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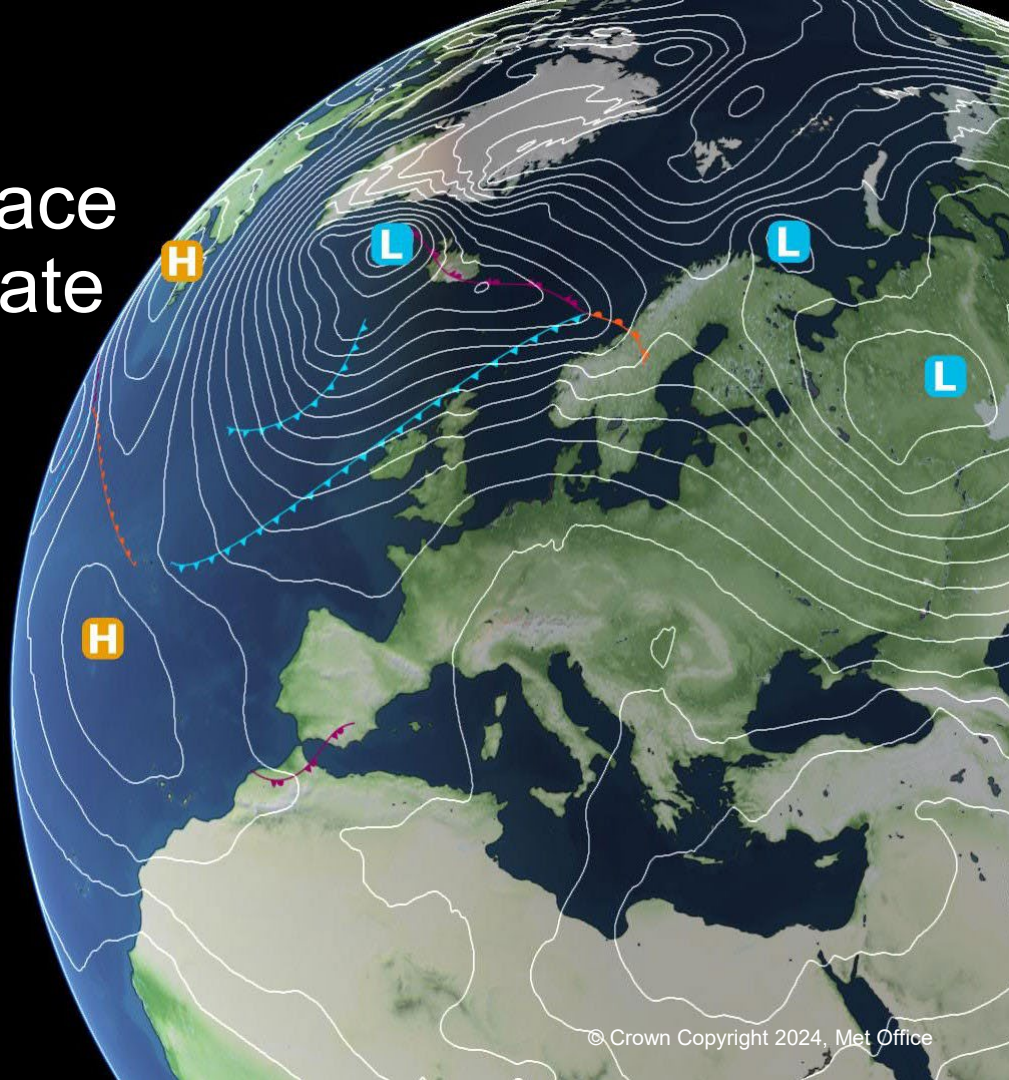
Use of satellite (land surface temperature) data in climate applications

Lizzie Good (Met Office)

Thermal Remote Sensing Workshop

4 December 2024



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Overview

- Some example climate applications for Land Surface Temperature (LST) – focusing on observations
- Relationship between LST and 2m-air temperature (T2m)
- Some things to consider when using *any* satellite data in climate applications

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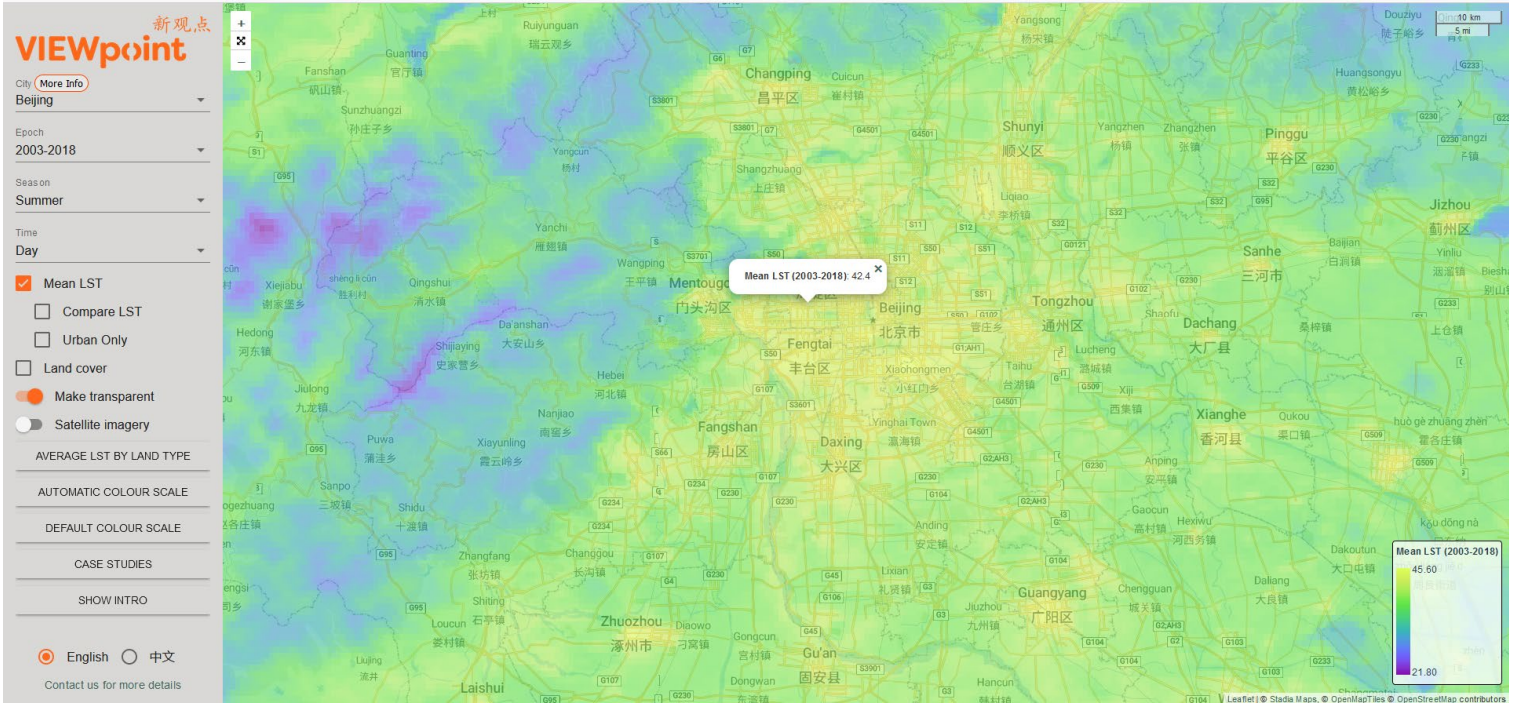
Example climate use cases for LST

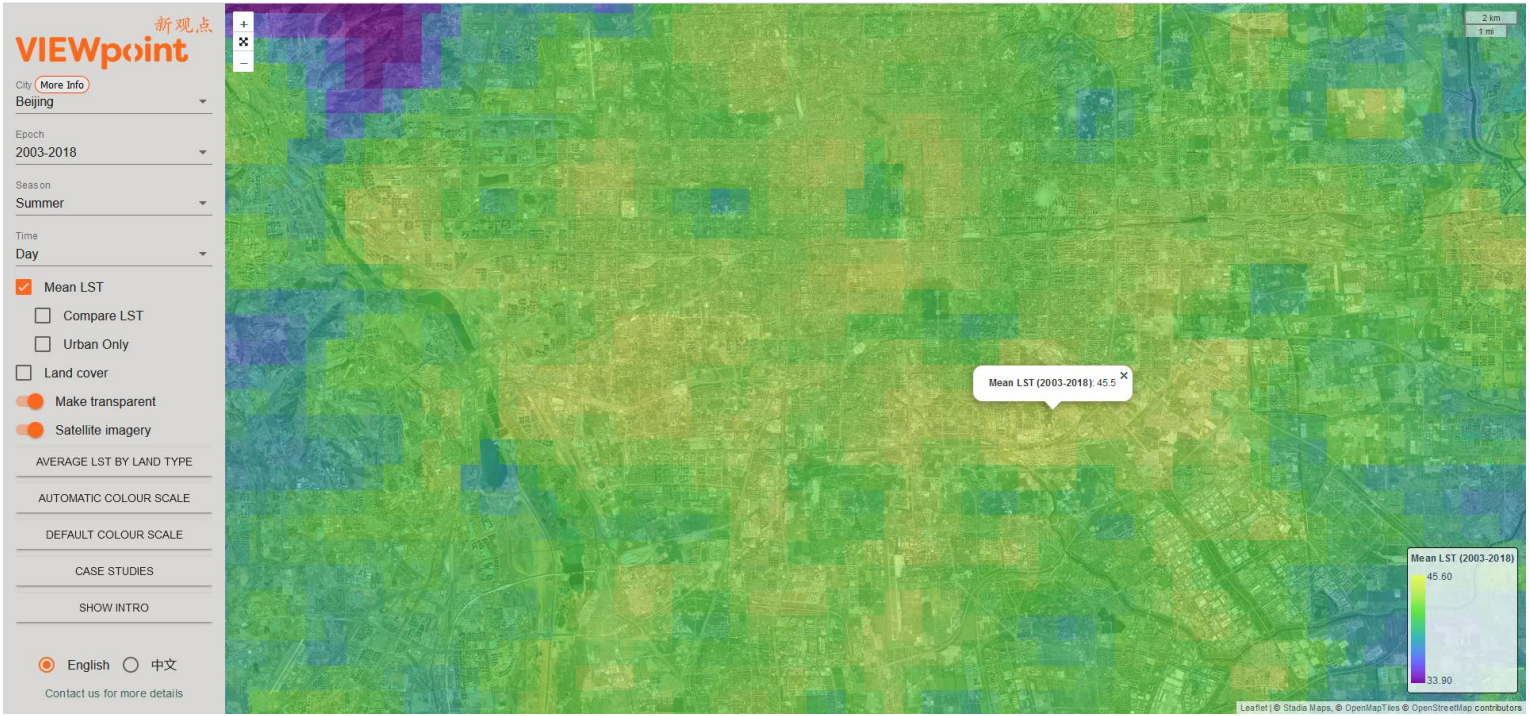
Example Tool - LST



https://the-iea.github.io/viewpoint-suhi/

- Satellite data are a great communication tool!
- Data shown are the mean over 16 years - a short ‘climatology’
- Summer
- Collaboration between the Met Office and the Institute of Environmental Analytics (IEA)

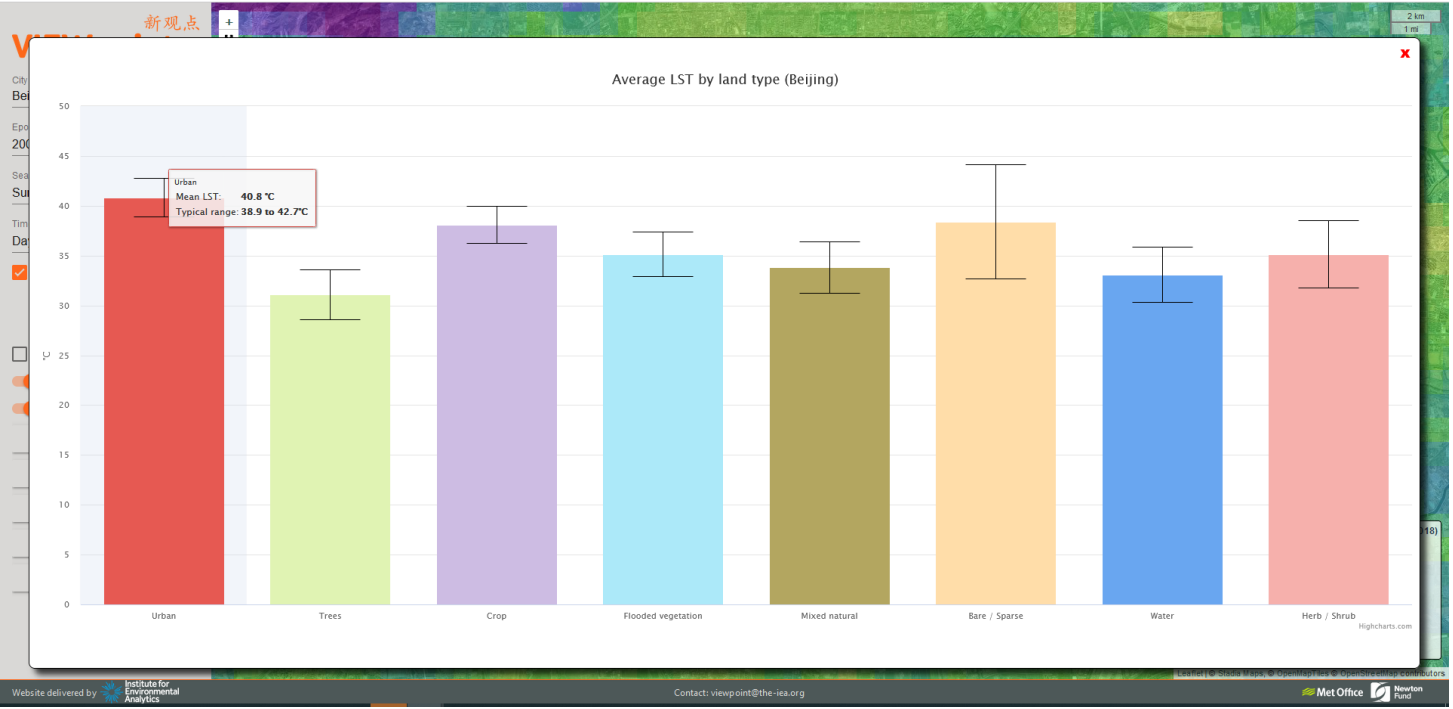
Example Tool - LST



- Can overlay a ‘Google type’ street view
- Can Zoom in and out
- Click on satellite LSTs

https://the-iea.github.io/viewpoint-suhi/

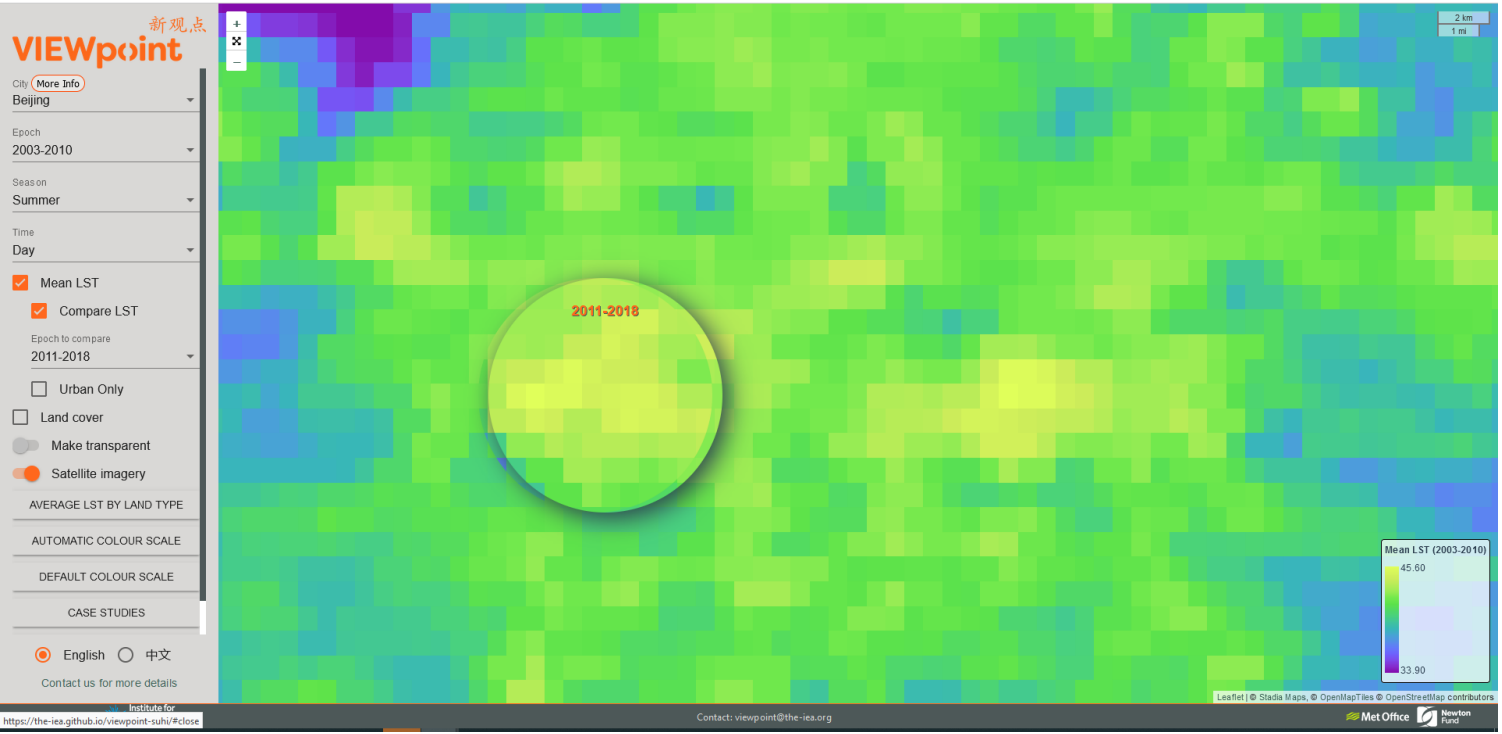
Example Tool - LST



- Can overlay land cover type
- Will show mean LSTs for some land cover classes
- Example is for summer

https://the-iea.github.io/viewpoint-suhi/

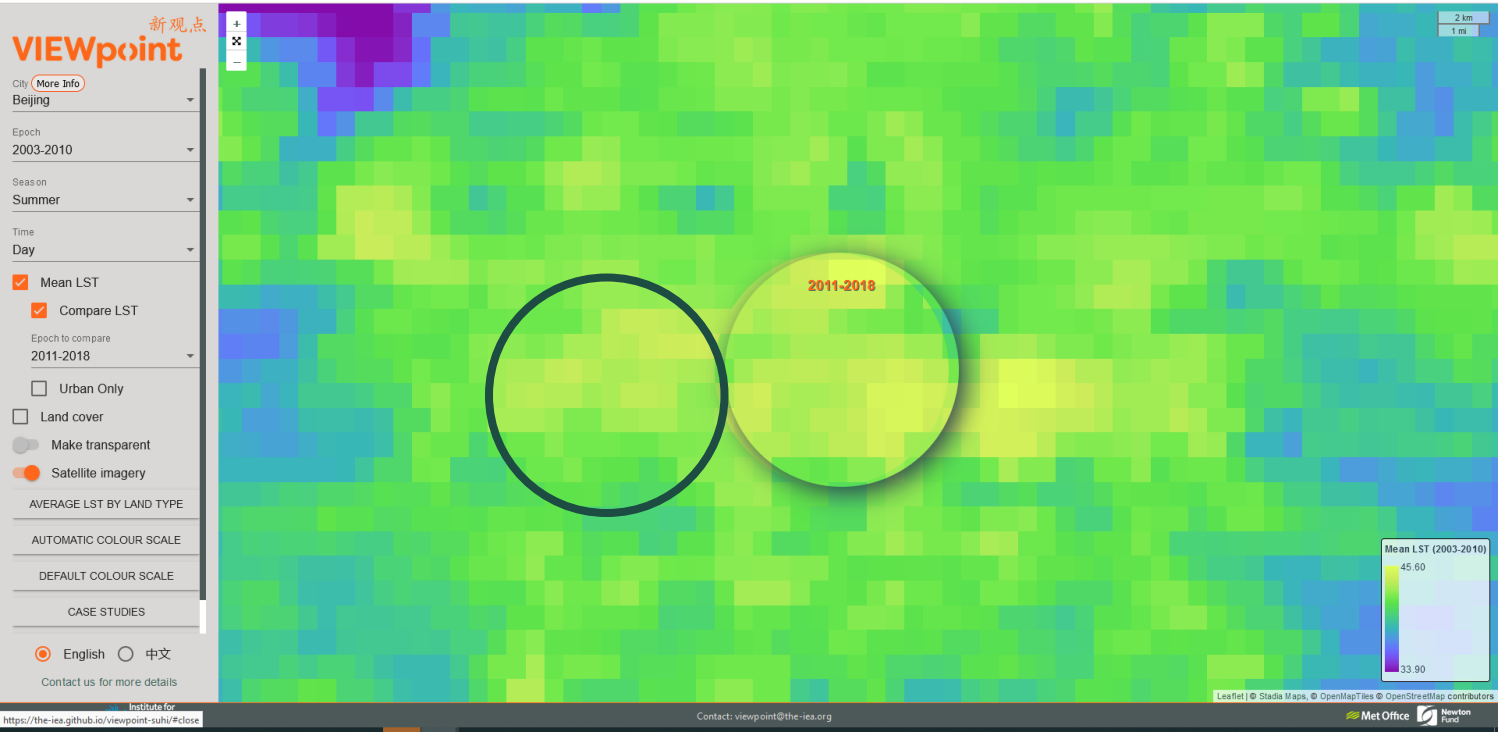
Example Tool - LST



- Can compare different time periods to see warming

https://the-iea.github.io/viewpoint-suhi/

Example Tool - LST



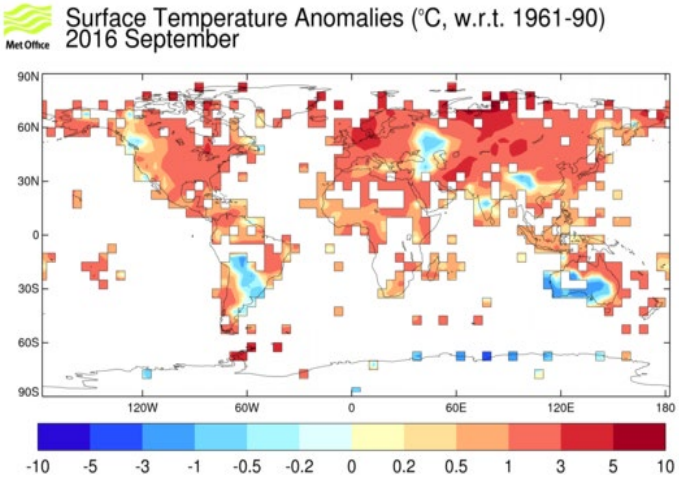
- Can compare different time periods to see warming
- Here 2003-2010 vs 2011-2018

https://the-iea.github.io/viewpoint-suhi/

Characterising Urban Heat Islands

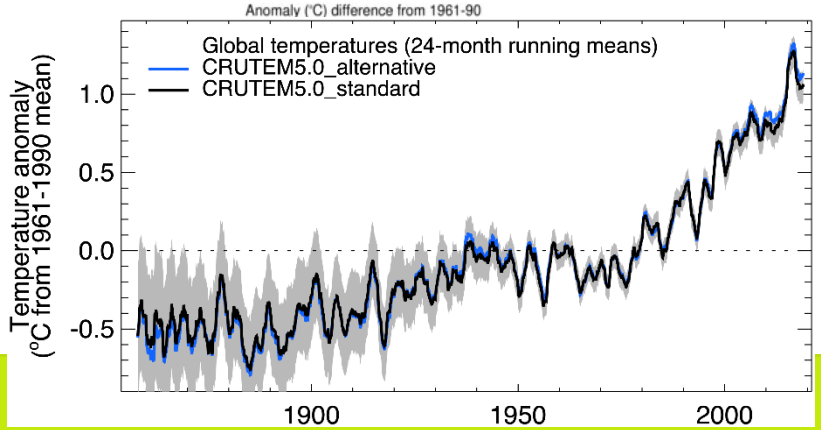
- Sue Grimmond's talk earlier today
- See talks at LST_cci workshop (Thursday & Friday)
  - Panagiotis Sismanidis '*Urban Nighttime Warming Trends derived from LST_cci MODIS Data*'
  - Irina Ontel '*Analyzing Seasonal Patterns and Temperature Extremes in Urban Areas Using MODIS Data*'
  - Alexandra Hurduc '*A multi-layer perceptron approach on downscaling land surface temperature for the study of surface urban heat island*'
  - Maria Gkolemi '*Analysis of urban surface temperature from satellite data with modelled 3D surface temperature*'
- Posters at the LST_cci workshop
  - Alexandra Hurduc '*On the suitability of different satellite land surface temperature products to study surface urban heat islands*'
  - Robert Elliott '*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*'
  - Giulia Guerri '*Nationwide surface thermal analysis to detect priority areas for urban mitigation interventions*'

Use of LST to Complement T2m (1)

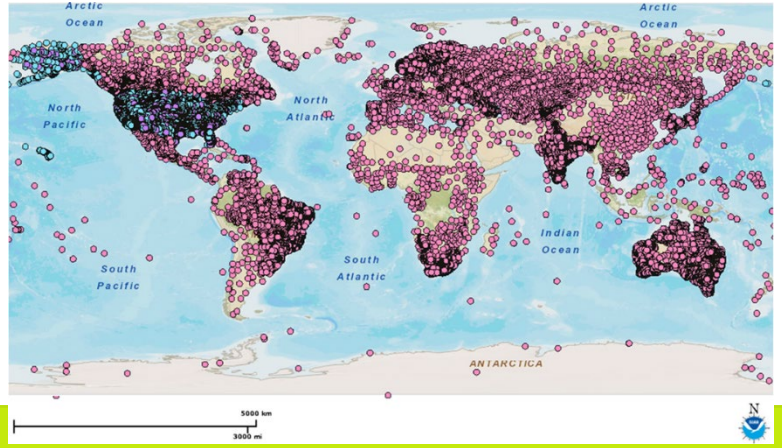


CRUTEM4 (http://www.metoffice.gov.uk/hadobs)

NB: CRUTEM4 superseded by CRUTEM5



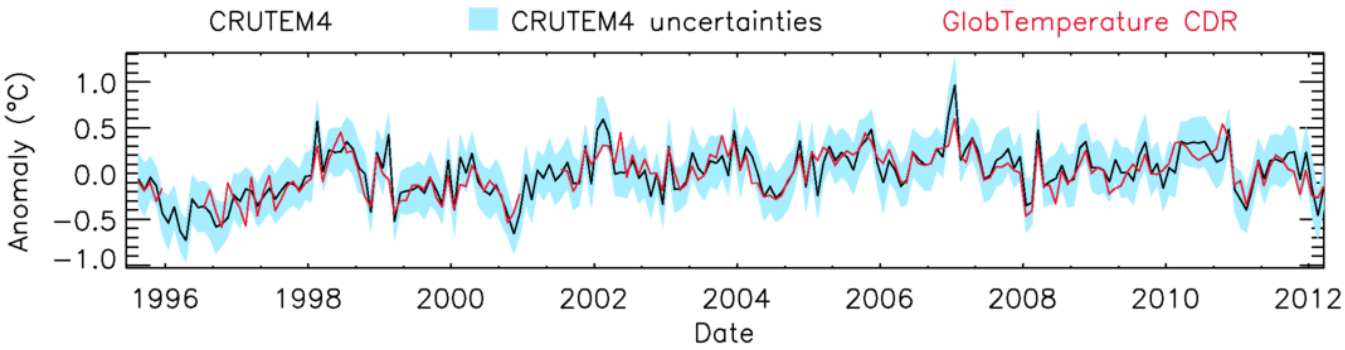
- Station air temperature ~2m (T2m) widely used to monitor climate change, quantify extremes, validate climate models, attribution studies, …
- However, station network is sparse



Source: National Centers for Environmental Information (NCEI)

Use of LST to Complement T2m (2)

Anomaly correlations ~0.9.



~90% of CDR anomalies within CRUTEM4 uncertainties

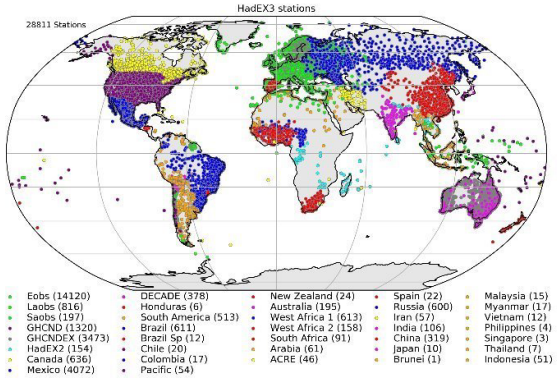
- CRUTEM4: a monthly mean homogenised gridded station anomaly data set at 5° lat/long (baseline: 1961-1990).
- LST & T2m anomalies and actuals are generally well correlated
- Potential for LST & T2m to be used synergistically

Anomalies represent the deviation from the 'normal' or 'baseline' climate – typically, we aim for 30+ years for a climatology, e.g. 1991-2020
Note WMO strict definition of what is a 'Climate Normal'

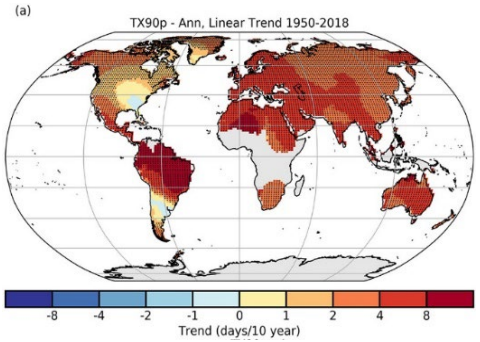
Good et al., 2017, A spatio-temporal analysis of the relationship between near-surface air temperature and satellite land surface temperatures using 17 years of data from the ATSR series, J. Geophys. Res. Atmos., doi:10.1002/2017JD026880)

Use of LST to Complement T2m Extremes (1)

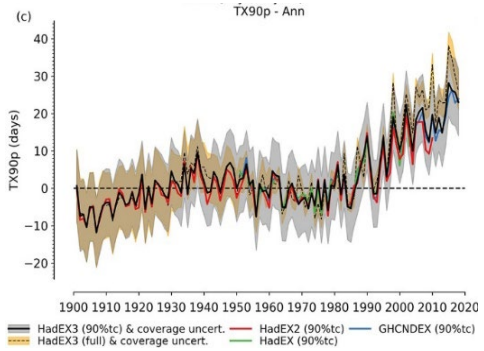
- HadEX3[1] is an in situ-based moderate extremes indices dataset for precipitation and T2m; used in IPCC reports.
- HadEX3 uses the Climpact indices (https://climpact-sci.org/) - a standardised set of climate indices originally recommended by the Expert Team on Sector-Specific Climate Indices (ET-SCI).
- 1901-2018 at a spatial resolution of 1.875° x 1.25° longitude-latitude.
- Used to examine how the frequency of moderate extremes are changing over time as well as evaluate models.
- Limitations:
  - Limited resolution
  - Unmonitored regions
  - Heavily interpolated in some areas
- Recent work suggests LST can be used to capture some similar signals in extreme temperatures



Stations used to produce the HadEX3 data set using the 1981-2010 baseline period[1]



Linear trends in annual series of TX90p over 1950–2018 (days/decade)[1]



Time series of HadEX3 (compared with HadEX, HadEX2 and GHCNDEX)[1]

1. Dunn et al. (2020). Development of an updated global land in situ-based data set of temperature and precipitation extremes: HadEX3. Journal of Geophysical Research: Atmospheres, 125, e2019JD032263. https://doi.org/10.1029/2019JD032263

Use of LST to Complement T2m Extremes (2)

- Example shown here uses microwave LST, but other recent work suggests IR LST may be similarly useful
- 'Threshold' indices (e.g. exceedance of 20 °C) are problematic due to LST vs T2m differences
- Other Climpact Indices show promise, particularly the percentile-based indices e.g. Northern Europe (AR6 id = 16)
- Overall good agreement
  - Correlations of $r \geq 0.76$
- For events:
  - TX90p = "warm days"
  - TN10p = "cool nights"
- Find the co-identifying of extreme events
- Some cases where LST indices shows extremes but not for T2m ("false positives")

Work by Josh Blannin (Met Office)

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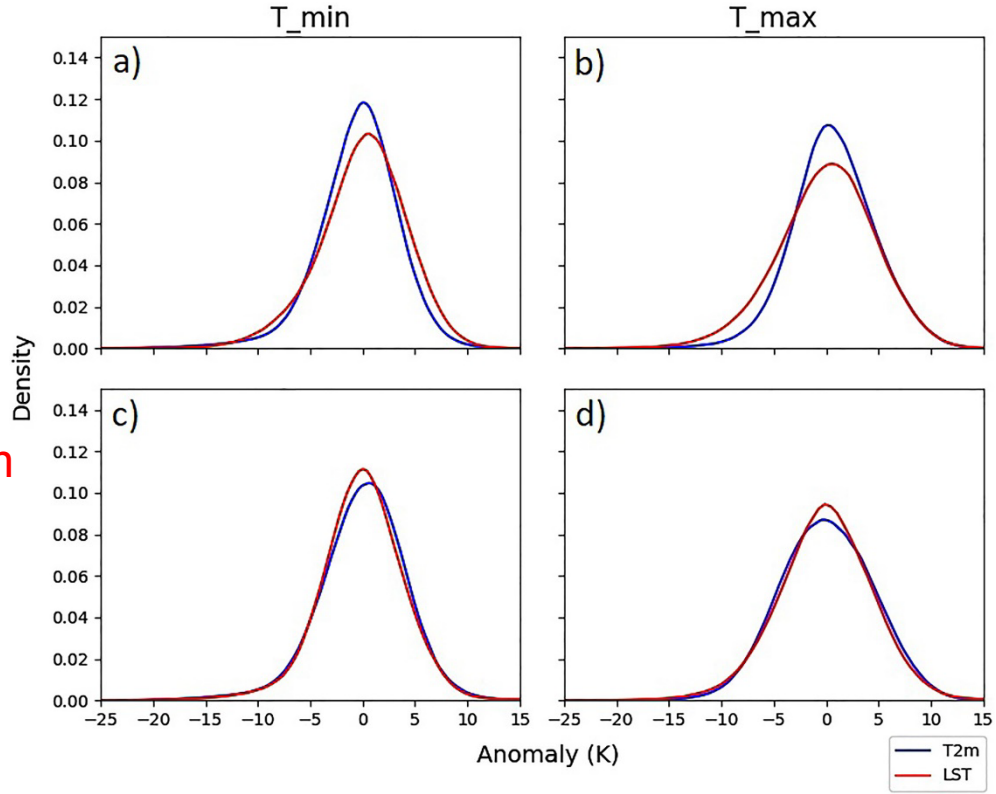
Relationship Between LST and T2m

LST vs T2m Daily Anomalies

LST_cci MODIS/Aqua – night & day
2002-2018
Station Tmin & Tmax

LST_cci Microwave LST – 6am & 6pm
1996-2020
Station Tmin & Tmax



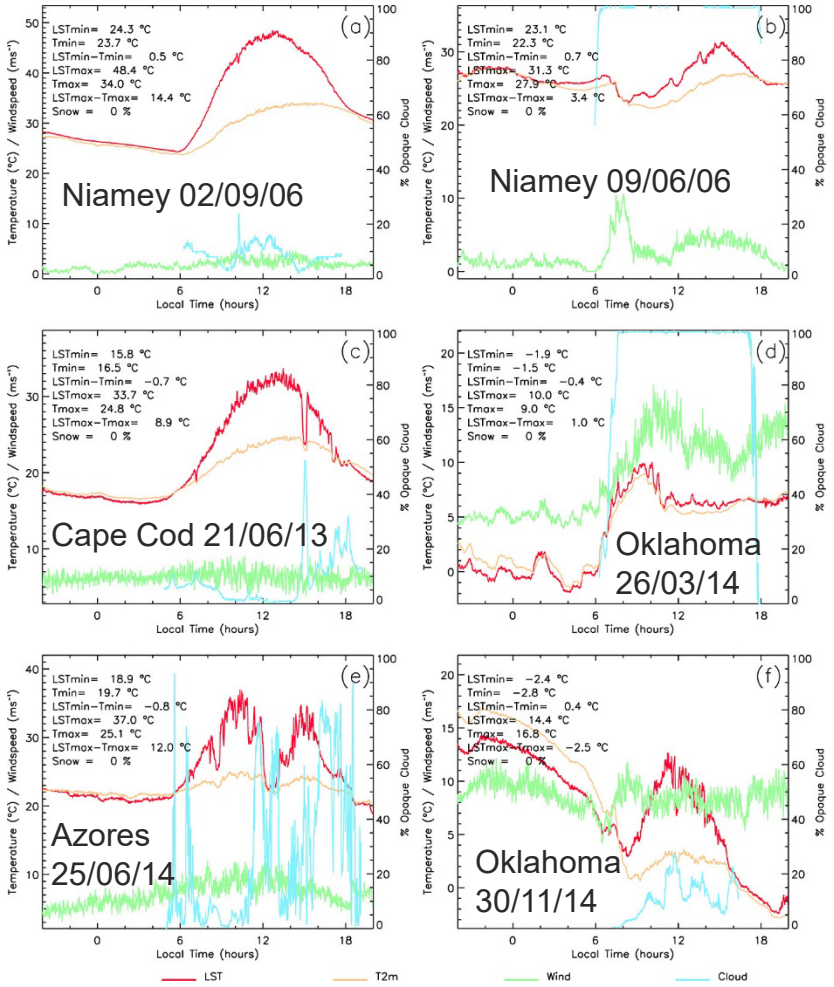
Good, E. J., Aldred, F. M., Ghent, D. J., Veal, K. L., & Jimenez, C. (2022). An analysis of the stability and trends in the LST_cci Land Surface Temperature datasets over Europe. Earth and Space Science, 9, e2022EA002317. https://doi.org/10.1029/2022EA002317

T2m vs LST (1)

Analysis between colocated *in situ* LST and T2m at Atmospheric Radiation Measurement (ARM) sites

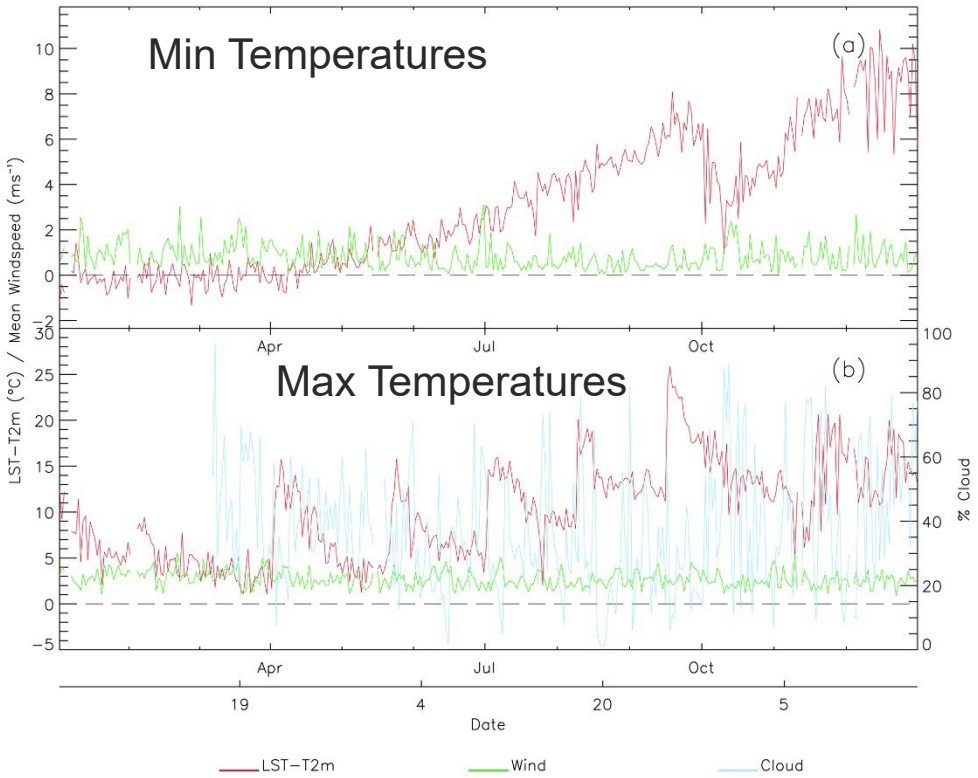
T2m vs LST relationship varies with many factors:

- Windspeed (b, d)
- Cloud cover (c, d, e)
- Weather systems (f)
- Vegetation (also vegetation health and density)
- Snow cover
- Surface roughness



Good, E. J. (2016), An in situ-based analysis of the relationship between land surface "skin" and screen-level air temperatures, J. Geophys. Res. Atmos., 121, 8801–8819, doi:10.1002/2016JD025318.

T2m vs LST (2)



Example here is from 2014 Amazonia ARM site

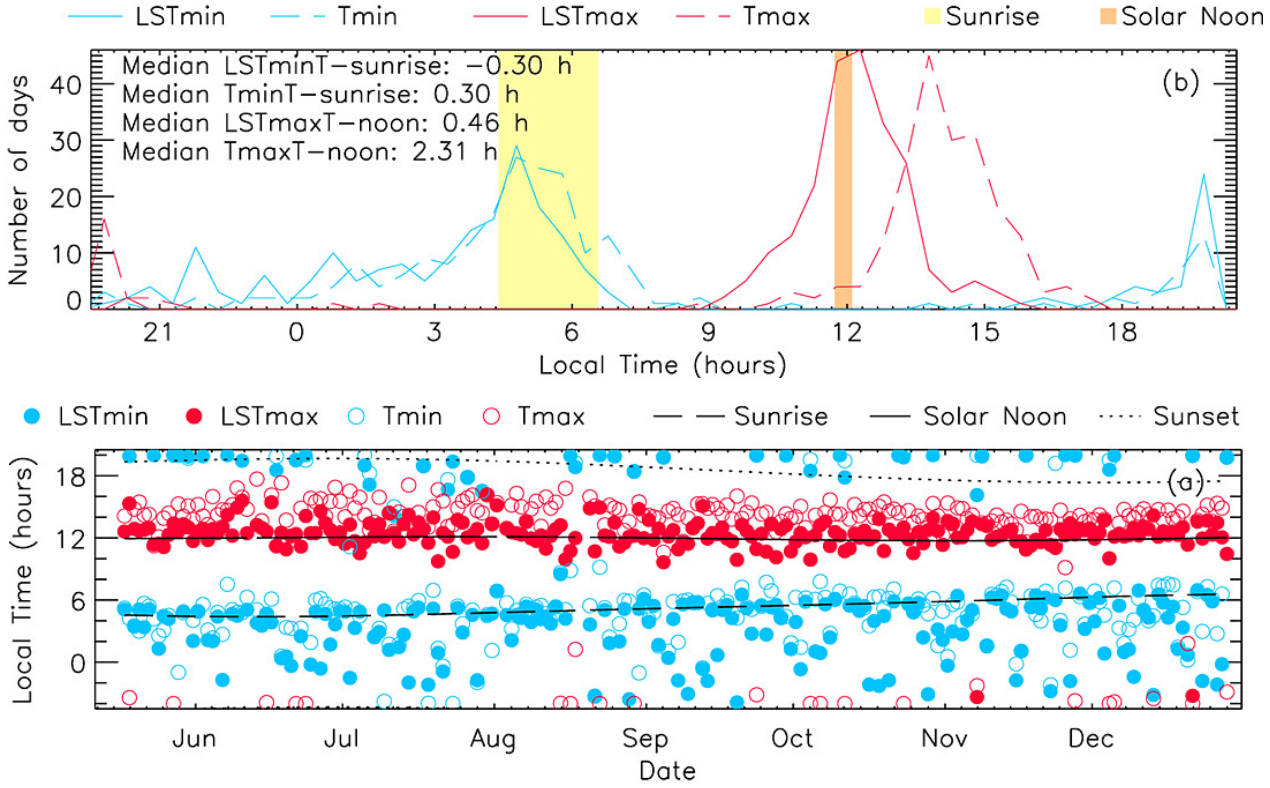
Red line shows LST-T2m
Green is windspeed
Blue is cloud

'Saw-tooth' effect could be due to regular mowing of the site:

- Mowing increases soil fraction and reduces vegetation => Large LST-T2m difference
- Grass grows again over time => LST-T2m converges

Good, E. J. (2016), An in situ-based analysis of the relationship between land surface "skin" and screen-level air temperatures, J. Geophys. Res. Atmos., 121, 8801–8819, doi:10.1002/2016JD025318.

T2m vs LST (3)



ARM Shouxian (HFE) between 11 May 2008 and 29 December 2008

Timing of daily max/min can be different for LST and T2m

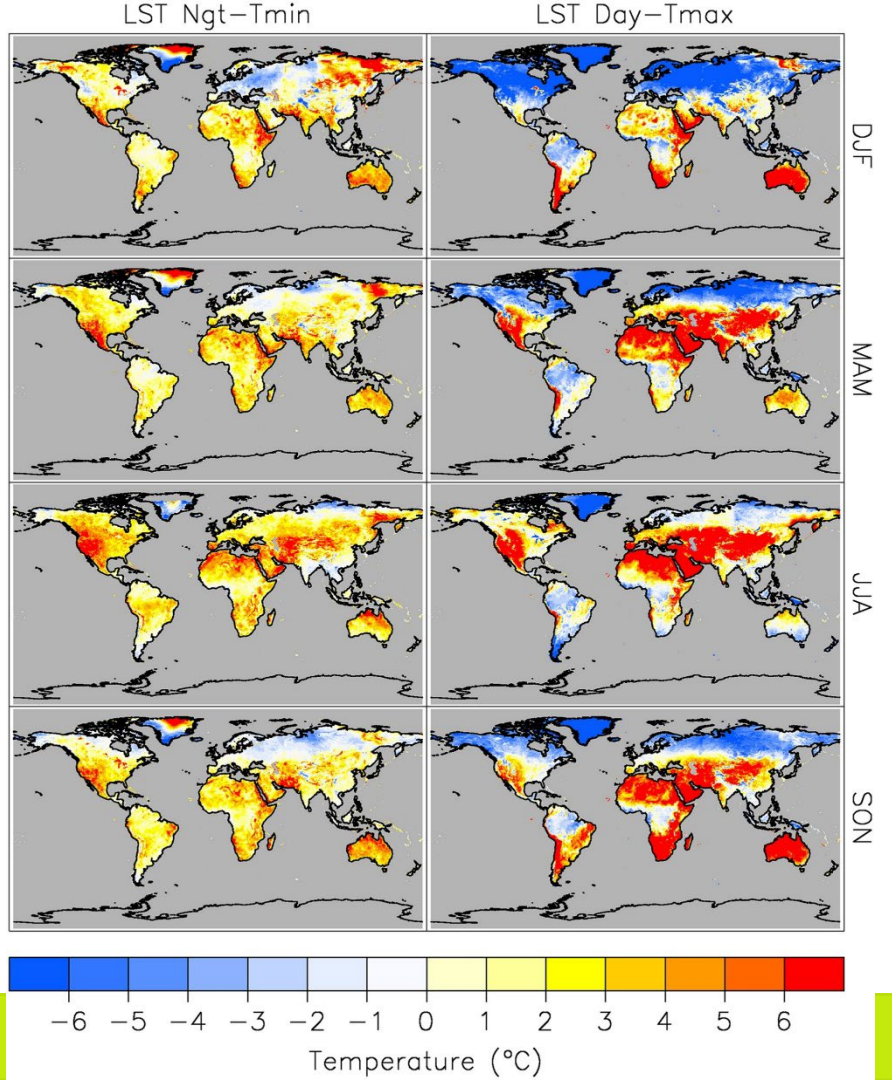
Tmin and LSTmin often occur at the same time (just before dawn)

LSTmax occurs near solar noon
Tmax occurs mid pm.

Good, E. J. (2016), An in situ-based analysis of the relationship between land surface "skin" and screen-level air temperatures, J. Geophys. Res. Atmos., 121, 8801–8819, doi:10.1002/2016JD025318.

Predicting T2m from LST

- There has been a lot of studies that have tried to predict ‘actual’ T2m from ‘actual’ LST
  - Very difficult problem, especially on a daily time scale because of these differences, especially with IR data that only shows clear sky.
  - Min/max LST and T2m are often very different
- Anomalies are well correlated and often very similar, especially over longer timescales (e.g. monthly)
  - This is likely to be a better approach



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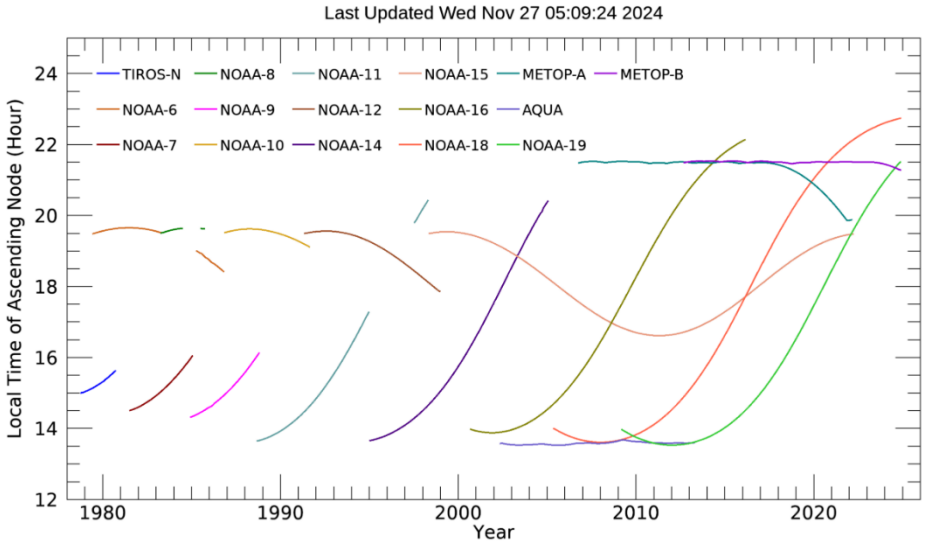
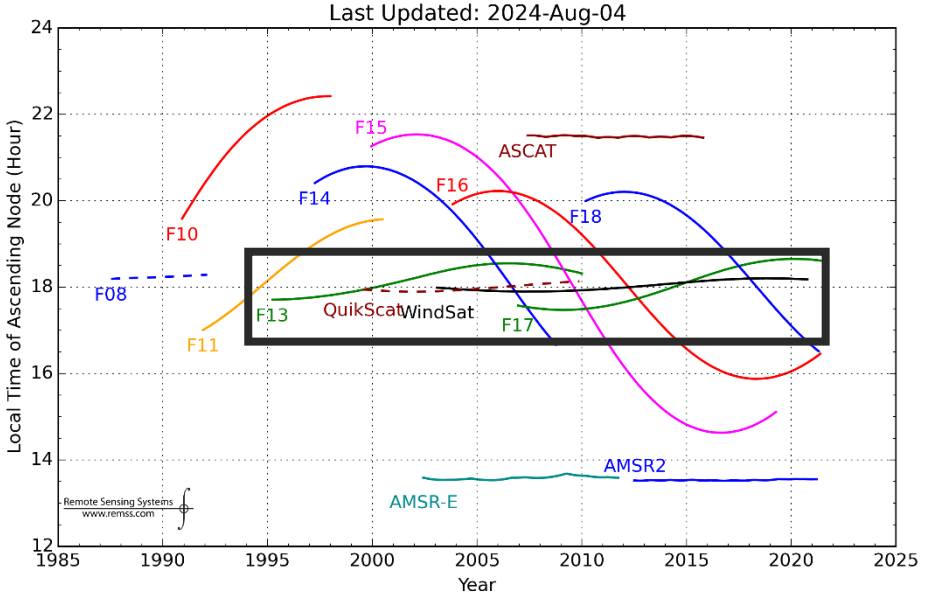
Use of *Any* Satellite Data in Climate Studies

Some of the things you need to bear in mind…

Instability: Orbital Drift (1)



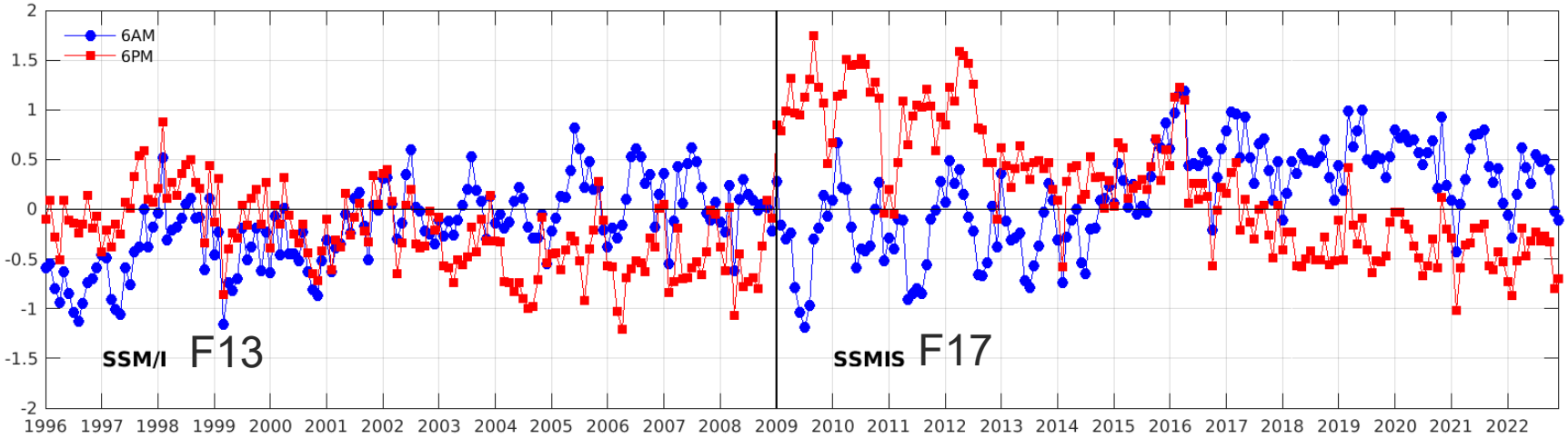


- Orbits take ~100 minutes -> approximately 14 orbits per day
- Some satellite overpasses drift with time – critical for some variables with diurnal variability, e.g. LST
- AVHRR – TIROS-N, NOAA-6/8/10
- AVHRR/2 – NOAA-7/9/11/12/13/14
- AVHRR/3 – NOAA-15/16/17/18/19, Metop-A/B/C

Figures source: https://www.remss.com/

Instability: Orbital Drift (2)

- Pseudo-global (Antarctica excluded) interannual monthly anomaly, time correction not applied.
- Note example is for microwave LST but the principle is the same for thermal data from different satellites
- LST has a strong diurnal and seasonal cycle



Figures source: Carlos Jiménez, Estellus

Instability: Orbital Drift (3)

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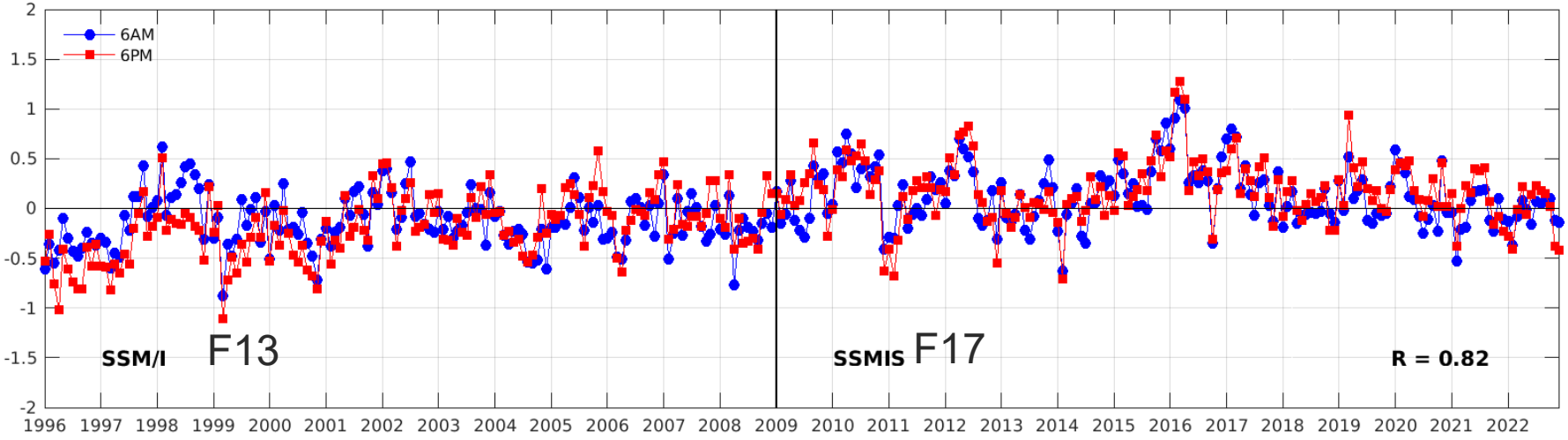
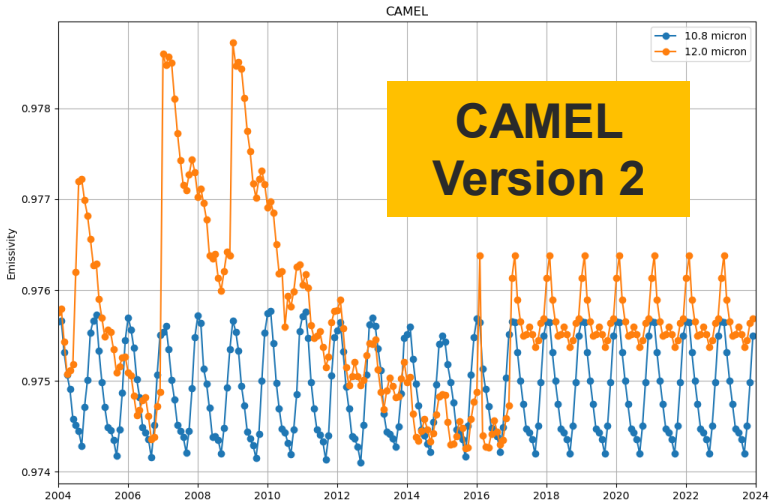
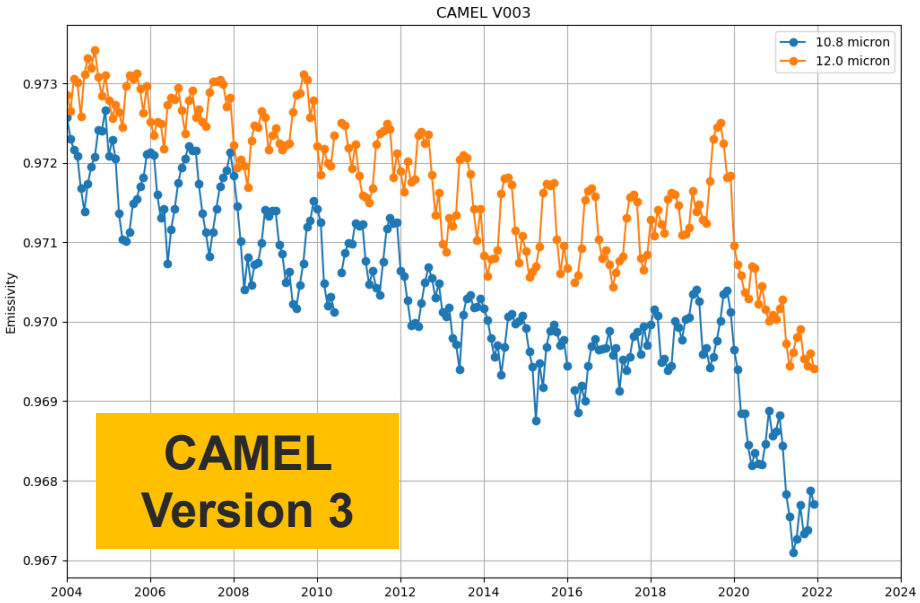


Figures source: Carlos Jiménez, Estellus

Instability: Input Data (1)





- Instability can also result from the input data used in retrievals
- **C**ombined **A**STER and **M**ODIS **E**missivity database over **L**and (CAMEL) – widely used!
- Produced by U. Wisconsin + NASA JPL
- Analysis shows global time series of data are not stable

Figure source: Sofia Ermida, IPMA

Instability: Input Data (2)

- Instability propagates through to LST time series
- Plot shows MODIS/Aqua minus ERA5 skin temperature =>Unstable LST
- However, note ERA5 is also likely to have some **non-climatic discontinuities**

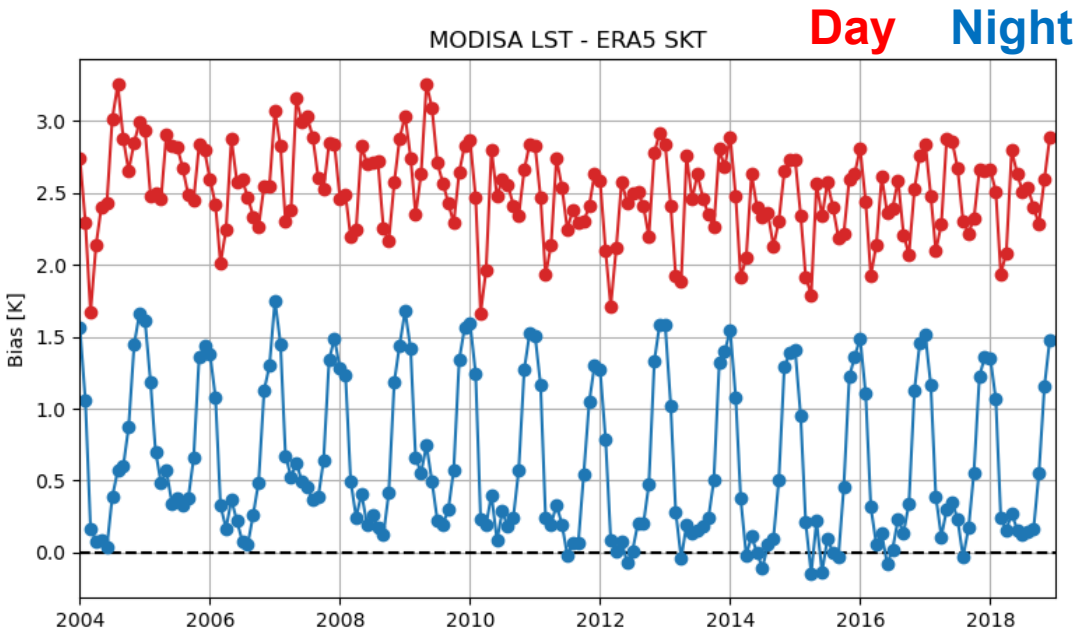
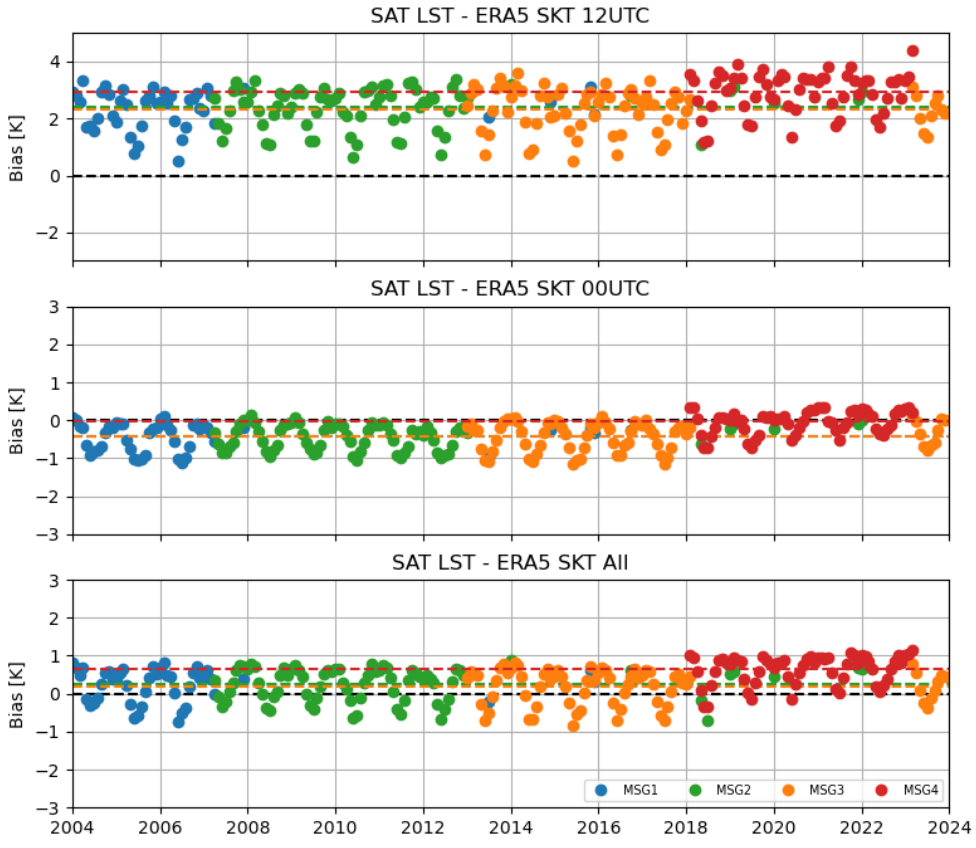


Figure source: Sofia Ermida, IPMA

Instability: Change of Sensor



Plot shows the LST differences between the MSG series produced for LST_cci and ERA5 (monthly averages)

Discontinuities between sensors are evident

Dashed line is the average of the all series to show the overall offset

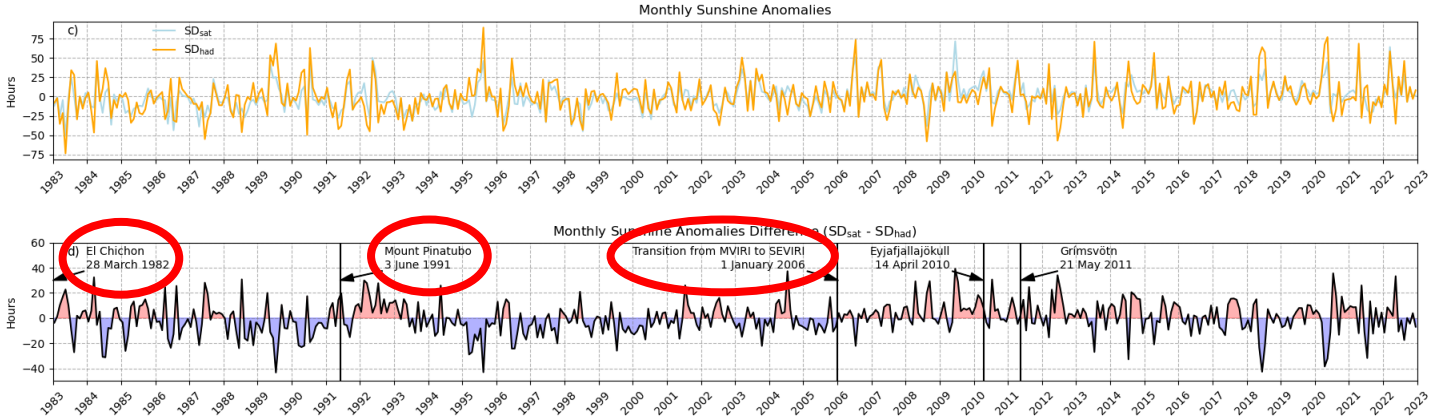
Important to note that ERA5 is not free from discontinuities! However, it can still be a useful test.

Figure source: Sofia Ermida, IPMA

Instability: Retrieval/Observational Errors

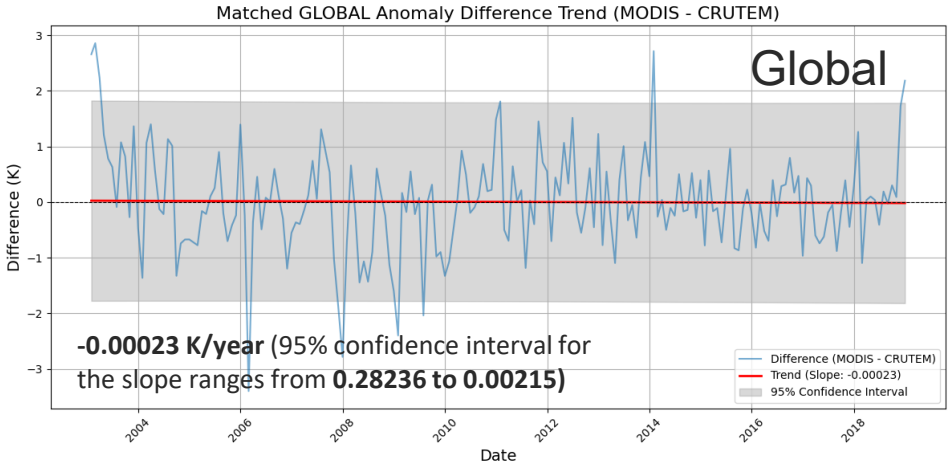
Satellite & HadUK anomalies

Satellite – HadUK anomalies

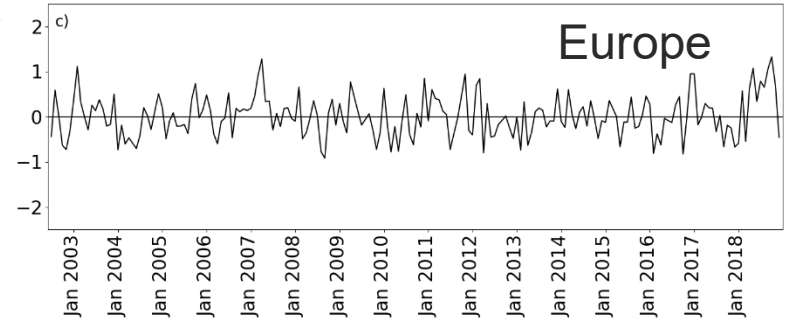


- Example shown for sunshine duration but the principle applies to any satellite retrievals
- Comparison here is for satellite vs gridded station over the UK for sunshine duration
- Some dust affects thermal remote sensing data, e.g. Saharan Dust

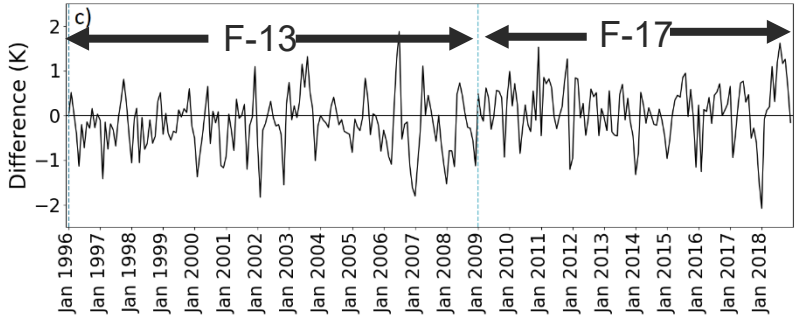
Key Message: Check Stability!!!



LSTnight-Tmin for MODIS/Aqua:
No significant trend 0.03 K/decade (-0.11 – 0.17) = stable



LSTdesc-Tmin for multisensor MW:
Significant trend 0.21 K/decade (0.10 – 0.32) = unstable
(but individual sensors are stable!)



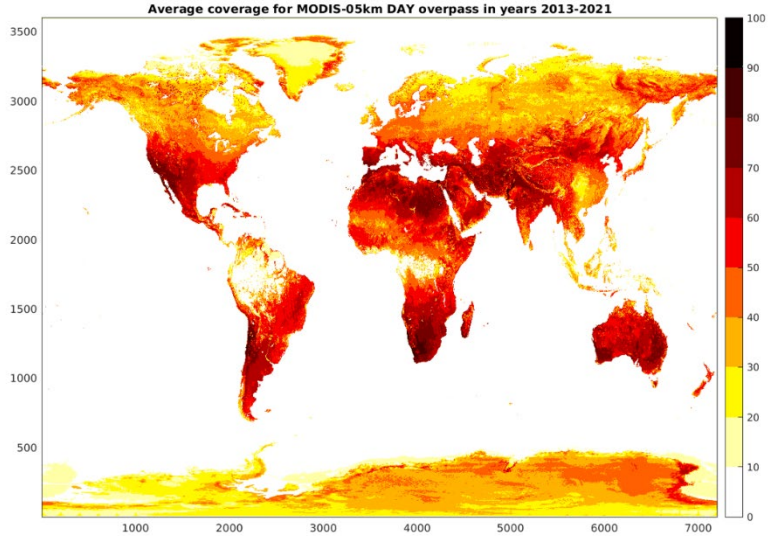
- Check the **stability of the dataset is sufficient for your application** if you are doing any time series analysis!
- Compare with other datasets: reference homogenised datasets are preferable, e.g. CRUTEM, homogenised daily station T2m data, etc. However, even ERA5 or other datasets can be useful.

Figure source above: Abi Waring, U. Leicester

Good, E. J., Aldred, F. M., Ghent, D. J., Veal, K. L., & 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

Consider the Observational Coverage

- Be aware that coverage is not 100%
- Gaps between swaths for all sensors (especially at lower latitudes)
- Gaps for applications that require clear sky



Figures source: Carlos Jiménez, Estellus

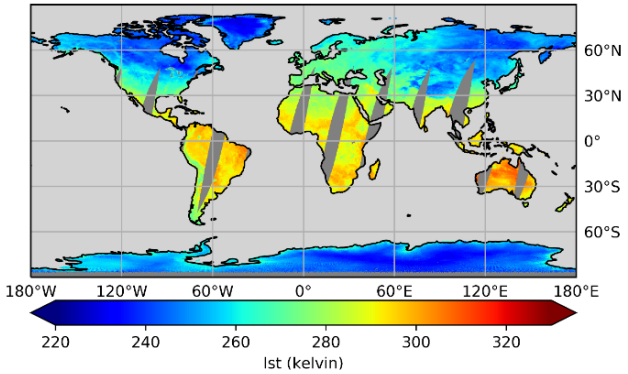


Figure 10: Example of SSMI_SSMIS_L3C daily ascending data. This product collates several orbits in each file.

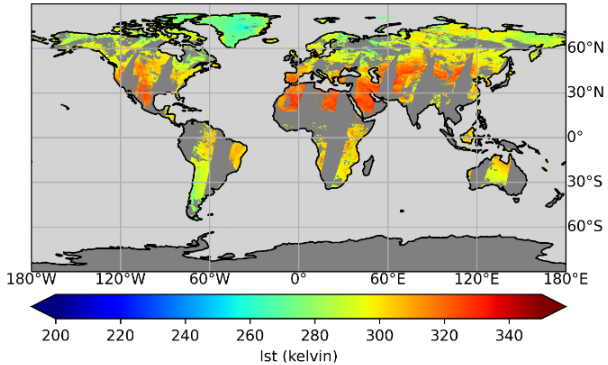


Figure 5: Example of SENTINEL3A_SLSTR_L3C_0.01 daily daytime data for 3rd August 2019. This product collates several orbits in each file. Cloud masking has been applied to this data.

Figures source: LST_cci PUG

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Concluding Remarks

- Satellite LST can be used for many applications
  - Can be used for vegetation health, water stress, monitoring surface temperatures (including urban vs rural & extremes), heat stress metrics, model evaluation, (potentially) attribution studies, …
- LST is not the same as T2m
  - Can be large differences that vary temporally so very difficult to predict T2m from LST
  - Anomalies seem to be well correlated – this is very valuable
- When using any satellite data for climate applications, you must consider the stability if this is relevant for your application (usually it is for climate)
  - Non-climatic discontinuities may result from merging different instruments, input data, satellite overpass time, calibration drift, retrieval errors, …
  - Verifying the stability (and accuracy) of your data should ***always*** be step 1!
  - Also bear in mind there are gaps in the majority of satellite records which may affect your results.