Earth Observation Laboratory
PhD Program in GeoInformation
DISP - Tor Vergata University

Wavenumber Spectra of High Resolution Optical Images for Characterizing Urban Features

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Goal

- Use of different wavenumber spectra produced by both one-dimensional and two-dimensional Fast Fourier Transform (FFT) of images, to quantitatively describe features of different urban environments;
- QuickBird images provided by Digital Globe Inc.
- Computation of statistically significant confidence intervals;
- Spatial scale characterization of urban features.

Characteristics of the data set

City	Acquisition Date	Spatial Resolution	Off Nadir Angle
New York	08/20/2002	2.4 meters	20.3 Degrees
Boston	09/20/2005	2.4 meters	18.4 Degrees
San Francisco	02/12/2006	2.4 meters	19.8 Degrees
Rome	07/19/2004	2.4 meters	23 Degrees

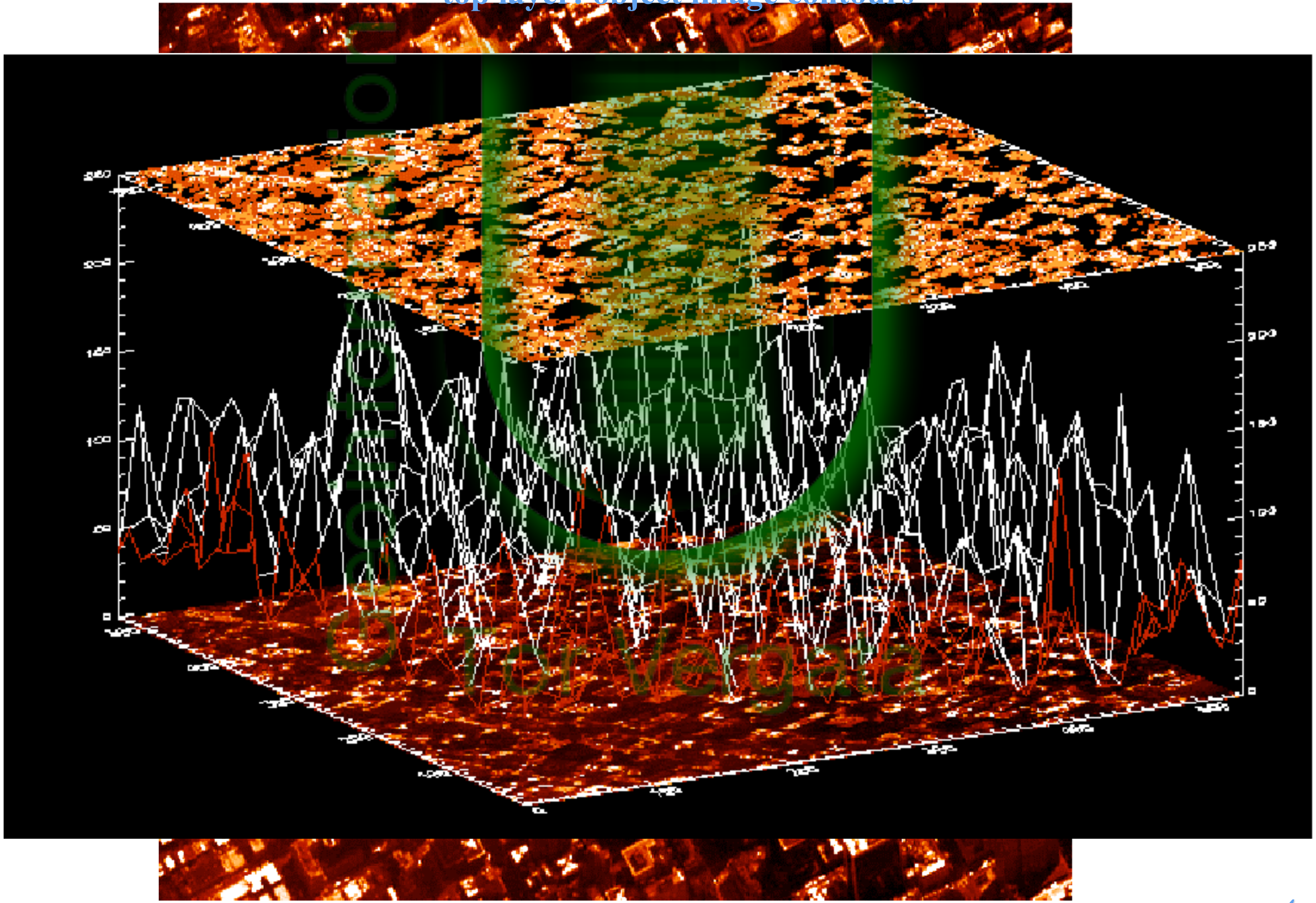
Urban areas selected: downtown, airport, high density, industrial/commercial

Results are reported for band 2 (green, high sensitivity to mineral urban surfaces) and some test sites

Two-dimensional FFT: urban features characterization

A selected typical downtown area of Manhattan (NY): the image shows a uniform distribution of the buildings

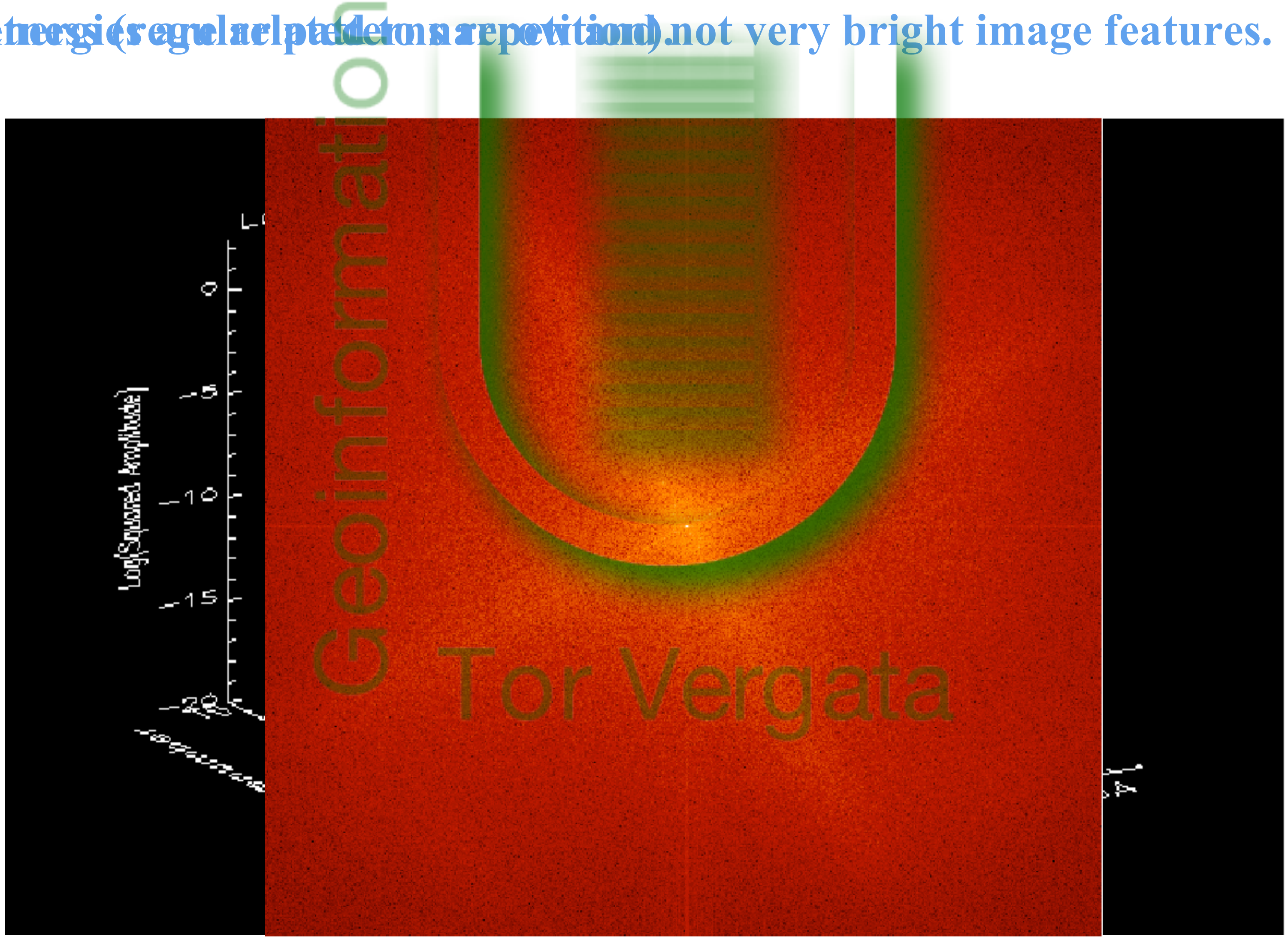
3D representation: bottom layer: original image; middle layer: pixels reflectance values; top layer: object image contours



Two-dimensional FFT: Wavenumber Spectra

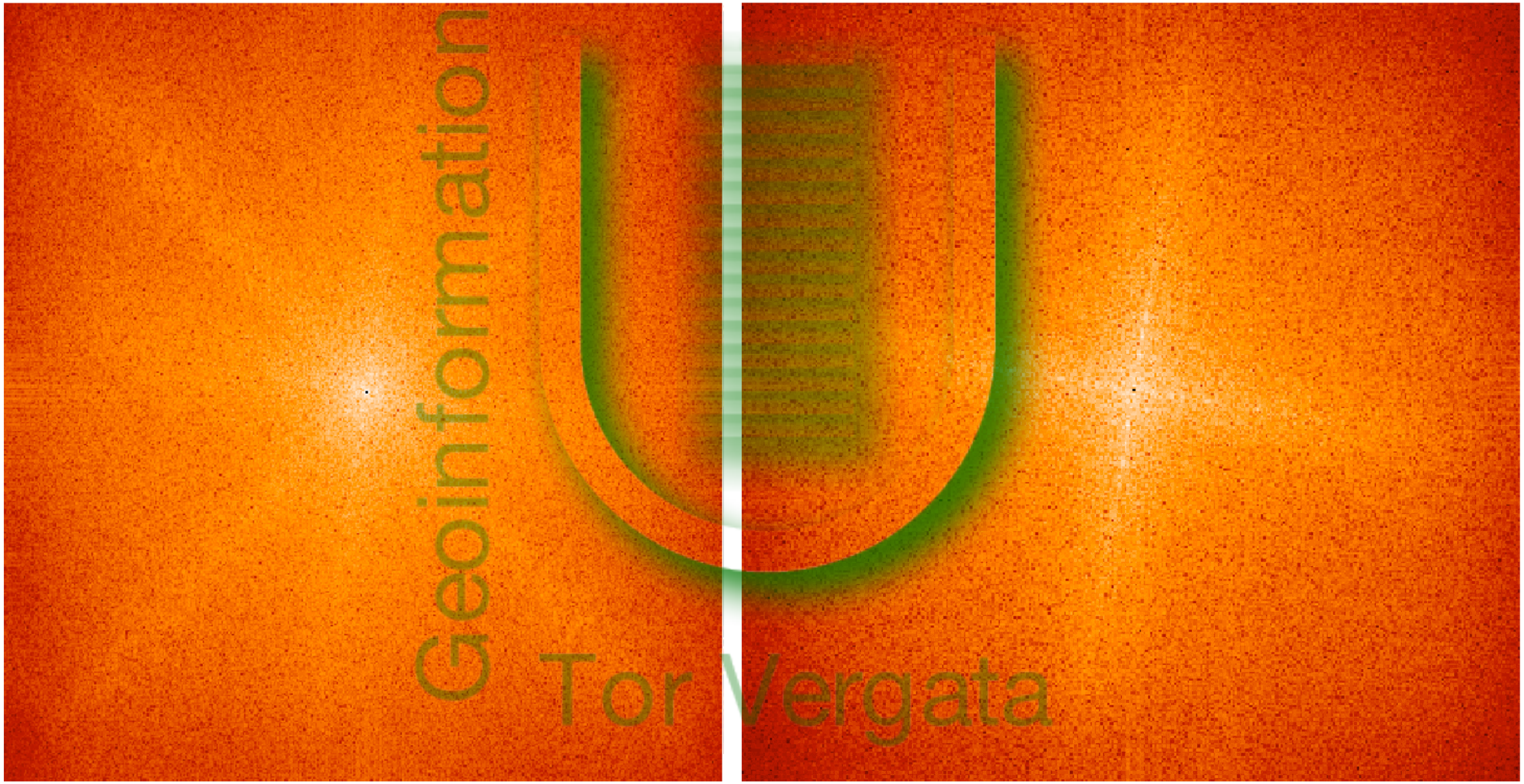
Two perpendicular spectral axes mapping building, road orientation and directionality from the main central peak along ESE and WNW directions. Low energies are related to small and not very bright image features.

The central large spectral energies [illegible] similarly oriented buildings, not very different in shape, size and brightness (regular patterns repetition).



Two-dimensional FFT: Wavenumber Spectra

High density areas of San Francisco: spectra comparison



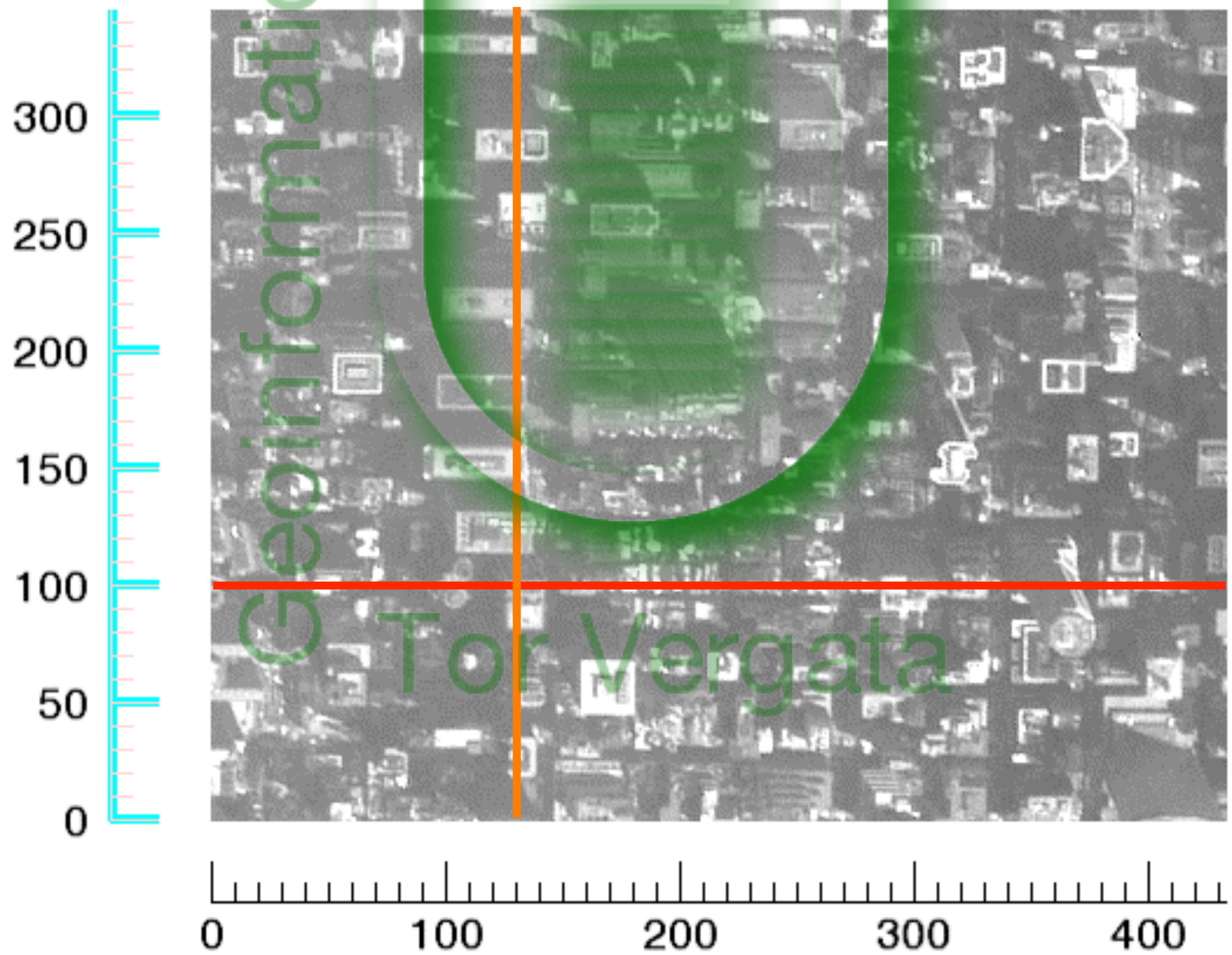
In downtown the wavenumber spectrum is more isotropic;

In the housing area energy is mainly distributed along two axes, according to road orientations.

One-dimensional FFT: urban feature characterization

Rotated image of downtown Manhattan, NY; rotation angle defined by the ridges of the two-dimensional Power Spectrum;

- **To eliminate spectral dependency on relative image acquisition angle**



One-dimensional FFT: urban feature characterization

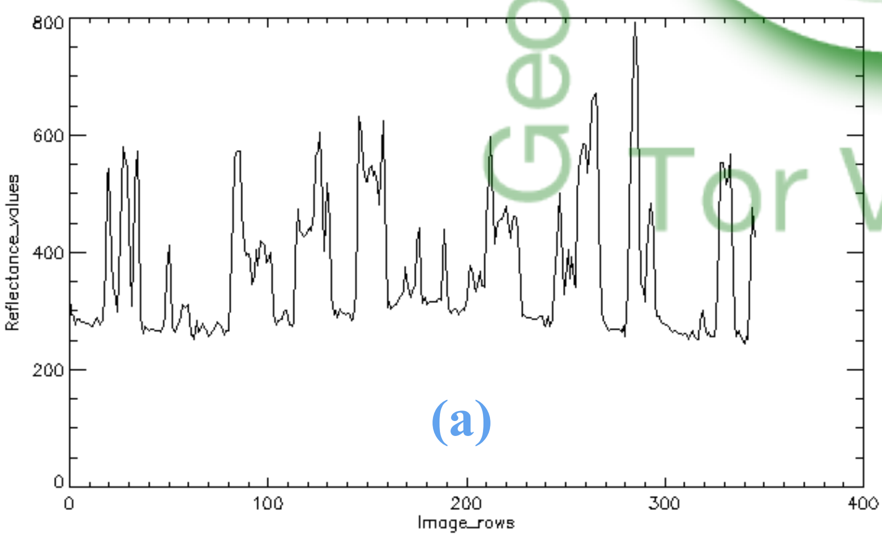
Fig. (a): Reflectance values relative to column 130: buildings spectral periodicity. Fig. (b): Power Spectrum (solid line) and smoothed power spectrum (dashed line);

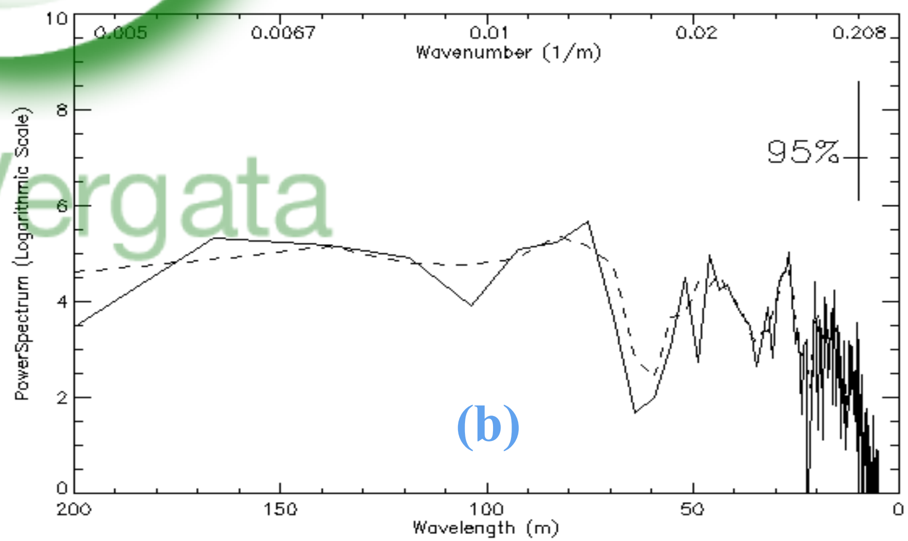
Chi-square distribution in logarithmic scale (Emery and Thomson, *Data Analysis Methods In Physical Oceanography*, Elsevier, Amsterdam, 2001):

$$\log[\nu / \chi^2_{1-\alpha/2,\nu}] \leq \log[G_{yy}(f)] - \log[G'_{yy}(f)] \leq \log[\nu / \chi^2_{\alpha/2,\nu}]$$

G_{yy} → (1-α)100%; ν = Degrees of Freedom (DOF) = 2K = 6;

Peak at 72 m represents the spatial periodicity of buildings (roof widths); peaks around 24, 48 m correspond to spatial periods of small bright features on roof tops (e.g. air conditioning installations and storages) along with smaller buildings.





One-dimensional FFT: urban features characterization

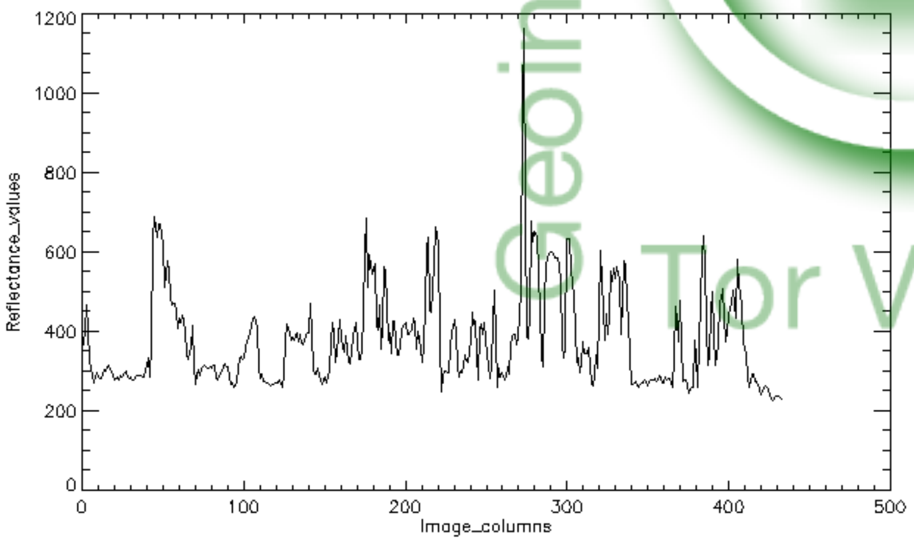
Reflectance values relative to row 100:

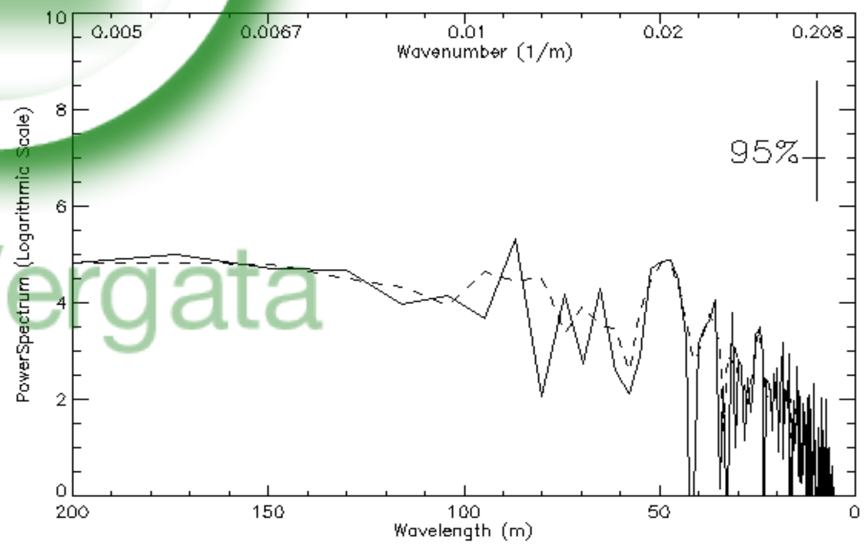
high peaks are caused by periodicity of both smaller and larger features (building tops).

The peak centred at 50 m corresponds to the spatial periodicity of small bright features (house roof tops).

The longer wavelength peak around 90 m is contributed by larger buildings.

Accuracy assessment by ancillary data comparison.

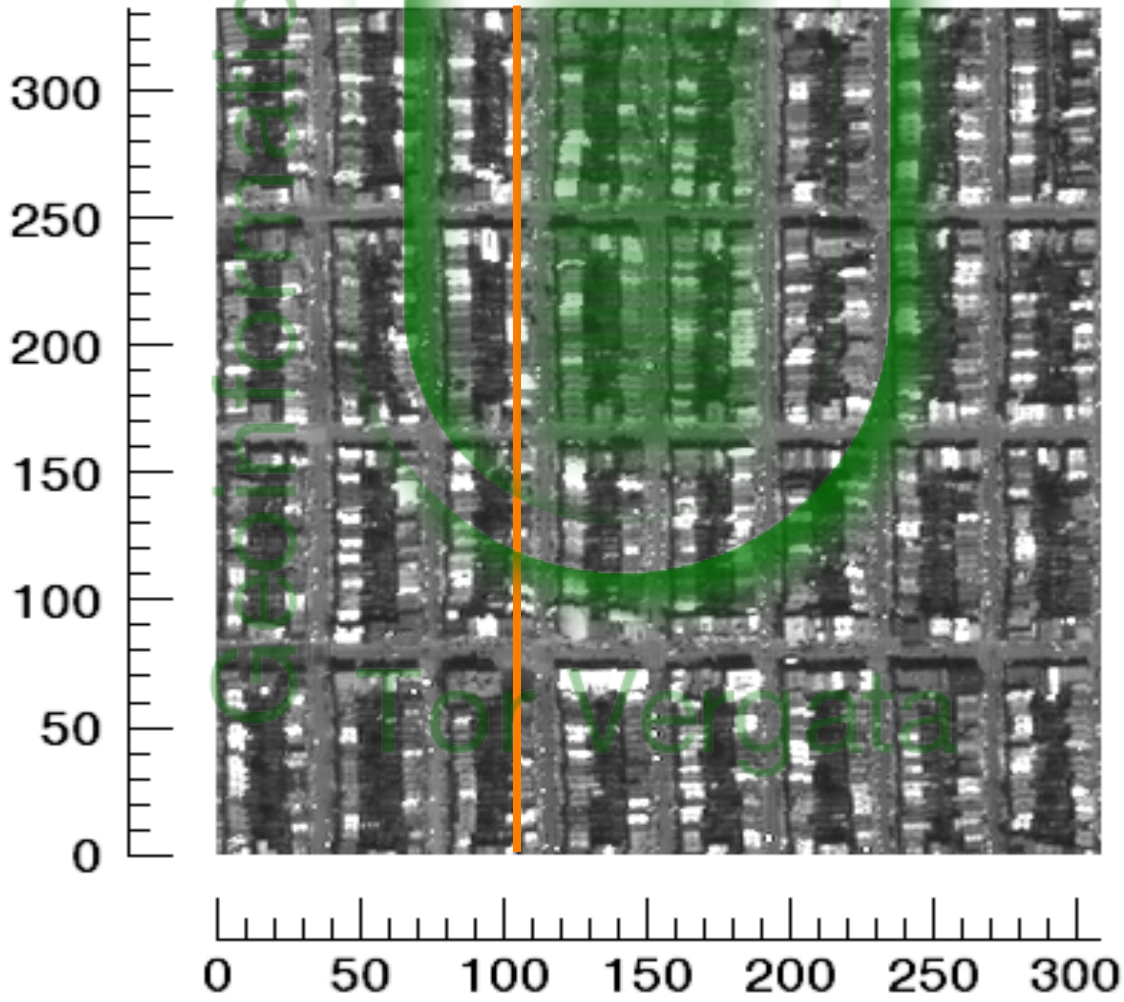




One-dimensional FFT: urban feature characterization

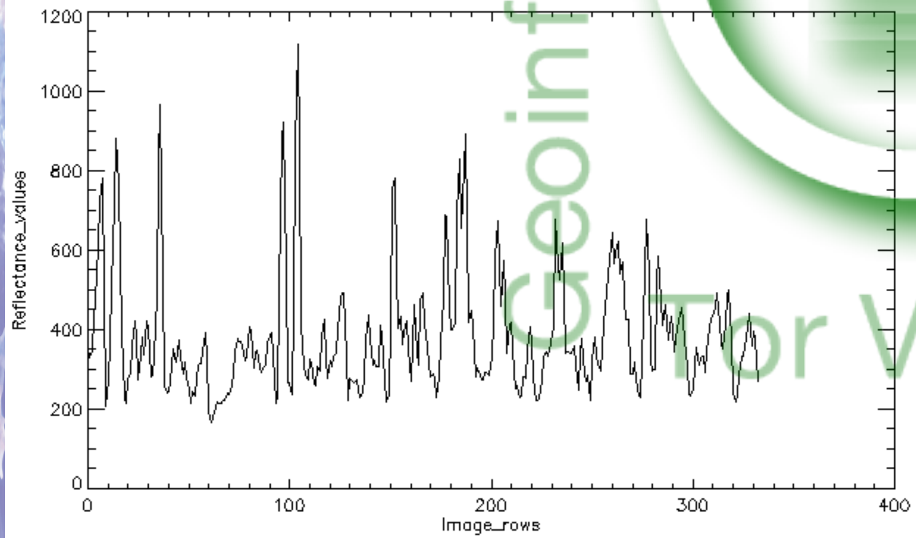
Rotated image of high density urban area of San Francisco.

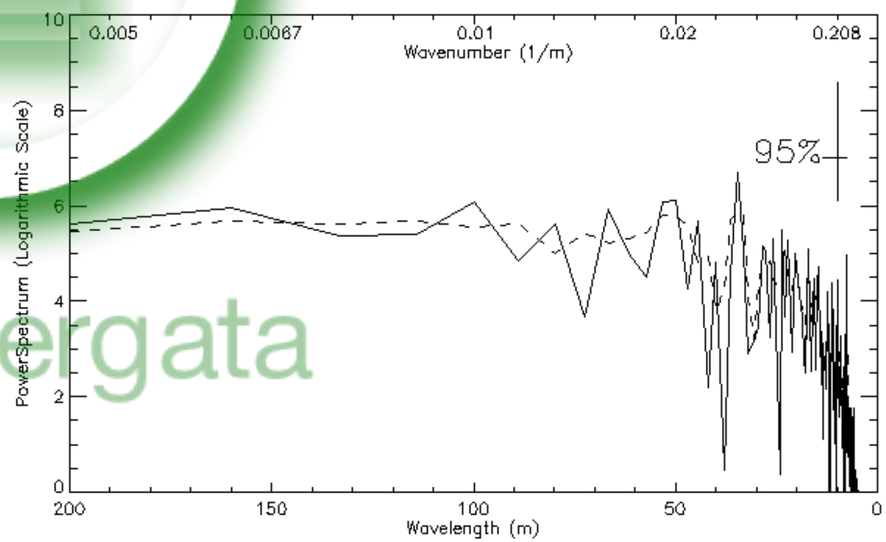
Numbers denote image rows and columns



Reflectance values relative to column 108 of San Francisco downtown area.

Long-wavelength periodicity is determined by blocks contoured by streets, within a block mid-wavelength periodicity is determined by lots, while houses within lots affect the short-wavelength spectrum.

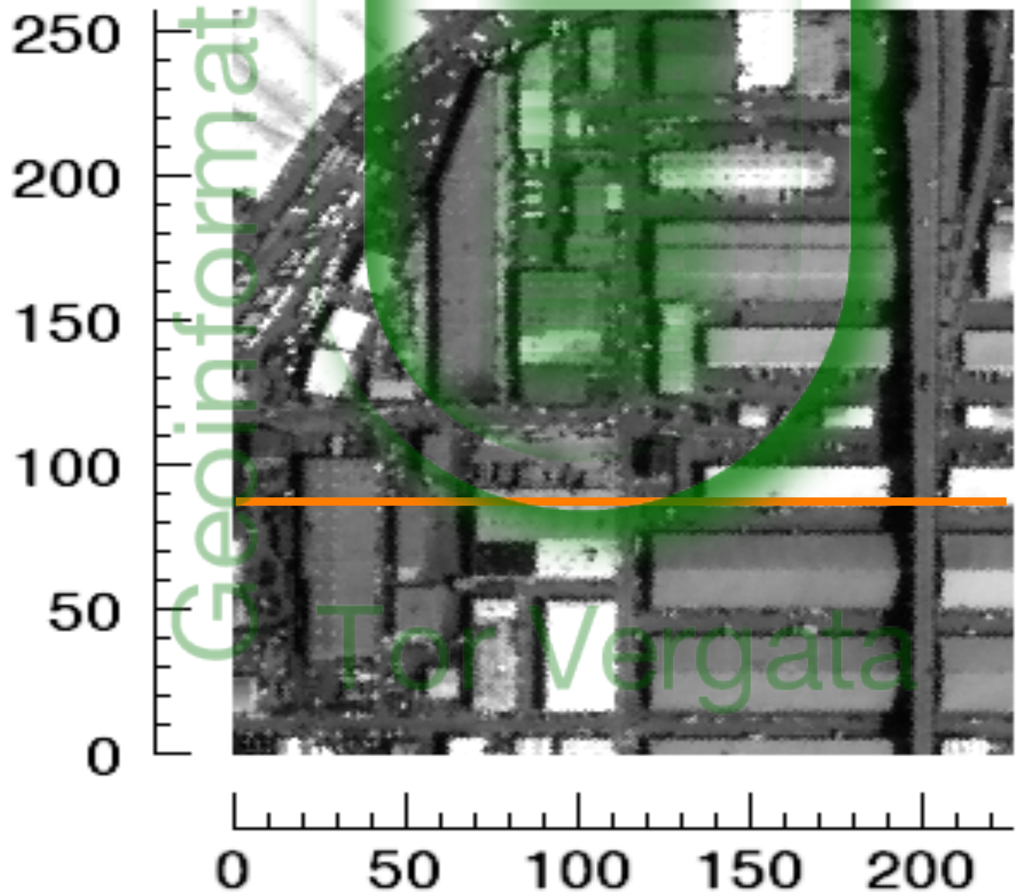




One-dimensional FFT: urban feature characterization

Rotated image of a commercial/industrial area of San Francisco.

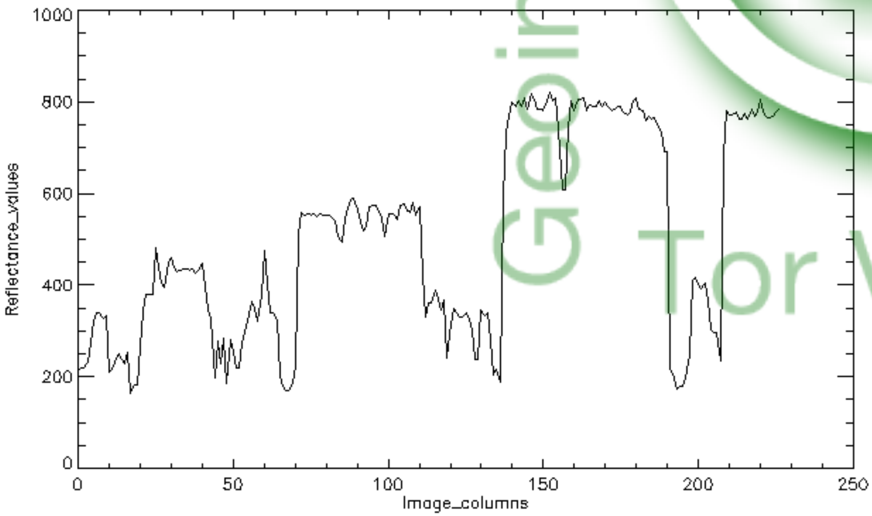
Numbers denote image rows and columns.

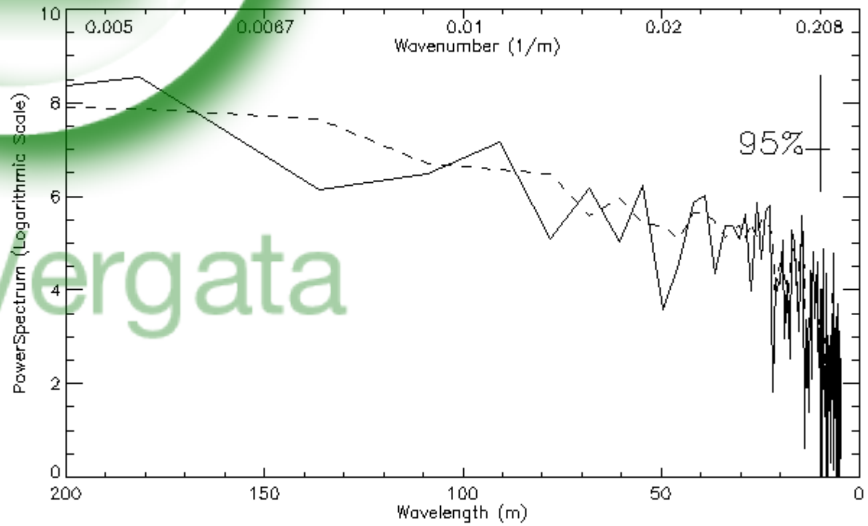


Reflectance values relative to row 88:

Most of the energy is contained in the long wavelength part of the spectrum;

Short-wavelength periodicity related to smaller bright features.





CONCLUSIONS I

The wavenumber spectra are shown to effectively allow the identification of high-level (object or region of interest) spatial features from the low-level (pixel) representation.

- **Wavenumber spectra result from spatial and spectral information of high-resolution images.**
- **Wavenumber spectra can represent global features of cities**
- **Spectral analysis highlights differences and analogies between cities in different locations, climates, history.**
- **Spectra characterize different urban environments within the same city**
- **Spectral characteristics may help understanding how the cities have been built and developed, according with topology.**

CONCLUSIONS II

- A straightforward analysis process and a particular ease for applicability due to the limited number of pre-processing steps which could be a source of uncertainty and errors
- A limited evaluation of processing parameters which may strictly depend on the image features
- Generalization ability: the methodology is suitable for different scenarios and other satellite data sources

FUTURE WORK:

- Change Detection
- Data Mining
- Multi Bands Analysis