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Modelling Urban Sensible Heat Flux at Multiple Spatial Scales: a Demonstration Using Multi-spectral Imagery and a Temperature-Emissivity Separation Approach

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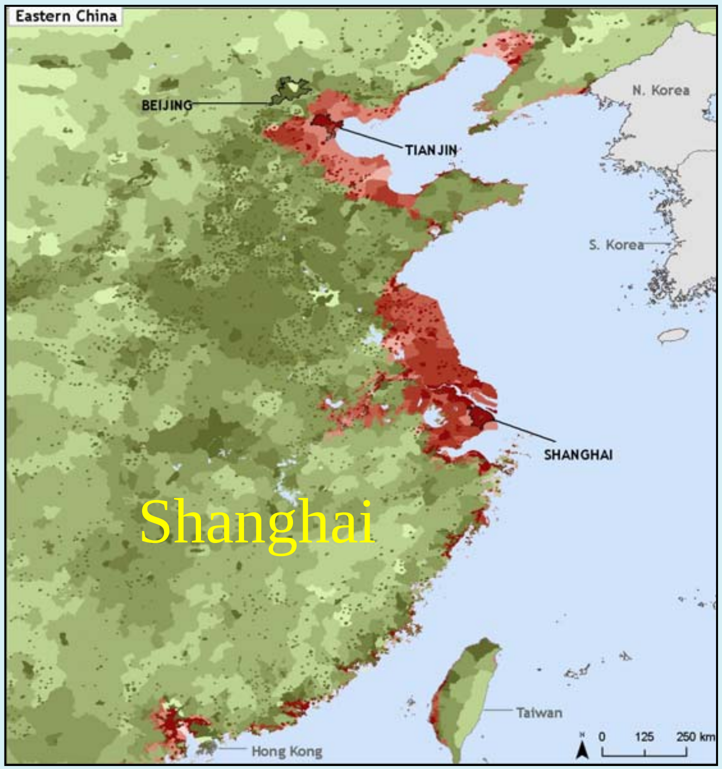
Second Workshop on Earth Observation in Urban Planning and Management:

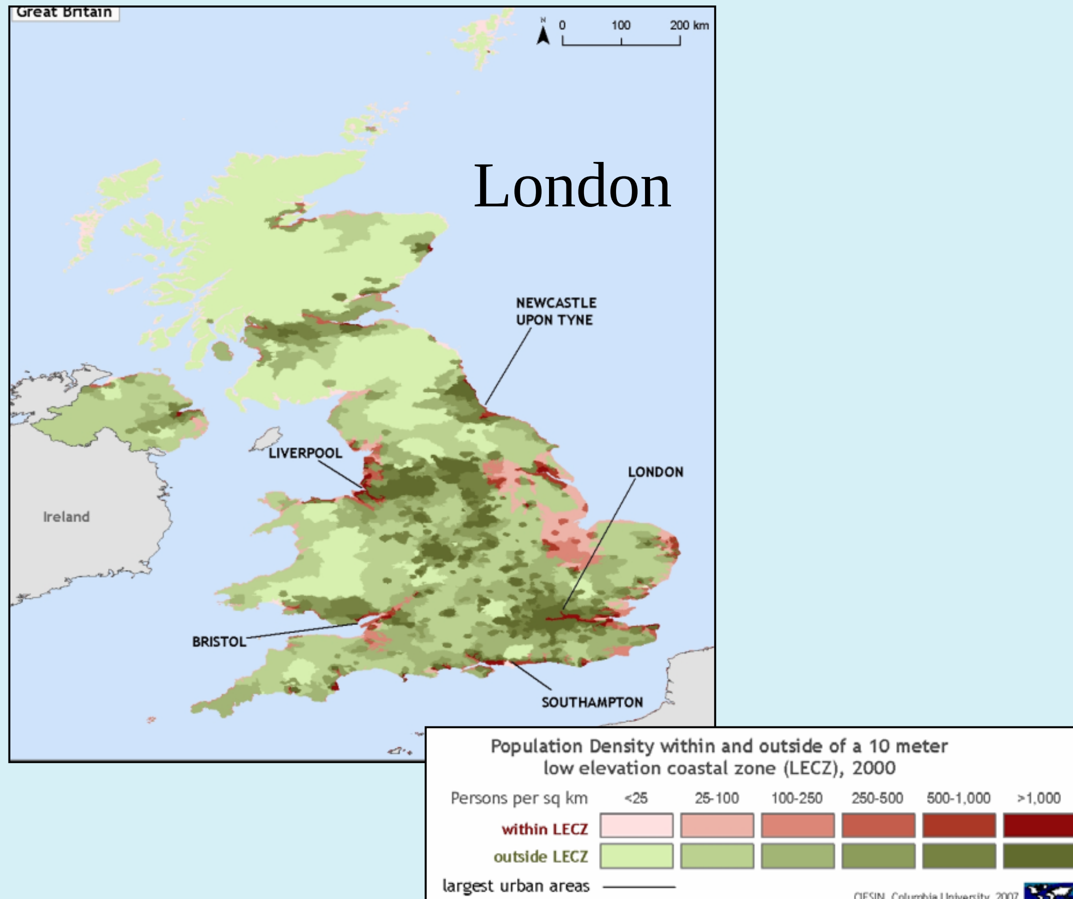
sub-theme Urban Heat Island/ Urban Climatology

The Hong Kong Polytechnic University, Hong Kong

Objective: Urban Energy Balance from Remote Sensing & Modelling

- Main emphasis is on spatial estimates of turbulent sensible heat flux (transfers heat from land surface to atmosphere)
- Using both airborne and spaceborne data (thermal/optical)





Methodology

Remotely Sensed Data Sources

- Airborne Operative Modular Imaging Spectrometer (OMIS)
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
  - One offers more precision and detail, the other more frequent observations.

Sensible Heat Flux Modelled Spatially

- Local-scale Urban Meteorological Parameterization Scheme (LUMPS)

Atmospheric Correction of RS Imagery

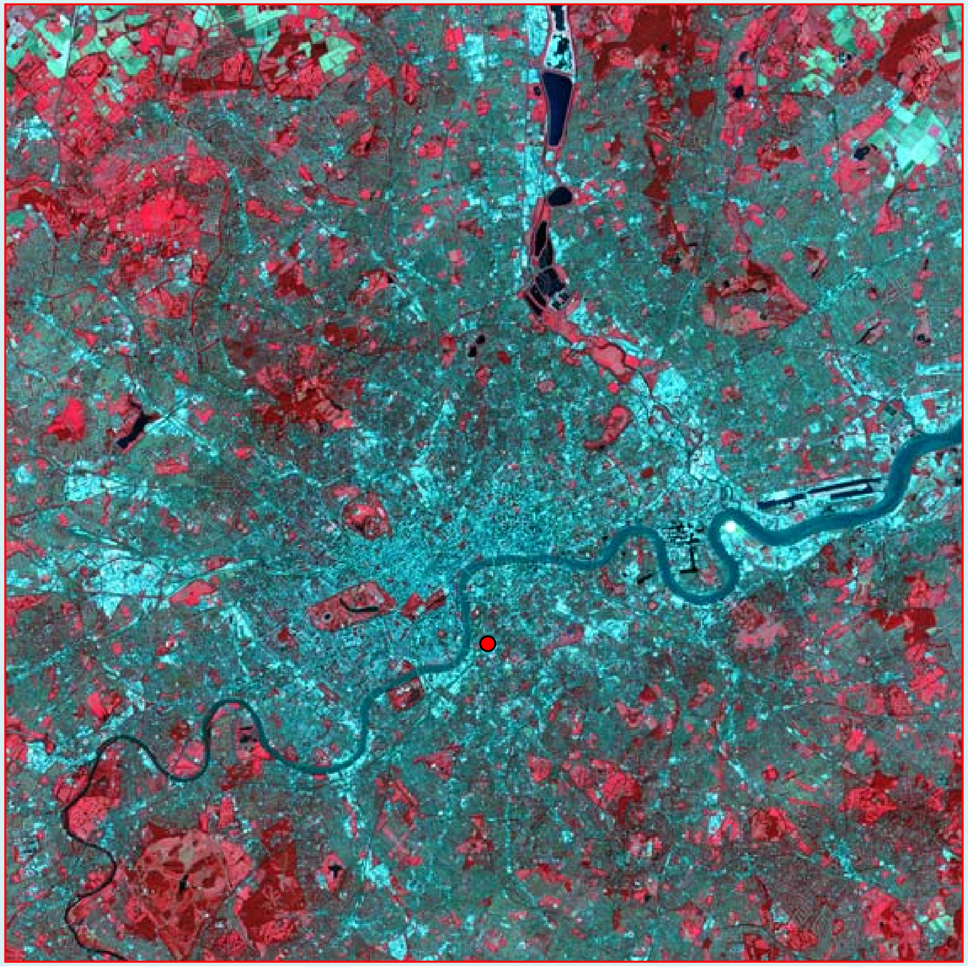
- MODTRAN v4 with atmospheric profile from radiosonde balloons

Surface Kinetic Temperature & Emissivity Determination

- Temperature-emissivity separation (TES) alg. (Gillespie et al., 1998) for ASTER
- Adapted for use with OMIS (different wavebands, more spectral channels)

Test Study Area : London, UK

ASTER Imagery London



- ASTER Spaceborne Data, London
    - 15 m spatial resolution VIS
    - 30 m spatial resolution SWIR
    - 90 m spatial resolution TIR
- Used to test and evaluate our own implementation of ASTER TES alg.
    - to retrieve surface kinetic temp
    - validate against in situ data
- After validation, TES then used on Shanghai OMIS data (more bands)

Measures reflected/emitted radiation at different λ, after passage through atmos. Use Temperature/Emissivity Separation (TES) alg. for surface kinetic temperature

Temperature/Emissivity (TES) Application

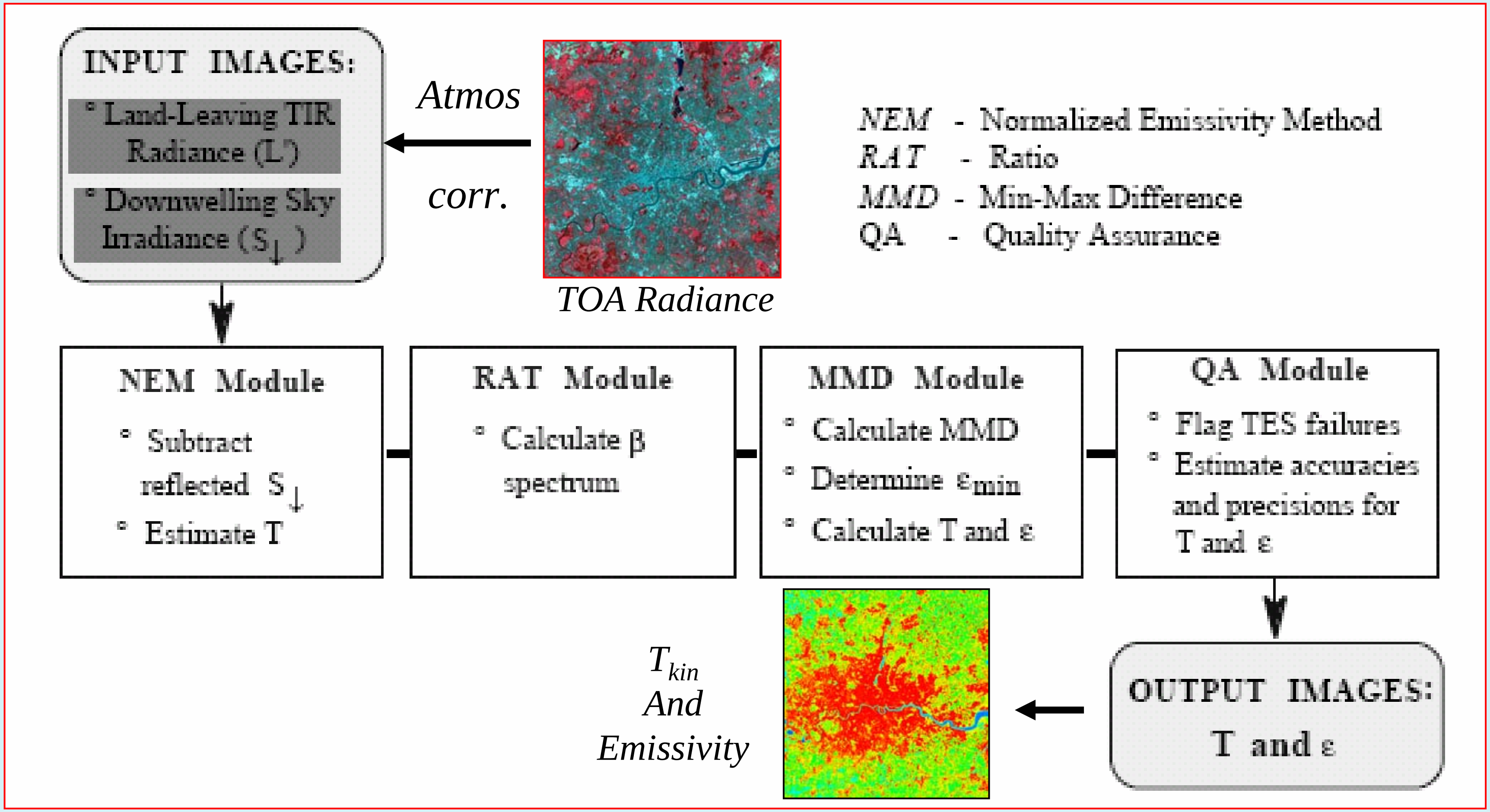
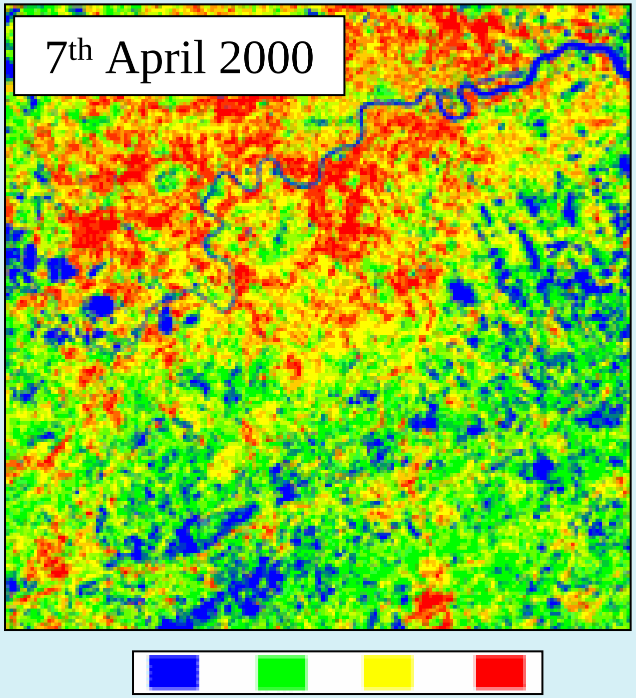
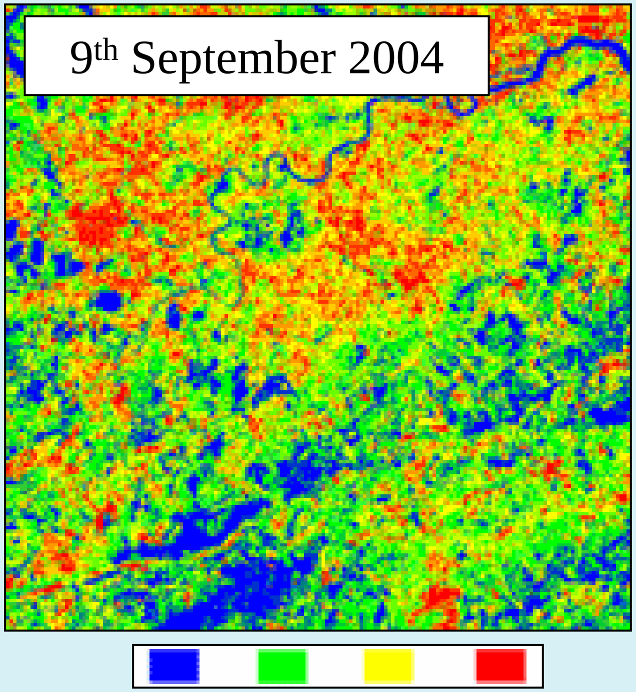


Figure 1. Basic design of the TES algorithm. The NEM module estimates normalized emissivities used to estimate reflected sky irradiance, which is removed iteratively, and then estimates the surface temperature T. T is used in the RATIO module to calculate normalized emissivities, or β values, which measure spectral shape. The MMD module calculates the Min-Max β difference, from which the minimum emissivity ε_{min} is found by empirical regression. The β spectrum is scaled by ε_{min} to give the TES emissivities, from which the surface temperature is calculated. Accuracies and precisions are calculated from data characteristics and measures of TES performance. A more detailed flow diagram is given in Figure 4.

London TES Evaluation in Urban Areas

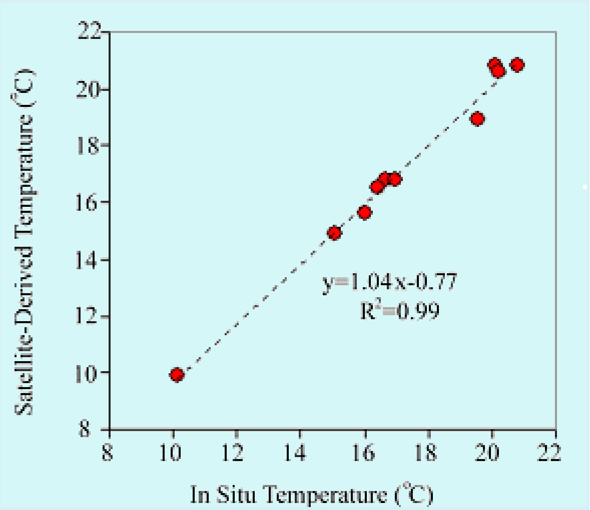
- ASTER imagery obtained at times of Thames water temperature 10 – 21° C
- Adjusted TOA radiances to surface leaving radiance (MODTRAN v4)
- Input into TES algorithm to calculate emissvity and kinetic temperature (T_k)
- T_k estimate compared to simultaneous measures of Thames water temp.





Surface Kinetic Temperature (°C)

TES-derived T_k vs *in situ*



rmse = 0.4 ° C
(bias = 0.1 ° C)

Airborne Sensor: Operative Modular Imaging Spectrometer (OMIS)

OMIS Developed by:

Shanghai Institute of Technical Physics (SITP, Chinese Academy of Sciences

Spectral range (µm)	Spectral Resolution (nm)	Number of Spectral Bands (Total :128)
0.46 - 1.10 (VIS)	10	64
1.06 - 1.70 (NIR)	40	16
2.00 - 2.50 (SWIR)	15	32
3.00 - 5.00 (MIR)	250	8
8.00 - 12.50 (TIR)	500	8
Detector types	Si, InGaAs, InSb and HgCdTe	
FOV	>70°	
Scan rate (Hz)	5-10-15-20 (selectable)	
Across track pixels no.	512	
Signal quantization level	12 bits	

OMIS flown on helicopter to give 6 m pixels (overflight time 14:00 hrs)

Main Study Area: Shanghai, China

2 km x 2 km region of central Shanghai, neighboring the Huangpu River

- OMIS Airborne Data, Shanghai
  - 6 m spatial resolution
  - VIS-SWIR-MIR-TIR
- Used to parameterise LUMPS model

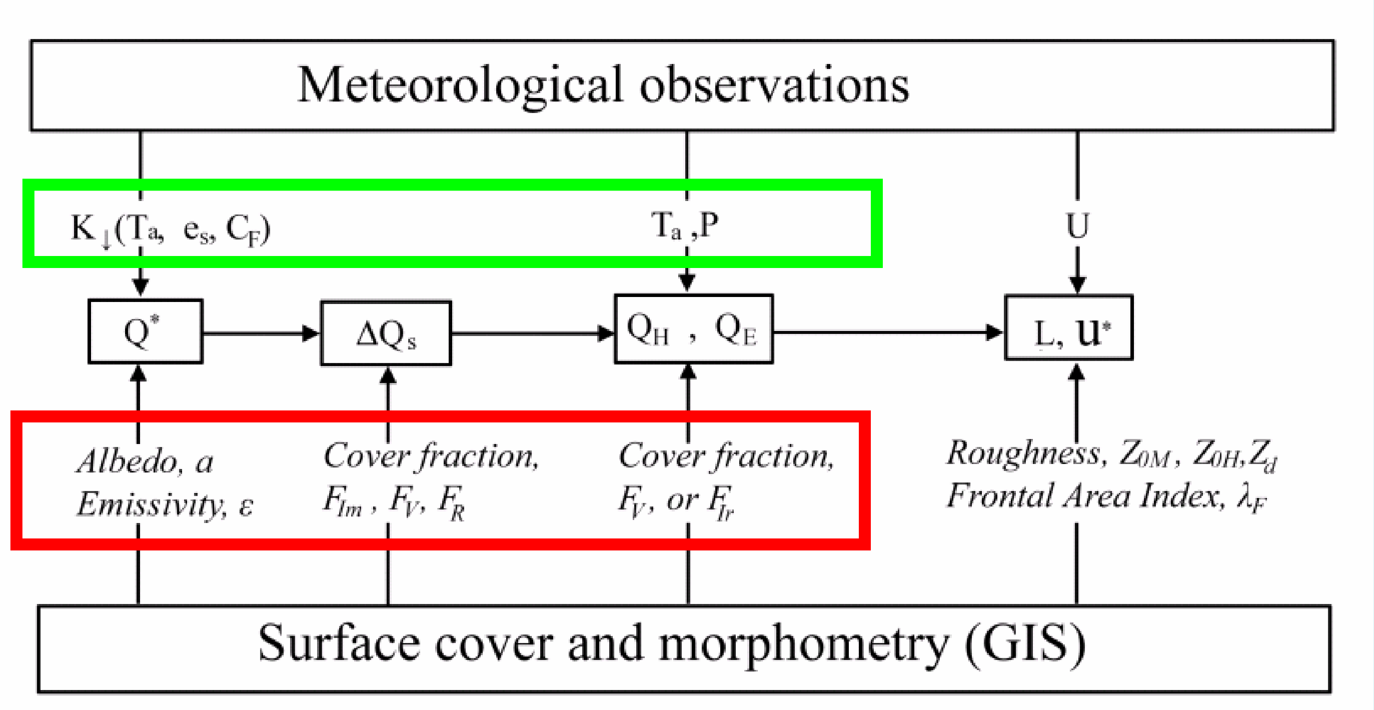
Met station provided air temp., wind speed, and relative humidity (and radiosonde)

Local-scale Urban Meteorological Parameterisation Scheme (LUMPS)

• Calculates ppartitioning of the net all wave radiation (Q*):.

$$Q* + Q_F = Q_H + Q_E + \Delta Q_S$$

net all wave radiation + anthropogenic heat = sensible heat + latent heat + heat storage



Obtained from Met Station

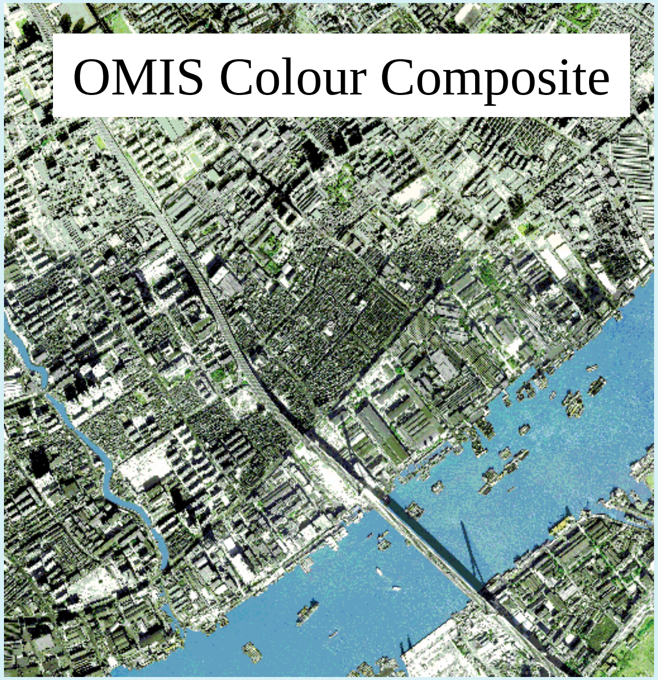
Obtained from RS Data

• LUMPS dependence only on relatively easily identifiable surface characteristics.

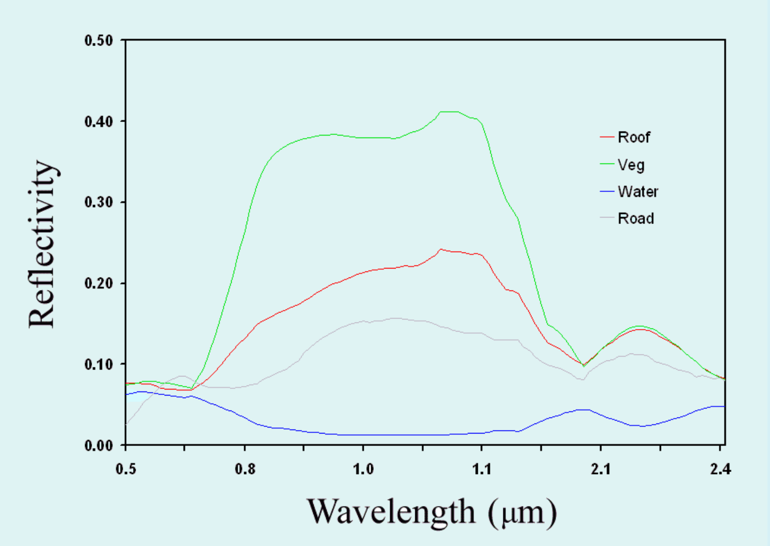
• Believed to offer an acceptable level of accuracy (Offerle, 2003).

Shanghai Land Surface Cover Characterisation for LUMPS

OMIS Colour Composite



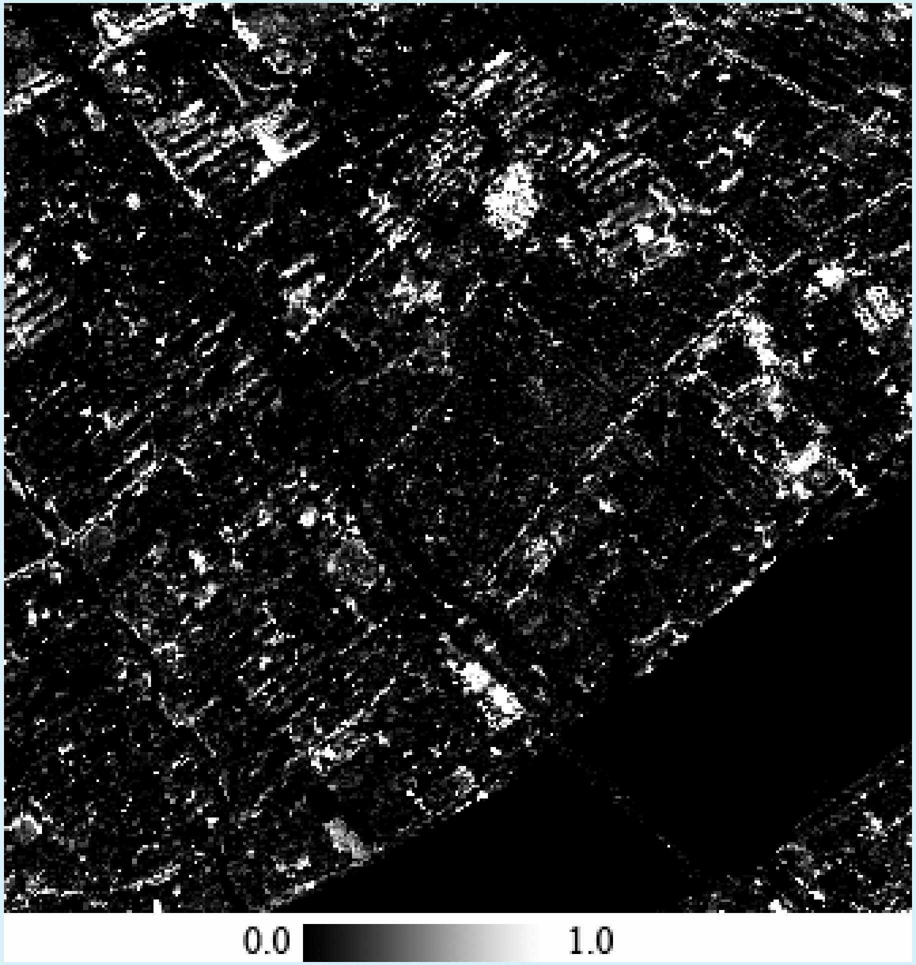
Empirical Line Method Calibration →



Fractional Cover Determination

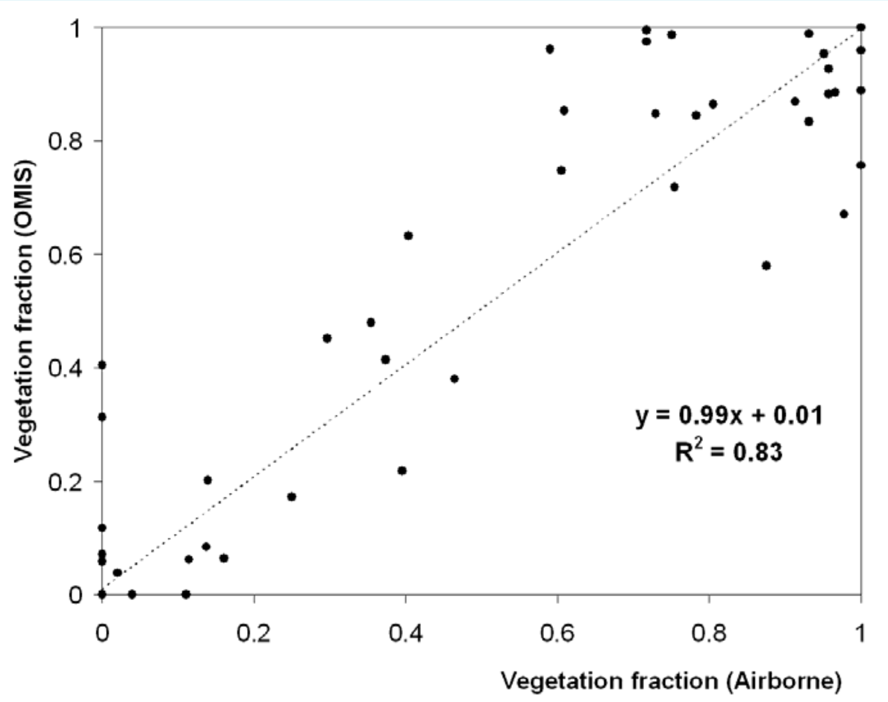
Shadow	Water	Vegetation	Buildings	Other Impervious
OMIS	OMIS	OMIS Aerial photograph (0.67 m)	Aerial Photograph Digital Topographic Map	OMIS – (Veg + Roof)
Manual analysis → Mask	Manual analysis → Mask	OMIS sub-pixel classification (Small 2001)		

OMIS-Derived Vegetation Fraction

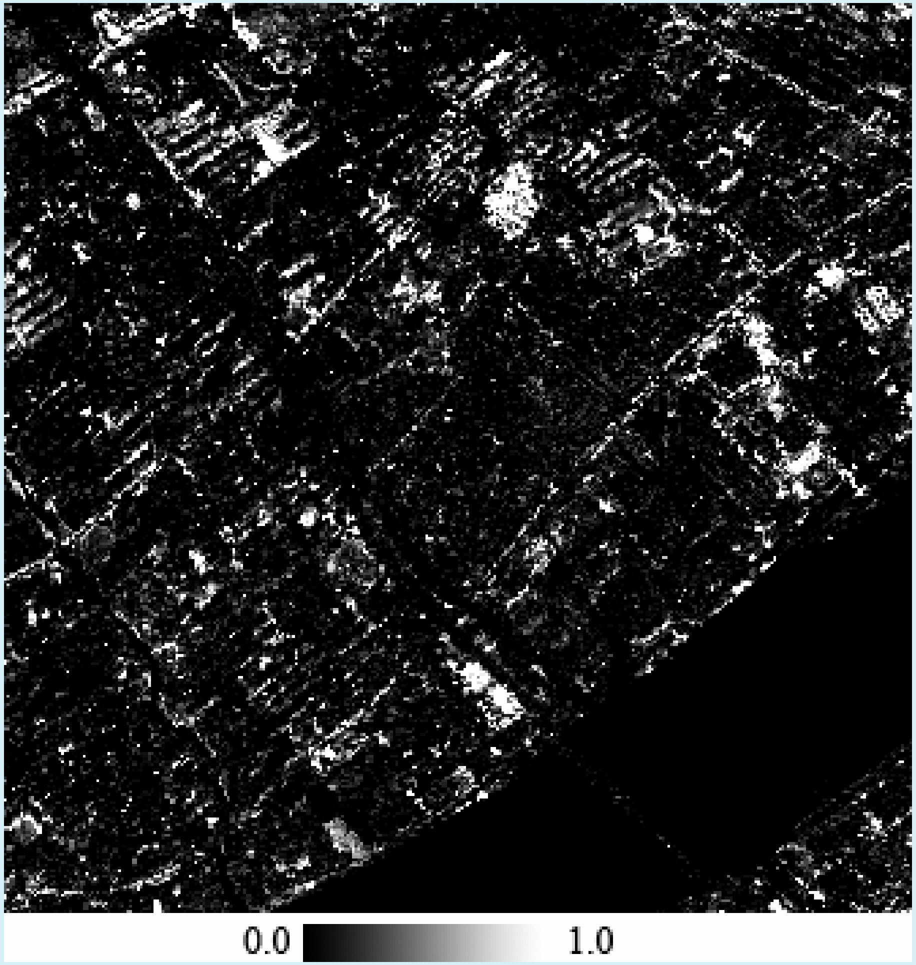


Vegetation Fraction
(Linear Mixture Modelling, Small (2001)

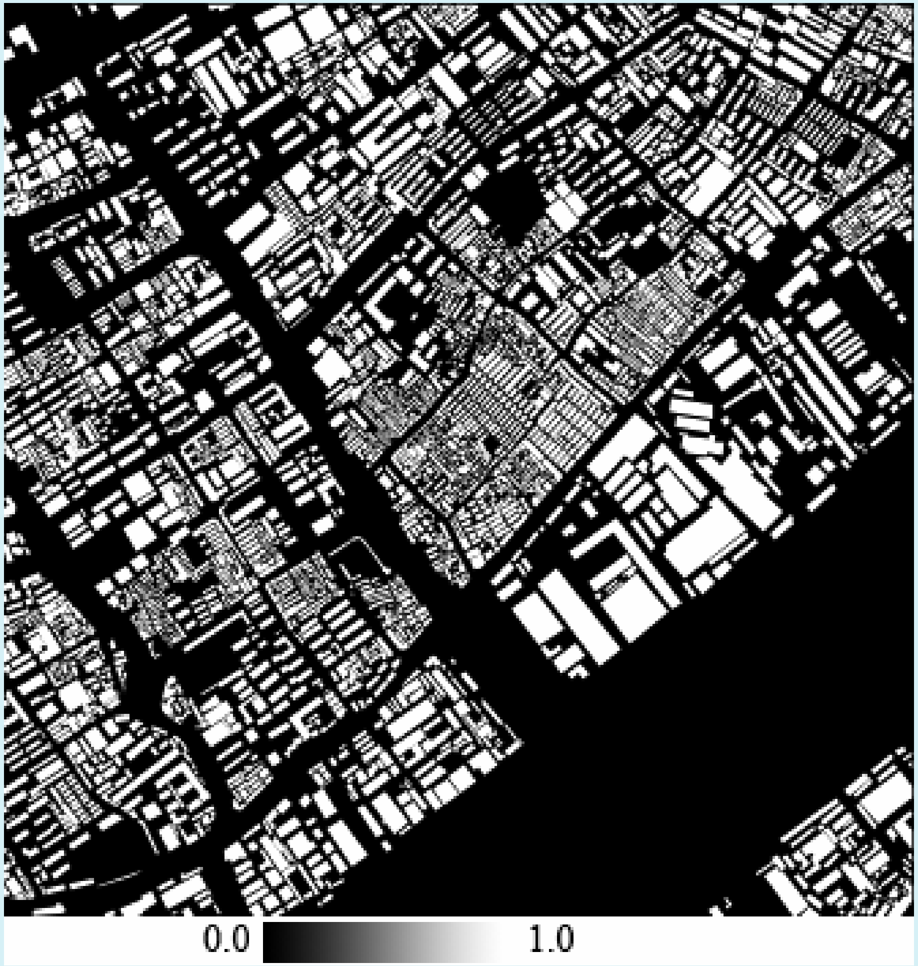
OMIS-derived Vegetation Fraction vs High Spatial Resolution Aerial Photo



Survey Map-Derived Building Fraction

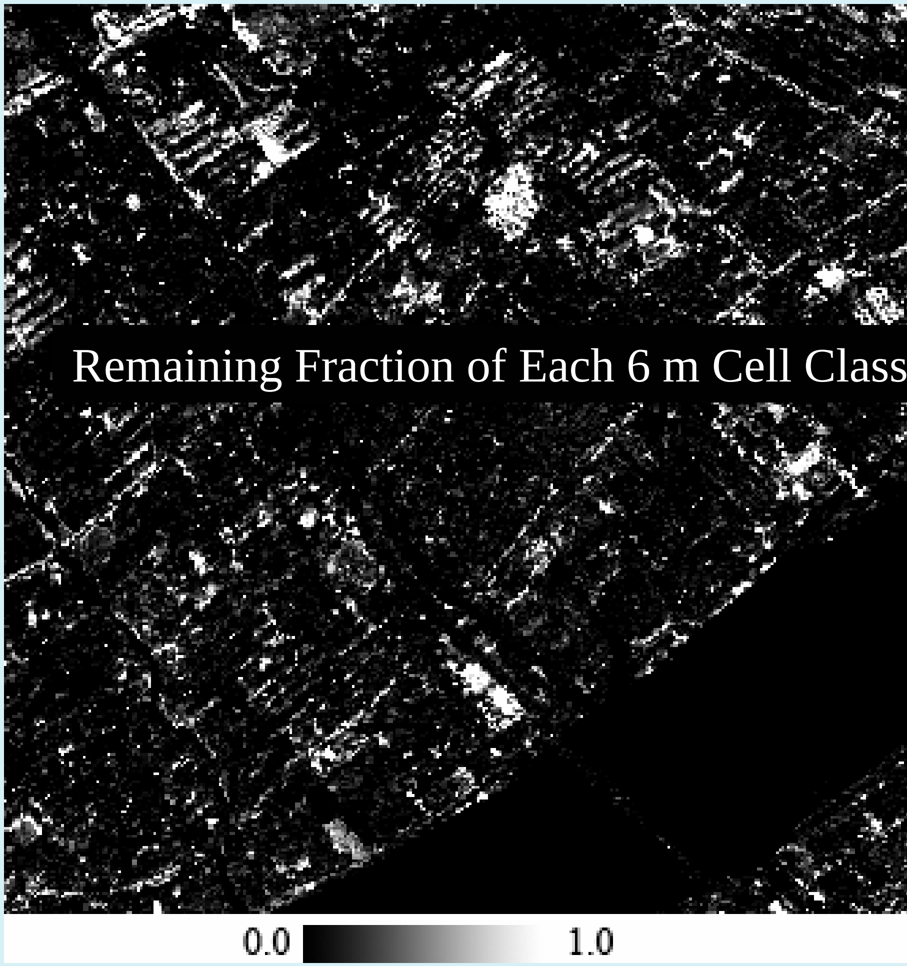


Vegetation Fraction
(OMIS/Linear Mixture Modelling, Small (2001)



Building Fraction
(1:2000 digital topographic map)

Survey Map-Derived Building Fraction

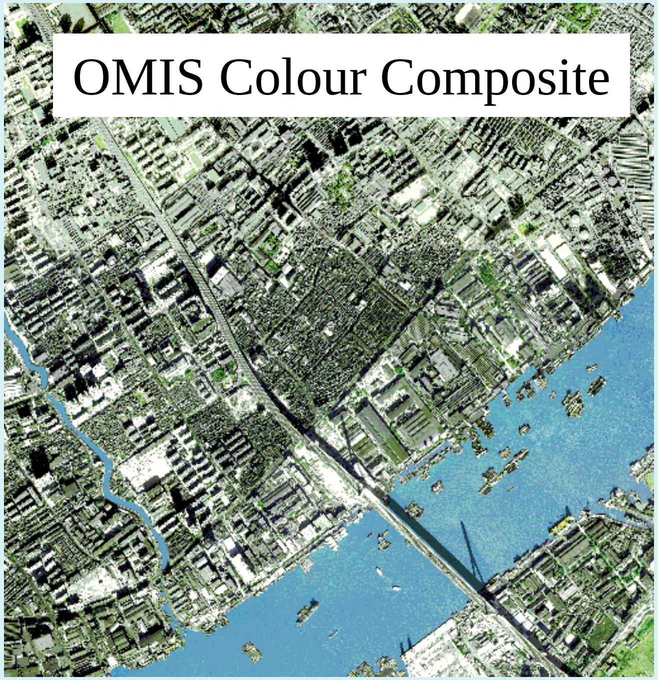


Remaining Fraction of Each 6 m Cell Classed as Other Impervious (Road, Pavement etc)

Vegetation Fraction
(OMIS/Linear Mixture Modelling, Small (2001)

Building Fraction
(1:2000 digital topographic map)

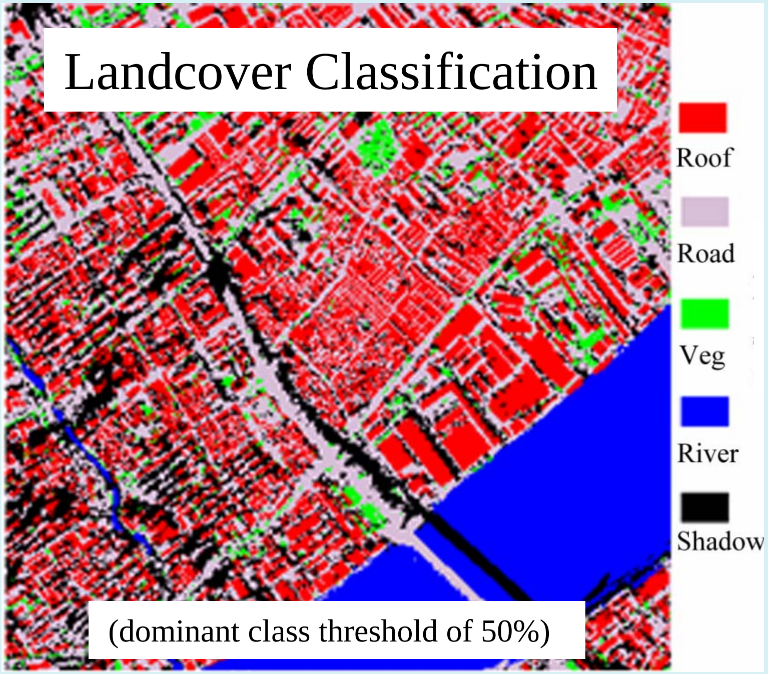
Shanghai Land Surface Cover Characterisation for LUMPS



Empirical Line Method Calibration

→

& Fractional Cover Classification



Fractional Cover Determination

Shadow 18%
- OMIS
- Manual analysis → Mask

Water 15%
- OMIS
- Manual analysis → Mask

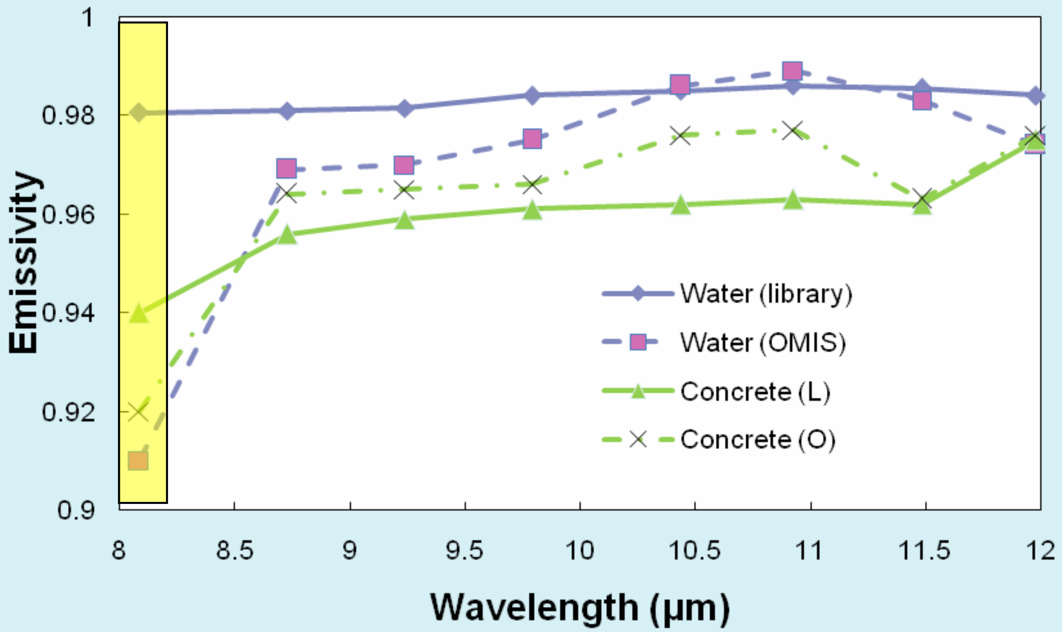
Vegetation 8%
- OMIS Aerial photograph (0.67 m)
- OMIS sub-pixel classification (Small 2001)

Buildings 32%
- Aerial Photograph Digital Topographic Map

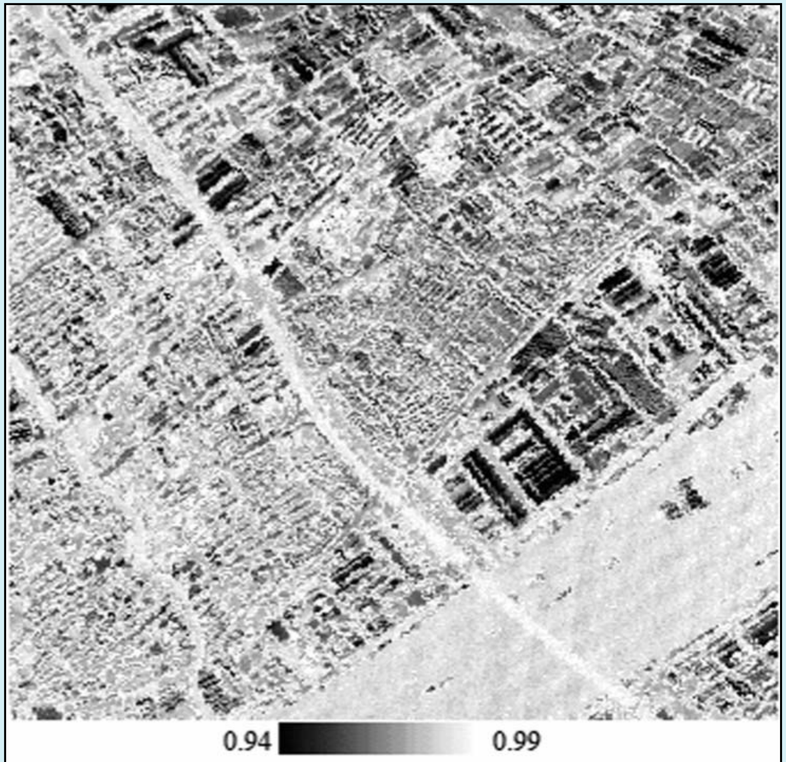
Other Impervious 27%
- OMIS – (Veg + Roof)

OMIS Surface Spectral Emissivity Evaluation

TES-Derived Spectral Emissivity vs Spectral Library



Broadband Emissivity Map



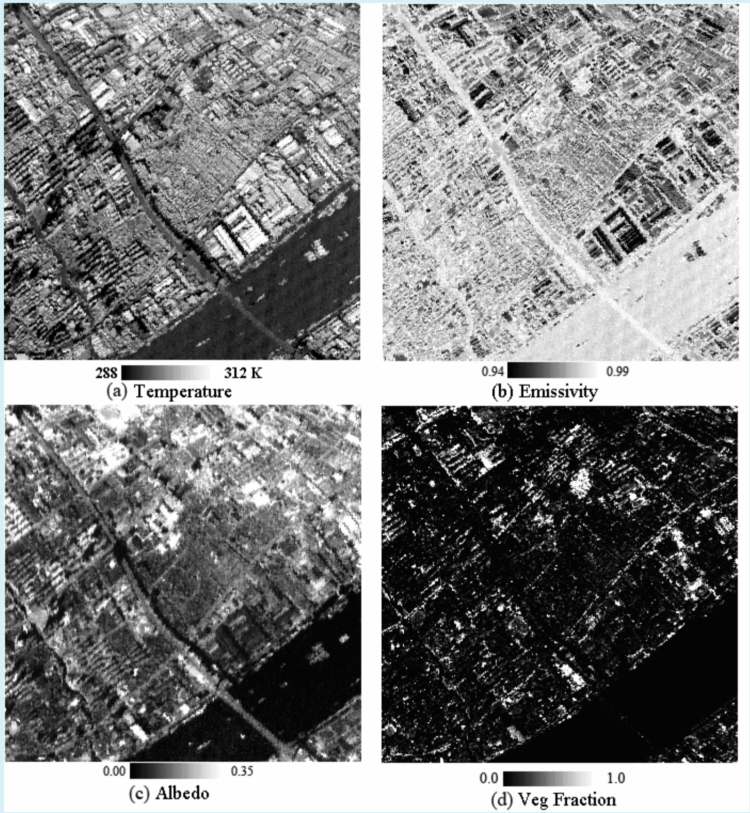
(d) Emissivity

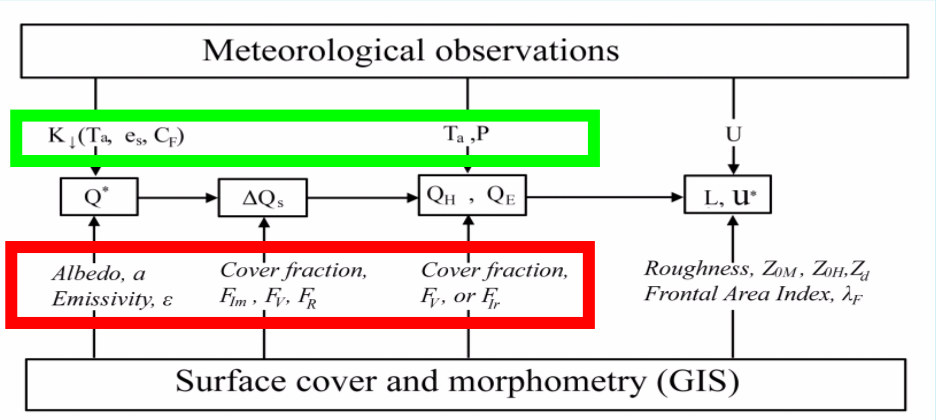
• Mean spectral emissivity difference (OMIS to Lib) is 0.005; max difference of 0.02

• Uncertainty of 0.1 in broadband emissivity corresponds to uncertainty of 45 Wm^{-2} in radiative heat flux 300 K (portion maybe compensated by reflected downwelling)

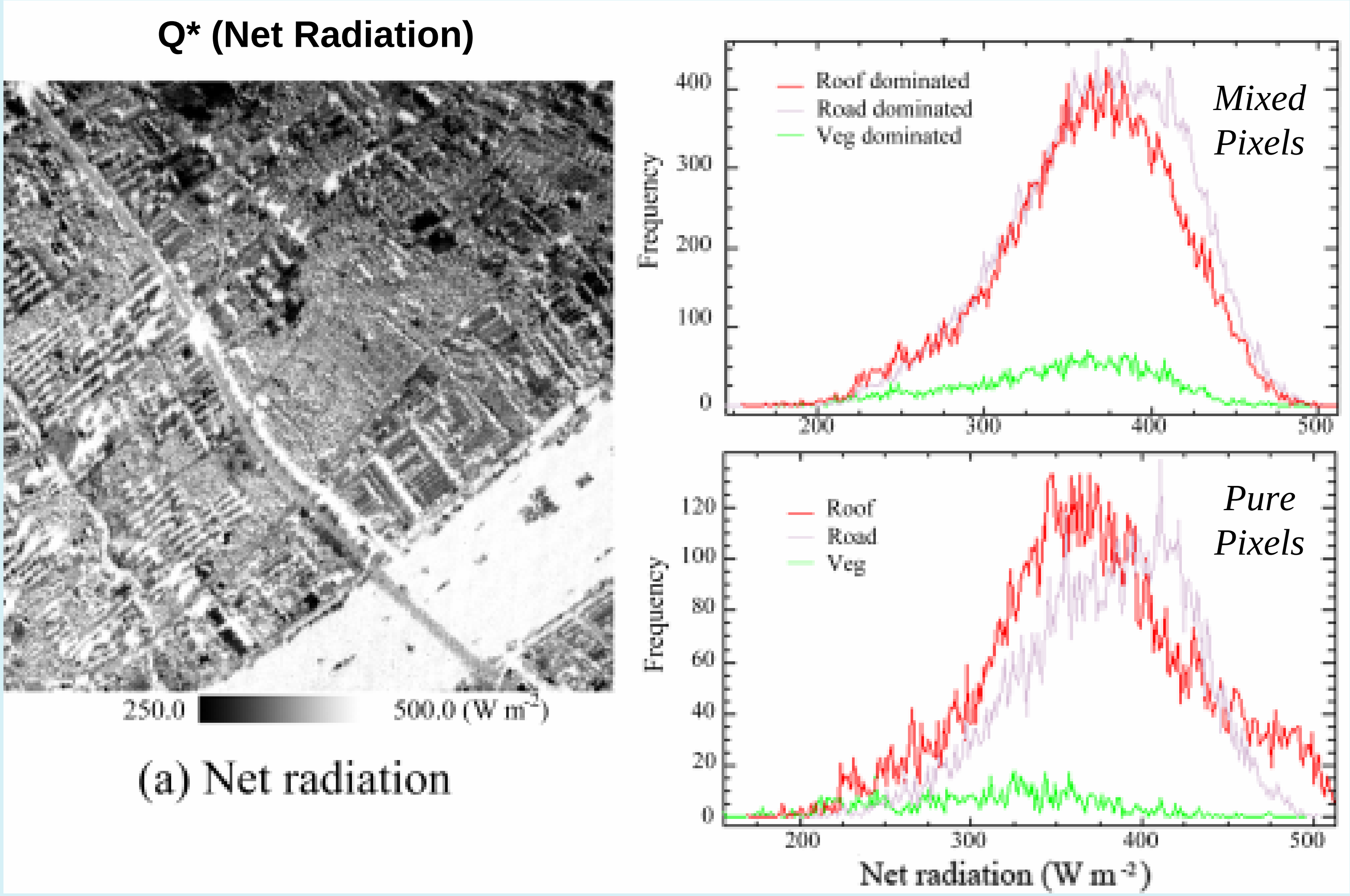
Summary of OMIS Data Processing & Input into LUMPS

- 8 Thermal IR bands
  - Processed using 8 band TES implementation to:
    - Surface Kinetic Temperature
    - Surface Spectral Emissivity
- 112 Visible bands
  - Processed to
    - Spectral Reflectance
    - Albedo & Veg Fraction



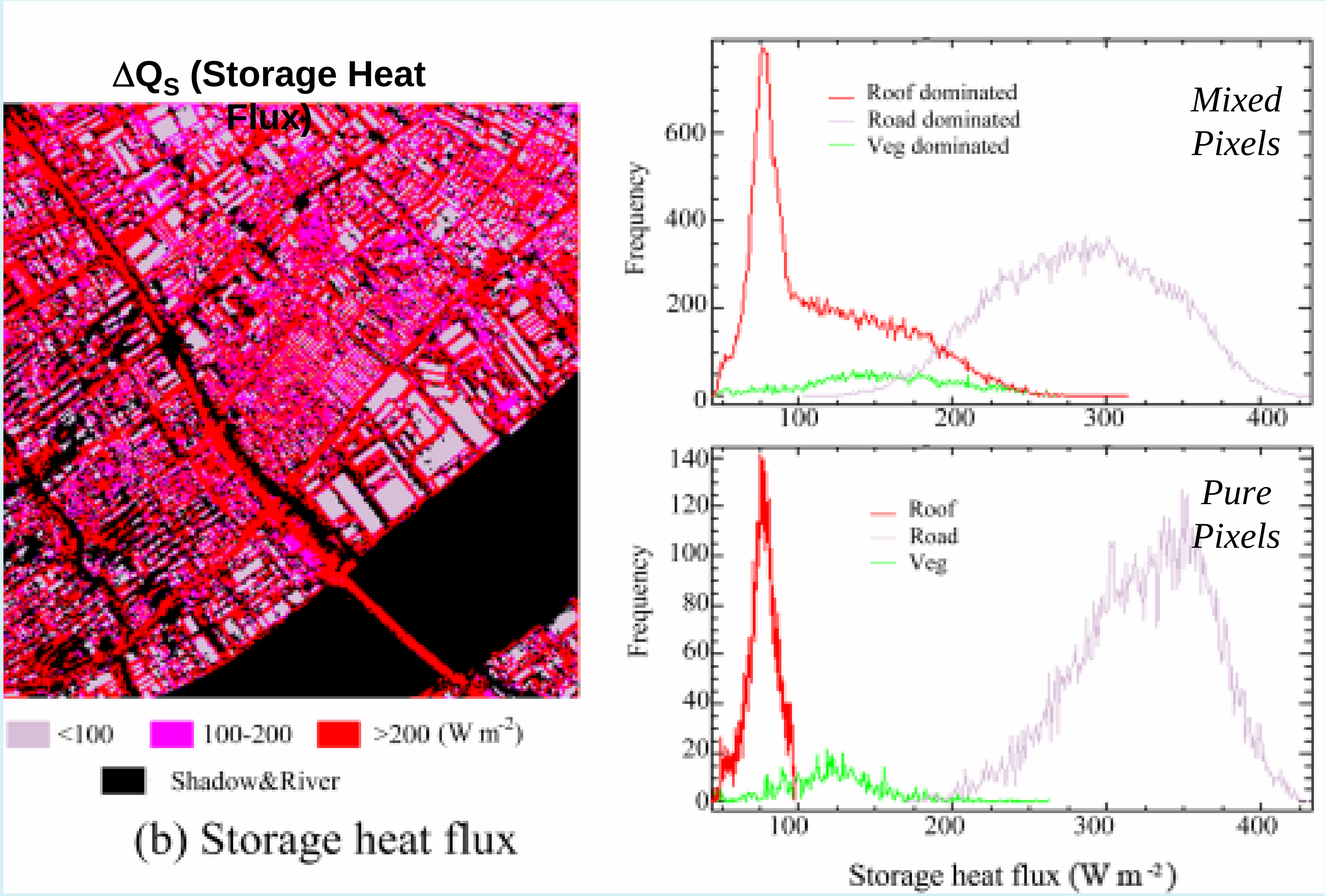


RESULTS: OMIS/LUMPS-Derived Fluxes (Net Radiation)



- Net radiation (Q*) distribution similar for the three landcover types
- Max difference (68 W m^{-2}) between pure veg and pure road 6 m pixels

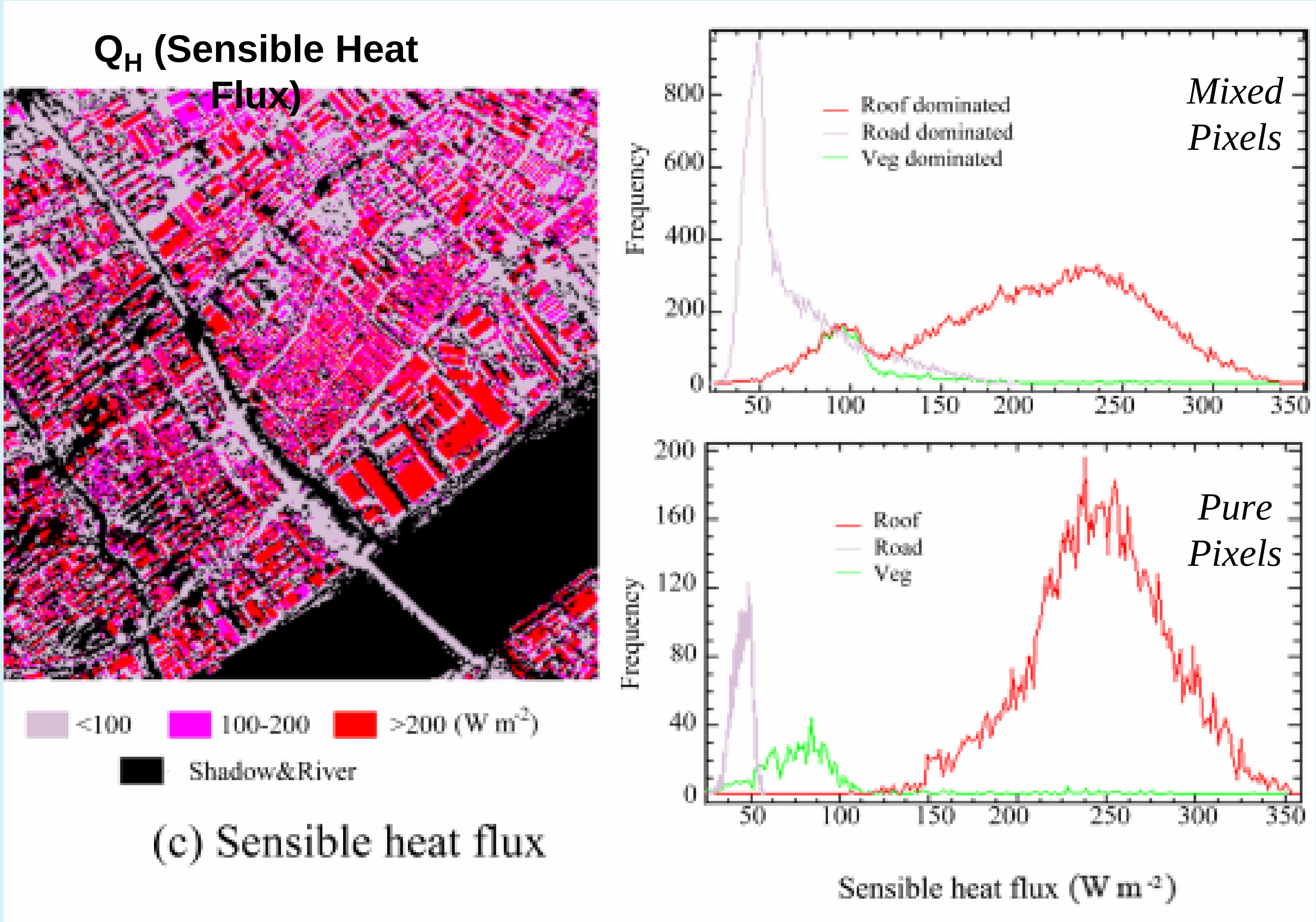
RESULTS: OMIS/LUMPS-Derived Fluxes (Storage Heat Flux)



(b) Storage heat flux

- Pure rooftops characterised by lowest storage heat flux (mean ~ 15% Q*)
- Pure roads/pavements have the largest storage heat flux (mean ~ 80% of Q*)

RESULTS: OMIS/LUMPS-Derived Fluxes (Sensible Heat Flux)



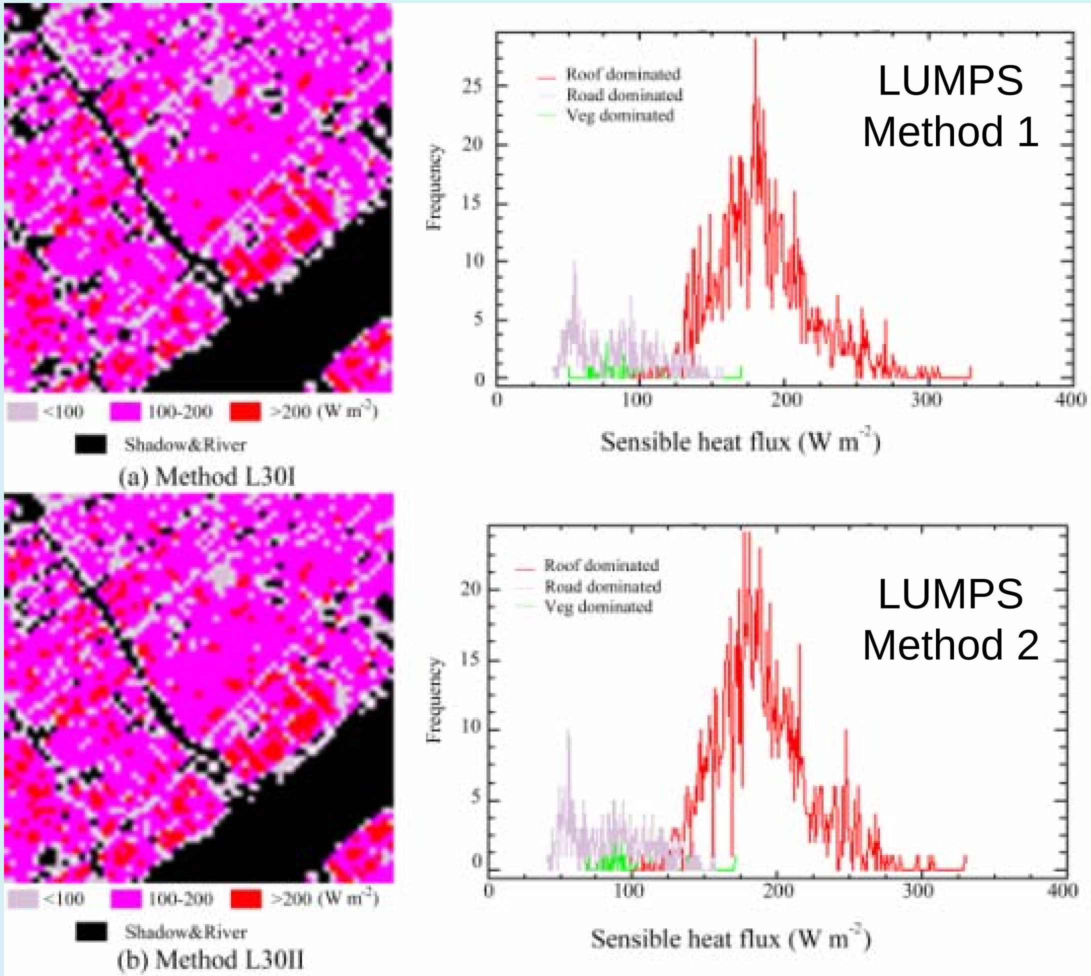
- Rooftops characterised by highest sensible heat flux (mean ~ 60% Q*)
- Roads/pavements have the lowest sensible heat flux (mean ~ 10% Q*)

Influence of Spatial Scale on Q_H (Wm^{-2})

Landcover (6 m)	Mixed Pixels (Q_H)		Pure Pixels (Q_H)		
	Mean	sd		mean	sd
Roof Dominated	199	62	Roof	255	44
Road Dominated	69	30	Road	45	5
Veg Dominated	104	43	Veg	84	45
All	**130**	81	All	**152**	109

- Spaceborne sensors have lower spatial detail (but more available data)
  - OMIS 6 m pixels ETM+ 30 - 60 m pixels ASTER 15 - 90 m
  - Aggregate OMIS data to lower spatial resolution to determine influence
    - Method 1: resample Q_H results to 30 and 90 m resolution
    - Method 2: resample OMIS imagery to 30 and 90 m resolution prior to classification
  - Calculate Q_H via LUMPS approach once more with degraded data – and compare Q_H (W/m^2) to original results obtained at 6 m

Influence of Spatial Scale (30 m)



← Meth1: Degrade Q_H output

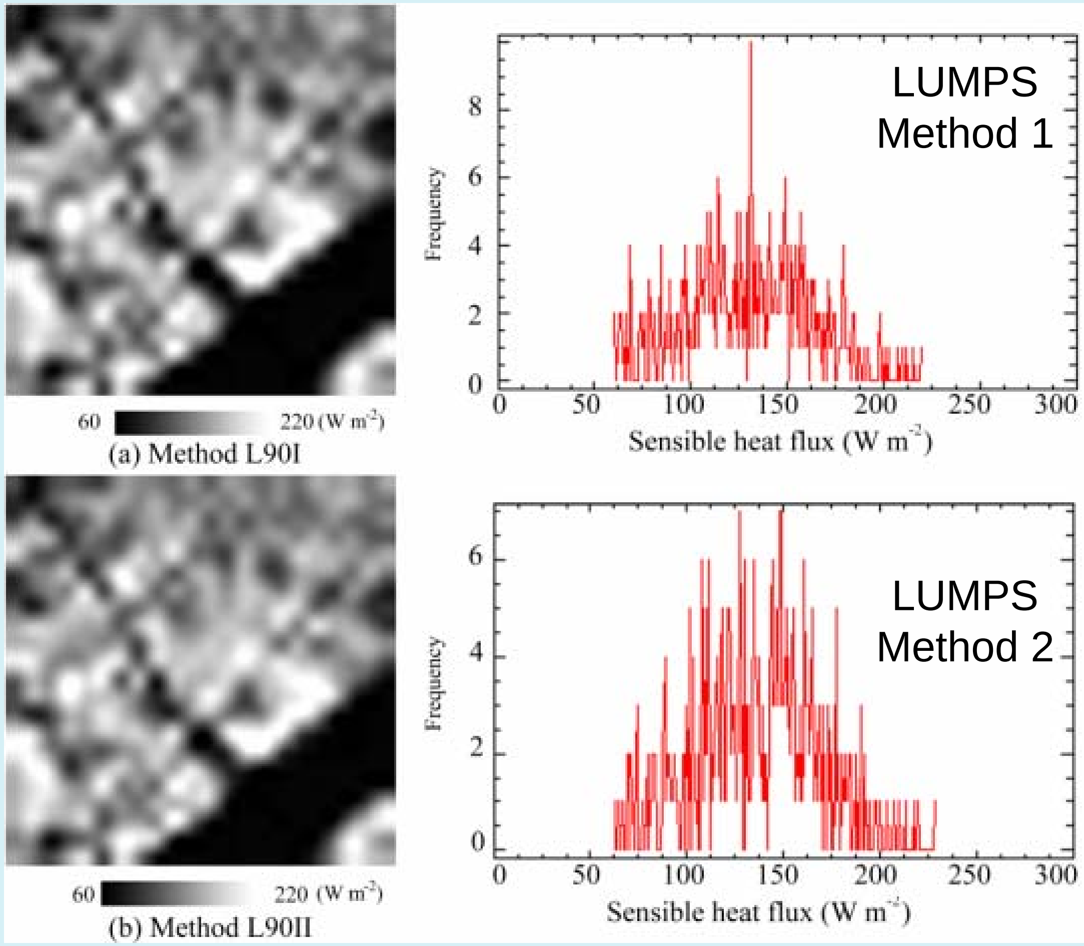
Degradation to 30 m spatial scale.

← Meth2: Degrade LUMPS inputs

Can still identify many dominated class pixels

Q_H	30m Method 1		30m Method 2	
	Mean	sd	Mean	sd
Roof	185	33	189	32
Road	83	28	85	28
Veg	87	21	97	21
All Pixels	**157**	**56**	**160**	**55**

Influence of Spatial Scale (90 m)



← Meth1: Degrade Q_H output

Degradation to 90 m spatial scale.

← Meth2: Degrade LUMPS inputs

Most pixels now fully mixed classes

Q_H	90m Method 1		90m Method 2	
	Mean	sd	Mean	sd
All Pixels	123	33	135	32

Final Comments & Conclusions

- Thermal remote sensing imagery with a GIS-type database provides data to allow calculation of energy fluxes by LUMPS
- Shanghai changes - land cover detail needs regular updates
- Using of spaceborne imagery maybe a practical solution for heat flux determination in urban areas where high resolution airborne data is only infrequently available
- Atm. & emissivity corrections seem ok - but still need 3D info.