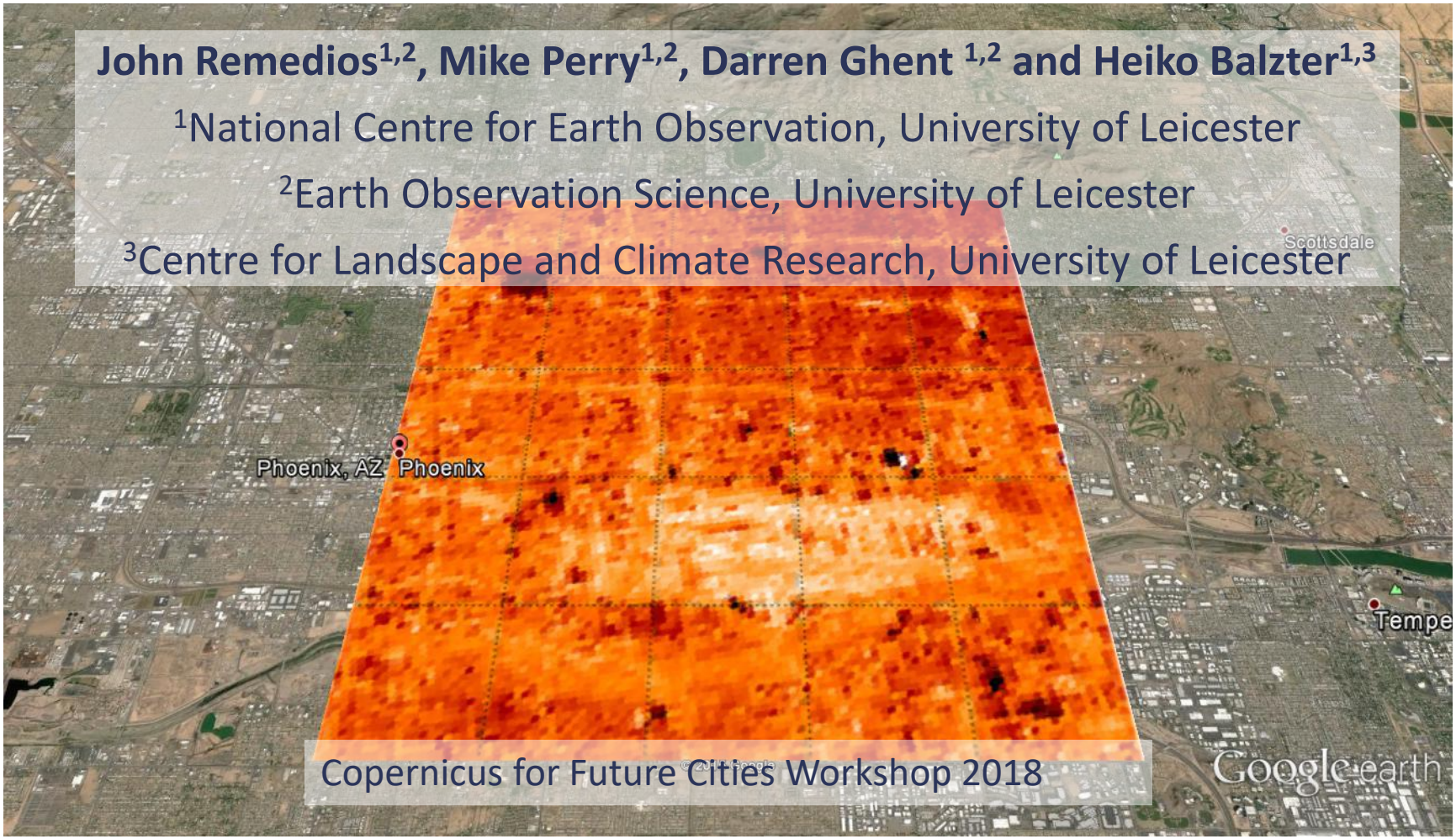
Observing changes in the urban thermal environment from space



John Remedios[1,2], Mike Perry[1,2], Darren Ghent [1,2] and Heiko Balzter[1,3]

[1]National Centre for Earth Observation, University of Leicester

[2]Earth Observation Science, University of Leicester

[3]Centre for Landscape and Climate Research, University of Leicester

Copernicus for Future Cities Workshop 2018

Introduction

- Temperature is a fundamental quantity impacting urban living and productivity, addressing the health and sustainability of city life
- Areas of high relevance:
  - Citizen health and comfort
  - Urban monitoring (sprawl, typology, density, heat stress)
  - Urban policy, planning and living
  - Urban microclimate
  - Climate adaptation and resilience
  - Built environment optimisation, materials, performance and legislation
- The monitoring and assessment of the thermal environment requires spatial resolution that so far has precluded air temperatures from being a viable parameter in most cities.
- In addition, land surface emissivity provides further information on surface properties adding to that available from other sensors.

Mike Perry | mp317@le.ac.uk | NCEO University of Leicester

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

NERC SCIENCE OF THE ENVIRONMENT

A HIERARCHY OF LST OBSERVATIONS

SCALES	MISSIONS	CALIBRATION	ACCURACY
5km, “fast” (15 mins+)	MSG, GOES, HIMAWARI…	Good to medium	Very good to moderate
1 km (re-visit dependent)	Sentinel-3, Terra/Aqua, JPSS	Excellent to very good	Very good to good
100 m	Landsat, ASTER	Next slide	Next slide

User needs are not met with sufficient accuracy and sufficient coverage

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

NERC SCIENCE OF THE ENVIRONMENT

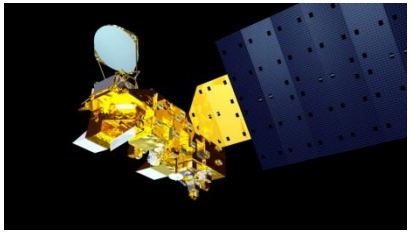
HI-SPATIAL RES INSTRUMENTATION

LANDSAT-8

- Two channels I thermal infra-red
- 100 m spatial resolution (30 m re-sampled)
- **16 day revisit**
- Poor calibration and stray light relative to medium resolution sensors. Ttwo channel retrievals not used
- Only allows retrievals of LST and not emissivity
- **Accuracies of 2 K at best** but on case by case
- **Semi-operational**

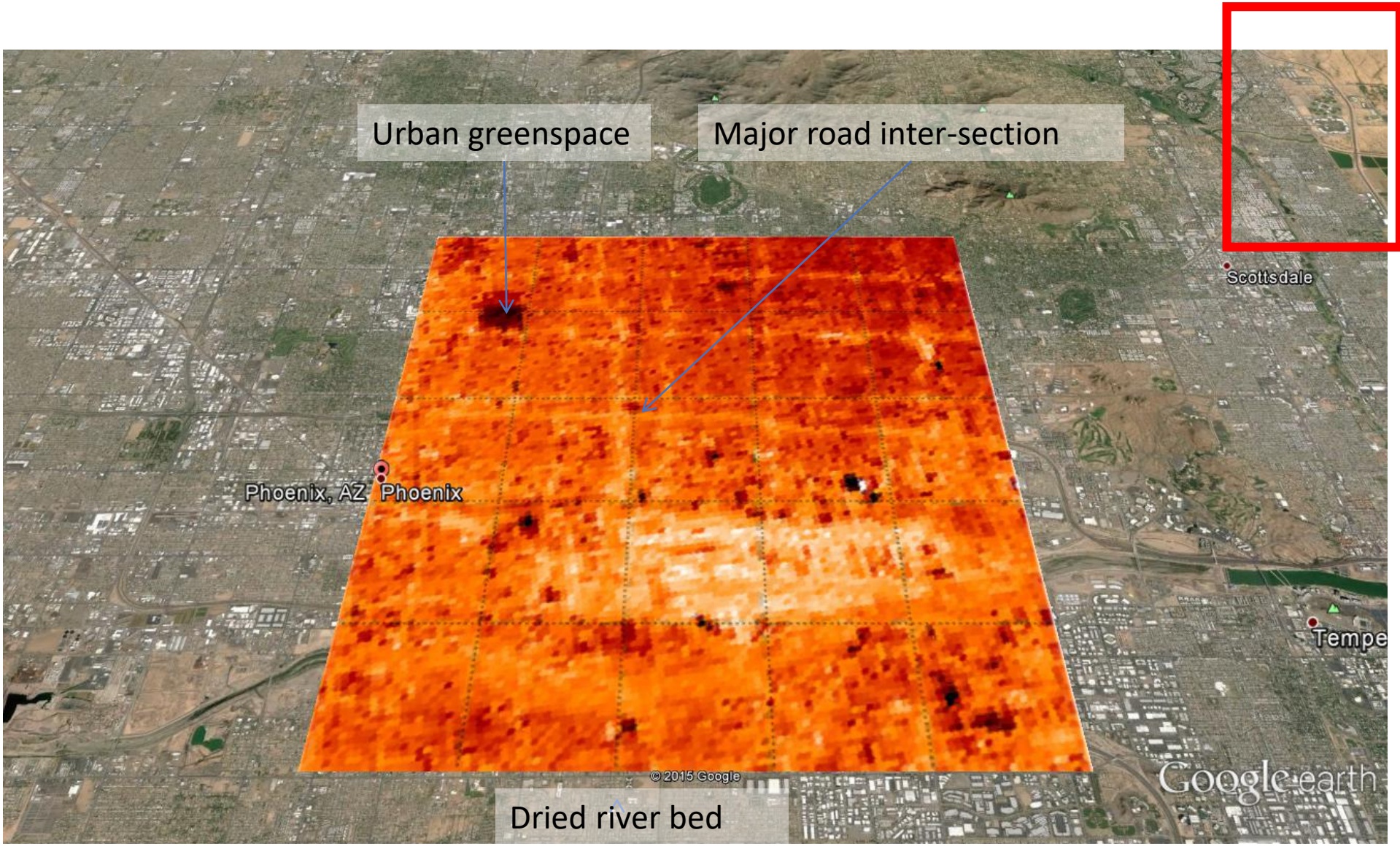
ASTER

- 5 channels in thermal infra-red
- 90 m spatial resolution
- **Tasking only** so sporadic coverage
- Relatively poor calibration
- Allows retrieval of both LST and emissivity (LST to ~1 K)
- **Non-operational and non-standard re-visit**

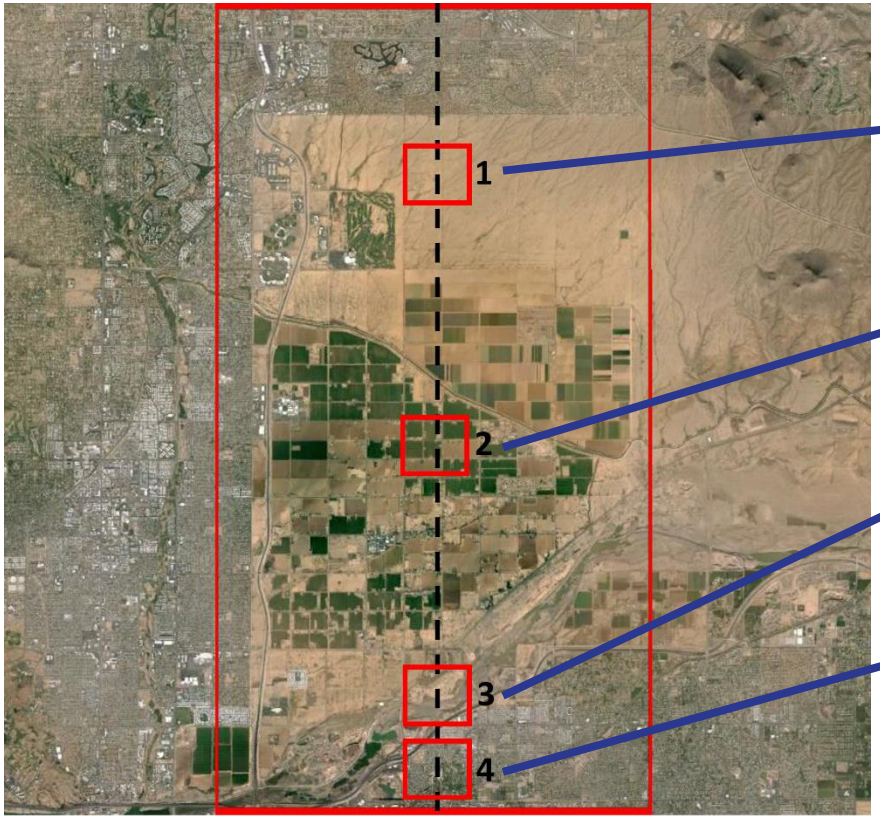


User needs are not met with sufficient accuracy and sufficient coverage

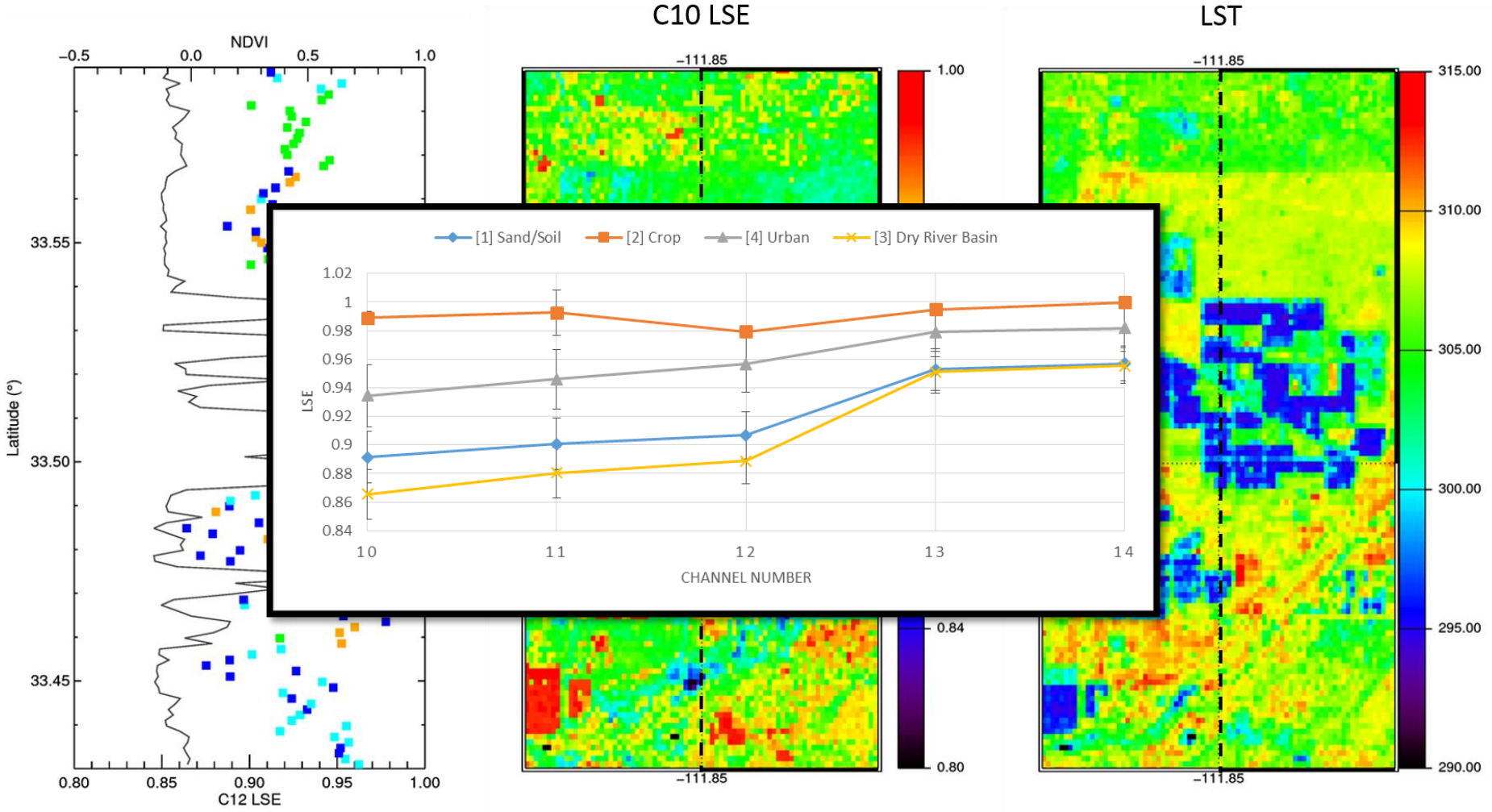
LST AND LSE WITH ASTER



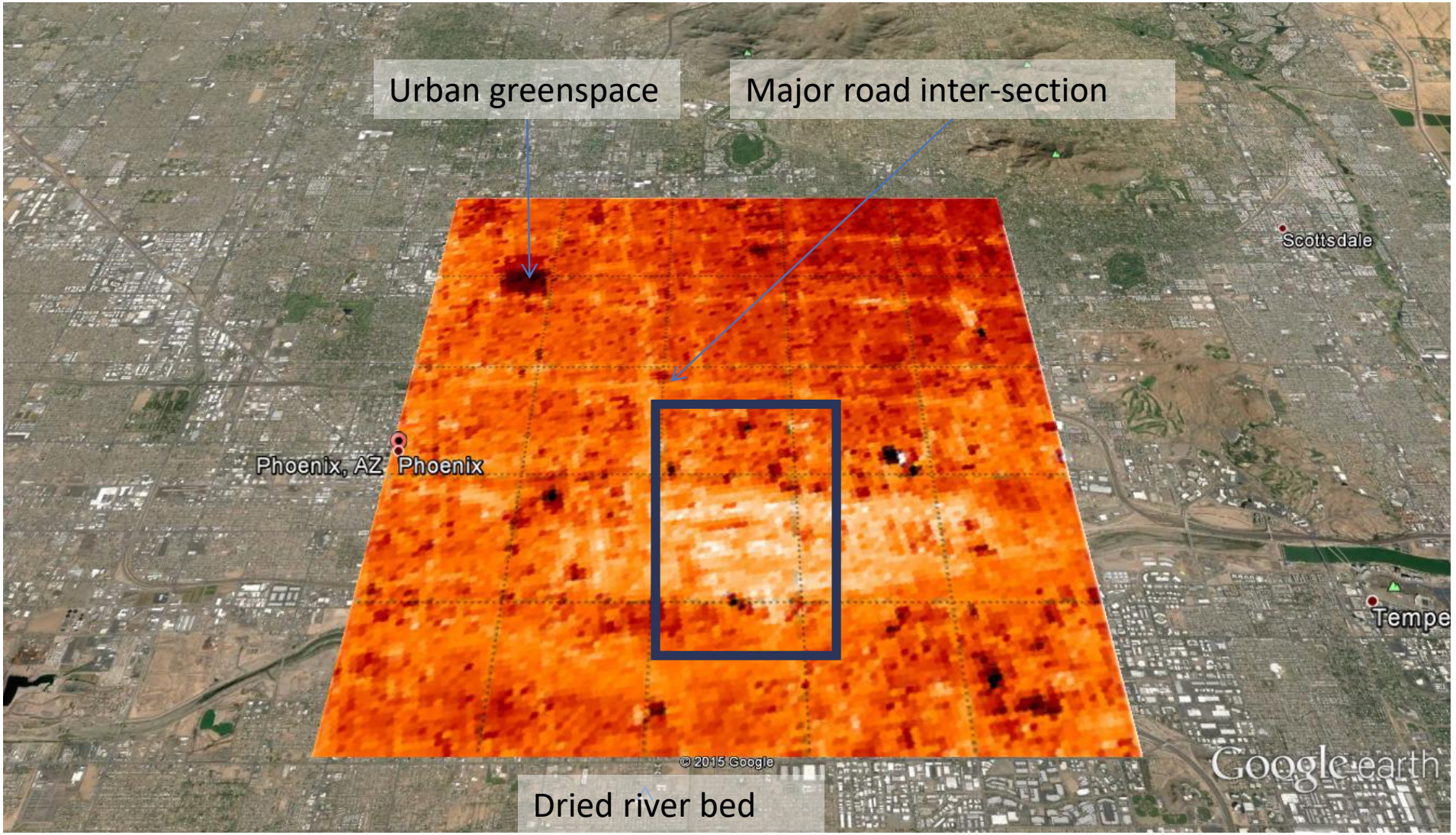
AGRICULTURE: PHOENIX



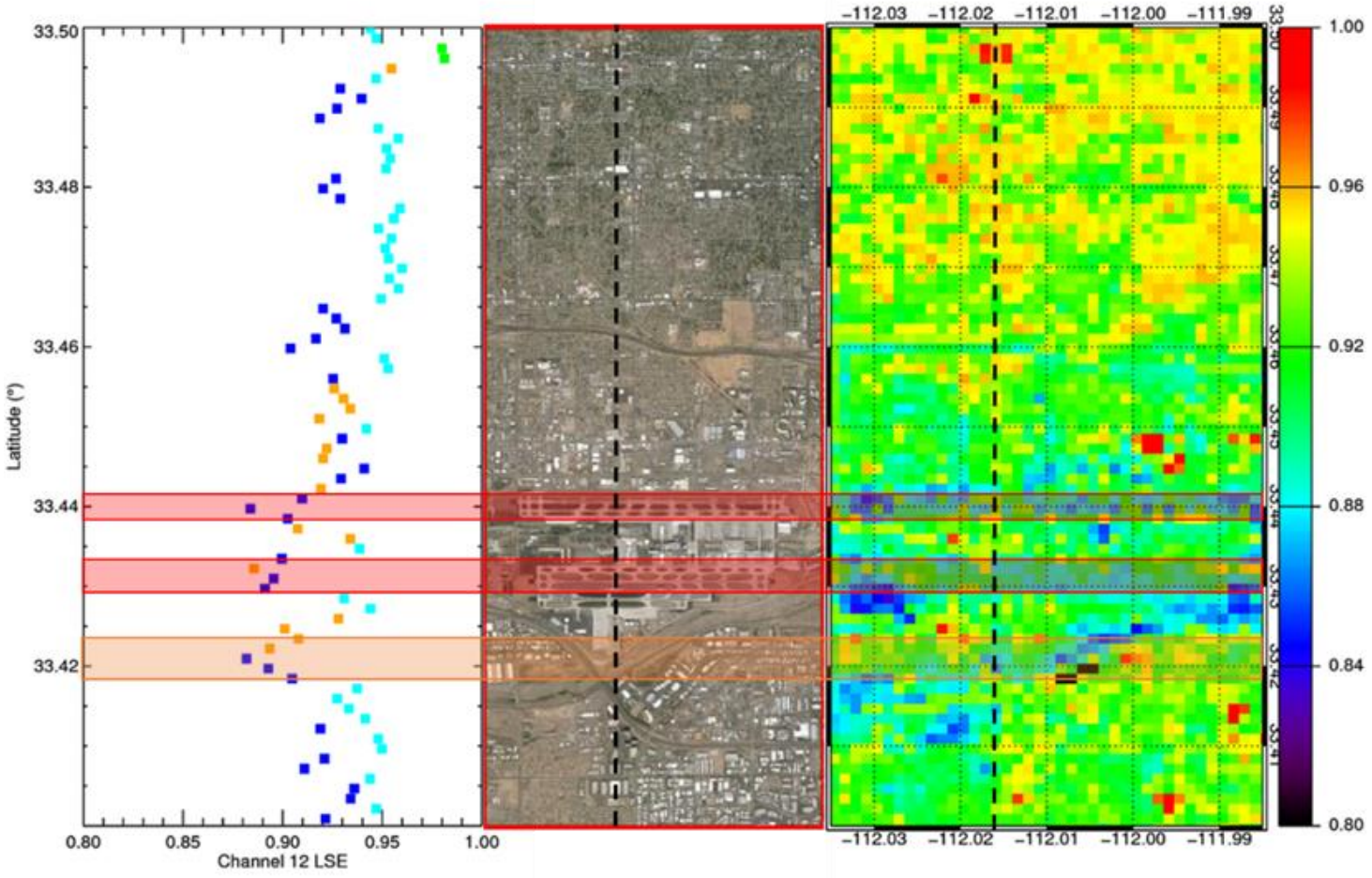
AGRICULTURE: PHOENIX



LST AND LSE WITH ASTER

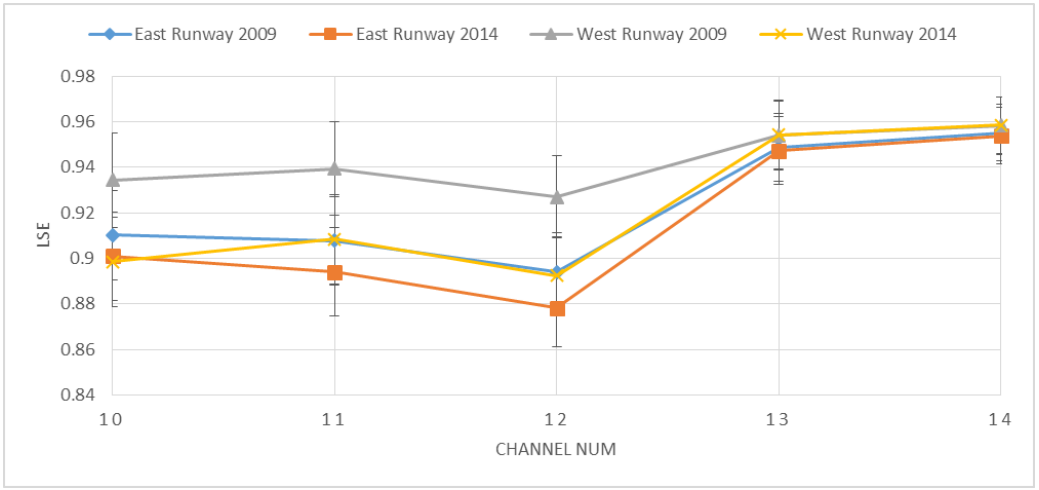


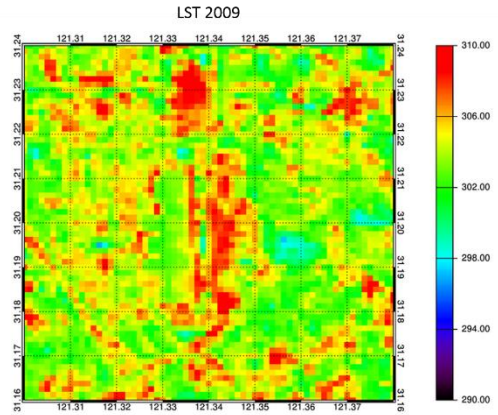
Urban and Natural Impervious: PHOENIX

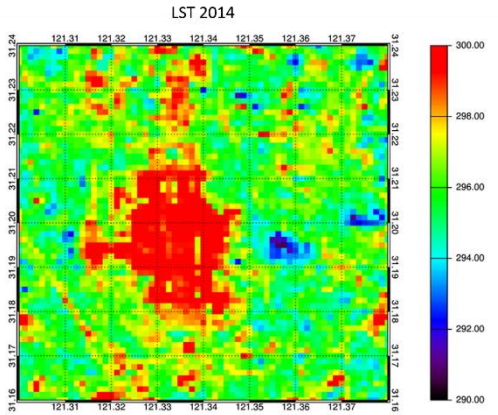


AIRPORT EXPANSION: SHANGHAI

Monitoring the LST and LSE change during the extension of Hongqiao Airport in Shanghai







National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

Urban Energy Balance

Satellite thermal remote sensing data is already being used to assess the Urban Energy Budget.

Knowledge of the land surface type combined with the Land Surface Temperature enables the calculation of the longwave fluxes and estimates of anthropogenic heat contributions

Right: A Study over Fuzhou, China by Zhang et.al. 2013 *

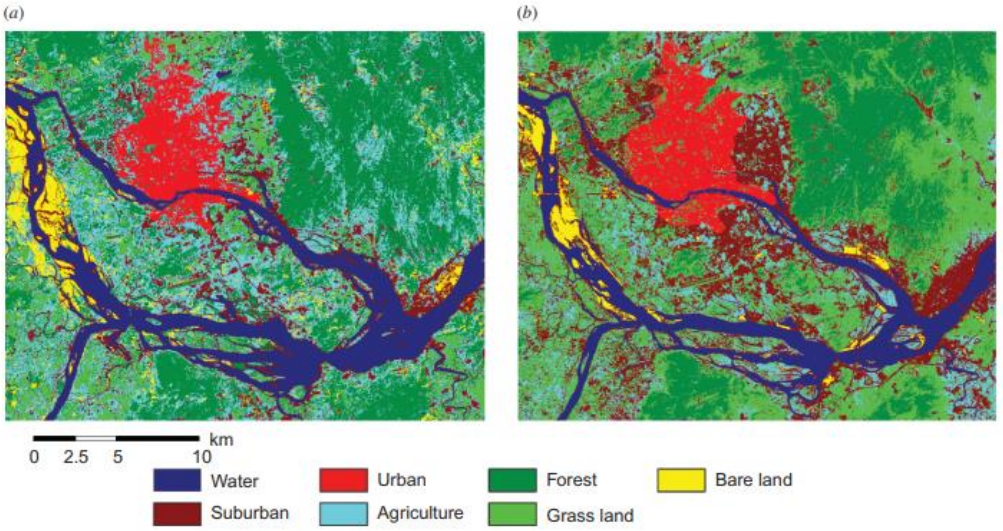


Figure 2. Land-cover types of the study area derived from the TM image acquired in 1989 (*a*) and ETM+ image acquired in 2001 (*b*).

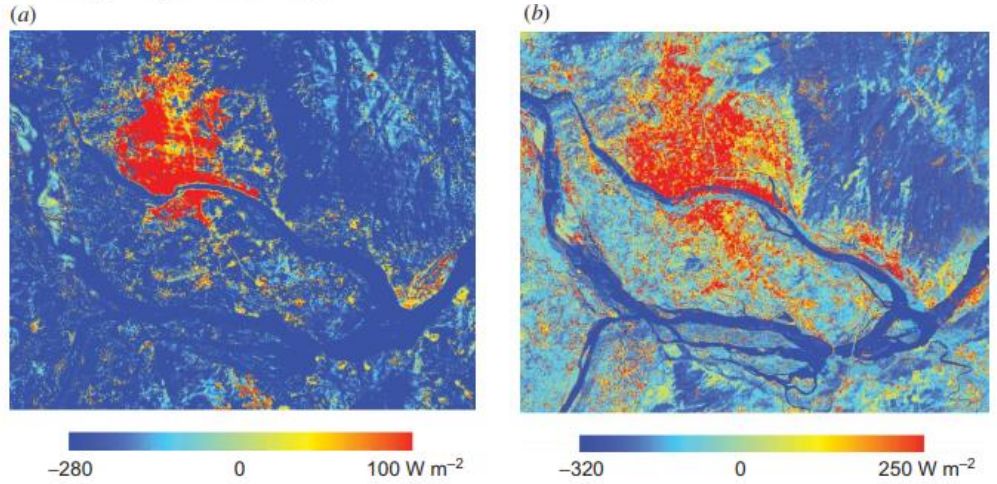


Figure 5. Anthropogenic heat discharge from sensible heat flux on (*a*) 15 June 1989 and (*b*) 4 March 2001.

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

* Youshui Zhang , Heiko Balzter & Xiongchang Wu (2013) Spatial–temporal patterns of urban anthropogenic heat discharge in Fuzhou, China, observed from sensible heat flux using Landsat TM/ETM+ data, International Journal of Remote Sensing

NERC SCIENCE OF THE ENVIRONMENT

Urban Heat Island Studies

LST has strong correlations with several key urban parameters.

Studies have been able to assess the spatial variability of the Urban Environment for different LULC regions.

Right: Study on the Urban Cool Island in Erbil, Rasul et.al. 2015 *

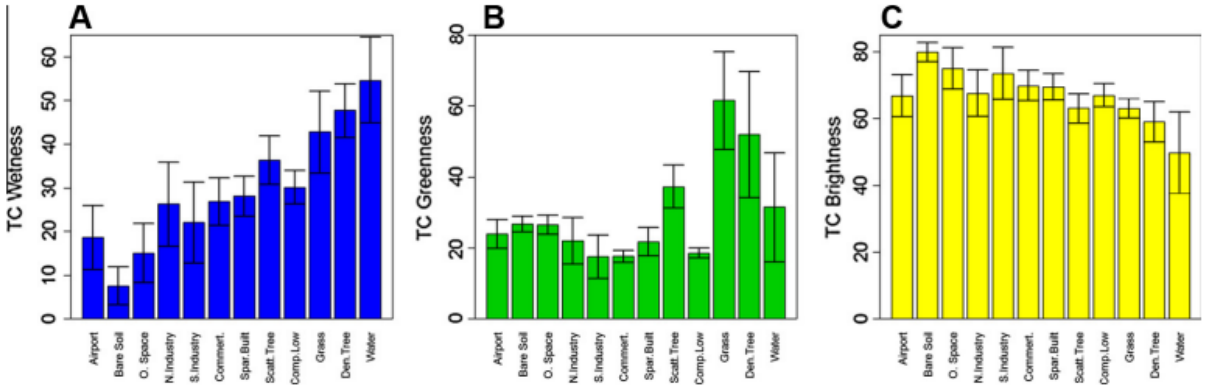


Fig. 4. Mean wetness, greenness and brightness for each LULC class during summer 2013.

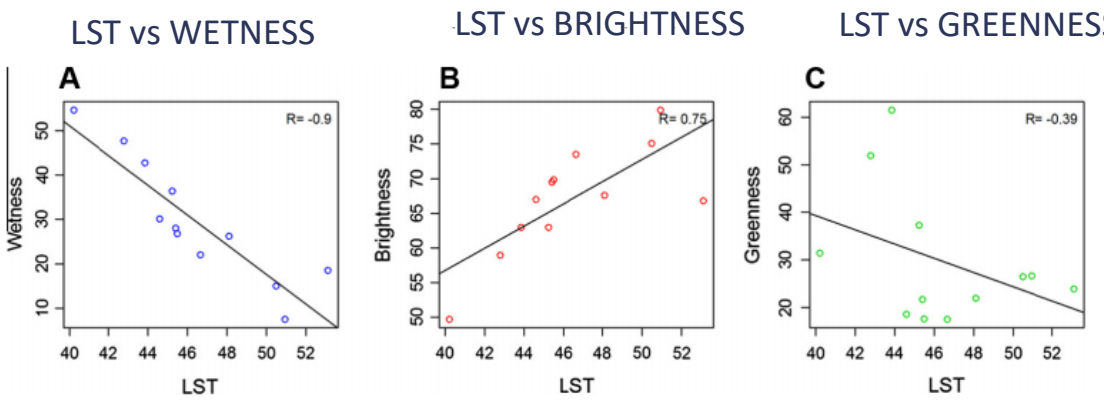


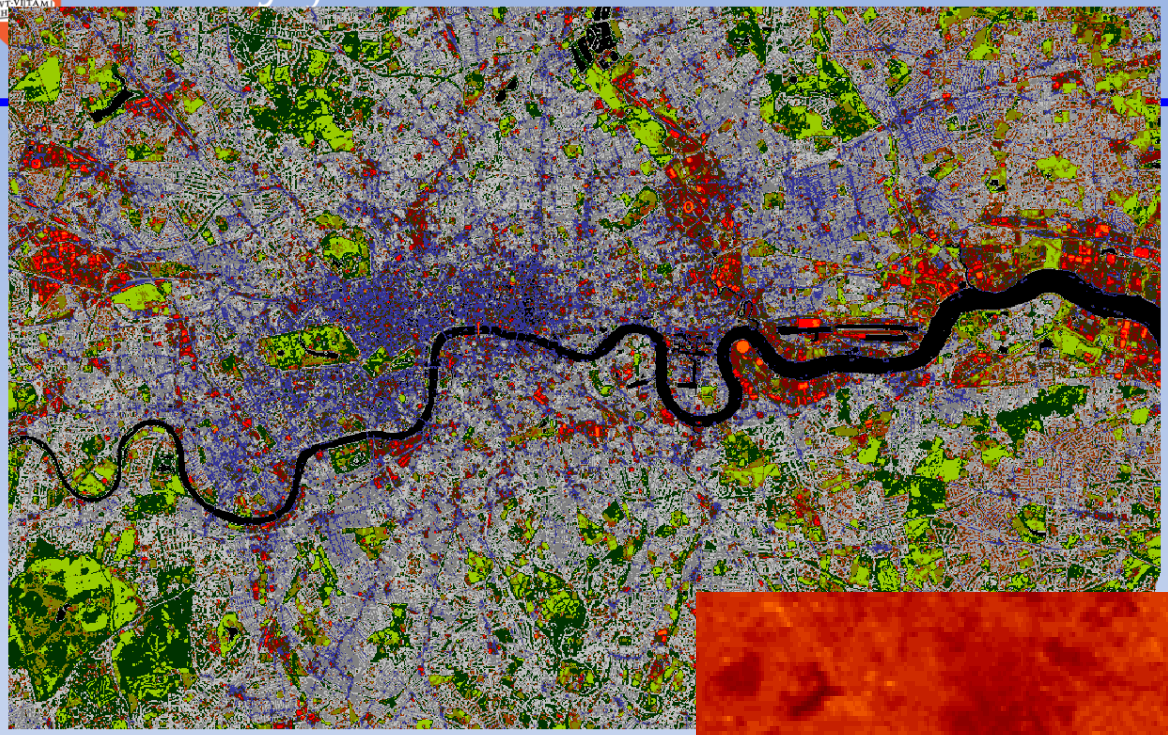
Fig. 5. Correlation coefficient between LST and wetness, brightness and greenness during summer 2013. Each plot represents a class of LULC.

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

* Azad Rasul , Heiko Balzter, Claire Smith (2015) Spatial variation of the daytime Surface Urban Cool Island during the dry season in Erbil, Iraqi Kurdistan, from Landsat 8, Urban Climate

NERC SCIENCE OF THE ENVIRONMENT

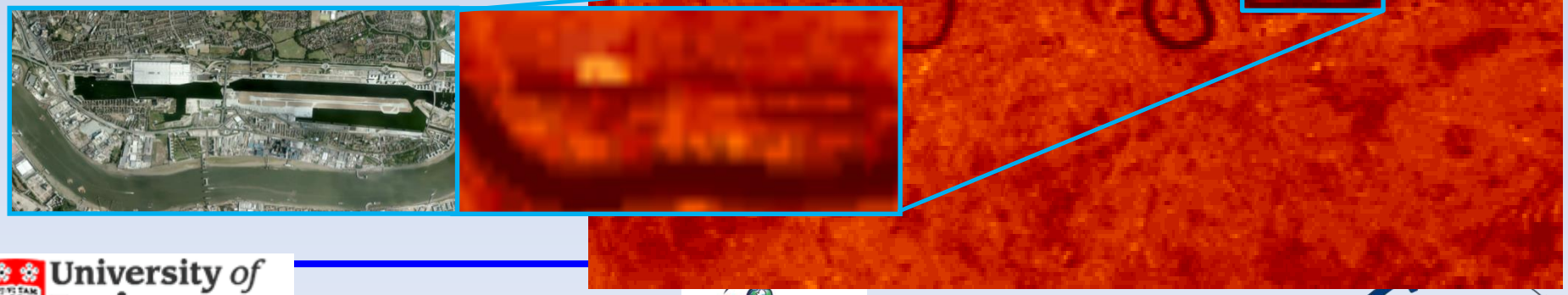
LONDON; M. Perry



Land classification over central London using k-means cluster analysis of 9 LANDSAT 8 channels. Capable of 30m resolution.

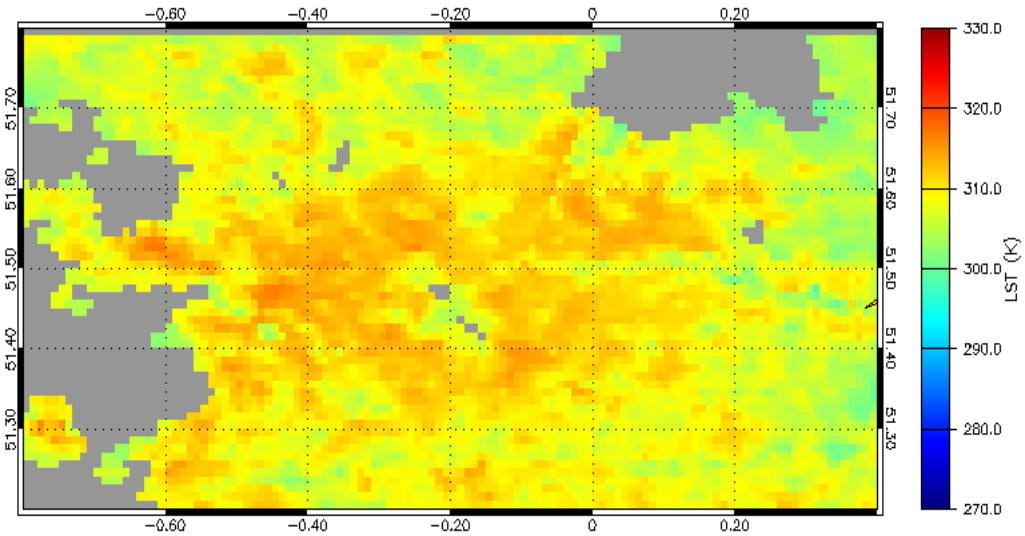
Greens – parks/trees,
Reds – more industrial,
Purple – dense urban/commercial,
Greys - represent different densities of urban/ residential cover.
Black - water

Surface temperature plot over central London using LANDSAT 7 thermal data 90m resolution. LST accuracy limited by a lack of high resolution urban emissivity data.



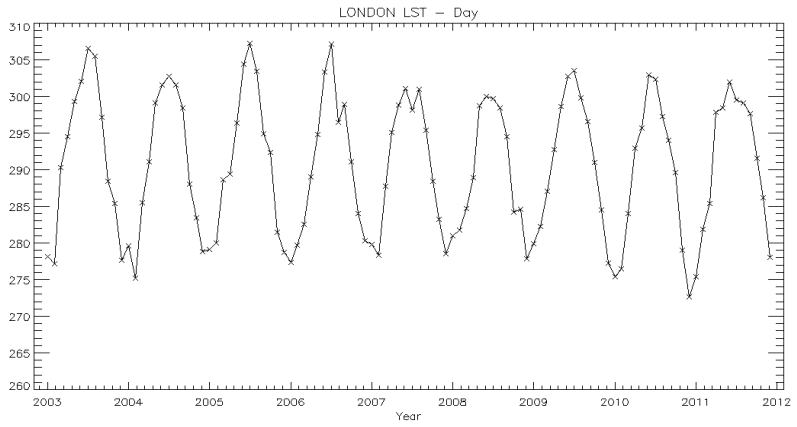
AATSR: London time series

AATSR Thermal imagery



Medium spatial resolution ~ 1km, with twice daily temporal sampling.

AATSR Temperature time-series



The temperature maps allow insight into a spatial snapshot of the highest risk areas as well as a detailed and accurate temporal progression of temperatures for the whole of London, giving an understanding of events such as heat waves on the city and the potential precursors of these spikes. Understanding these factors would allow steps to be taken which could potentially reduce the effect of heat related health hazards.

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

NERC SCIENCE OF THE ENVIRONMENT

Application Review

Domain	Application
Volcanoes and Earthquakes	Eruption clouds
	Tropospheric plumes
	Hot spots and active lava flows
	Post eruptive studies on lava flows
	Detection of Earthquakes
	Pre-eruptive detection for volcanoes
Fires	Detection of fires
	Estimation of burnt area
	Estimation of fire intensity and severity
	Detection of coal mine fires
	Detection of potential coal fires
Hydrology	Detection of water stress in crops
	Detection of water stress in forest
	Detection of evapotranspiration in crops
	Detection of evapotranspiration in River Basin
	Detection of evapotranspiration in continents
	Growing Degree Day estimations
	Growing Degree Day mapping
	Cooling Degree Day estimations
	Prediction of floods
	Monitoring of floods
	Mapping irrigated land

Domain	Application
Urbanisation	UHI: Surface temperature maps
	UHI: Vegetation maps
	UHI: Land cover/Land Use
	UHI: Building Information
	UHI: Air Quality
	Air pollution
	Differentiate between urban and industrial zone
	Oil spill detection
	Plume detection
	Mapping malaria potential regions
	Arthropod vector ecology and disease distribution
	Mapping cholera potential regions
	Mapping meningitis outbreak
	Asbestos-cement detection over non-accessible areas
	Detection of minefields
	Security and surveillance
	Industrial/power plant monitoring
	Trafficability (off-road soil moisture content)
Surface Variability	Soil composition
	Identifying geothermal resources
	Mapping geothermal anomalies
	Mapping dynamic variability of surface temperature

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

NERC SCIENCE OF THE ENVIRONMENT

Application Review - Urbanization

Domain	Level - 2								Level -1	
	Application	Geophysical variable	Spatial resolution	Coverage	Temporal resolution	Uncertainty	Supporting Data	NEdT (@300 K)	Minimum TIR Spectral Resolution	Other Spectral ranges
Urbanization	UHI: Surface temperature maps	LST	<100 m	Global	Weekly (Day/Night)	<1.0 K		<0.2 K	2 bands (10-12 µm)	
	UHI: Vegetation maps	Maps	10-100 m	Local to Regional	Monthly	<1.0 K	Land cover maps	<0.2 K	2 bands (10-12 µm)	Multispectral
	UHI: Land cover / Land Use	Maps	10-100 m	Local to Regional	Monthly	<1.0 K	GIS	<0.2 K	2 bands (10-12 µm)	Multispectral-SAR
	UHI: Building Information	LST	1-10 m	Local	Monthly	<1.0 K	City maps	<0.2 K	2 bands (10-12 µm)	SAR
	UHI: Air Quality	LST	20 m – 1 km	Local to Regional	Daily- Monthly	<0.5 K	Atmospheric models	<0.1 K	Undefined	UV-VIS
	Air pollution	Radiance	<100 m	Local to Regional	Daily (noon)	<0.5 K		<0.1 K	Hyperspectral (3-15 µm)	
	Differentiate between urban and industrial zone	Storage heat flux	100 m	Local	Sub-Daily	<2.0 K	Met data + surface roughness	<0.4 K	Multispectral (≥3 bands in 8-12 µm)	VNIR
	Asbestos-cement detection over non-accessible areas	Radiance + emissivity	3-50 m	Local	Daily to Monthly	<0.01	Mineralogical compositions + in situ measurements	<0.2 K	Hyperspectral (with band at 9.44 µm)	VNIR
	Detection of minefields	LST	1-5 m	Local	Sunrise/Sunset	<0.5 K	Emissivity + Water vapour	<0.1 K	2 bands (10-12 µm)	VNIR
	Security and surveillance	BT	10-15 m	Regional	NRT-Daily	<0.5 K	DEM	<0.05 K	1-channel	VNIR
	Industrial/power plant monitoring	LST	10-15 m	Local	NRT-Daily	<2.0 K	Sonde measurements	<0.4 K	Hyperspectral	VNIR
	Traffic ability (off-road soil moisture content)	LST	100 m	Regional	NRT-Daily	<2.0 K	DEM, reanalysis, emissivity	<0.4 K	2 bands (10-12 µm)	SAR

Conclusions

- Temperature is a critical attribute of city characterisation
- Land surface temperature (LST) are already proving useful in many studies of cities.
- High spatial resolution of sensors are necessary to truly achieve detailed and consistent description of cities:
  - Operational
  - Accurate (calibration, multiple channels for LST and emissivity)
  - 50 m spatial resolution
  - Good re-visit capability
- High spatial resolution sensors need to be linked to 1 km and geostationary sensors to provide an integrated temperature for urban areas.
- Derivation of urban LST and application will need integration with other geospatial data sets and models (energy balance, urban meteorology etc.)

Mike Perry | mp317@le.ac.uk | NCEO University of Leicester