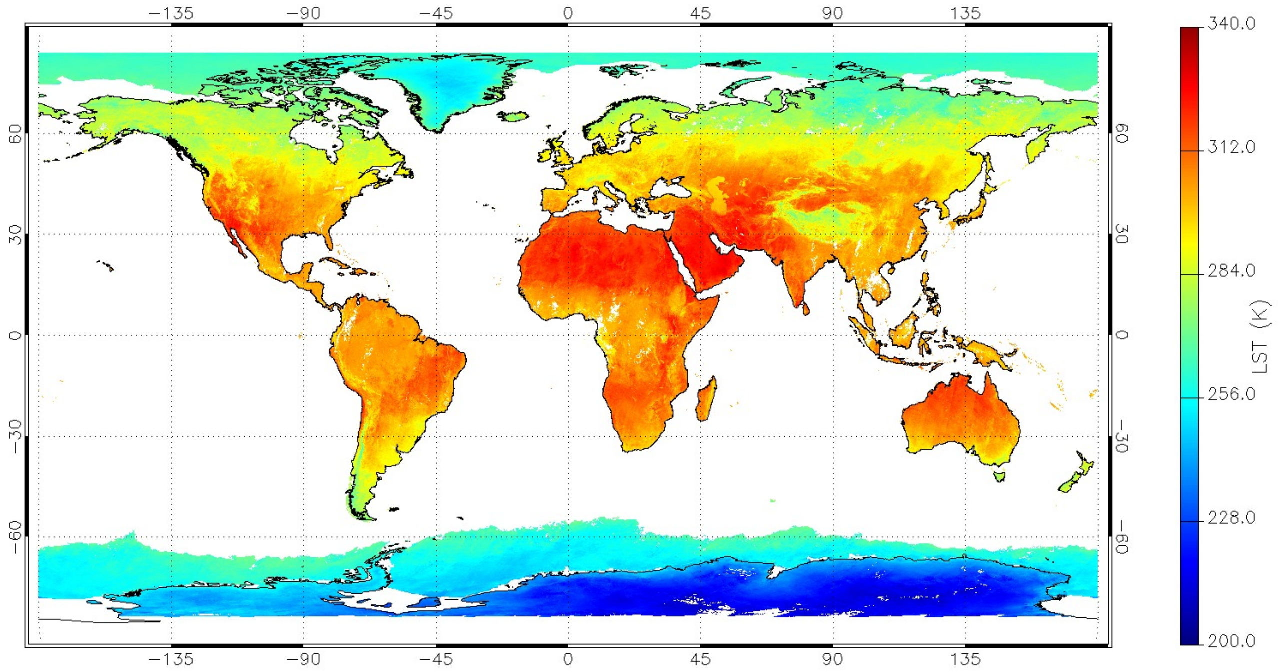
LAND SURFACE TEMPERATURE CCI: APPROACHES TO LONG-TERM DATA FOR CLIMATE

DARREN GHENT AND THE LST_CCI TEAM

Land Surface Temperature CCI is crucial for climate model evaluation in regions where few in situ measurements of surface air temperature exist



- Products driven by the User Requirements
- Consistency in calibration, algorithms, uncertainty models and cloud detection, over all land, land ice and sea-ice surfaces

USER REQUIREMENTS

LST CCI User Requirements

	Threshold	Breakthrough	Objective
Dataset length	10 years	30 years	> 30 years
Spatial resolution	1 km	< 1 km	< 1 km
Temporal resolution	6 hours	1 hour	< 1 hour
Accuracy	1 K	0.5 K	0.3 K
Precision	1 K	0.5 K	0.3 K
Stability	0.3 K / decade	0.2 K / decade	0.1 K / decade

GCOS LST Requirements

Item	Type	Value
Horizontal resolution	G	<1 K
	B	<1 K
	T	1 K
Temporal resolution	G	<1 hour
	B	1 hour
	T	6 hours
Timeliness	B	2 days
	T	30 days
Required Measurement Uncertainty	G	<1 K
	B	<1 K
	T	<1 K
Stability	G	0.1 K per decade
	B	0.2 K per decade
	T	0.3 K per decade

High quality data more important than spatially complete fields

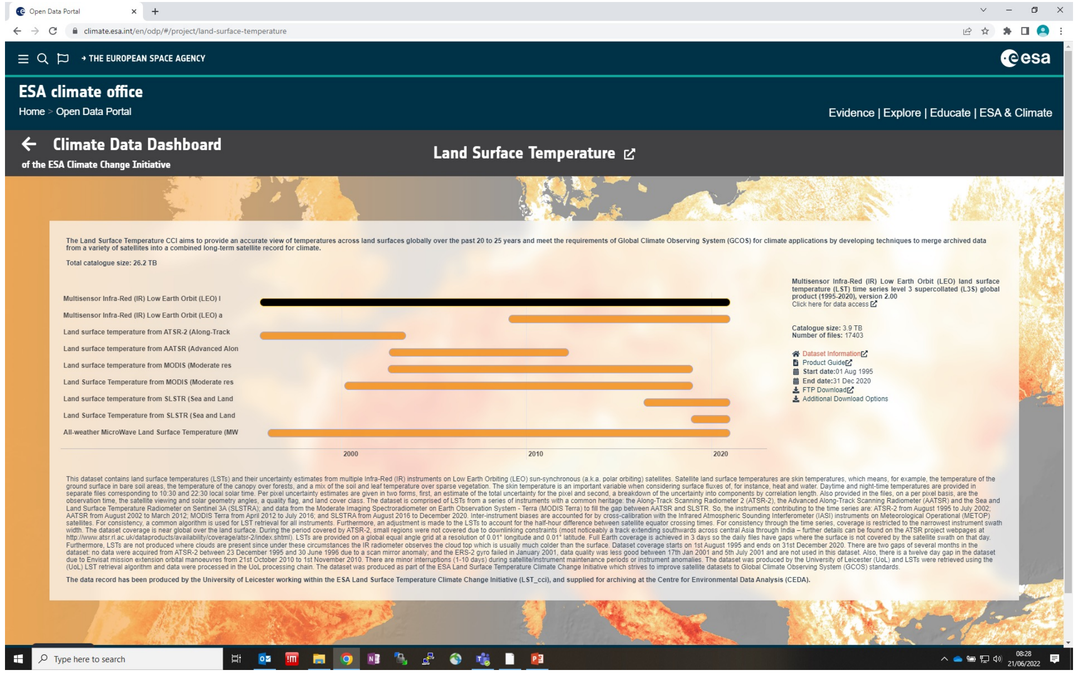
High temporal resolution more important for global studies

High spatial resolution more important for local studies

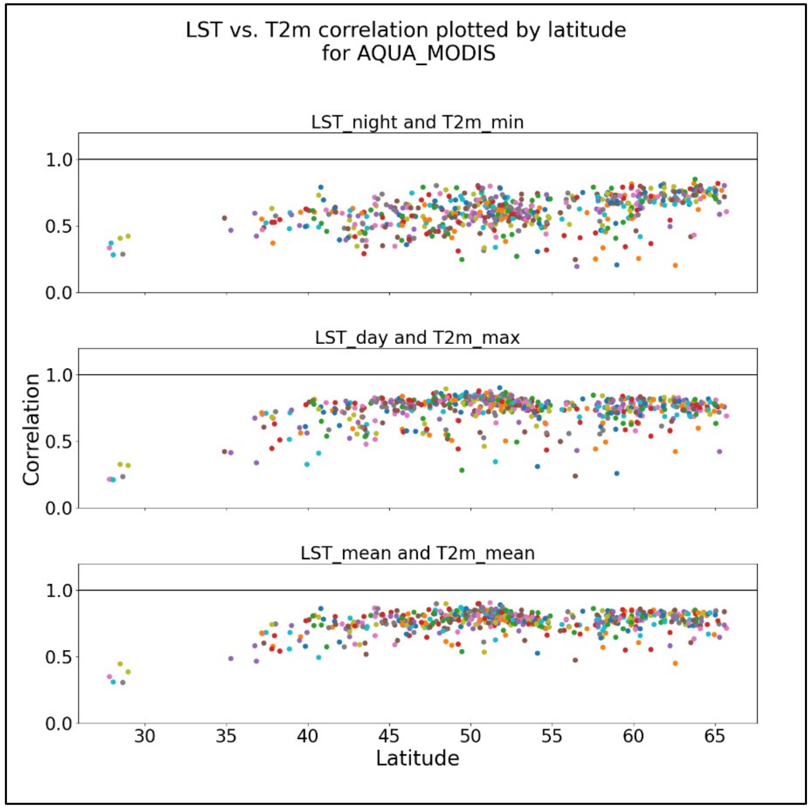
Dataset length is more important for global studies, whilst high data resolution is more important for local studies

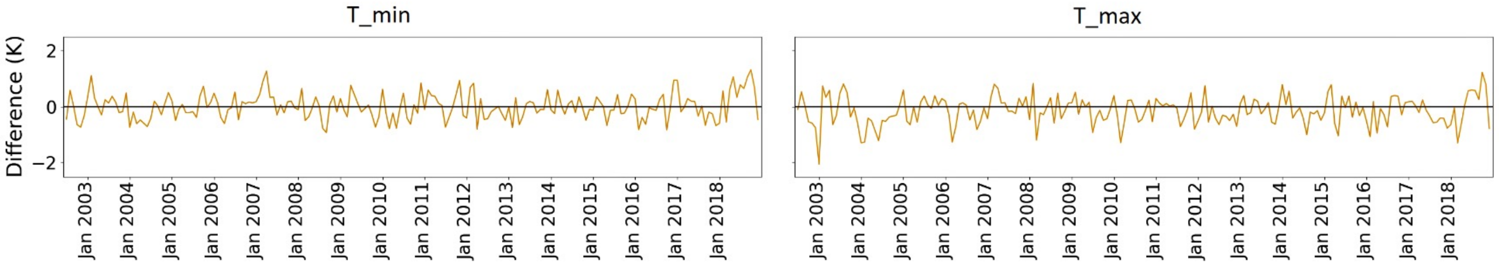
LST ECV Products

Instrument	Satellite(s)	Phase-1	Phase-2 Cycle 1	Phase-2 Cycle 2	Products
ATSR-2	ERS-2	1995-2003	1995-2003	1995-2003	0.01° Daily + Monthly
AATSR	Envisat	2002-2012	2002-2012	2002-2012	
MODIS	Terra	2000-2018	2000-2021	1999-2023	
	Aqua	2002-2018	2002-2021	2002-2023	
SLSTR	Sentinel-3A	2016-2020	2016-2021	2016-2023	
	Sentinel-3B	2018-2020	2018-2021	2018-2023	
AVHRR/3	NOAA-15 to 19		2010-2021	1998-2021	0.05° Daily + Monthly
	Metop-A to C		2007-2021	2007-2023	0.01° Daily + Monthly
AVHRR/2	NOAA-7, 9, 11, 12, 14			1981-2005	0.05° Daily + Monthly
VIIRS	Suomi-NPP + JPSS-1			2012-2023	0.01° Daily + Monthly
SEVIRI	MSG-1-4	2004-2020	2004-2021	2004-2023	0.05° Hourly
Imager	GOES 12,13,16	2009-2020	2004-2021	2004-2023	0.05° 3-hourly / Hourly
JAMI	MTSAT 1-2	2009-2015	2009-2015	2009-2015	0.05° 3-hourly
AHI	Himawari 8-9			2015-2023	0.05° Hourly
SSM/I	DMSP F-13,17	1995-2018	1995-2021	1995-2023	0.25° Daily
AMSR-E	Aqua		2002-2011	2002-2011	0.125° Daily + Monthly
AMSR2	GCOM-W			2012-2023	
Merged IR CDR	GEO+LEO IR above	2009-2020	2004-2021	2004-2023	0.05° 3-hourly
ATSR-S3 CDR	ATSR, MODIS, SLSTR	1995-2020	1995-2021	1995-2023	0.05° Daily + Monthly
Prototype EO-SIP AVHRR	NOAA + Metop			1982-2019	0.01° Daily
Prototype HR	Landsat Downscaled SLSTR / MODIS		2019-2021	2014-2023	100m select areas
Prototype IR+MW	Multiple			2010	



Example LST_cci AQUA-MODIS: Dataset Stability





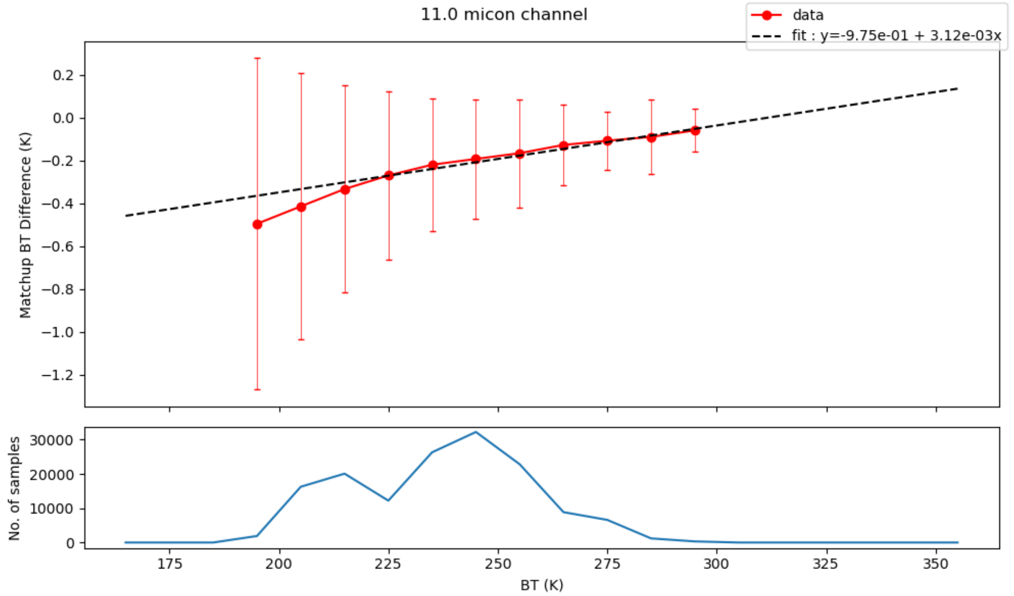
- Compared LST_cci anomalies with homogenised near-surface air temperature anomalies from EUSTACE dataset.
- LST vs T2m correlations are significantly improved in in the datasets recently released to the CCI Open Data Portal (compared to earlier versions).
- Conclusion is datasets, such as LST_cci Aqua-MODIS, are considered homogeneous and thus suitable for use for robust climate trend analysis.
- Good et al., 2022, *An Analysis of the Stability and Trends in the LST_cci Land Surface Temperature 1 Datasets over Europe*, ESS

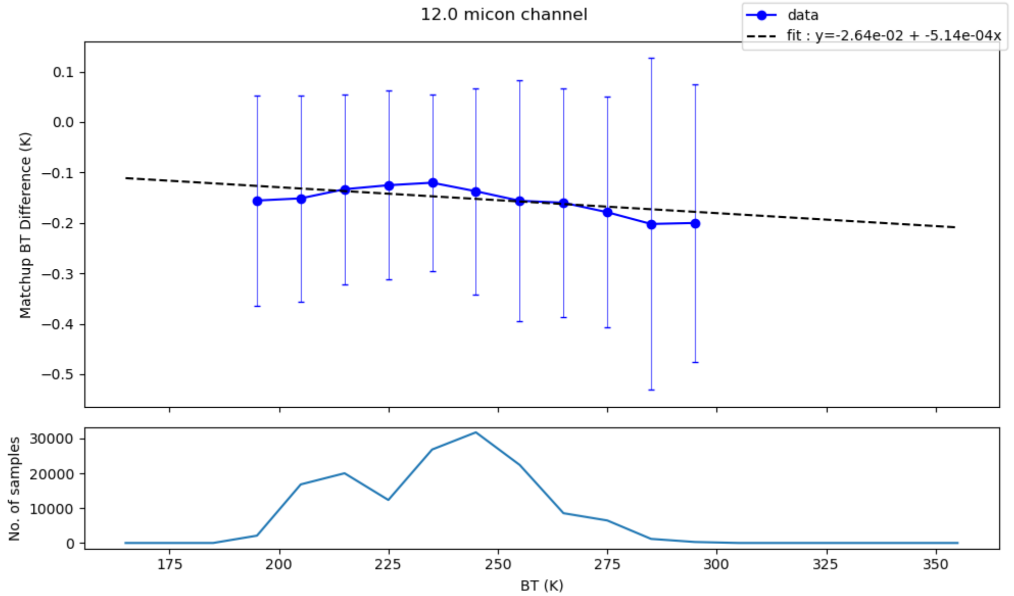
Intercalibration with IASI

- Intercalibration in BT space with BTs processed from IASI spectra using test instrument SRFs sourced from NWPSAF.
  - Method has GSICS heritage (SEVIRI)

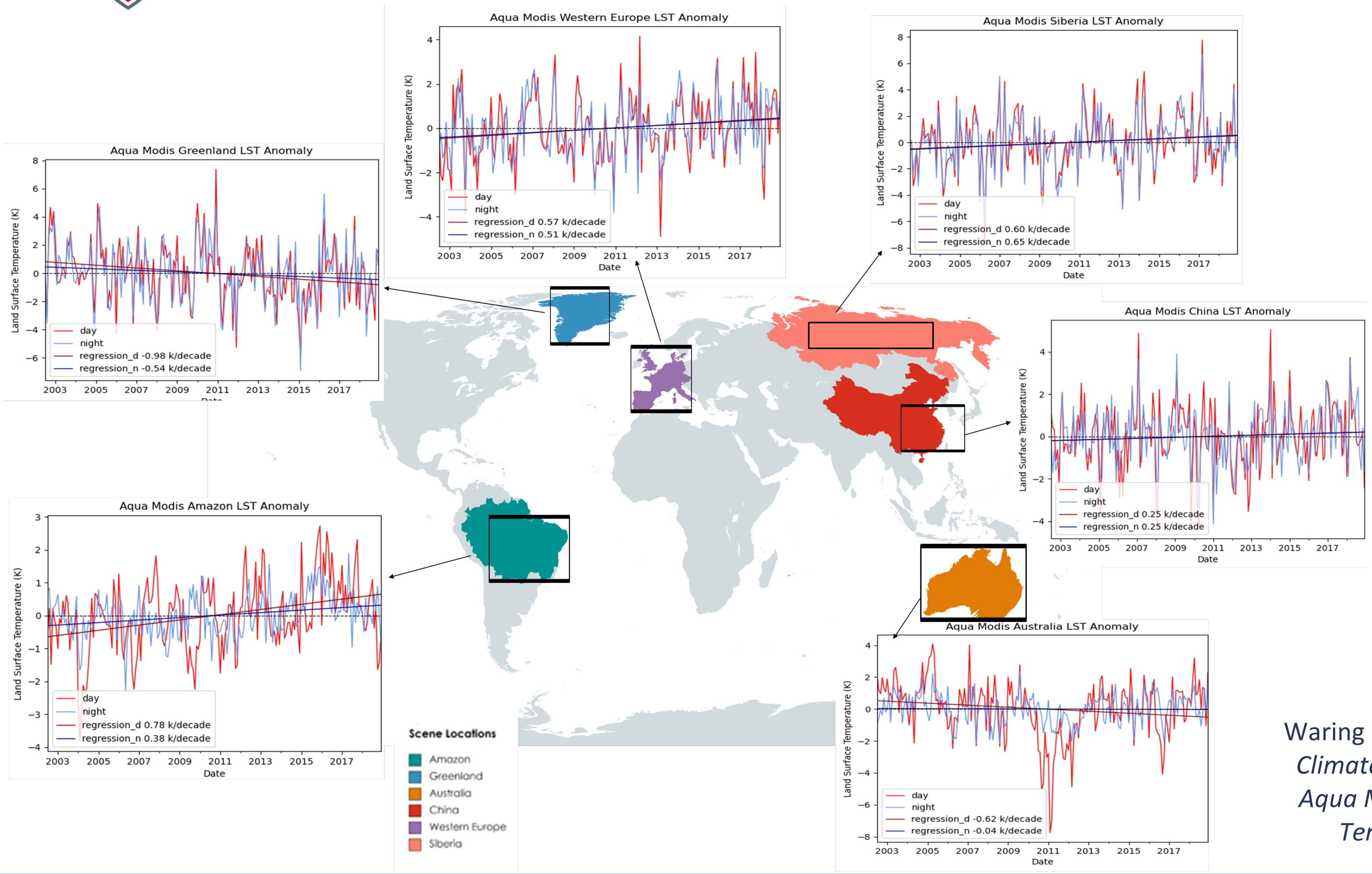
- Phase-2 updates to approach:
  - BT calculation: Convolve Planck function with SRF to get more accurate estimate of BT – requires radiance to BT LUT
  - extended temperature range by including ocean pixels – requires processing MODIS ocean pixels from L1B to L3U
  - acquired IASI reprocessed data (CDR 2007 – 01/2017)
  - improved matchup with IASI pixel
    - using 0.01° L3U MODIS (on 10 ° x 10 ° tiles)
    - checking L3U pixel within IASI pixel ellipse
  - Aiming for temperature dependent bias correction.

Aqua MODIS Temperature dependency
11 micron: + 3.1 mK/K (rms residuals 0.161 K)
12 micron: -0.5 mK/K (rms residuals 0.0628 K)





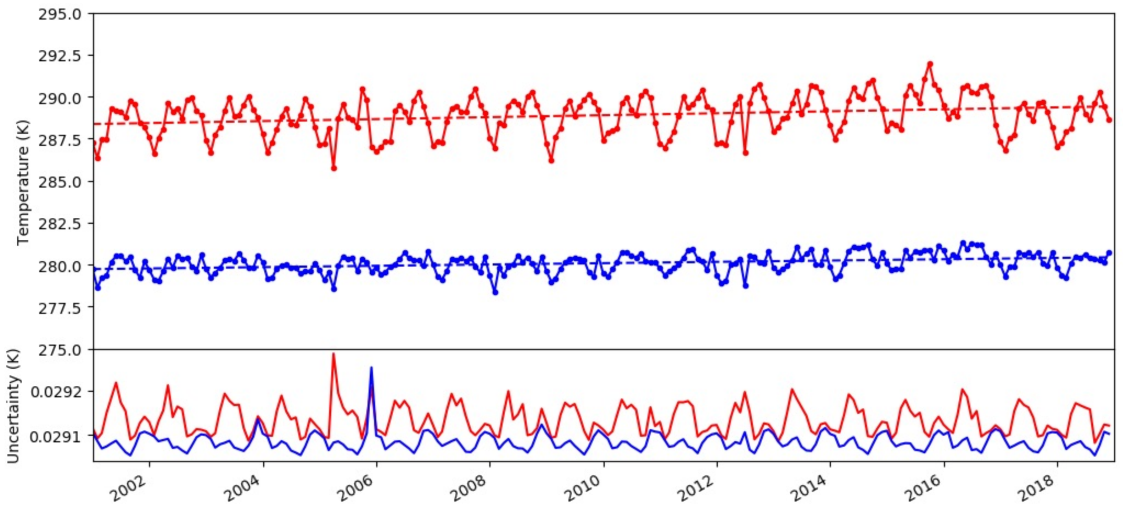
AQUA-MODIS: REGIONAL ANALYSES

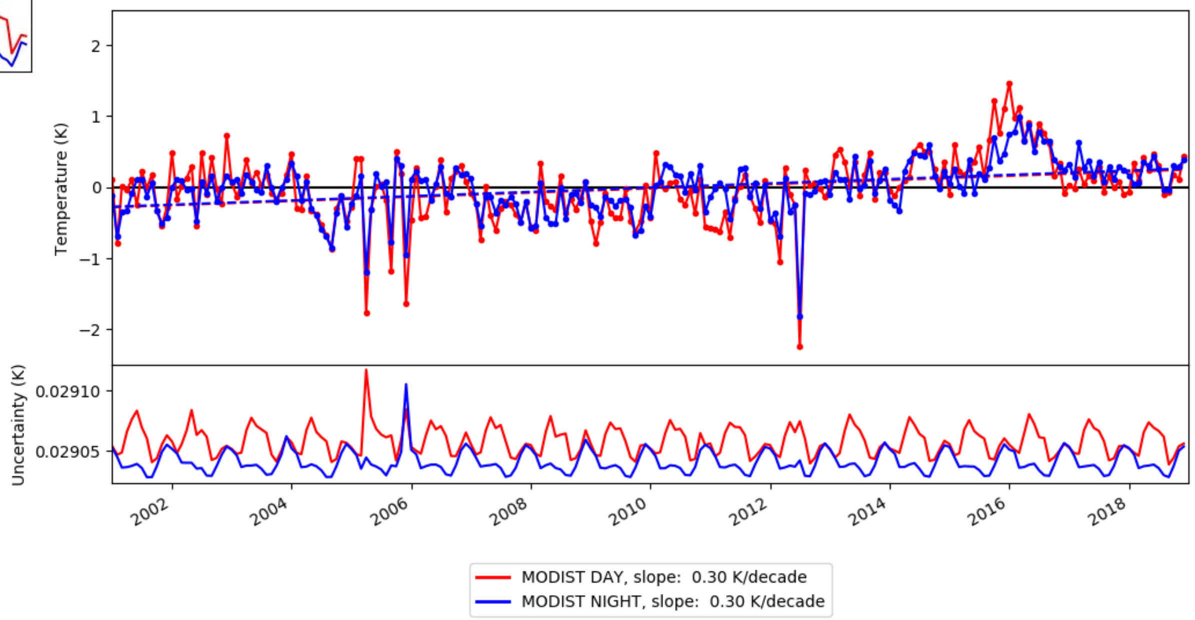


Waring et al., 2023, *Regional Climate Trend Analyses for Aqua MODIS Land Surface Temperatures*, IJRS

EXAMPLE LST_CCI TERRA-MODIS: 18-YEAR LST CDR

Global Terra-MODIS LST and anomalies





ATSR-S3 CDR

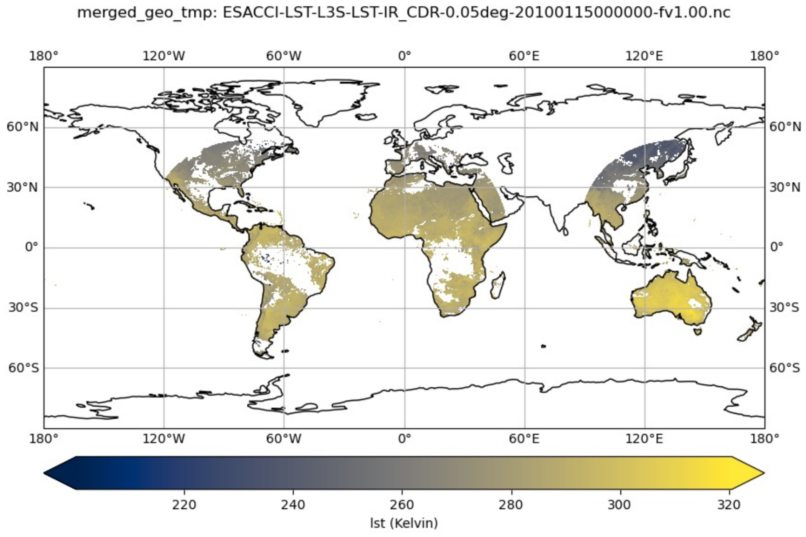
- Long-term LST Climate Data Record (CDR) from ATSR-2, AATSR, SLSTR with Terra MODIS filling gap between AATSR and SLSTR

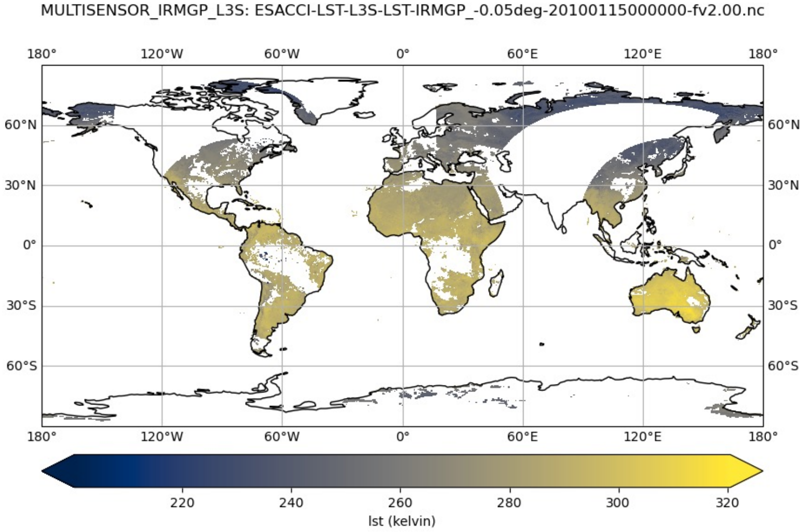
- Current product release:
  - Took advantage of improvements to single sensor records to build a multi-sensor CDR
  - Intercalibration of sensors with IASI
  - Time correction applied to account for different overpass times
  - View angle restriction for consistency across instruments
  - Perry, M. et al. (2020). *Multi-Sensor thermal infrared and microwave land surface temperature algorithm intercomparison*, Remote Sensing

- Improvements being made:
  - Extend geographical coverage over sea-ice
  - Incorporate improvements to single sensor algorithms such as further advances in uncertainty characterisation and cloud-clearing
  - Improvements to intercalibration
  - Time correction – improve diurnal model to reduce uncertainties in the time correction

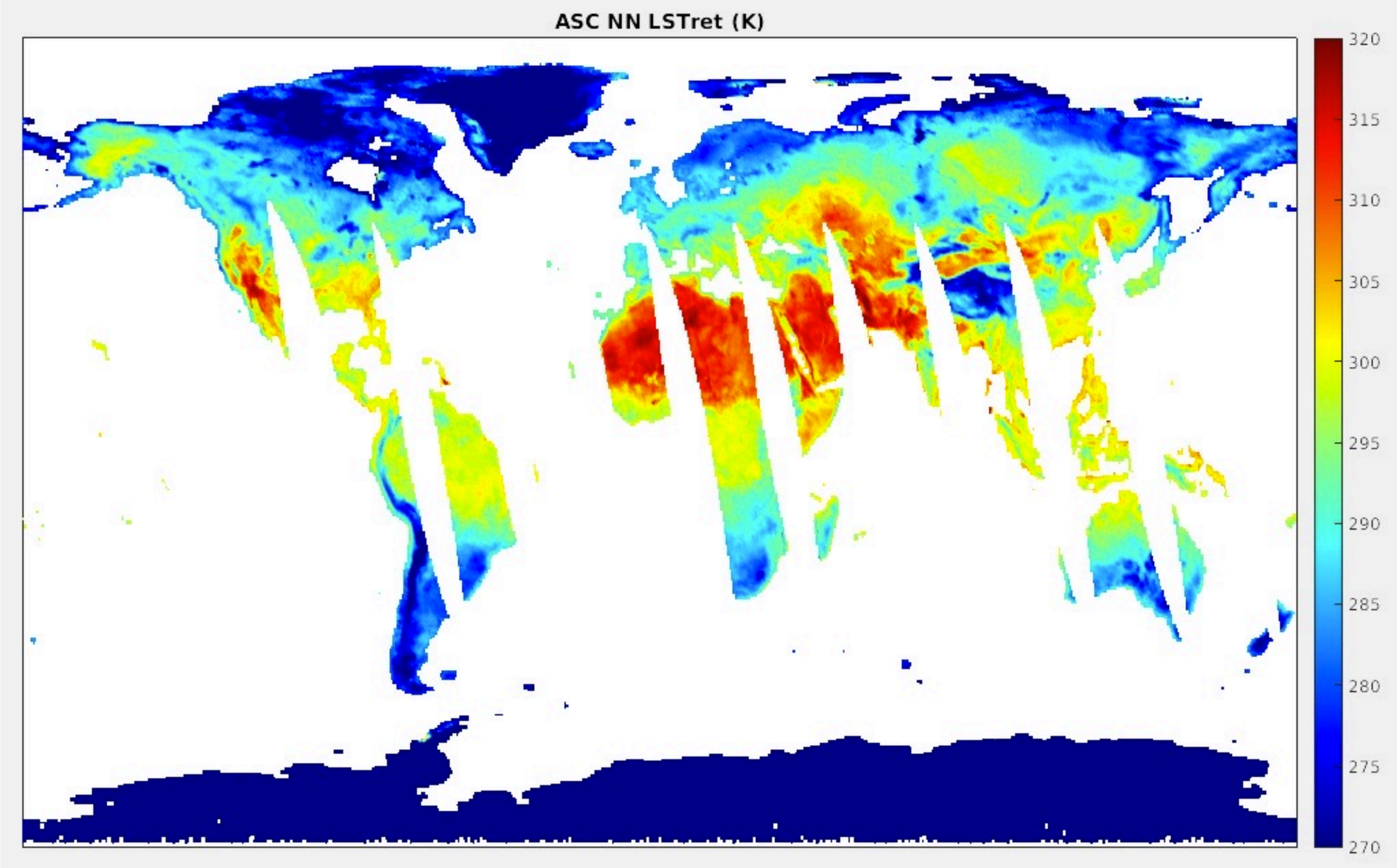
MERGED IR CDR

- The aim of the Merged IR CDR is to integrate polar and geostationary infrared-based LST to deliver information on the diurnal variation of LST at a global scale, including for the polar regions:
  - The LEO IR and GEO IR data are combined using all the building blocks in place for consistency across products
  - LSTs fields are provided at 3 hourly intervals each day (00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 UTC); Temporal coverage is 2009 – 2020
  - Instruments include: GEOs - IMAGER s on GOES 12 and 13; Advanced Baseline Imager on GOES 16, SEVIRIs on MSGs 1-4; JAMI on MTSAT 1 and 2; LEOs - AATSR; MODIS on Aqua and Terra; SLSTRs on Sentinel-3A and Sentinel-3B.
- Future improvements:
  - Extend the Merged IR CDR forwards through to 2023 and backwards to 2004
  - Include data from AVHRR/3 from NOAA and Metop, and new sensors such as VIIRS and Himawari





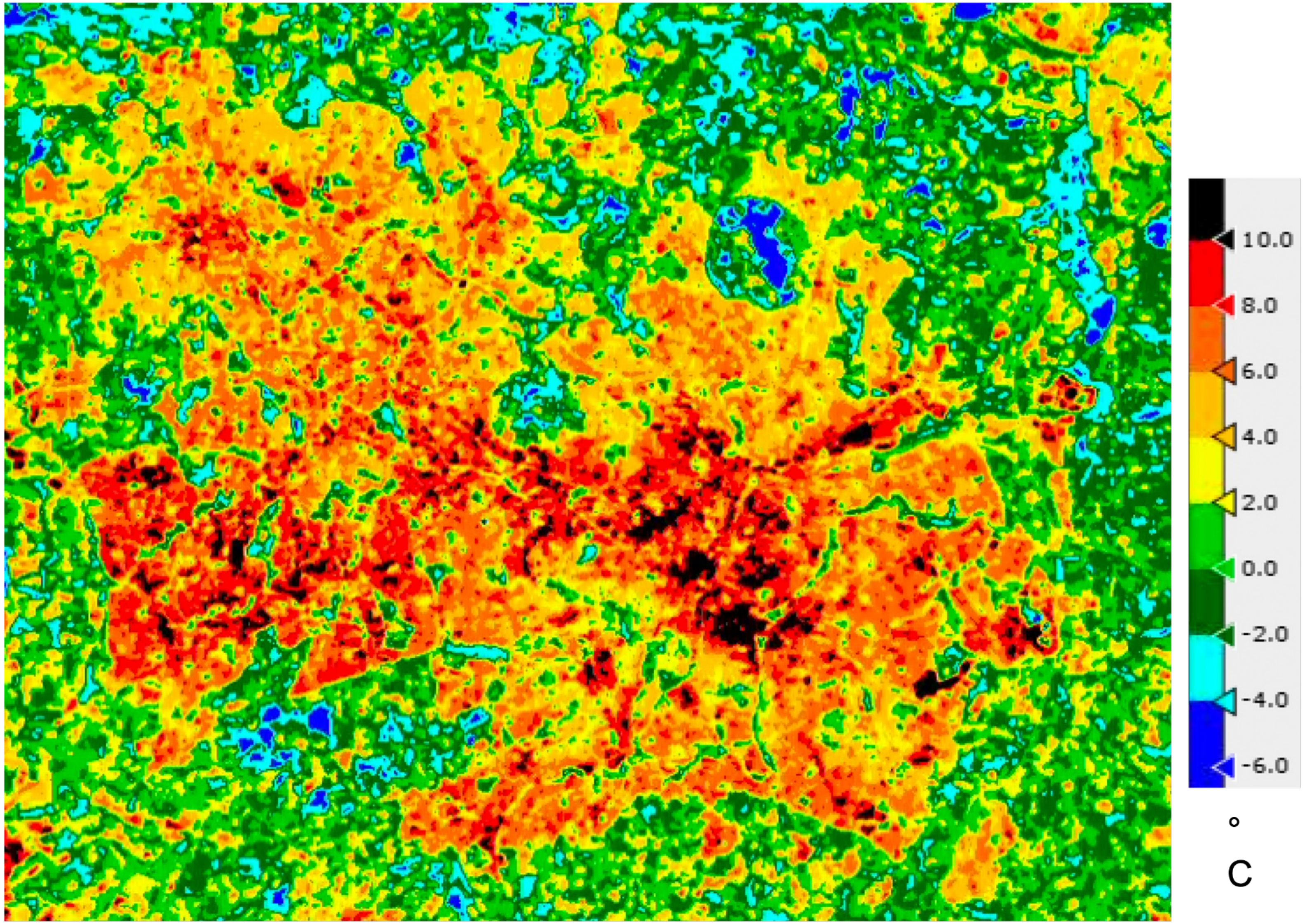
2015/06/15 6.30 PM **LST (K)**



- L2 retrievals by a NN regression trained on previous database
- Processing full 1996-2008 SSM/I (F13) and 2009/2020 SSMIS (F17)

- Birmingham's UHI for July 2021

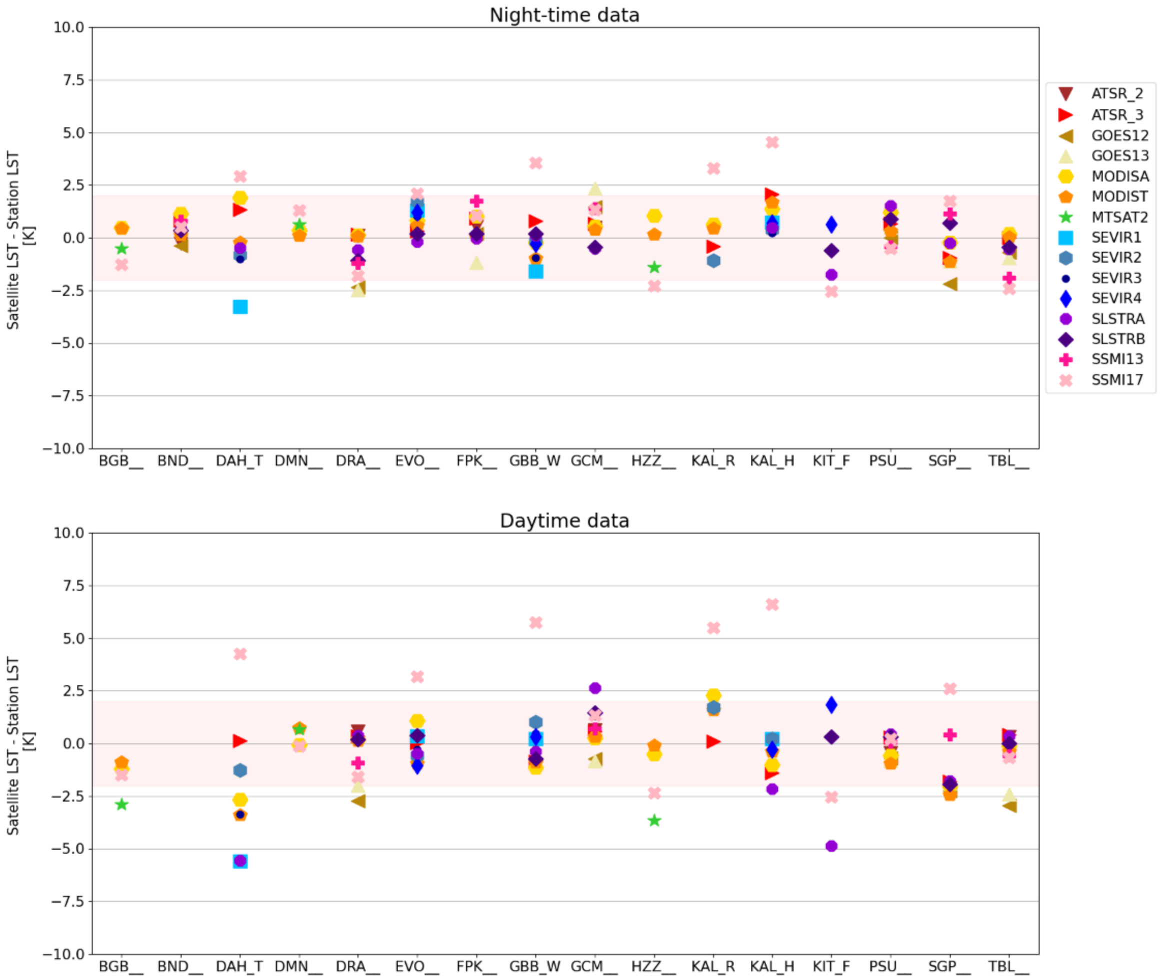
- By considering the 90th percentile of pixels it was found that the City Centre experienced higher temperatures of 11.7 ± 2.5 ∘C when compared with a rural background



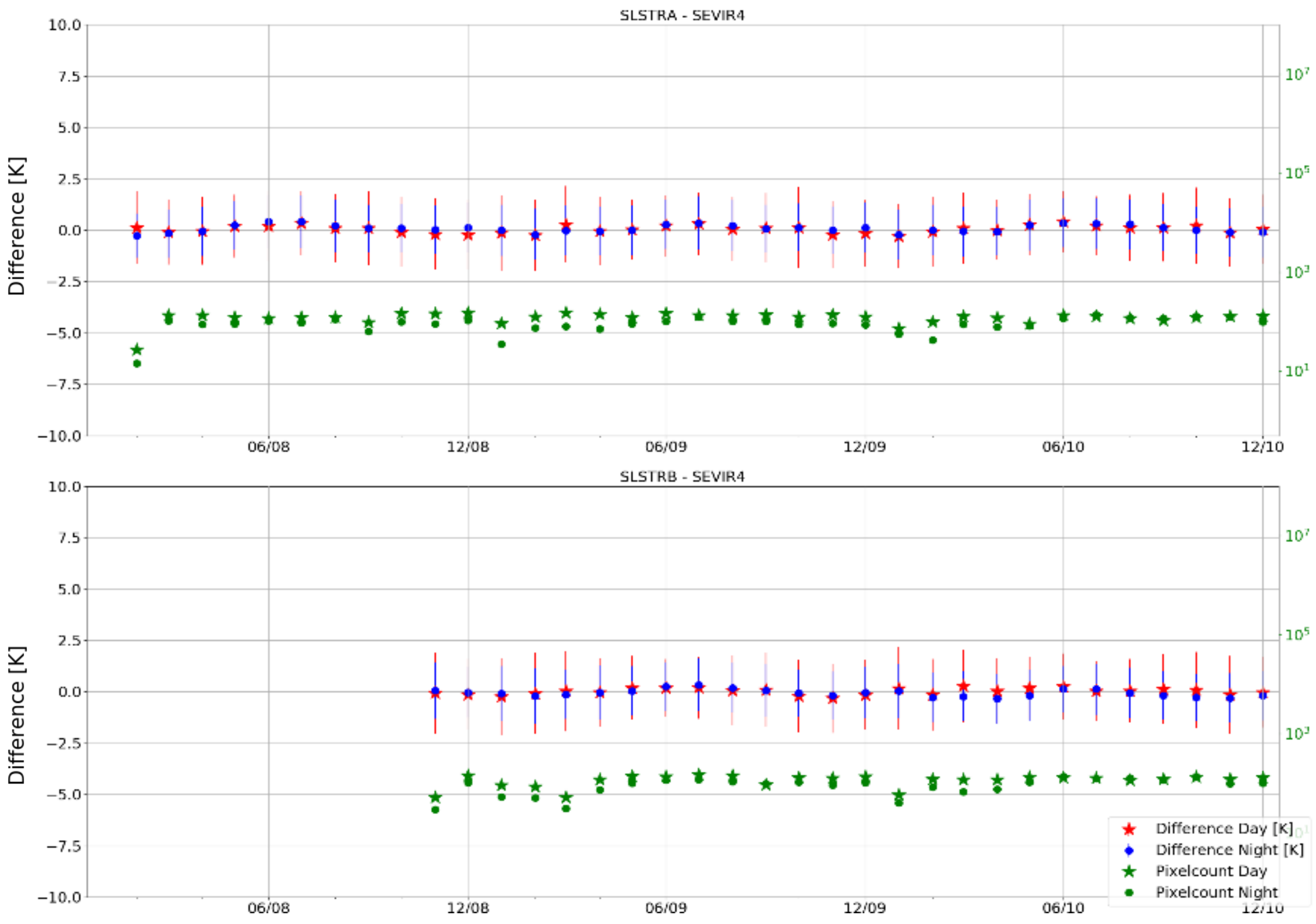
LANDSAT 8: CASE STUDY (WITH OS) – EXETER (UK)

With the detailed OS overlay, the data can clearly be seen to correspond to the expected land uses, with parks / playing fields and a cemetery showing lower LST, and industrial regions presenting the highest LST values.

- Bias: median(satellite LST – in situ LST)
- LST_cci IR products are performing well for most stations
- Night-time bias smaller, slightly larger differences in daytime bias (depending on station)
- MW data sets: larger footprint than IR data sets and so representativeness with respect to in situ station is more challenging



INTERCOMPARISONS – RESULTS OVER AFRICA 2018 - 2020



PHASE-1: USER CASE STUDIES

Team	Title
Met Office Hadley Centre	Regional and Global Trends in LST
DMI	Assimilating Greenland ice sheet surface ice temperature into atmosphere and ice sheet models
Ruhr University Bochum	Characterisation of Surface Urban Heat Islands
MPI-BCG	Biosphere-atmosphere exchange of sensible and latent heat
MeteoRomania	Intercomparison and integrated use of LST in urban climate studies
LIST	Integration of LST into a physically-based surface energy balance model

Cheval, S., Dumitrescu, A., Irașoc, A., Paraschiv, M-G., Perry, M., and Ghent, D. (2022). MODIS-based climatology of the Surface Urban Heat Island at country scale (Romania), Urban Climate, 41, 101056

Good, E. J., Aldred, F. M., Ghent, D. J., Veal, K. L., and Jimenez, C. (2022). An Analysis of the Stability and Trends in the LST_cci Land Surface Temperature Datasets over Europe. Earth and Space Science, 9, e2022EA002317, https://doi.org/10.1029/2022EA002317

Karagali, I., Barfod Suhr, M., Mottram, R., Nielsen-Englyst, P., Dybkjær, G., Ghent, D., and Høyer, J. L. (2022). A new L4 multi-sensor ice surface temperature product for the Greenland Ice Sheet, The Cryosphere, 16, 3703–3721

Mallick, K., Baldocchi, D., Jarvis, A., Hu, T., Trebs, I., Sulis, M., Bhattarai, N., Bossung, C., Eid, Y., Cleverly, J., Beringer, J., Woodgate, W., Silberstein, R., Hinko-Najera, N., Meyer, W. S., Ghent, D., Szantoi, Z., Boulet, G., Kustas, W. P. (2022). Insights into the aerodynamic versus radiometric surface temperature debate in thermal-based evaporation modeling. Geophysical Research Letters, 49, e2021GL097568

Sismanidis, P., Bechtel, B., Perry, M., and Ghent, D. (2022). The Seasonality of Surface Urban Heat Islands across Climates. Remote Sensing, 14, 2318

Key Activities for Phase-2

- Improve intercalibration of polar-orbiters
- Extension to Algorithm Intercomparison exercise to include new algorithms
- The best algorithm for each respective sensor
- Extend the cloud assessment under different conditions
- To correct for the drift in local time
- To properly characterise the clear-sky only sampling uncertainty
- Extend coverage of LEOs to include sea-ice
- Develop an experimental all-sky product from combining IR and MW LST

USER CASE STUDIES IN PHASE-2

UCS #1 (Met Office Hadley Centre): Investigate the feasibility of a satellite moderate temperature extremes data set to supplement the HadEX3 dataset

UCS #2 (DMI): Impact of ESA LST CCI IST products on the Arctic Copernicus Marine Service (CMEMS) SST/IST product

UCS #3 (RUB): Investigating the diurnal heating and cooling of cities using LST data retrieved from high resolution IR sensors

UCS #4 (Met Office Hadley Centre): Comparison between LST and reanalysis ‘skin’ temperature time series

UCS #5 (MeteoRomania): Intercomparison and application of LST_cci datasets and provision of new derived LST datasets over Europe

UCS #6 (LIST): UNITE (EvalUatiNg DIurnal Dynamics of Evaporation and Temporal Integration Impacts in Evaporation Modeling)

SUMMARY

- An expected accuracy and precision of all the LST ECV Products will be < 1 K.
- An assessment of the stability of LST ECV Products to ensure they meet they threshold requirement < 0.3 K / decade.
- A global thermal infrared LST CDR from ATSR through to SLSTR with record length of 28 years.
- A passive microwave time series from SSM/I and SSMIS with record length of over 28 years.
- A passive microwave time series from AMSR-E and AMSR-2 with record length of over 21 years.
- The long-term time series from AVHRRs from the 1980s to present is also expected to make significant contributions towards the GCOS requirements.
- Implementation of existing FCDRs, and where these are not available intercalibration of level-1 data for CDRs.
- Time difference corrections of level-1 data for multi-mission CDRs.

SUMMARY

- Consistency across all LST ECV Products, in terms of retrieval algorithms, uncertainty characterisation, and coefficient generation.
- Optimisation of best cloud clearing detection across new sensors.
- The project is ensuring where possible consistency is maintained with other ECV products.
- First climate quality LST at high spatial resolution from Landsat and downscaling developments.
- Fully independent and rigorous product validation and intercomparison extended to new sites and external datasets.
- Significant increase in maturity levels of all LST ECV Products
- Demonstration of climate applications resulting in several journal papers published, accepted, or in review – many led by users in the Climate Research Group.