High Spatial, Temporal, and Spectral Resolution Instruments for Modeling/Monitoring Urban Areas

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Description:

There is critical need to adequately model, monitor land cover/land use, biophysical, and societal changes in the urban environment and assess climate change impacts on cities. The Hyperspectral Infrared Imager (HyspIRI) is a Decadal Survey tier 2 sensor that is well developed and can be used to satisfy this need.

- With urbanization burgeoning around the world, there is a critical need to acquire data on urban environments at high spatial, temporal and spectral resolutions
- HyspIRI is ideally suited to gather data at high spatial, temporal, and spectral resolutions for quantifying and modeling land cover, biophysical, and societal characteristics of urbanization and its effects at local, regional, and even global scales.
- Deployment of the HyspIRI sensor as related to developing a better understanding of urbanization within the purview of two of the five Earth science themes defined in the Request for Information for ESAS2017 is associated with: **(I) Weather and Air Quality: Minutes to Subseasonal; and (IV) and Climate Variability and Change: Seasonal to Centennial**.

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Rationale:

- For the first time ever, the majority of the world's population lives in cities and this proportion continues to grow.
- By 2030, 6 out of every 10 people will live in a city, and by 2050, this proportion will increase to 7 out of 10 people.
- Almost all urban population growth in the next 30 years will occur in cities of developing countries, with most of this growth in “megacities” – those cities with 10 million inhabitants or more (UN, 2014).
- Thus, we are living in the first ‘urban century’ which will have profound impacts on the spatial ‘footprints’ of cities on planet Earth.
- Remote sensing data from orbital platforms are of key importance in the synthesis of these data along with other ancillary spatial data, to develop a better comprehension of the individual components of the urban ecosystem.

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The Urban Ecosystem:

- The urban ecosystem functions through the interaction of four separate but integrated constituents: the biotic complex; the physical complex; the social complex; and the built complex (Pickett et al., 1997).

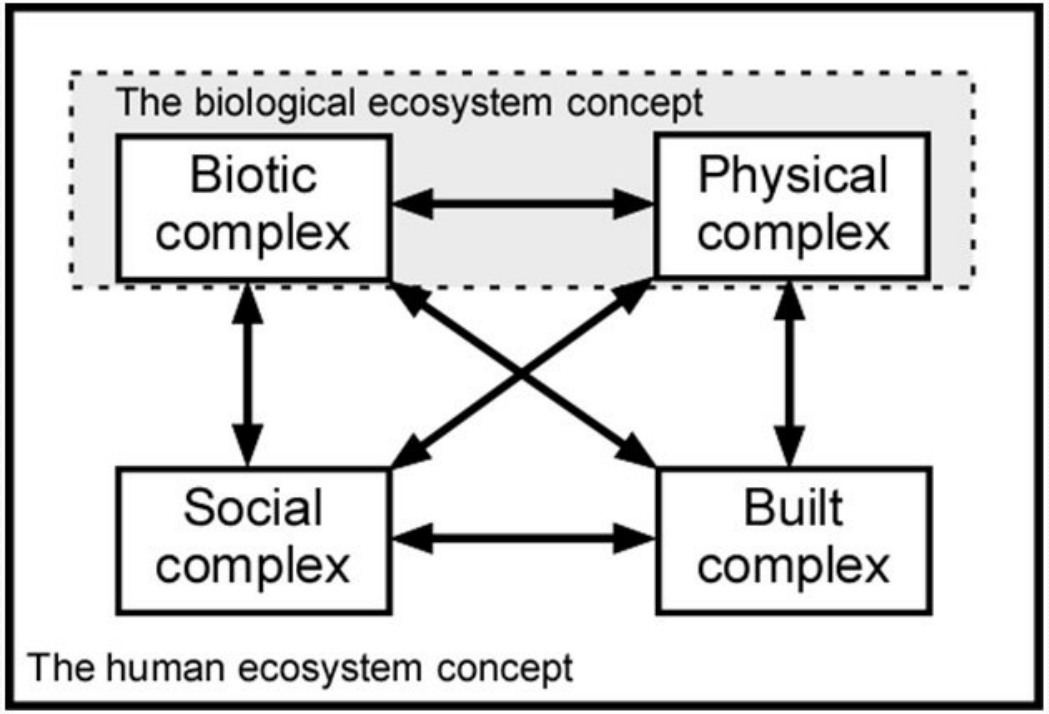

Figure 1. Diagram of the urban ecosystem concept. (Source: Baltimore Ecosystem Study: http://besurbanlexicon.blogspot.com/2011/12/human-ecosystem.html).

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- Overall, the interplay of these four constituents and assessing the causes and effects that drive or influence the outcomes from their interactions has multifaceted ramifications.
- Each of the individual 'complexes' given in Figure 1 is in itself an ecosystem.
- **The Biotic complex** consists of the flora, fauna, and human entities that comprise the biological urban landscape
- Here it is not only the land cover content that is extant such as forests, wetlands, or agricultural lands, but even more so the arrangement of these 'natural' land covers within and around urban areas that is of importance to the health of the biotic complex
- Assessments of how much land cover change from 'natural' to impervious has occurred through time is important information that is used by decision makers and urban planners in assessing where urban expansion has taken place, and where growth will occur along the rural-urban interface.

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- **The urban physical complex** consists of both the physical attributes and processes that interact to form the physical environment across or over cities.
- Attributes here include those related to the atmosphere (e.g., wind, precipitation, clouds) or land-atmosphere energy exchanges such as thermal energy fluxes or those related to plant oxygen-CO_2 exchanges with the atmosphere.
- The physical complex also includes those elements related to the urban hydrosphere such as rivers, lakes, wetlands, watersheds, water runoff, and infiltration, and the impacts of rainfall over cities (e.g., flooding).
- It also includes the output from the built environment such as waste water, and the amount of water needed to maintain the overall structure of the city.

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- **The urban built complex** is familiar to us as the 'city' where the land surfaces ubiquitous to the urban environment such as buildings, houses, rooftops, roads, parking lots exist.
- The built complex may be thought of as the 'urban fabric' upon which the morphology of the city rests.
- It is extremely heterogeneous and where land surface types are juxtaposed and intertwined with one another to comprise this fabric.
- **The urban social complex** consists of the attributes that relate to human health, welfare, economics, and social interactions that occur within the urban environment.
- Here the inflows, outflows and exchanges of people, materials, and finances occur, and where segmentation of the social environment takes place through population migration (e.g., neighborhood gentrification, socio-economic class distinction).
- The social complex is perhaps the most complicated of all four of the complexes that comprise the overall urban ecosystem because of the vagaries of the human dimension and volatility to both internal and external forces that shape the socio-economic environment of the city.

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Coupling of Urbanization with Urban Climate:

- Because the urban surface regulates much of the urban climate, there is a tight coupling between land use and regional climate modeling.
- Urban climate modeling refers to micro and small-area estimates of temperature, wind speed and direction, atmospheric pressure, humidity, precipitation, energy fluxes, and atmospheric particulates in an urban area.
- Many studies show that the underlying land cover influences urban atmospheric and surface temperatures.
- A particular challenge in urban climate analysis and modeling is acquiring data with requisite cell sizes to match thermal elements and fluxes and data collected at the time scales to effectively monitor diurnal temperature variations.
- Day/night thermal differences related to characteristics of urban morphology, such as building size, orientation, and spacing and the availability of green space, show that the relative spatial location of land covers influences temperature more so than actual surface composition.

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The Urban Heat Island Effect:

- The Urban Heat Island effect (UHI) results from elevated temperature over urban areas due to thermal energy characteristics of urban surface materials that absorb incoming shortwave solar radiation and re-emit this energy as longwave radiation from surfaces common to the city landscape (e.g., pavement, rooftops)
- Studies modeling UHI have been used to quantify the drivers of the UHI, to determine approaches to mitigate heat, and to analyze human, plant, and animal health, changes to rainfall patterns, and energy and water use
- The UHI may increase heat-related impacts by raising air temperatures in cities approximately 1–6 ^{o}C over the surrounding suburban and rural areas due to absorption of heat by dark paved surfaces and buildings; lack of vegetation and trees; heat emitted from buildings, vehicles; and air conditioners; and reduced air flow around buildings.
- Partitioning of the urban thermal surface across the landscape is fundamental to understanding how the individual surface types that are ubiquitous to cities (e.g., rooftops, pavement) are vital to understanding urban land-atmosphere dynamics

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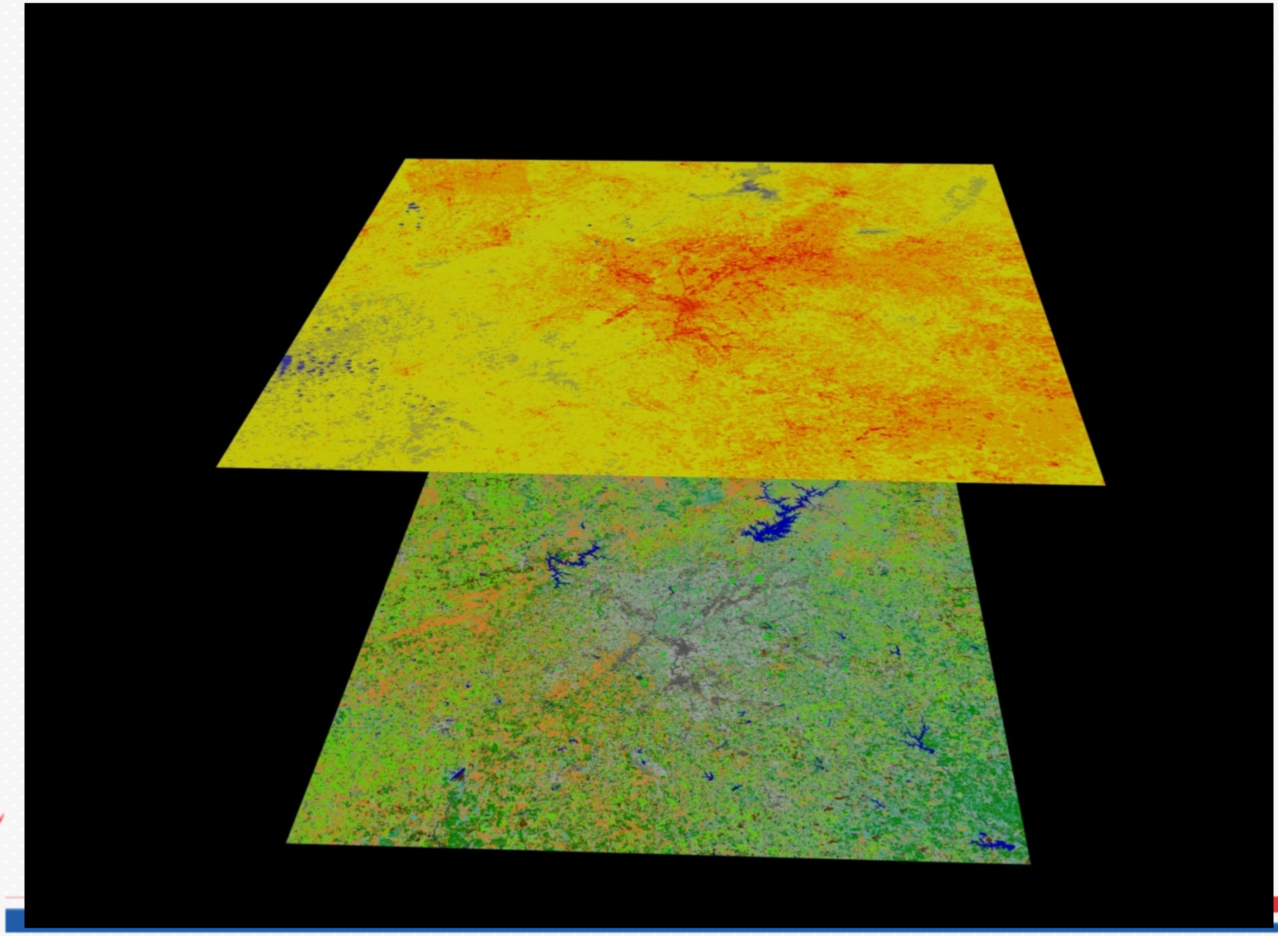
The Urban Heat Island Effect:



The majority of research on the UHI has been focused on deriving land surface temperatures (LST) from thermal infrared (TIR) remote sensing data and their relationships with urban surface biophysical characteristics, especially with vegetation indices and land use and land cover types.

Figure 2. Atlanta Georgia's urban extent in gray (bottom) and corresponding thermal responses (top) as derived from Landsat TM data, (Source: Quattrochi and Luvall, co-authors).

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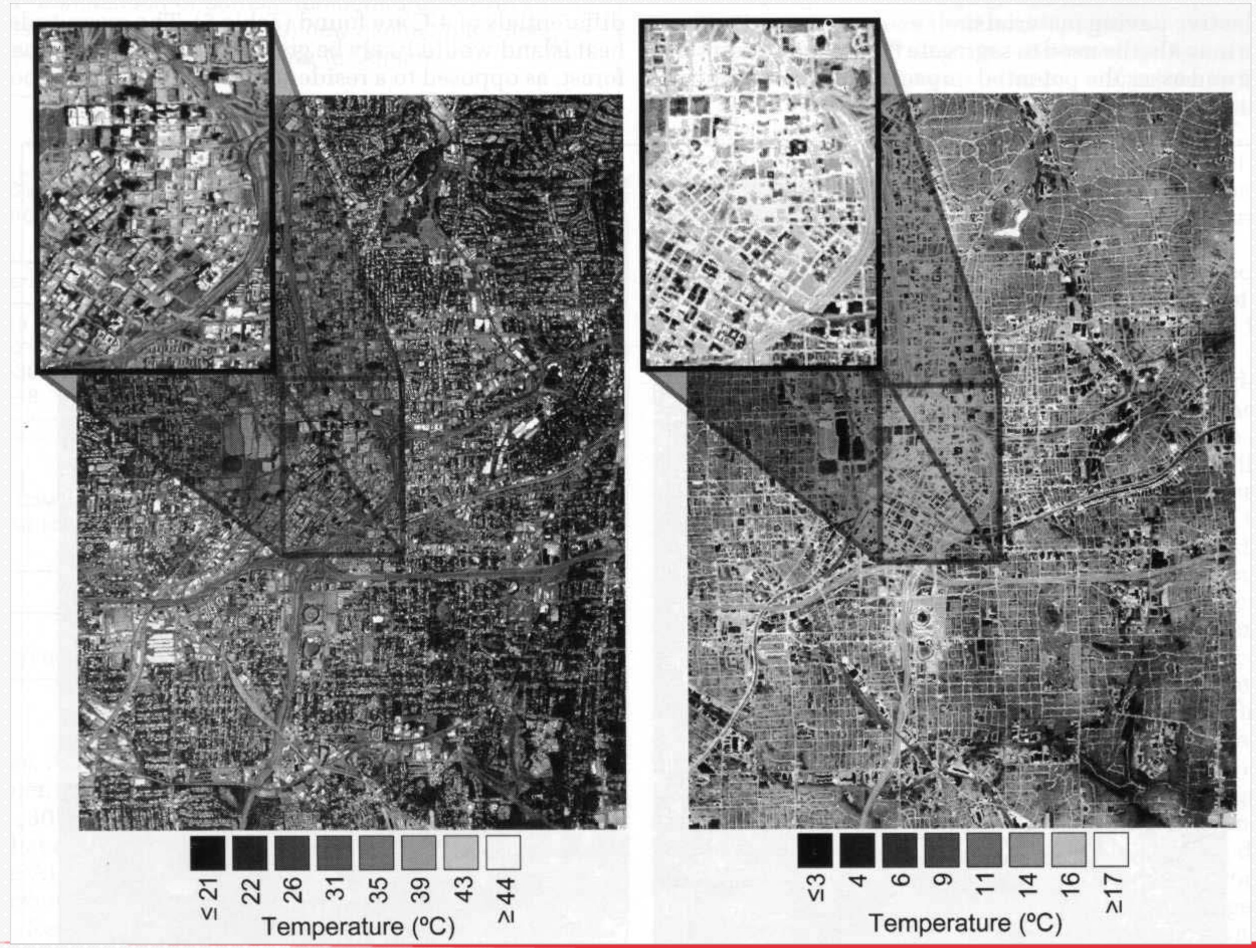

Figure 3. High spatial resolution (20 m) thermal infrared aircraft data collected over Atlanta, GA for daytime (left) and nighttime (right). The images demonstrate the detail that can be discerned about surface temperatures thermal energy fluxes from different urban surfaces from high spatial resolution data. (Source: Quattrochi, D.A., J.C. Luvall, D.L. Rickman, M.G. Estes, Jr., C.A. Laymon, and B.F. Howell, 2000. A decision support information system for urban landscape management using thermal infrared data. *Photogrammetric Eng. and Remote Sensing*, 66(10): 1195-1207).

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Key Requirements:

The key requirements for a sensor capable of collecting high spatial, temporal, and spectral resolution data over urban areas are founded in two fundamental science questions:

1. How does urbanization affect the local, regional, and global environment?
2. Can we characterize this effect to mitigate its impact on human health and welfare?

These basic science questions can in turn be broken down into three related sub-questions:

I. What are the relationships of land cover/land use change as they affect energy balances over the city?;

II. What are the dynamics of the UHI on a spatial and temporal scale and what is the impact of the UHI on biophysical, climatic, and environmental processes?

III. How can characteristics associated with human health such as factors influencing heat stress and surface temperatures, affect vector-borne diseases as a function of urbanization?

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Affordability Achieving Required Measurements in the Decadal Timeframe:

- HyspIRI with its hyperspectral VSWIR and multispectral TIR capabilities is extremely well suited for providing high spatial, temporal and spectral resolution data for modeling/monitoring land cover, biophysical, and societal changes in urban environments.
- The VSWIR and TIR data obtained by HyspIRI can be used to provide integrated higher level datasets for use in developing detailed quantitative information on spectral responses, surface temperatures, and albedo for the surface material types that comprise the heterogeneous urban landscape.
- Studies have shown (e.g., Roberts et al.,. 2012) illustrate that HyspIRI will provide accurate measurement of the differences between urban surfaces, given its high spatial, temporal, and spectral resolutions.
- Science Questions and Requirements matrix supports the potential capabilities of HyspIRI for furthering our understanding urban biophysical/human/social interactions.

Thermal Remote Sensing in Land Surface Processes, 2nd Edition

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Chapter 1: Introduction
Update of the 1st edition, why this book is necessary, description of the books' overall contents
Chapter 2: A Brief Review of Thermal Infrared Remote Sensing
TIR theory, modes of heat transfer, atmospheric windows, solar heating and the diurnal temperature cycle, blackbody radiation, thermal properties of surface materials, etc.
Chapter 3: TIR Global Imagers and Sounders
GOES, MODIS, ASTER, VIIRS, Landsat, etc.
Chapter 4: TIR Data for Quantification and Analysis of Land-Atmosphere Interactions
Use of TIR date for measuring and quantifying land-atmosphere energy dynamics and fluxes
Chapter 5: Thermal IR Remote Sensing Data of Vegetation and Ecosystem Energy Fluxes
Methods and models for assessing vegetation energy fluxes
Chapter 6: Thermal IR Remote Sensing for Assessment of Evapotranspiration and Soil Moisture Availability
New methods and models for using TIR data to determine evapotranspiration and soil moisture availability and vegetation stress
Chapter 7: The NASA ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)
Description of ECOSTRESS and how it will be used to measure the temperature of plants and use that information to better understand how much water plants need and how they respond to stress
Chapter 8: Geological and Geothermal Applications of TIR Data
Examples of new developments and methods of how TIR data can be used for geological and geothermal mapping and analysis and identifying changes in Earth surface composition

Chapter 9: TIR Data for Monitoring Volcanoes

Examples of new developments and methods ins using TIR remote sensing data for volcano surface temperature and thermal manifestation of active volcanoes

Chapter 10: TIR Data for Snow and Ice Mapping

New developments in the use of TIR remote sensing data for mapping snow and ice features and temperatures

Chapter 11: TIR Remote Sensing of Gaseous and Particulate Emissions in the Atmosphere

How TIR remote sensing can be used to evaluate gaseous and particulate emissions in the atmosphere and examination of new developments in furthering this area of research

Chapter 12: TIR Remote Sensing Data for Natural Hazards Risk Assessment Detection and Mapping

TIR sensors for detecting and mapping natural hazard risks such as forest fires and wildfires and new methods and models for characterizing natural hazard risks

Chapter 13: Thermal Remote Sensing of the Urban Environment

Use of TIR data for new and innovative assessment of urban land surface temperatures, surface heat fluxes, urban heat island quantification urban-atmosphere energy fluxes

Chapter 14: Applications of TIR Data in Public health

How TIR remote sensing data can be used for public health applications such as vector-borne disease assessment and risk mapping, and human heat stress

Chapter 15: Summary and Insights Into the Future of Thermal Remote Sensing

Suggestions are welcome