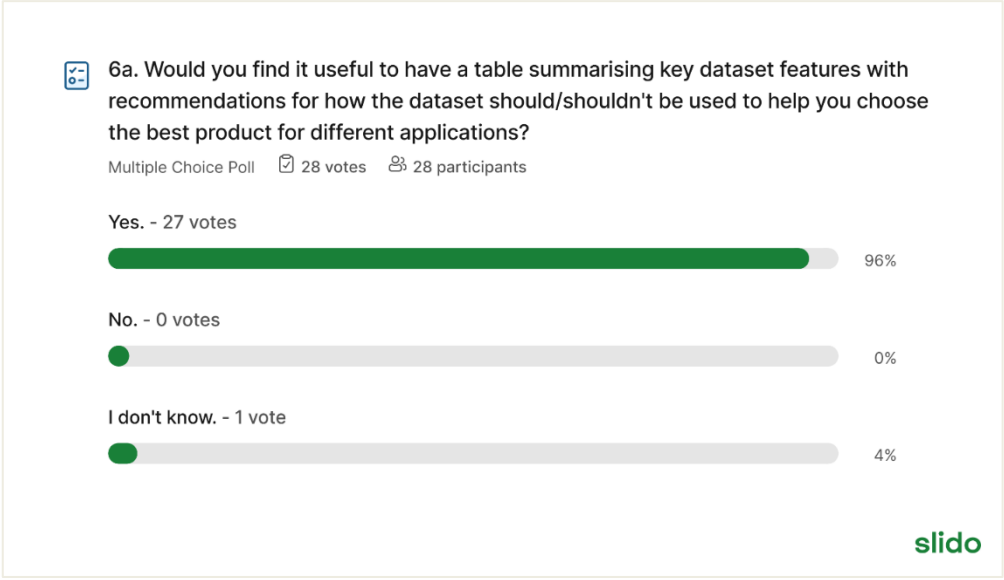

Figure 4-15: Slido result - 6a. 'Would you find it useful to have a table summarising key dataset features with recommendations for how the dataset should/shouldn't be used to help you choose the best product for different applications?' Number of respondents = 28.

Question 6 asked about information that LST_cci should provide to help data users. Question 6a asked if participants would find it useful to have a table summarising key dataset features with recommendations for how the dataset should/shouldn't be used. Participants were shown the table available to beta users of the LST_cci data (Figure 4-14). The table lists the key features of the data and includes 'Good for …' and 'Take care with …' columns. Of the 28 responses, 27 were yes and 1 was I don't know. Results are shown in Figure 4-15.

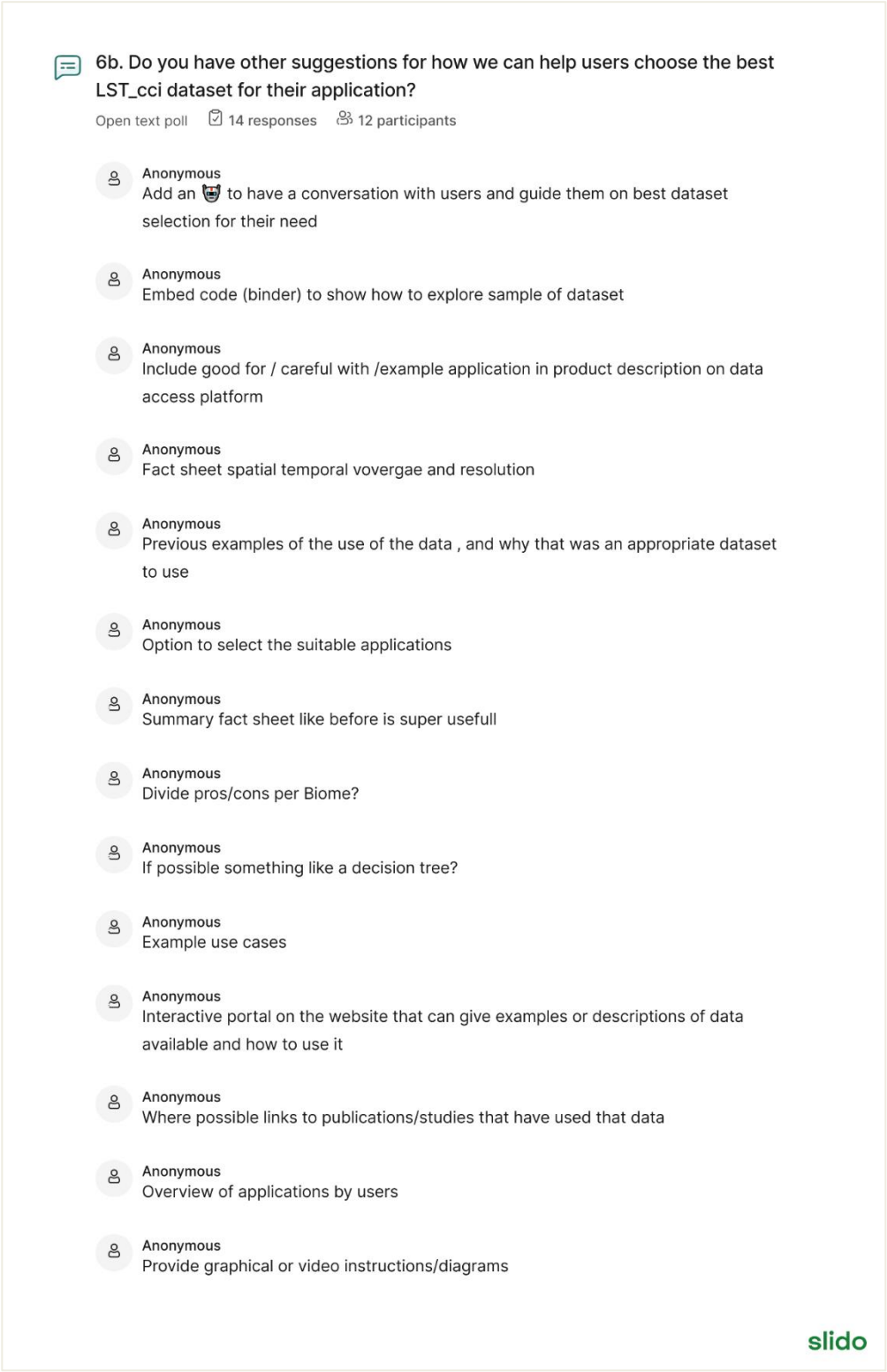

Figure 4-16: Slido result - 6b. 'Do you have other suggestions for how we can help users choose the best LST_cci dataset for their application?' Number of respondents = 12.

Question 6b asked for suggestions on how LST_cci could help users choose the best LST_cci dataset for their application. A full list of responses is given in Figure 4-16).

Responses covered:

- providing information on choosing most suitable dataset for application by means of a demon or decision tree;
- summary fact sheet covering dataset properties,
- list of good for / careful with;
- example code for exploring dataset;
- graphical or video instructions;
- example use cases,
- list of publications that have used data
- information should be available on data access platform

In discussion, it was noted that advice on which product to use should not be too prescriptive as the user knows their application best. Information on where and how to raise issues with the data should be available. Currently beta users are able to log issues perhaps there should be a public issues log.

- **Recommendation 14: Include a table of key features based on the table already available to beta users that provides advice to user in helping them to choose the most suitable LST_cci dataset for their application. This could include references to existing studies that use LST data.**

- **Recommendation 15: Provide the means for users to provide feedback on LST_cci datasets, e.g. report issues.**

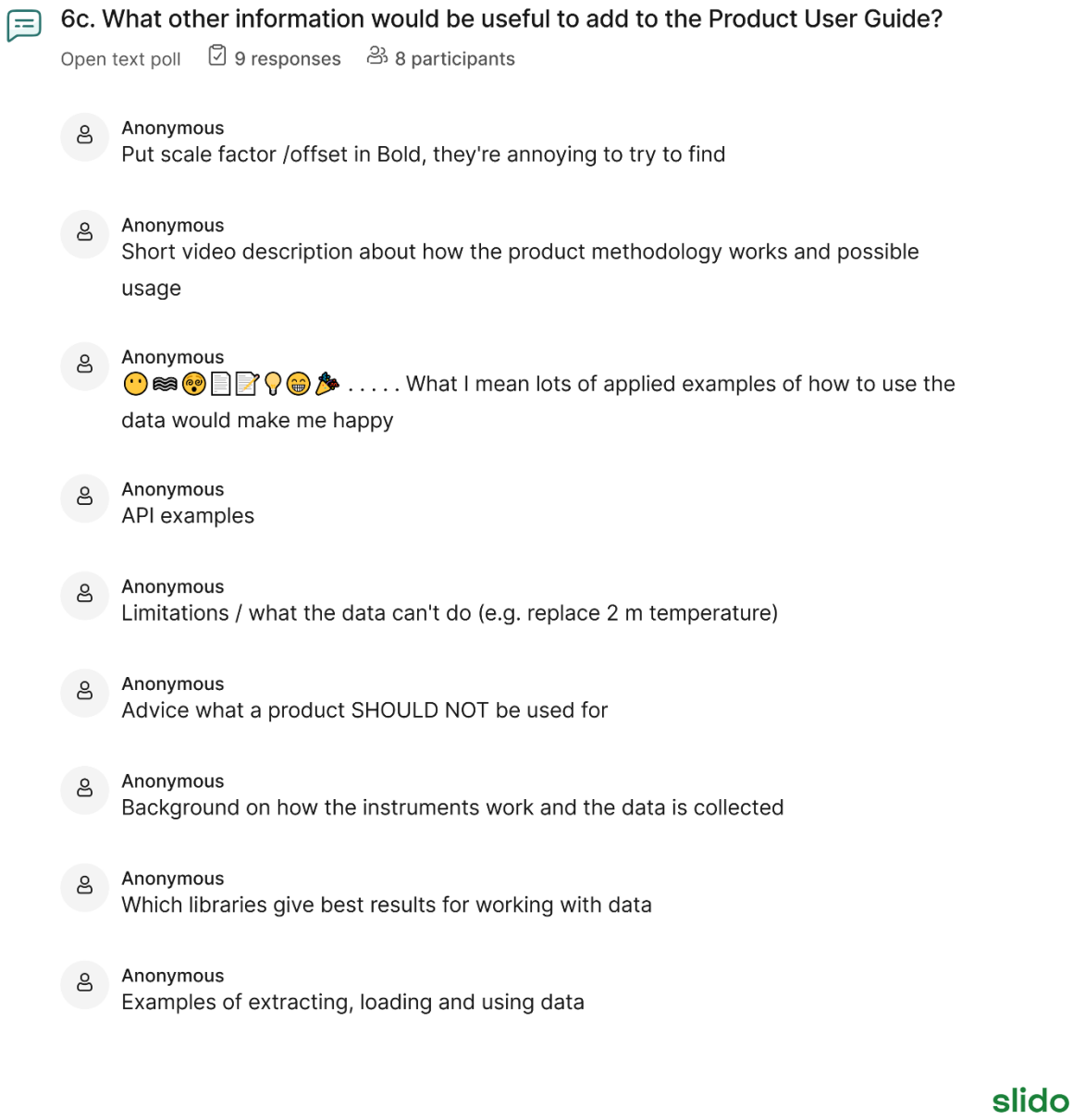

Figure 4-17: Slido result - 6c. 'What other information would be useful to add to the Product User Guide?' Number of respondents = 8.

Question 6c asked what other information would it be useful to add to the Product User Guide?

There were 9 responses from 8 participants, the full list of responses is shown in Figure Figure 4-17. Some participants wanted information on the limitations of the products and what they should not be used for. Some wanted examples of code routines to read and use the data. Some wanted background information on the sensors and algorithms. Note, an overview of the algorithms already appears in the PUG V2.0. One participant wanted variable scale factors and offsets to be easily found. This participant had not used LST_cci data before.

- **Recommendation 16: The PUG could include code examples for reading and plotting the data.**
- **Recommendation 17: The PUG could include a description of the scope of other relevant documents and sign-posts to these documents (PSD, ATBD, CAR, PVIR, E3UB).**

4.1.2. Summary of Recommendations

These key recommendations are explained and numbered here, where LST-UWR2024-REC-01 for example refers to Recommendation 1 in the main body of text:

ID	Recommendation
LST-UWR2024-REC-01	Continue to improve engagement with the climate modelling and climate services communities.
LST-UWR2024-REC-02	Seek opportunities for further outreach activities to publicise LST_cci data.
LST-UWR2024-REC-03	Provide training in how to obtain and use LST_cci data.
LST-UWR2024-REC-04	Project team to consider whether it is worth producing products with few users, noting that there were many users who were not at the workshop who currently use LST_cci products.
LST-UWR2024-REC-05	The product user guide should indicate suitable applications or each product - the characteristics of the product, its suitability for various applications, limitations, etc.
LST-UWR2024-REC-06	Provide information in the PUG on the pros and cons of using VIIRS as a follow-on to Aqua MODIS.
LST-UWR2024-REC-07	The gridding method for VIIRS should choose the pixel nearest the nominal overpass time. This is the method used for all previous IR products and is consistent with the Aqua MODIS products.
LST-UWR2024-REC-08	Consider provision of emissivity data used in the retrieval to be included in LST_cci products. However, a better understanding of why users would like these data would be useful to ascertain before this addition is included. This could be explored at the next user workshop in 2026.
LST-UWR2024-REC-09	Consider providing more information on proximity to cloud, cloud probability and uncertainty in cloud masking.
LST-UWR2024-REC-10	Consider providing digital elevation model output on the spatial resolution of the satellite LST data.
LST-UWR2024-REC-11	Consider providing wind speed information e.g. from ERA5 (which is currently used for T2m).
LST-UWR2024-REC-12	To provide gap-filled LST_cci products.
LST-UWR2024-REC-13	Seek opportunities to provide LST in real time, e.g. through C3S.
LST-UWR2024-REC-14	Include a table of key features based on the table already available to beta users that provides advice to user in helping them to choose the most suitable LST_cci dataset for their application. This could include references to existing studies that use LST data.

ID	Recommendation
LST-UWR2024-REC-15	Provide the means for users to provide feedback on LST_cci datasets, e.g. report issues.
LST-UWR2024-REC-16	The PUG could include code examples for reading and plotting the data.
LST-UWR2024-REC-17	The PUG could include a description of the scope of other relevant documents and signposts to these documents (PSD, ATBD, CAR, PVIR, E3UB).

5. Summary

The LST_cci 2024 User Workshop was a 1.5-day in-person event that took place 5-6 December 2024. 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 2020 and 2022 workshops, which were held online, the 2024 workshop took advantage of an opportunity to hold a joint in-person event with the Thermal Remote Sensing Special Interest Group (https://thermal-rs.earsel.org/). This was in order to maximise attendance at the workshop following lower attendance at the 2022 workshop compared the 2020 event; many of the attendees from the preceding Thermal Remote sensing workshop stated on for the LST_cci workshop.

In response to delegate and project team feedback from the 2020 and 2022 User Workshops, and some specific LST_cci requirements previously defined in in the project (AD-01), the following new/updated workshop elements were adopted for the 2024 event:

- A 'hands on' practical to demonstrate how to use LST_cci and provide some sample Python code was included in the workshop agenda. This session was run by the ESA Knowledge Exchange team. The Python code and CCI toolbox remain available after the event.
- LST user requirements were gathered in an interactive session using the online survey tool, Slido (www.slido.com), to ask delegates for specific feedback and new recommendations for LST_cci data products during the session. 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.
- Posters were advertised during a dedicated lightning presentation slot in plenary for presenters to advertise their poster.
- Uncertainties in LST_cci products continued to be a focus for the workshop, which included a presentation on day 1 about the justification for providing and using uncertainty information.

The workshop sessions were recorded and the intention is to make these recordings available online at a later date. In the meantime, the agenda and all available slides/posters from the workshop are available online at https://climate.esa.int/en/projects/land-surface-temperature/workshops/lst-user-workshop-documents-2025/. In general, feedback from the workshop was very positive and has provided some useful aspects to consider for future events (see Section 3.2).

The key recommendations resulting from the user requirements gathering session at the workshop are explained and numbered here, where LST-UWR2024-REC-01 for example refers to Recommendation 1 in the main body of text:

ID	Recommendation
LST-UWR2024-REC-01	Continue to improve engagement with the climate modelling and climate services communities.
LST-UWR2024-REC-02	Seek opportunities for further outreach activities to publicise LST_cci data.
LST-UWR2024-REC-03	Provide training in how to obtain and use LST_cci data.
LST-UWR2024-REC-04	Project team to consider whether it is worth producing products with few users, noting that there were many users who were not at the workshop who currently use LST_cci products.

ID	Recommendation
LST-UWR2024-REC-05	The product user guide should indicate suitable applications or each product - the characteristics of the product, its suitability for various applications, limitations, etc.
LST-UWR2024-REC-06	Provide information in the PUG on the pros and cons of using VIIRS as a follow-on to Aqua MODIS.
LST-UWR2024-REC-07	The gridding method for VIIRS should choose the pixel nearest the nominal overpass time. This is the method used for all previous IR products and is consistent with the Aqua MODIS products.
LST-UWR2024-REC-08	Consider provision of emissivity data used in the retrieval to be included in LST_cci products. However, a better understanding of why users would like these data would be useful to ascertain before this addition is included. This could be explored at the next user workshop in 2026.
LST-UWR2024-REC-09	Consider providing more information on proximity to cloud, cloud probability and uncertainty in cloud masking.
LST-UWR2024-REC-10	Consider providing digital elevation model output on the spatial resolution of the satellite LST data.
LST-UWR2024-REC-11	Consider providing wind speed information e.g. from ERA5 (which is currently used for T2m).
LST-UWR2024-REC-12	To provide gap-filled LST_cci products.
LST-UWR2024-REC-13	Seek opportunities to provide LST in real time, e.g. through C3S.
LST-UWR2024-REC-14	Include a table of key features based on the table already available to beta users that provides advice to user in helping them to choose the most suitable LST_cci dataset for their application. This could include references to existing studies that use LST data.
LST-UWR2024-REC-15	Provide the means for users to provide feedback on LST_cci datasets, e.g. report issues.
LST-UWR2024-REC-16	The PUG could include code examples for reading and plotting the data.
LST-UWR2024-REC-17	The PUG could include a description of the scope of other relevant documents and signposts to these documents (PSD, ATBD, CAR, PVIR, E3UB).

These recommendations will be considered in the updated version of the User Requirements Document (URD) [AD-02], which underpins the development of LST products within the LST_cci project.

6. Appendix A: List of Institutes/Companies

Aistech Space
Booking Holdings
Charles University in Prague
constellr GmbH
Danish Meteorological Institute
Earth-i
eLEAF
Estellus
European Space Agency
Foundation for Research and Technology Hellas (FORTH)
Georg August University of Göttingen
German Aerospace Center (DLR)
GFZ Potsdam (German Research Centre for Geosciences, Potsdam)
Instituto Dom Luiz (IDL)
Portuguese Institute for Sea and Atmosphere (IPMA)
Karlsruhe Institute of Technology
Liege University
MetOffice
MeteoRomania
National Research Council of Italy, Institute of Bioeconomy
OroraTech GmbH
Politecnico di Torino
Research Institute for Regional and Urban Development
Ruhr University Bochum
SatVu
Scott Polar Research Institute
Sparkgeo
STFC RAL Space
Surrey Satellite Technology Ltd
Tematics
UKCEH (United Kingdom Centre for Ecology and Hydrology)
Universitat de València
University of Birmingham
University of Leicester
University of Reading
University of Salzburg (PLUS)
University of Twente
University of Zurich
VITO (Flemish Institute for Technological Research)
Wageningen University and Research

7. Appendix B: User Presentation Abstracts

7.1.1. User Case Studies

UCS#2: Assessment of ESA LST_cci Sea-Ice Surface Temperatures (IST) in the Arctic
Ioanna Karagali (DMI)

The authors report the impact of ingesting ESA LST_cci L3C Single Sensor Products (SPP) into the Copernicus Marine Service Arctic L4 SST/IST Multi-Year Product. They used ESA LST_cci Level 2P IST from SLSTR on Sentinel3A and Sentinel3B and MODIS on Aqua and Terra and produce Level 3 collated (L3C) single-sensor products for each sensor/platform. An assessment of L3C SSP with in situ observations from SIMB3 and Qaanaaq show very good results. The added advantage of the LST_cci data is their contribution to increased data availability. Overall, there is a positive impact of the LST_cci data on the L4 SST/IST product evident as reduced bias and standard deviation values with respect to in situ observations. In future, ESA LST_cci IST will be ingested into CMEMS Arctic L4 SST/IST Reanalysis.

UCS#1: Moderate extremes indices based on LST
Josh Blannin (Met Office)

The authors aim to produce a satellite-based extremes indices product to compliment the HadEX3 in situ-based moderate extremes indices dataset for precipitation and 2m air temperature. HadEx3 has some limitations: limited resolution, and some regions are unmonitored. The ESA LST_cci Microwave data product is chosen due to lesser cloud impact thus improving data availability. Station 2m air-temperature is obtained from NCEI GHCNd. Distributions of LST and T2m temperatures are similar, but with LST being slightly cooler (in IPCC AR6 regions 1 & 16). There are several promising threshold- and value-based indices in AR6 region 16 – these will be investigated further across the other AR6 regions. Percentile-based indices for AR6 region 16 show good correlation and identification of moderate extreme events and will also be investigated in other AR6 regions.

UCS#3: Urban Nighttime Warming Trends derived from LST_cci MODIS Data
Panagiotis Sismanidis (RUB)

The authors describe how they calculate city temperature trends using LST_cci MODIS. They describe their custom implementation of the City Clustering Algorithm and method of assigning uncertainties to city mean daily LST. The trend is calculated as the Theil-Sen slope of the monthly anomalies. Globally, the nighttime LST of urban areas increases by 0.06 ± 0.02 K/year. 5% of these cities exhibit trends higher than 0.1 K / year. Cities in continental climates, Eastern Europe, China and Middle East warm faster that the rest.

UCS#5: Analyzing Seasonal Patterns and Temperature Extremes in Urban Areas Using MODIS Data
Irina Ontel (MeteoRomania)

This study aims: to examine the seasonal LST variations across urban, peri-urban and rural areas; to investigate the seasonal LST trends across different cities of Romania during 2002-2021; and to examine shifts in the seasonality and LST extremes in urban areas during 2002-2021. ESA CCI Terra MODIS and Aqua MODIS LST V4.00 products were used to generate seasonal LST means for daytime and night time. The methods for determining trends, seasonality and extremes are described. The difference between urban and peri-urban areas is greater in summer and insignificant in winter. During the day, the

differences are insignificant for most cities, but increase at night. The trends of daily LST maxima are of significant increase in winter and autumn regardless of the area, and those of minima are significant in winter and summer. In terms of seasonality, cities in the central and western part of the country have a longer season, due to an earlier start and a later end. In other cities, only the end of the season occurs later, while the start does not show a significant trend. The length of season ranges between 50 and 140 days, with a mean amplitude of 100 days. Satellite data have proven to be useful tools in analyzing the spatial variation in surface temperature and identifying differences between urban, peri-urban and rural areas.

7.1.2. LST Applications

constellr HiVE, a land surface temperature monitoring mission for better resource accountability
Christophe Lerot (constellr)

constellr is a space data and services company leading the way in delivering daily, global land surface temperature (LST) data with the ambition to serve the agriculture sector to make it more efficient and more sustainable, supporting food security. As any plant stress causes leaf temperature changes, LST is a direct indicator for crop health. Compared to other parameters derived in the visible range, LST measurements provide earlier warnings of upcoming potential damages, which allows for rapid mitigation actions. In addition, LST data provides crucial information for many other applications such as the monitoring of urban heat islands and infrastructure, the tracking of wildfires, and more generally the monitoring of ecosystems.

To feed all those sectors with high quality LST data, constellr follows a two-fold approach. First, the deployment of the HiVE (High-precision Versatile Ecosphere monitoring mission) constellation is going to be initiated in early 2025. It consists of micro-satellites in the 100 kg class carrying state-of-the-art high-resolution thermal infrared (TIR) as well as visible and near-infrared (VNIR) sensors on a sun-synchronous orbit at an altitude of approx. 550 km. We anticipate a remarkable 1-day temporal resolution by the end of 2026 with 5 satellites in orbit, 30 meters spatial resolution for the TIR bands (up to 10m for the VNIR bands) and a unique 1.5K accuracy on the final LST product. In parallel, constellr is planning to make available the LSTfusion product, which offers its customers a harmonized daily 30m spatial resolution surface temperature product based on the fusion of constellr HiVE data with publicly available datasets from other thermal sensors. This product combines our proprietary high accuracy LST retrieval algorithm with a data assimilation scheme to minimize the effects of diurnal temperature cycles, spatial resolution differences and differences related to the use of different algorithms and input data (e.g. emissivity, atmospheric information).

In this presentation, we will briefly introduce the constellr activities, the status of the HiVE mission and the development of the LSTfusion product. This will be complemented with a few use cases illustrating the added value of high resolution daily thermal data for the customers.

A new methodology to generate infrared Land Surface Emissivity including directional effects
Sofia Ermida (IPMA)

Land Surface Emissivity (LSE) is a critical variable in the quantification of the surface energy budget and for the estimation of surface parameters from earth observation data, including Land Surface Temperature (LST). A widely used semi-empirical method to estimate LSE is the Vegetation Cover Method (VCM), however it originates large LSE uncertainties over desert and sparsely vegetated regions, due to the limited number of land cover types used to describe them. The TES algorithm, which is also extensively used, allows direct separation between emissivity and temperature and has been used to operationally

produce LST and LSE based on multiple sensors. This method has shown to provide LSE estimates with good accuracy, however most validation exercises are conducted over desert sites. Validation over vegetated scenes is more complex given the high heterogeneity of surface elements with contrasting spectral characteristics. Over such surfaces, several authors have argued that emissivity estimates that use visible and near-infrared observations are generally amongst the most accurate, since the reduced spectral contrast decreases the accuracy of the direct retrievals. Furthermore, direct methods require accurate atmospheric corrections, being very sensitive to errors in the atmospheric data.

A new LSE product is proposed that is based on the merge of the two widely used methods. Our aim is to take the best of each method, considering their differential performance over a wide diversity of surface conditions. As such, over vegetated areas, where spectral contrasts are reduced and retrievals using TES are more difficult, we use the VCM method, while over bare areas, where the VCM cannot estimate the spatial variability of the LSE, the TES is preferred. Furthermore, we propose a new calibration of the TES algorithm that allows a direct retrieval of the angular dependence of LSE. The new calibration makes use of the so-called multi-sensor method, where overlapping observations from different sensors are used to estimate the directionality of LSE.

The proposed methodology was applied to observations from the GEO Ring (SEVIRI onboard MSG and IODC series, ABI onboard GOES-R, AHI onboard HIMAWARI-8) and VIIRS onboard Suomi-NPP, to derive channel and broad-band emissivities in the 3-14 µm range. The product shows good agreement with in-situ, with accuracies of 0.009 and 0.014 in the 8-14 µm and 3-8 µm regions, respectively.

The methodology described in this article will be used by the LSA-SAF for LST production from current and upcoming EUMETSAT missions.

Identification, characterization and correction of directional effects in high-resolution LST

Louis Snyders (VITO)

Remote sensing retrieved land surface temperatures (LST) depend, besides on the time of acquisition, on the position of both the thermal sensor and the Sun. The difference in sun-sensor geometry can result in LST differences up to several Kelvins. An accurate estimation of LST and LST-derived products, e.g., evapotranspiration and drought indicators, requires characterizing and correcting for these directional effects. These directional effects will influence LST retrieval of upcoming high spatial resolution thermal infrared (TIR) satellite missions, such as LSTM and TRISHNA, which include measurements under large zenith viewing angles (up to 35°). Therefore, addressing this issue is crucial in the preparation of these missions. Since LST measurements from thermal satellite observations are currently unavailable at the required spatial and temporal resolution for adequate crop monitoring several thermal sharpening approaches have been developed. The Sen-ET algorithm combines 1 km thermal data from Sentinel-3 (S3) and 20 m optical data from Sentinel-2 to generate a (sub-)daily time series of LST at 20 m resolution. Two factors, in particular, affect the quality and reliability of this product: (1) the quality of the sharpened LST product itself, which remains hard to validate and (2) the directionality effects, especially present for sensors with wide viewing angles such as S3, and which are currently not properly accounted for. My research investigates how thermal satellite data from multiple sources can be optimally combined to identify and correct for directional effects. I propose a cross calibration method between numerous pairs of quasi-simultaneous high-resolution LST observations from S3 and the ECOSTRESS. This approach allows to identify, characterize and correct for directional effects. The research aims to contribute to the development of an operational directional correction for high-resolution TIR data, which can be exploited by upcoming high-resolution thermal missions such as LSTM, TRISHNA, and SBG.

Improving Satellite-based Land Surface Temperature Estimates in Dust-Contaminated Atmospheres: A Generalized Split-Window Algorithm Dependent on Dust Aerosol Optical Depth

Francesco Stante (IPMA)

Satellite-based land surface temperature (LST) is most commonly estimated from radiometric measurements in the thermal infrared atmospheric window (8–13 µm) using retrieval algorithms that account for land surface emissivity and atmospheric effects. However, current operational LST retrieval algorithms do not consider the effect of heavy aerosol loading on the retrievals, and their accuracy is significantly reduced in regions affected by dust aerosols, such as the Sahara Desert and surrounding areas.

Our work presents a simple solution to improve LST estimations in dust-contaminated atmospheres, by introducing dust aerosol optical depth (DuAOD) as an additional variable on which the coefficients of the Generalized Split-Window (GSW) algorithm are dependent – in addition to total column water vapor (TCWV) and satellite viewing zenith angle (VZA).

To calibrate the DuAOD-dependent GSW we created a dataset containing a wide variety of surface and atmospheric conditions which includes dust aerosol mixing ratio profiles from CAMS' EAC4 atmospheric composition reanalysis. Top-of-atmosphere brightness temperatures used for calibration of the GSW coefficients were simulated using RTTOV.

Our results show that a DuAOD-dependent GSW achieves significantly higher accuracies in LST estimation across DuAOD conditions. With synthetic data, a traditional, aerosol-independent GSW has increasing errors with DuAOD, reaching up to 5 K for DuAOD between 0.6 and 0.8 (and low VZA), while a DuAOD-dependent GSW maintains median errors below to 2 K across DuAOD classes. Validation against in situ LST measurements from stations in Dahra (Senegal), Évora (Portugal), Niamey (Niger), and Gobabeb (Namibia) confirm these improvements in LST estimation.

A three-channel variant of the DuAOD-dependent GSW (using SEVIRI channel 8.7 µm, in addition to 10.8 and 12.0 µm) was also tested, showing similar improvements to the two-channel version. However, due to the large uncertainties of channel 8.7 µm emissivities, the two-channel version is favoured.

The accuracy of the proposed DuAOD-dependent GSW relies heavily on the quality of DuAOD estimates used as input. For MSG-SEVIRI LST estimations the only viable DuAOD product appears to be CAMS' forecasts or reanalysis, as they uniquely provide the necessary spatial coverage and temporal resolution of SEVIRI observations on an operational basis. However, the CAMS DuAOD products have limitations in accuracy that would potentially introduce additional errors in LST estimates. We are currently exploring methods to filter the CAMS DuAOD product in order to limit the impact of inaccurate DuAOD values.

Long-term Trends of LST from a new Daytime-normalized AVHRR Time Series over Central and Southern Europe

Philipp Reiners (DLR, DFD)

For monitoring conditions repeatedly over large areas, satellite derived Land Surface Temperature (LST) has become an indispensable tool. However, to make climate relevant statements and quantify the impact of land surface variables over long time, we need sensors that are available for more than 30 years. The Advanced Very High-Resolution Radiometer (AVHRR) is the only sensor offering spatially and temporally continuous daily measurements for the past 40 years. The German Aerospace Center's (DLR) TIMELINE project focuses on producing a consistent multi-decadal time series from AVHRR data (covering three AVHRR sensors on 16 NOAA platforms) for Europe and North Africa. Nevertheless, variations in

observation times among AVHRR sensors affect the recorded temperature, introducing discontinuities to the AVHRR LST time series. Additionally, there is the orbit drift, which gradually shifts observation times throughout a sensor's lifespan. The resulting challenges in interpreting the AVHRR LST time series are likely the main reason why AVHRR observations are not yet part of established long-term LST products.

Several orbit drift correction methods have been developed to address orbit drift and observation time inconsistencies in the AVHRR LST time series, However, existing models often oversimplify spatial and temporal variations, limiting their effectiveness in diverse landscapes like Europe. For this study, we integrated our AVHRR LST time series with geostationary SEVIRI LST data. The daytime normalization was achieved through pixel-specific correction terms derived from a diurnal cycle model based on SEVIRI observations. The resulting dataset offers daily maximum LST at 1 km resolution over the past 40 years for Central and Southern Europe. Previous validation attempts have revealed, that the resulting time series shows a stable behaviour towards the CCI LST time series and the discontinuities between the different NOAA platforms were minimized.

Here, we present our analysis of long-term LST trends using this daytime normalized LST product. The trends were assessed using the Mann-Kendall significance test and Theil-Sen slope estimation, focusing on trends with a significance level of $p < 0.1$. Furthermore, the trends were categorized by land cover and elevation. To validate our results, the derived trends are compared to existing long-term LST records from ERA 5 and air temperature measurements.

Intercomparison of SEVIRI Land Surface Temperature with ERA5 reanalysis over Africa

Riccardo Monfardini (University of Reading)

Land surface temperature [LST] can be measured remotely from satellites, with geostationary satellites giving high temporal resolution over a wide area; this allows a comparison with ERA5 hourly skin temperature data to determine differences in observed and modelled representation of the diurnal cycle.

LST is retrieved from Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Radiometer (SEVIRI) infrared channels (10.8 & 12.0 µm) using the generalised split window parametric algorithm, suitably efficient and robust for operational use. LST retrievals are sensitive to uncertainty in water vapour content, land emissivity and directional effects. The land type and orography of the underlying surface can also have a significant impact on the retrieved temperature.

The LST dataset is provided by Land Surface Analysis Satellite Application Facility and compared to ERA5 skin temperature data after appropriate cloud filtering and coarsening to match the 0.25° resolution. The sensitivity to land type of the diurnal temperature difference is investigated using the high resolution CCI land cover dataset which defines 22 land classes.

ERA5 skin temperature shows a cold bias during the day, the magnitude of which is dependent on vegetation cover.

Currently LST retrievals are not assimilated. Understanding the diurnal biases between satellite LST observations and the model output will benefit future reanalysis through LST data assimilation.

Use of LST data for producing data for the FAO-WaPOR portal: past, present and future

Henk Pelgrum (eLEAF)

The FAO-WaPOR portal is a publicly accessible near real time database using satellite data that allows the monitoring of agricultural water productivity at different scales.

eLEAF is responsible for the production of data on evaporation, transpiration, interception, NPP and relative soil moisture content at three different spatial scales for the FAO-WAPOR portal: global data at 300m, continental data (Africa, Middle East, Pakistan and Colombia) at 100m and locally at 20m (30+ irrigation districts). For each of these spatial scales LST data is used to produce the aforementioned datasets.

The presentation will discuss not only the use of LST to derive these products, but also on the practicalities of producing these data at scale. How to cope with missing data due to limited availability, or due to cloudy conditions. Also discussed is the need for additional datasets such as meteorological data, optical satellite data to get the most out of the LST data.

Finally we look at the future and will discuss the planned use of the upcoming LST missions for production of global data on agricultural water productivity and the benefits they will bring compared to the already existing LST missions.

Using LST to better understand land atmosphere interactions and improve predictions

Christopher Taylor (CEH)

In this presentation we show the value of LST data in illuminating mechanisms by which soil moisture feeds back on the atmosphere. LST provides a valuable complement to soil moisture from microwave due to its combination of space/time resolution, allowing sub-daily analysis of land surface state on scales of kilometres. Recently we have been using LST from the CCI project (both thermal infra-red and microwave) alongside other datasets to characterise the evolution of flash droughts and the surface interaction with the atmosphere. We have also been analysing how soil moisture influences the triggering of deep convective storms across Africa, using the LandSAF LST product. The availability of LST in near real time has allowed us to work with national forecasting services in Africa to create tools for nowcasting severe weather, including incorporation of LST within machine learning algorithms.

A multi-layer perceptron approach on downscaling land surface temperature for the study of surface urban heat islands

Alexandra Hurduc (IDL)

Machine learning is a subfield of artificial intelligence, rooted into statistics. It is a flexible and interdisciplinary tool that can be used for solving several types of problems. This work focused on the use of multi-layer perceptron (MLP) to solve a regression type problem: downscale land surface temperature (LST) from the SEVIRI sensor onboard Meteosat Second Generation series of satellites to a 750 m spatial grid. The choice of an MLP in preference of other machine learning algorithms was motivated by the intention of developing the simplest algorithm that provides acceptable results. Data from VIIRS onboard Suomi National Polar-Orbiting Partnership was used to compute the target LST. The resulting model was trained on 2019-2022 data and its performance accessed on 2023 data. To compare downscaled LST at different hours than the ones retrieved by SNPP, data from three additional sensors were used: VIIRS onboard both Joint Polar Satellite System 1 and 2 and the SLSTR onboard Sentinel 3A.

The comparison between the target and the models' results are optimistic given that its performance on new data is similar to its training performance, i.e. no overfitting. The distribution of model temperature values follows the one of target temperature values.

The new downscaled dataset is then used to analyze the diurnal behaviour of the surface urban heat island with an improved spatial resolution than the one a geostationary is able to provide.

Analysis of urban surface temperature from satellite data with modelled 3D surface temperature
Maria Gkolemi (FORTH)

Surface temperatures are important to the surface energy balance. In cities, surface temperatures impact human thermal comfort and building energy consumption/losses. The large vertical component in cities has implications for satellite-based Land Surface Temperature (LST) retrieval because of the limited sensor viewing angle. In-situ measurements and modelling can provide useful information to complement satellite observed LST. Here, we compare modelled surface temperature to satellite derived LST for several areas in Berlin, Germany.

High resolution satellite-derived LST was compared against detailed modelled urban surface temperature. The 3D urban surface temperature was modelled using an extension of the energy balance model TUF-3D (Krayenhoff & Voogt, 2007) including a vegetation component (Nice et al., 2018). Model parameterization included detailed information on the urban surface and form. Earth Observation data products (detailed land cover, building and vegetation heights) were used to parametrize the 3D urban surface and form and urban material properties, following Hertwig et al. (2024) used data from Chartered Institution of Building Services Engineers (CIBSE) guides (Environmental Design, 2006) and TABULA database (TABULA WebTool, n.d.) for building archetypes. VTUF-3D is run for multiple areas of ~2 km2 extent with different characteristics (e.g. densely built, parks). The meteorological forcing observed in the vicinity is used (Fenner et al 2024). The simulations are compared to nadir looking Landsat (30 m resolution) and ASTER (90 m) LST data products for each area. Following, similar comparisons will be performed for satellite thermal sensors with off nadir viewing angles (i.e. ECOSTRESS) and lower spatial resolution (i.e. Sentinel-3, MODIS) to assess their potential in retrieving accurate surface temperatures for urban areas including the dependence on scale.

7.1.3. Poster Presentations

Towards subdaily Land Surface Temperature

Christian Mollière (OroraTech GmbH), Lukas Kondmann, Josephine Wong, Martin Langer, Julia Gottfriedsen

With global temperatures rising, we anticipate a growing demand for temperature-related Earth Observation products to help users analyse, plan and mitigate the entailing effects. Examples include heat waves in urban spaces, irrigation management in agri- and silviculture, assessment of wildfire risk and more. To make timely decisions, users will need frequent and up-to-date observations of their areas of interest. Public data products build a good foundation for these users, given their scientific quality and free availability. Yet, most data products are only available in limited resolution and temporal cadence. This can pose significant challenges to individual users, who are interested in smaller-scale dynamics of the land surface temperature in their area. Particularly in cloudy areas, even daily observation can often fail due to dense cloud cover.

Our developments towards a constellation for frequent and rapid detection of wildfires on a global scale further enable us to explore potential LST data products. The use of uncooled microbolometer arrays allows us to scale our sensor network cost-effectively and fast, due to the reduced system requirements and cost. The long-wave IR bands provided by our payload allow for the retrieval of LST at a GSD of 200m. Beginning in 2025, we will deploy a constellation of sensors in a late afternoon LTAN, which is particularly well suited for the detection of wildfires. This will give us a daily revisit globally. Further additions to the constellation are already being manufactured, with the long-term goal of reaching hourly or even more frequent revisits. The user requirements for wildfire detection justify our pursuit to scale to this extent.

The implications for a sub-daily or even hourly LST product at 200m GSD are subject to our ongoing research.

We present the early prototype of our LST data product, based on our technical precursor mission FOREST-2. Using a single-band retrieval approach we see early validation results against the SURFRad ground station network of below 5K RMSE. The calibration of our sensor array is still in active development and we are working towards achieving even better radiometric performance. Our research suggests that frequent observations can be used to accurately model the LST time series on the ground, despite the lower radiometric precision when compared to other LST data products. Additionally, we show the impact of very frequent revisits on the observability of cloudy targets, showing an almost two-fold increase in clear observations throughout the year.

Assessing the accuracy of LST_cci products and analyzing LST trends in the Iberian Peninsula

Raquel Niclos (Departament of Earth Physics and Thermodynamics, University of Valencia), **Sara Arribas**, Martín Perelló-Roselló, Jesús Puchades, César Coll, & Enric Valor

LST is an essential climate variable defined by the Global Climate Observing System (GCOS). Recent studies show that the Mediterranean region is warming 20% faster than the rest of the world. Therefore, the analysis of thermal trends in Spain can be key to show the climate change impact over a highly affected region. In this study, we first evaluated different versions of the LST_cci products using ground thermal-infrared radiance data acquired at the Valencia Test Site, i.e., a homogeneous rice paddy area with three very different land covers throughout the year due to the rice phenology (full vegetation cover, bare and flooded soils, i.e., water surfaces). Specifically, EOS-Terra and EOS-Aqua MODIS LST_cci products and Sentinel-3A and Sentinel-3B SLSTR LST_cci products were validated, together with operational and alternative LST algorithms. Systematic uncertainties of around 1.2-2 K and random uncertainties up to 1.5 K were shown for v2 to v4.00 of the LST_cci MODIS L3C products, leading to total uncertainties (RMSD or R-RMSD) around 1.5-2 K (far lower than 4 K obtained for the v1 uncertainties). V4.00 slightly reduces systematic uncertainties compared to v4.aa, although v4.00 still overestimates ground LSTs at the Valencia test site. Lower systematic uncertainties were shown for the operational products, with total uncertainties from <1 K to 1.5 K. In the case of the SLSTR validation, similar results were obtained for the LST_cci product and the operational product, with systematic uncertainties from 1.5 to 1.7 K and RMSDs from 2 K to 2.4 K. However, in this case, the uncertainties were much lower using an alternative algorithm proposed. Finally, we analyzed LST trends with the complete LST_cci EOS-Aqua MODIS L3C 0.01˚ dataset (2002-2021) over the Iberian Peninsula. The analysis showed significant LST trends in the 22% of the area, with a mean value of 0.1 K/year at daytime, while the area with significant trends was 34% with a mean value of 0.07 K/year at nighttime. Similar trend values were found over Europe in previous studies.

Hyperspectral Soil Property Mapping Using Thermal Infrared (LWIR) Imagery

Helge Daempfling (GFZ Potsdam), Robert Milewski, Sabine Chabrillat

To address food security and climate change challenges, the European Commission and the MOSES project advocate for soil quality mapping and monitoring. Soils, as the largest terrestrial carbon reservoir,

are crucial to ecosystem health. This study investigates the use of advanced thermal hyperspectral sensors to evaluate topsoil properties. The objective is to establish reference databases and validate airborne applications for soil property estimation using these sensors in a laboratory setting. We combined field measurements of bare soil pixels with lab measurements and chemical analysis of various soil samples. A workflow from on-site and lab measurements to airborne measurements was developed using samples from global study sites, including Greece and Italy. In the LWIR thermal infrared region, soil properties such as quartz and feldspar can be detected, which are not visible in the VNIR and SWIR regions. This approach extends existing VNIR and SWIR spectral analysis methods to thermal (LWIR) analysis of soils.

Our study sites are located in Northern Greece (Western Macedonia) in the intensively agricultural areas around the Amyntaio lignite mine. Over 250 soil samples were collected in several field campaigns from 2018 to 2023, covering the highly variable soils of the region. In 2019, an airborne survey acquired a hyperspectral dataset with the HySpex (VNIR+SWIR) and Hyper-Cam (LWIR) hyperspectral imaging systems covering the study site. We established a workflow for on-site soil sampling, temperature, and emissivity measurements using an Agilent handheld FTIR system and automated temperature loggers buried close to the soil surface. In the laboratory, we tested hyperspectral thermal measurements using pre-heated samples and a heating plate setup to gain a strong SNR and reduce reflection effects from the surroundings. We developed, tested, and implemented a laboratory TES to create a soil emissivity reference database that allows direct comparison and validation of airborne thermal measurements. The measured emissivity spectra were used to characterize the measurable properties of soils in the thermal region, such as quartz and feldspar content, as well as SOC.

We aim to create a sophisticated workflow for processing hyperspectral LWIR images, including testing different atmospheric correction methods and approaches for temperature-emissivity separation, exploiting the high spectral resolution of the Hyper-Cam. We plan to create a thermal hyperspectral soil spectral library that serves as a basis for the post-processing and analysis of airborne thermal hyperspectral images. Using this chemically validated hyperspectral soil database, we aim to derive several important soil parameters from the hyperspectral thermal images and create parameter maps. We particularly exploit the LWIR spectral information to improve the estimation of coarse texture soils that lack distinct spectral absorption characteristics in the VNIR-SWIR (e.g., sand content, quartz, and feldspar mineralogy). Additionally, we aim to validate soil products derived from recent relevant satellite sensors (e.g., EnMAP, ECOSTRESS) and simulate upcoming next-generation hyperspectral optical and thermal multispectral satellite missions (ESA CHIME and LSTM, NASA/JPL SBG) to evaluate their potential for quantitative soil properties mapping on larger scales.

Emissivity correction of 3D thermal model based on image processing and deep learning

Shaojuan Xu (Research Institute for Regional and Urban Development, Dortmund, Germany)

Many cities have set the goal of being climate-neutral by 2023. Reducing CO2 emissions from buildings requires improving building energy efficiency. Using airborne thermal imaging to detect building energy leaks is an essential technique for assessing building energy efficiency. Many studies have used small UAVs equipped with infrared cameras for single-building envelope scanning or aerial planes with vertical

cameras for city-scale building roof scanning. Our study built a constellation of one vertical and four oblique cameras on the aerial plane and conducted a thermographic survey at the city scale, aiming to capture thermal images of building roofs and facades and create a 3D thermal model. The biggest challenge is to conduct emissivity correction of the nadir and oblique thermal images according to different building materials in the complex urban environment.

We developed an image processing-based workflow with deep learning support for the emissivity correction tasks. In addition to the thermal images collected from our survey, we used the existing high-resolution aerial photos collected by RGB sensors, including both oblique and nadir cameras. In the first step, we applied deep learning on the nadir RGB images to classify building materials into six classes. Then, we employed texture mapping to oblique RGB images to extract building façade images, which were later classified into six classes based on deep learning. A similar image processing is also applied to thermal images, including extracting the thermal images for the building roof from the nadir images and the thermal images for building facades from the oblique image. Finally, we assigned each material class an emissivity value on the RGB images and transferred these values into thermal images to correct temperature values on the thermal images.

After emissivity correction, we attached the thermal images as textures to existing 3D building models to create our 3D thermal model. Since the used 3D building models are in the LoD2 format, which includes the roof and façade as separate elements, we can calculate the average temperature value for each building's roof and façade. The final 3D thermal model enables us to visualise the energy leaks from buildings and quantitatively evaluate building energy efficiency.

On the suitability of different satellite land surface temperature products to study surface urban heat islands

Alexandra Hurduc (Instituto Dom Luiz - IDL), Sofia L. Ermida, Carlos C. DaCamara

Remote sensing satellite data has been a crucial tool in understanding urban climates. The variety of sensors with different spatiotemporal characteristics and retrieval methodologies gave rise to a multitude of approaches when analyzing the surface urban heat island effect (SUHI). Although there are considerable advantages that arise from these different characteristics (spatiotemporal resolution, time of observation, etc.), it also means that there is a need for understanding the ability of sensors in capturing spatial and temporal SUHI patterns. For this, several land surface temperature products are compared for the cities of Madrid and Paris, retrieved from five sensors: the Spinning Enhanced Visible and InfraRed Imager onboard Meteosat Second Generation, the Advanced Very High Resolution Radiometer onboard Metop, the Moderate-resolution Imaging Spectroradiometer onboard both Aqua and Terra, the Thermal Infrared Sensor onboard Landsat 8 and 9. These products span a wide range of LST algorithms, including split-window, single channel and temperature-emissivity separation methods.

Results show that caution must be taken when characterizing SUHI based on few observations per day, as these may not fully characterize the range of intensities. This can translate in different SUHI intensity or signal (positive/negative). Also, as cities and their surroundings are highly heterogeneous surfaces, low

spatial resolution datasets may dampen the spatial patterns. Analysis of the diurnal, seasonal and inter-annual variability of the SUHI also suggest low consistency on the variability as given by each product. Therefore, works focusing on the study of the SUHI based on a single product may be significantly affected by the choice of product. We also found significant biases between the products even when considering the same resolution and time of observation. Validation of LST products over urban areas is very difficult due to the high heterogeneity, therefore care must be taking when basing SUHI studies on a single LST product. Moreover, the low sampling rate joined with observations not matching the hours of extremes for either LST or SUHI, and pixel sizes much larger than surface heterogeneity may lead to discrepancies between SUHI results and consequently, making it difficult to compare studies, even when representing the same climate and degree of urbanization.

Downscaling urban Land Surface Temperature variations across different land cover types using high-resolution satellite imagery

Liliia Hebryn Baidy (Scott Polar Research Institute, University of Cambridge), Prof Gareth Rees

Urban areas exhibit complex land surface temperature (LST) patterns due to the heterogeneous nature of land cover. Understanding these variations is critical for studying urban heat dynamics and their relationship with different types of land cover. Commonly used medium-resolution satellite data, such as Landsat, provide LST at a spatial resolution of several tens of metres, which may be insufficient for capturing significant fine-scale thermal variations within urban environments. This study aims to analyse LST variations across different land cover types in Tromsø, Norway, by enhancing the spatial resolution of LST data to 3 metres using downscaling based on PlanetScope imagery. The main objective of this research is to examine the spatial distribution of LST across various urban land cover types, utilizing multispectral indices such as NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), and NDBI (Normalized Difference Built-up Index). Initially, Landsat 8 imagery for 2023 was collected to compute LST at a 30-metre resolution, providing a baseline for thermal analysis. Concurrently, high-resolution PlanetScope imagery with a 3-metre resolution was employed to derive the necessary spectral indices. The downscaling approach integrates regression analysis, where the multispectral indices from PlanetScope serve as predictors for the coarser-resolution Landsat LST. To implement this, random sample points were generated within the urban area of Tromsø, from which the LST values and corresponding spectral index values were extracted. A multiple linear regression was performed on these sample points to establish relationships between LST and the indices. The resulting regression model was then applied to PlanetScope imagery to downscale the LST data to a 3-metre resolution. The enhanced-resolution LST maps enabled a detailed analysis of the thermal behaviour of various land cover types, such as built-up areas, green spaces, and water bodies. The results revealed significant temperature differences between land cover types, with built-up areas showing the highest surface temperatures, indicative of urban heat islands, while vegetated and water-covered areas exhibited lower temperatures. This research demonstrates the effectiveness of downscaling methodologies in enhancing the

spatial resolution of LST data and their applicability in urban thermal studies. The integration of high-resolution multispectral indices from PlanetScope imagery and coarser LST data from Landsat allowed for

a more granular analysis of urban thermal patterns, providing valuable insights into the spatial variability of LST across different land cover types.

Performance validation of a commercial radiometer

Tom Snelling (STFC RAL Space), Dave Smith, Dan Peters, Tim Nightingale

In this poster I will describe the thermal validation of a commercial radiometer against calibration blackbodies used for sea surface temperature. These calibration procedures have been well established through the SISTeR instrument operation over the past 30 years. We will apply these techniques to the commercial radiometer and assess its performance.

Towards subdaily Land Surface Temperature

Abigail Waring (University of Leicester), Darren Ghent, Mike Perry, Jasdeep Singh Anand, Karen L Veal and John Remedios

Land surface temperature (LST), latent and sensible heat fluxes are a strong indicator of warming climate trends and are affected by rising greenhouse gases (GHGs) and influence Earth's weather and climate patterns. This is predominantly through the reduction of energy exiting Earth's atmosphere, resulting in an increased energy budget. Key objectives for the UN Framework Convention on Climate Change (UNFCCC) investigates how Earth observations from Space could support the UNFCCC and the Paris Agreement in closing Earth's energy budget imbalance. Improving global LST observations from satellite data in aid of improving climate warming predictions is crucial to fulfilling this. #

Through a PhD project within the National Centre of Earth Observation (NCEO) and interfacing with the ESA Climate Change Initiative Land Surface Temperature (LST_cci) project, we aim to better understand the diurnal variability in global LST. This will be achieved by creating the first fully integrated all-weather LST dataset that can be utilised against climate models and other temperature datasets.

Here I will show some published first results of understanding the merging of these LST data. This will demonstrate high-resolution global infrared LST trends with propagated uncertainties for the first time, from the Aqua MODIS instrument.

All-sky LST observations are required and crucial for many climate applications. Clear-sky bias is a key problem with infrared observations and is a challenge for climate science. This understanding of infrared LST trends is a precursor to further research on how to utilise complimentary LST data, such as microwave LST, to harmonise and produce an all-sky merged global LST product.

A low cost, small satellite constellation approach to rapidly monitor Land Surface Temperature for Urban and Agricultural applications over UK and Europe, with optimised cross calibration to ESA and Copernicus missions

Robert Elliott (Surrey Satellite Technology Ltd)

No abstract available

Nationwide surface thermal analysis to detect priority areas for urban mitigation interventions

Giulia Guerri (Istituto per la BioEconomia (IBE) Consiglio Nazionale delle Ricerche), Gennaro Albini, Alfonso Crisci, Michele Munafò, Marco Morabito

No abstract available

Development of a Climate Web Application on the EO Data Hub

Dan Ormsby (Sparkgeo)

No abstract available

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