Using Remotely Sensed Data to Map Urban Vulnerability to Heat

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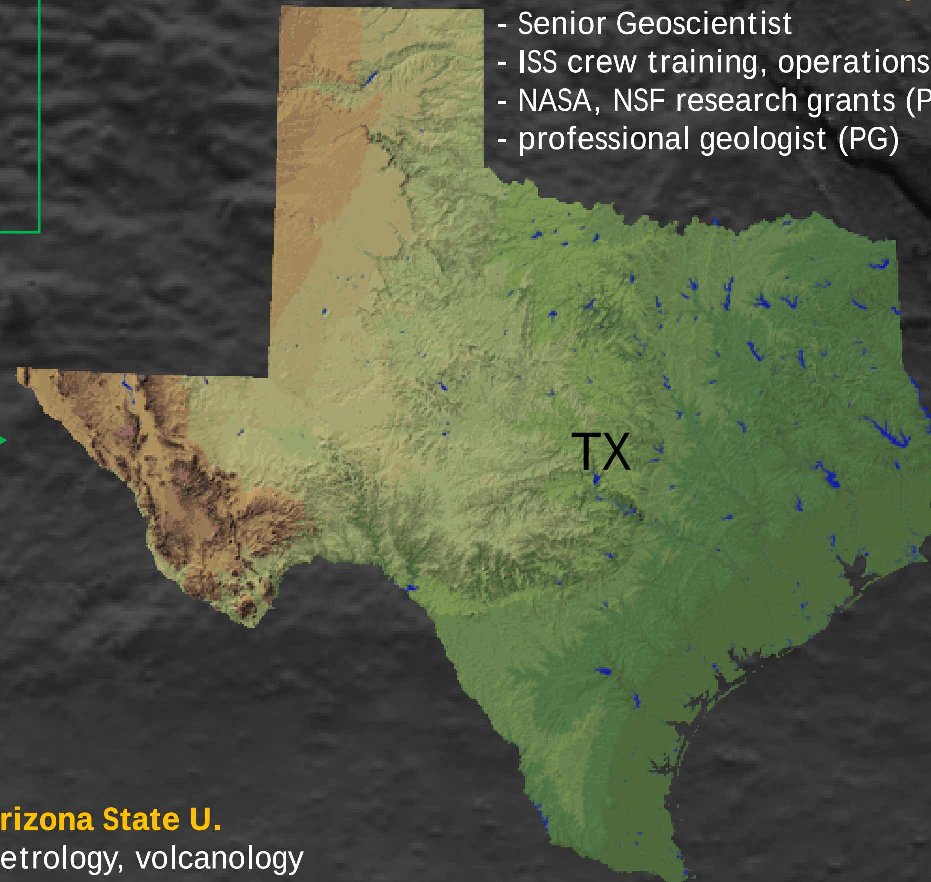
So, How Did I Get Here?

BS 1988, UMass-Lowell
- environmental science/geology
- geochemistry, petrology
- job as optical mineralogist

Crew Earth Observations 2004 -, NASA JSC
- Senior Geoscientist
- ISS crew training, operations, research
- NASA, NSF research grants (PI, co-I)
- professional geologist (PG)



MS 1992, Arizona State U.
- igneous petrology, volcanology
- job as professional consulting geologist (RG)

PhD 2000, Arizona State U.
- thermal IR remote sensing, geomorphology
- postdoc studies in urban geologic and ecologic remote sensing

Shaded relief maps from National Elevation Dataset courtesy of USGS/EROS (not to scale)

Remote Sensing (RS) is…

- ***Obtaining information about an object or phenomena without direct contact***
- Different information is obtained at different wavelengths
- Information is the result of electromagnetic wave interactions with solids, liquids, and gases – physics and chemistry, not magic
- Planetary atmosphere defines “windows” useable for remote sensing
- Optical sensors are passive (radar and LIDAR are active)

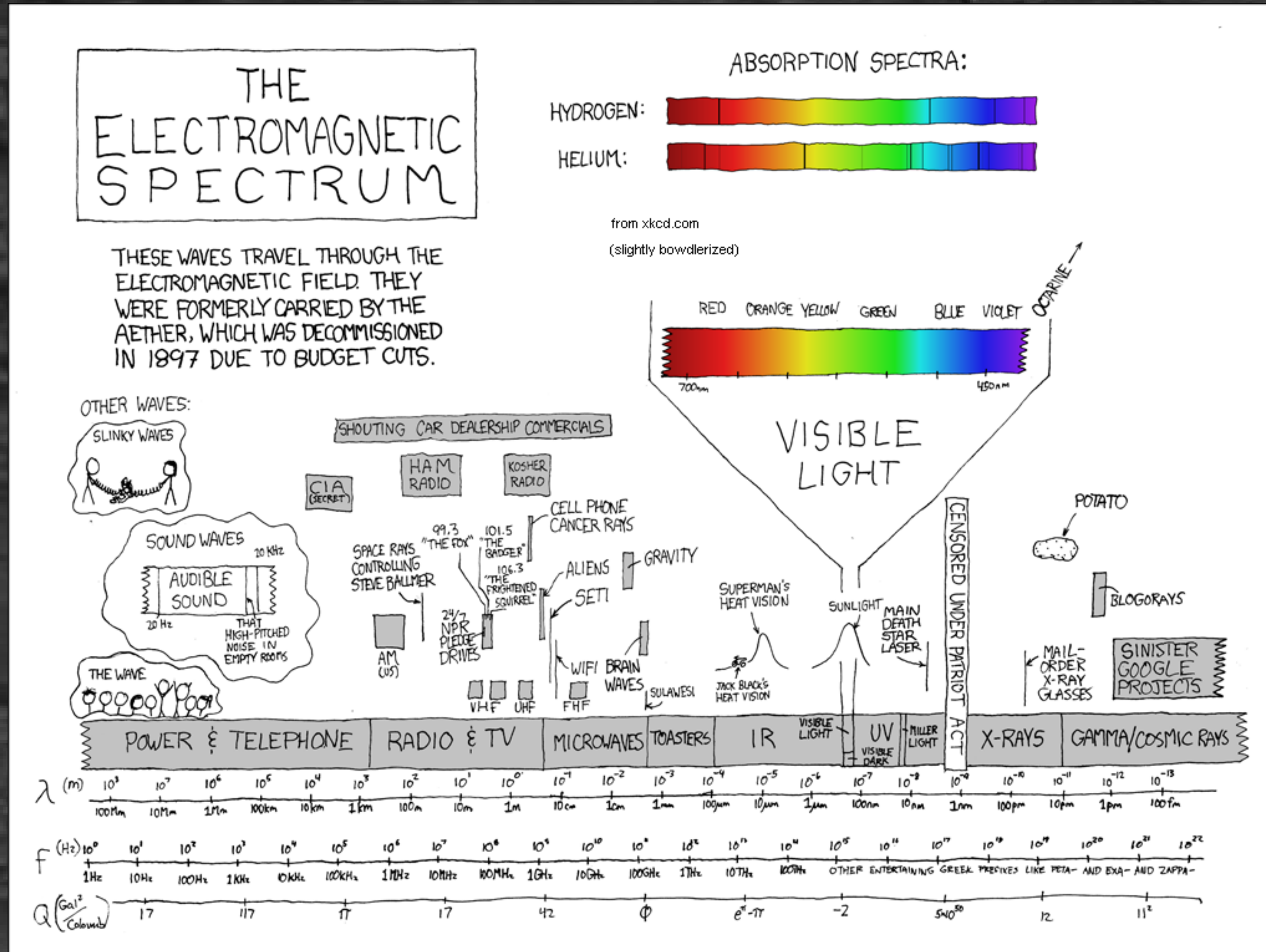
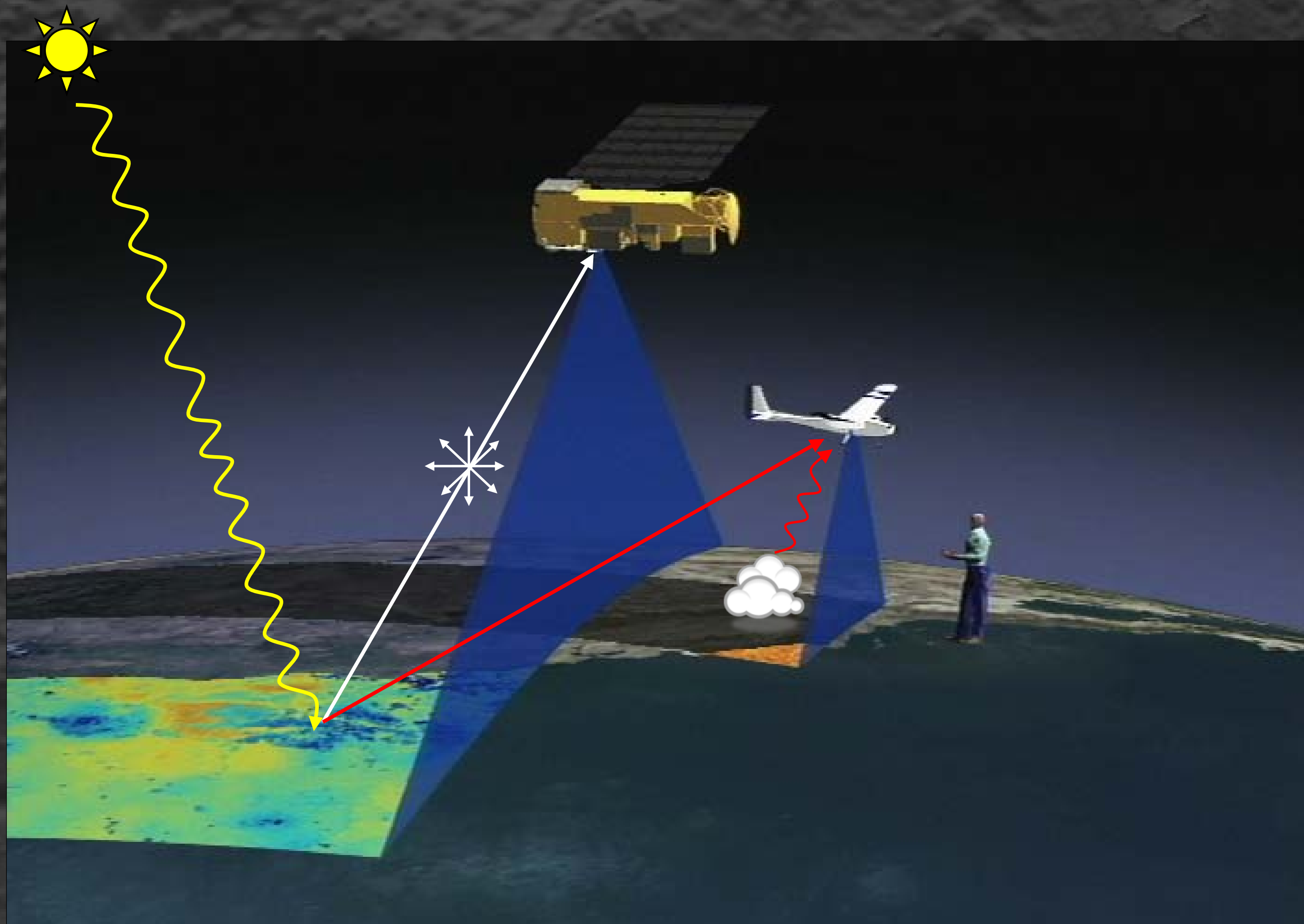


Image source: http://math.emich.edu/~aross15/coursepack3419/electromagnetic_spectrum.png

Usefulness of RS data for a given application is determined by spatial, spectral, and temporal characteristics

Speed of light (c) = 299,792,458 m/sec

Frequency = c/wavelength



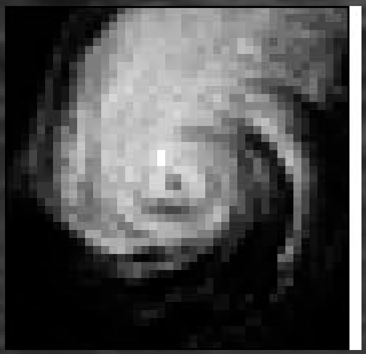
Base image source: NASA/Goddard Space Flight Center, Scientific Visualization Studio

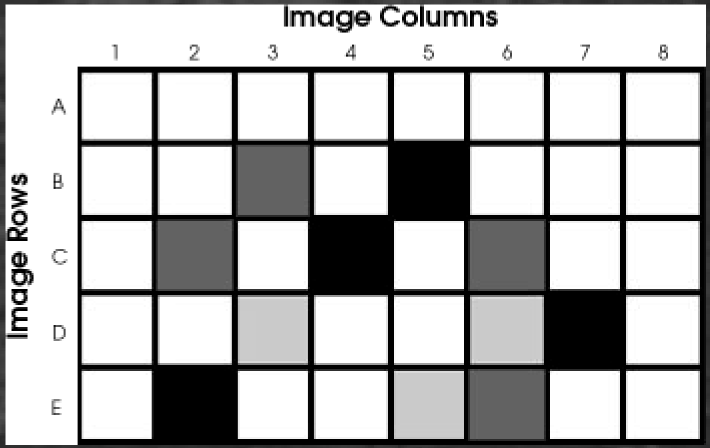
Incident energy is reflected, transmitted, or emitted from surficial materials; sensor sees mixture of energy from multiple surface materials and atmosphere

For passive systems, information is obtained from only the uppermost surface (~130 microns, or 1.5 X width of human hair); no depth profiles!

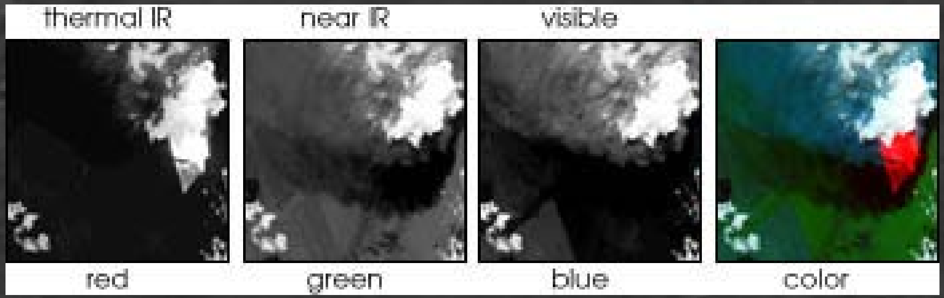
Fundamentals - Pixels

Digital images are made up of square picture elements, or pixels:



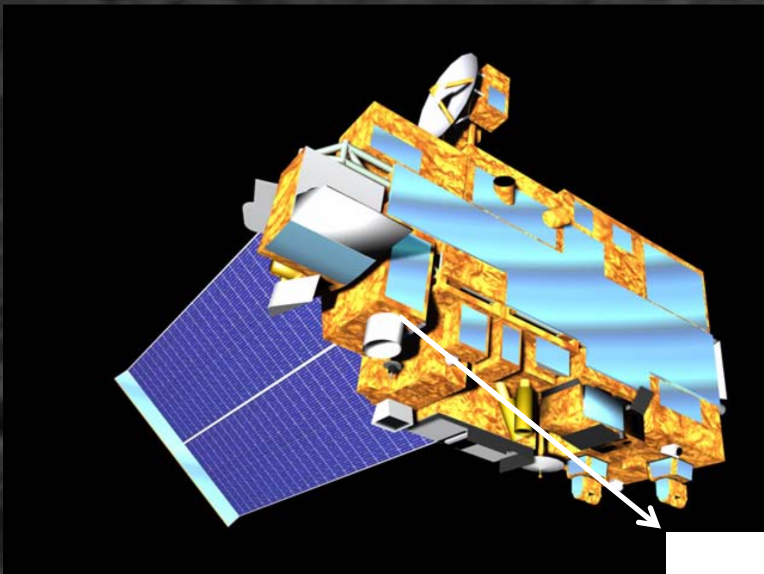


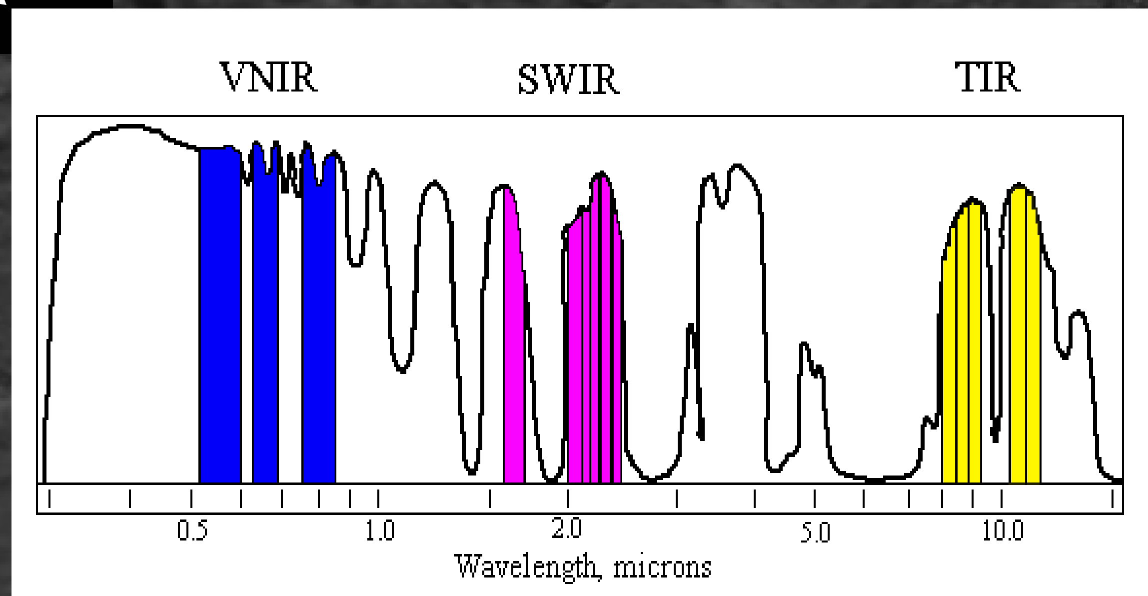
Bright pixels indicate a strong return of energy from the surface in a given band/wavelength; you can merge three bands of information together to form a color image that our eye/brain can understand:



Images courtesy of
NASA Earth Observatory
http://earthobservatory.nasa.gov

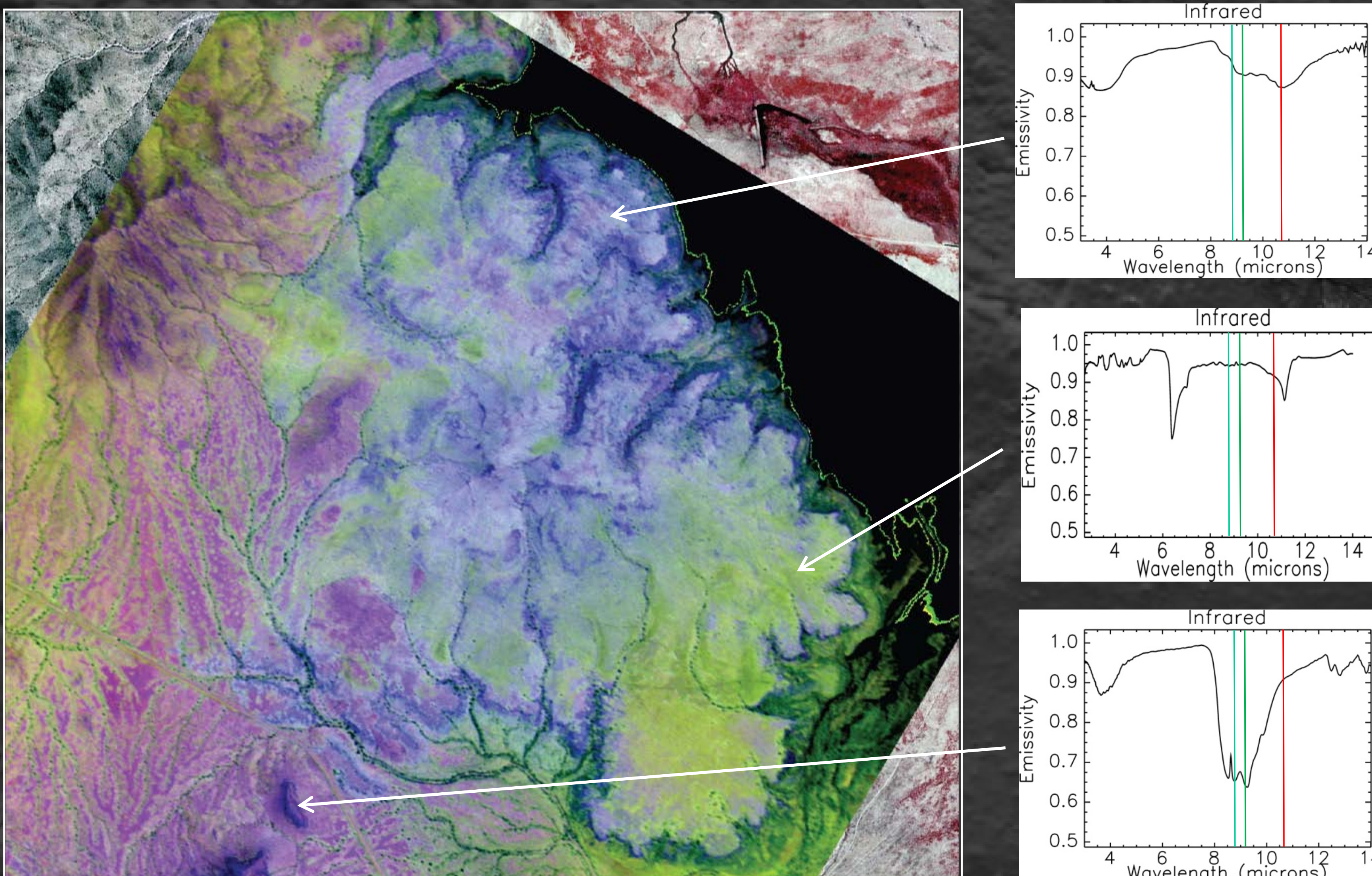
Sensor Design





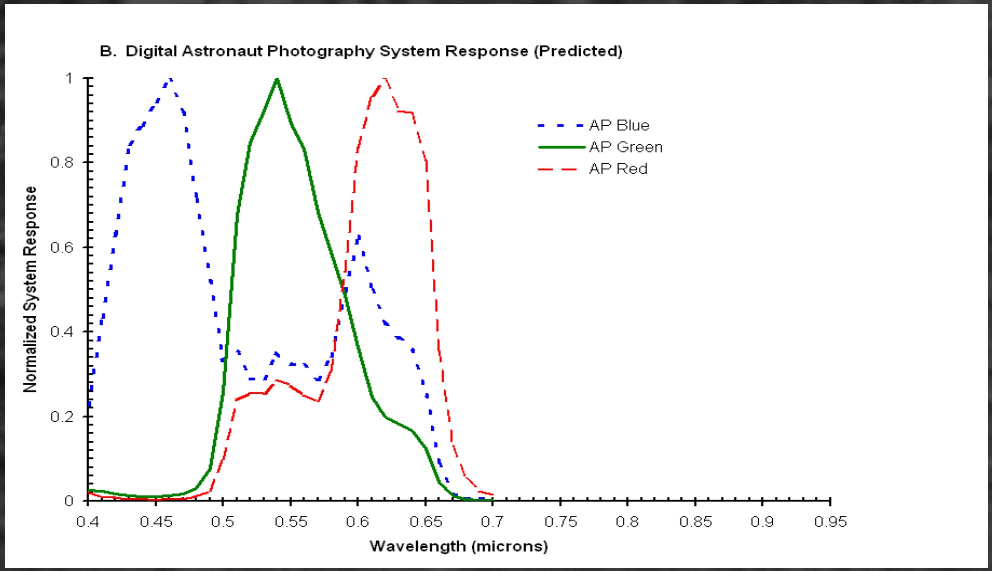
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

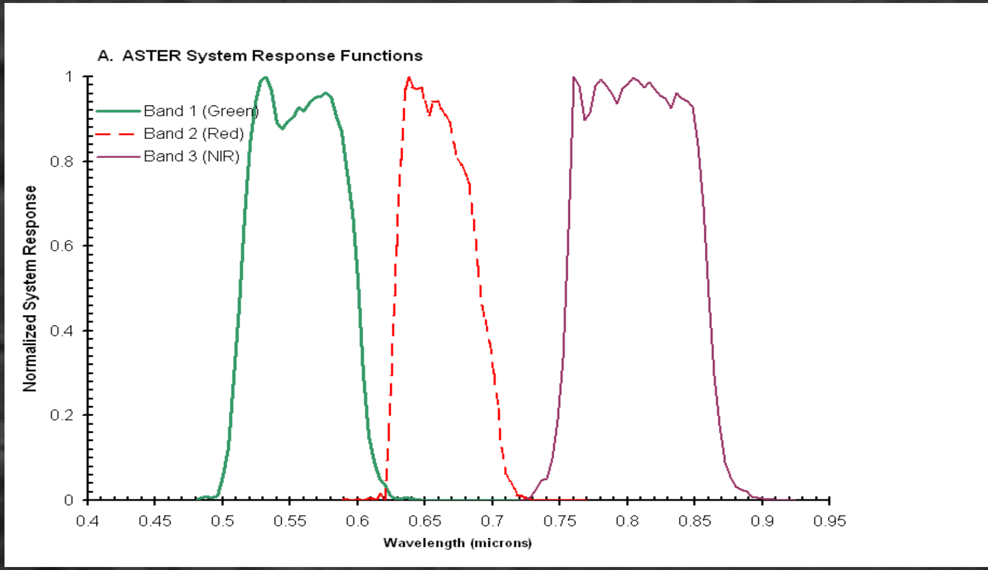
Remote sensing instruments are designed with *bands* or channels that are sensitive to different wavelengths – the degree of response to a material in the different bands determines its spectral "fingerprint"



Warford Ranch Shield Volcano (Arizona), TIMS thermal infrared data

Astronaut Photography





- AP acquired since 1960s as part of Apollo, Skylab, Mir, Shuttle, and ISS missions

- Extensive database of images with variable look angles, spatial resolutions, and repeat times complements automated sensor data archives

- Digital camera AP now approaching commercial spatial resolutions (4 m/pixel) for significantly lower cost

- Nikon high-end digital cameras now in use aboard the ISS

Crew Earth Observations Experiment

Nikon D2Xs Camera

Image source: Nikon

Effective pixels	12.4 million
Image sensor	CMOS sensor, 23.7 x 15.7mm size, 12.84 million total pixels
Image size	Full Image: [L] 4,288 x 2,848-pixel / [M] 3,216 x 2,136-pixel / [S] 2,144 x 1,424-pixel

How much detail can we capture with current cameras? - Burj Khalifa Tower, Dubai

ISS022-E-24940, acquired Jan 13 2010, 400 mm lens

Houston, TX: ISS023-E-78463, taken on Feb. 28, 2010 with Nikon D3

esoG NASA Crew Earth Observations Experiment

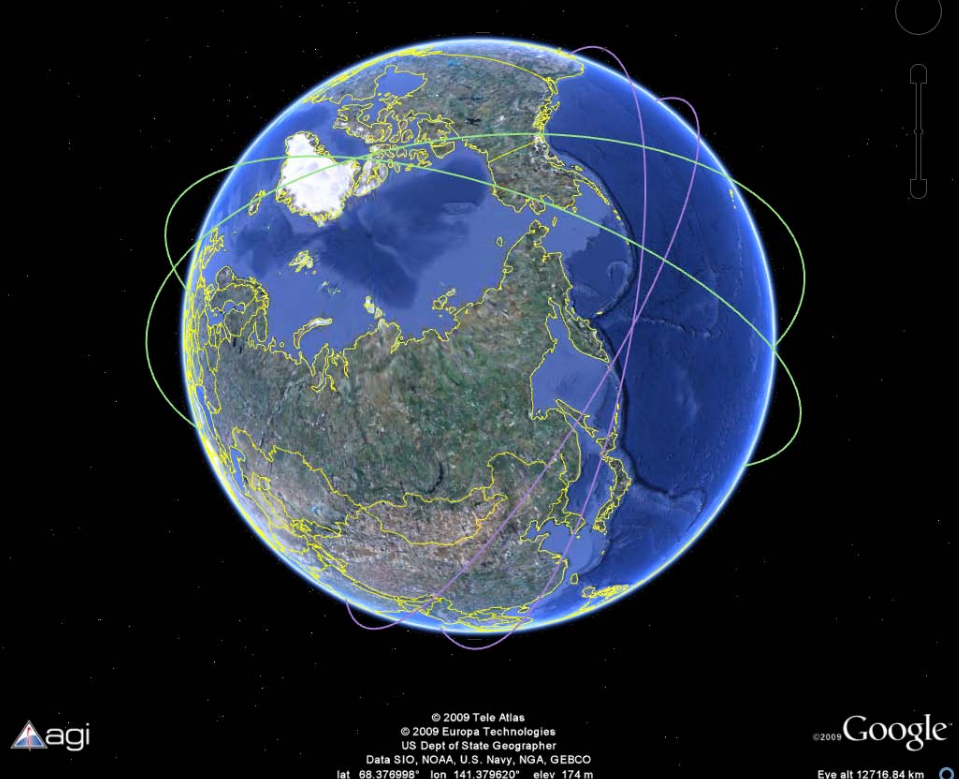
Crew Earth Observations (CEO)

- Science team based at NASA Johnson Space Center
- Currently tasked with performance of Crew Earth Observations experiment payload aboard the ISS
- Astronaut training for specific science objectives (includes urban areas, ecological monitoring sites, glaciers, deltas, megafans, volcanoes, impact craters)
- Download and cataloging of images for entry into database, curation of astronaut photography database
- Distribution of data to collaborating scientists and performance of research in ecological land cover classification and change dynamics, Mars analogs, volcanic hazards
- Educational outreach (NASA Earth Observatory, Public Affairs Office, NASA Hurricane Resource web site, Google Earth, Expedition Earth and Beyond)

Fundamentals – Temporal Coverage

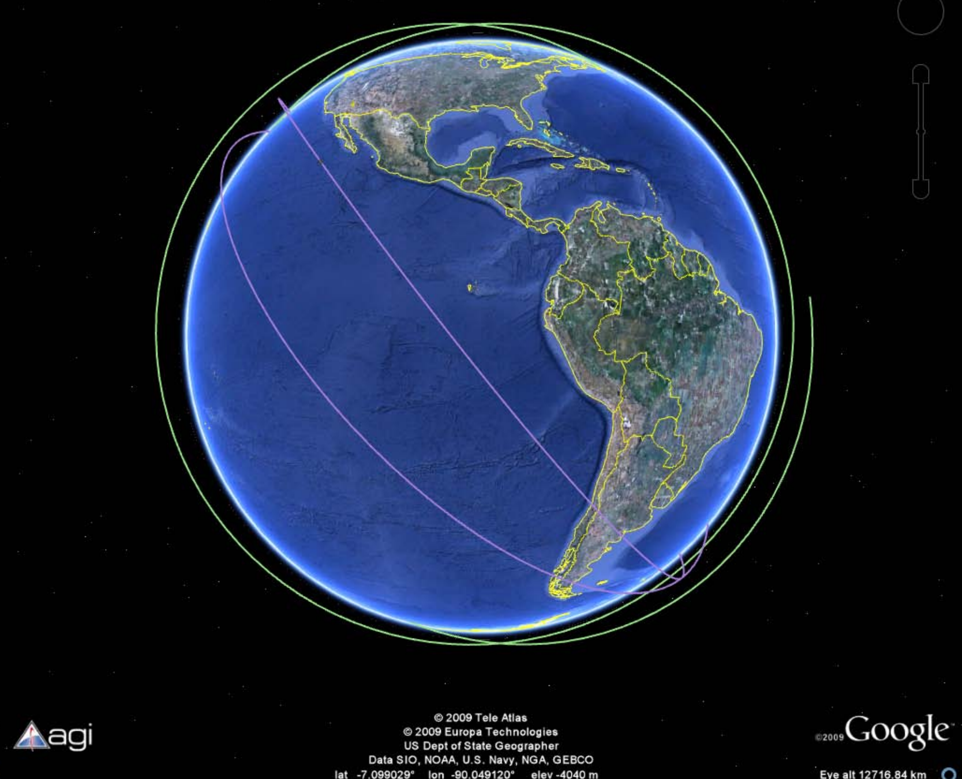
Polar orbit

- sun-synchronous – designed for long term repeatability of data
- Typically nadir viewing, crosses every point on Earth ~ 12-14 days near local solar noon/local midnight
- Landsat series collecting data since 1972
- Pointing capability, satellite constellations



Inclined Equatorial Orbit

- sun-asynchronous – similar illumination for 3-4 days every 90 days
- nadir to highly oblique imagery possible from hand-held cameras, WORF
- ISS now being considered for new Earth obs sensors
- provides opportunity to collect unique datasets for scientific study, operational monitoring



esoG NASA Crew Earth Observations Experiment

Scanning the Surface – Analyzing Remotely Sensed Data

Broad approaches to doing science with remotely sensed data:

Visualization

- RGB and greyscale images good for initial discrimination of surficial materials, measurement of features, detection of change over time, display of specific measurements (such as surface temperature)

Classification

- Classification of image pixels using statistical analysis of variability (numerous techniques) – useful for automated mapping of surficial materials (asphalt vs. bare soil for example)

Spectral Analysis/Indices

- Useful for determining elemental or material components in a single image pixel
- Can extract detailed material identifications from geologic, biologic, and built materials

Urban Vulnerability to Climate Change: A system dynamics analysis

NSF-funded grant, PI Sharon Harlan
School of Human Evolution and Social Change, Arizona State University
Co-PIs Grossman-Clarke, Lant, Martin, Stefanov

Hypotheses

•Exposure to excessively warm weather threatens human health in all types of climate regimes.

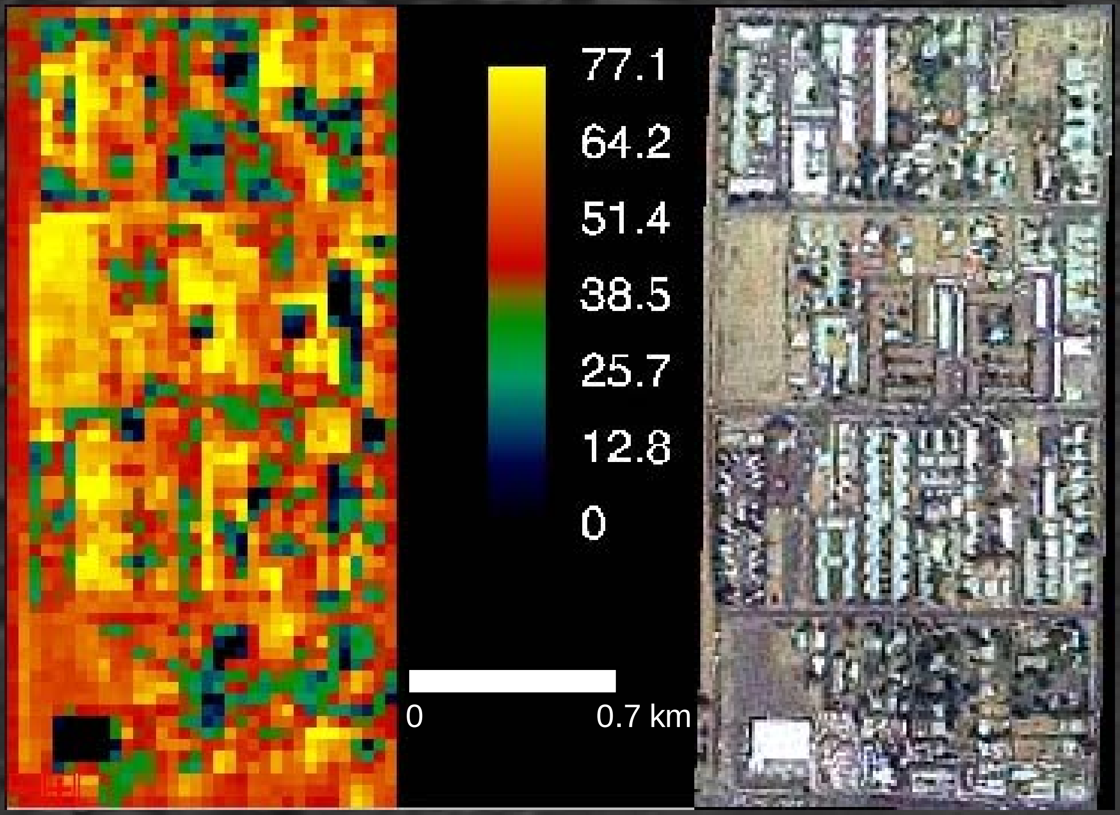
•Heat kills and sickens multitudes of people around the globe every year – directly and indirectly.

•Climate change, coupled with urban development, will impact human health.

•Phoenix is an ideal laboratory for studying urban heat islands under extreme climate conditions.

•Social factors are critical in vulnerability analysis.

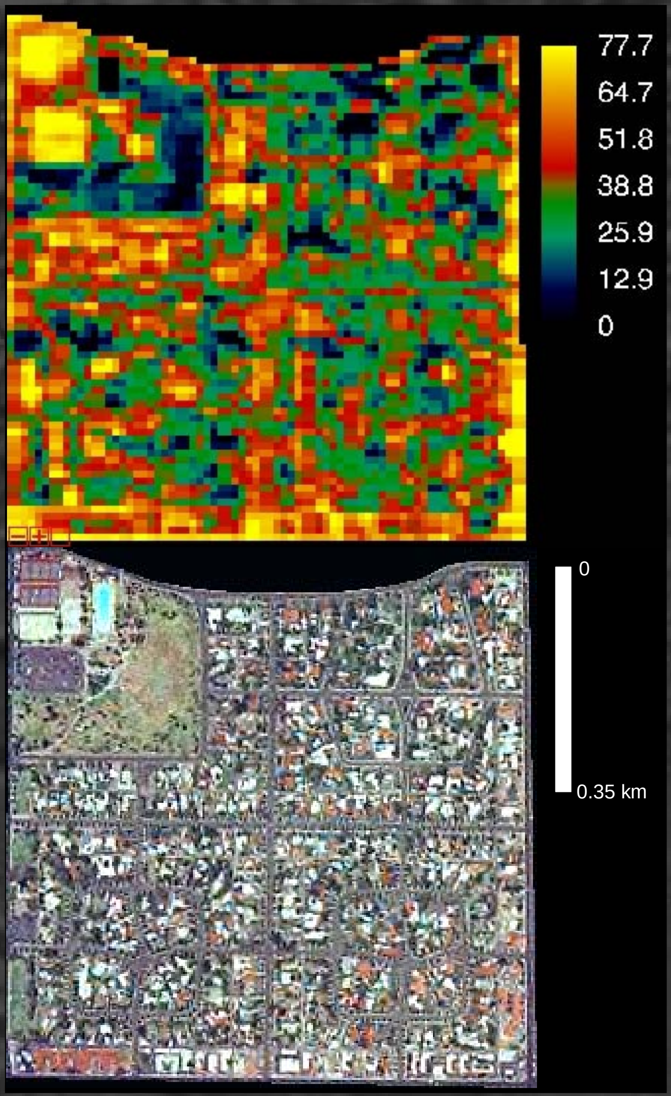
Surface T Map – Xeric or “Zeroscape” Low-Income Neighborhood



NSF Biocomplexity Grant
to Harlan, Brazel, Larson, Stefanov

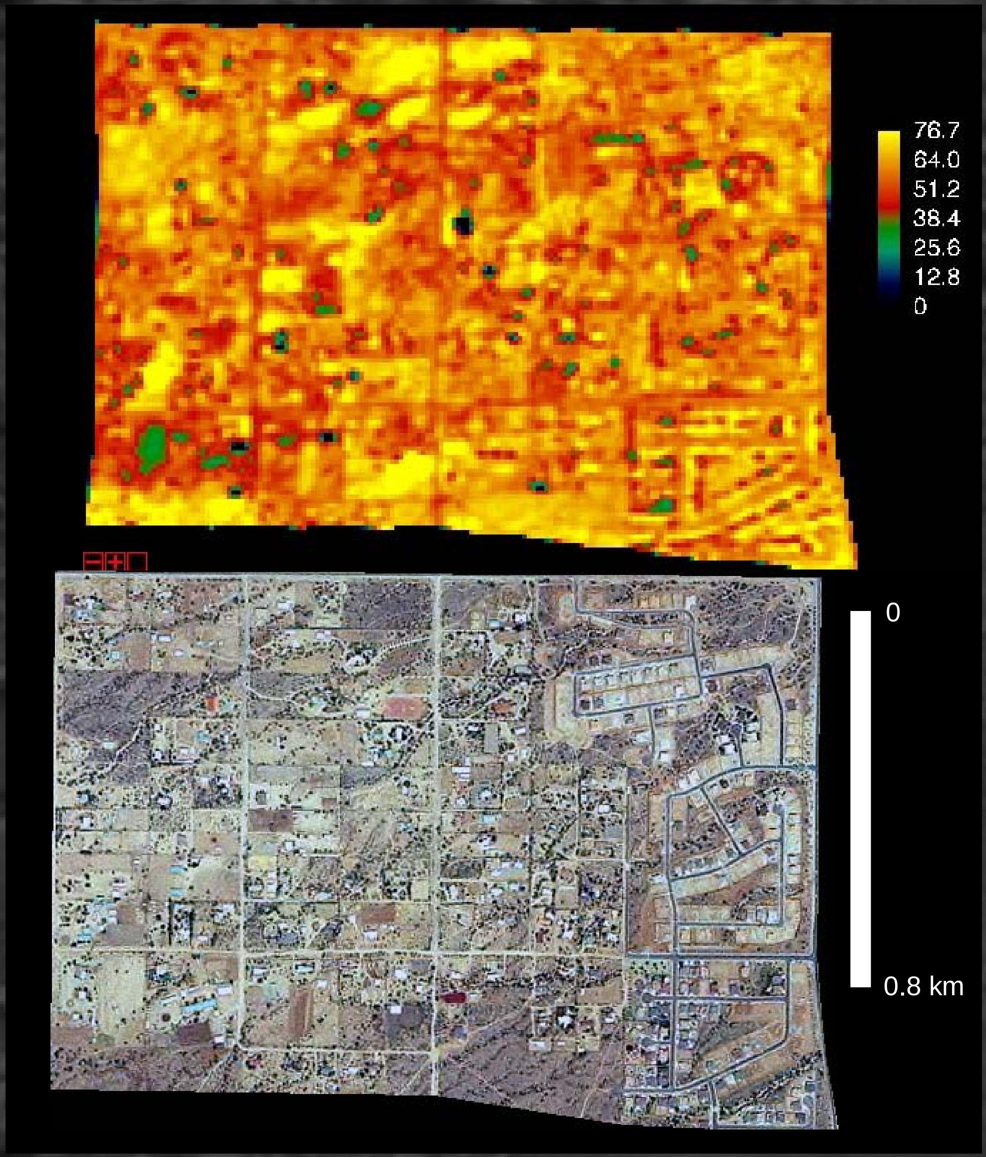
Left – MASTER surface T; Right – 3 m/pixel digital aerial orthophotography

Surface T Map – Mesic High-Income Neighborhood

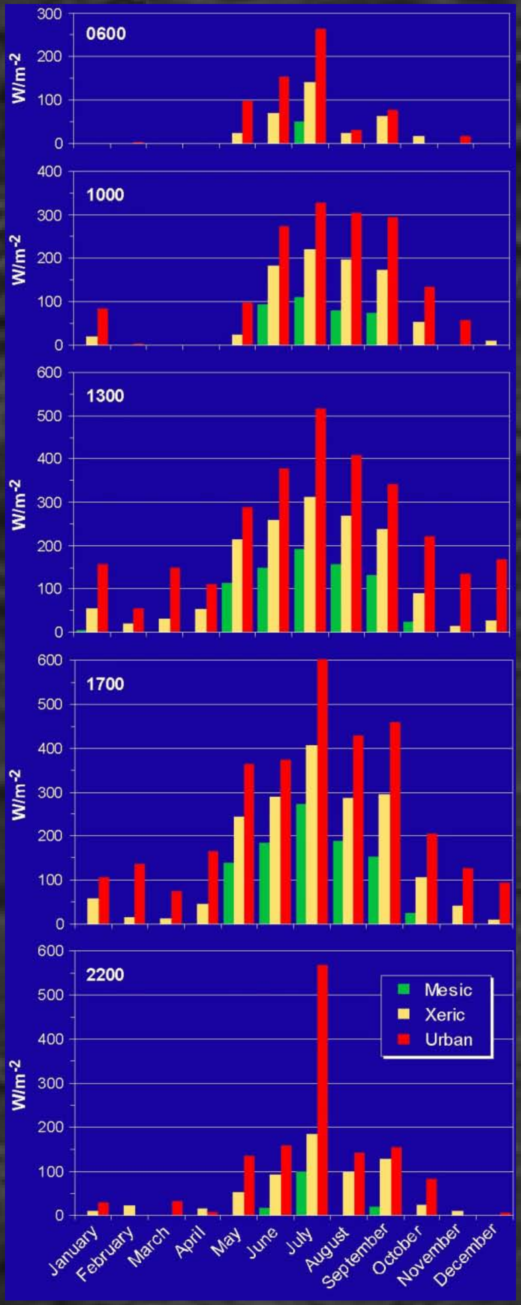


Top – MASTER surface T; Bottom – 3 m/pixel digital aerial orthophotography

Surface T Map – Xeric High-Income Neighborhood



Top – MASTER surface T; Bottom – 3 m/pixel digital aerial orthophotography



Results from OUTCOMES Model

Urban residential or "zeroscape"

Mesic residential

Xeric residential

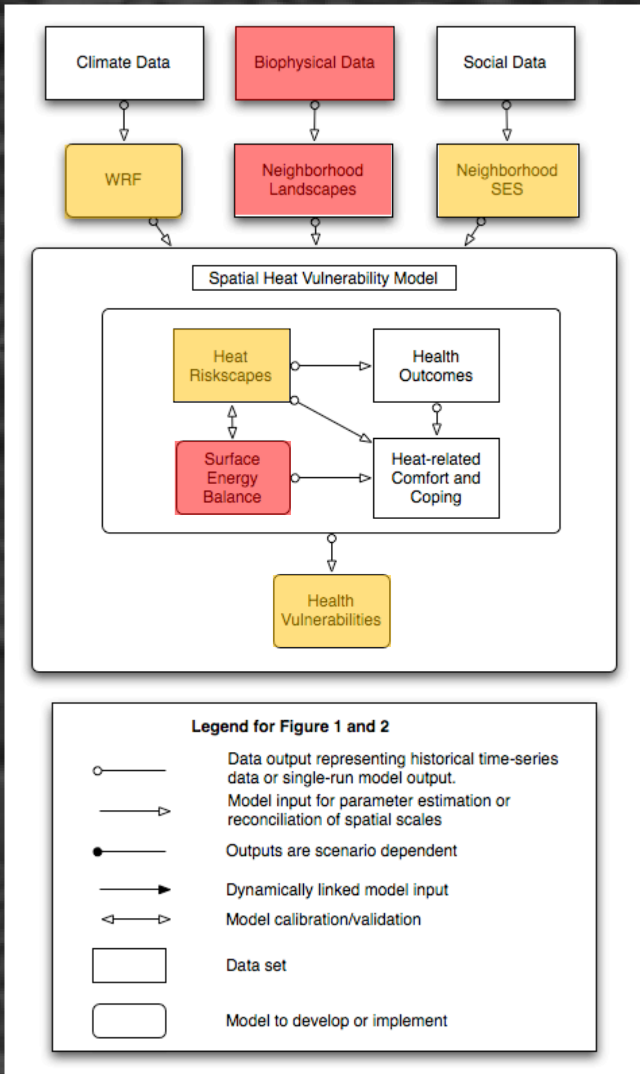
Overarching Research Questions

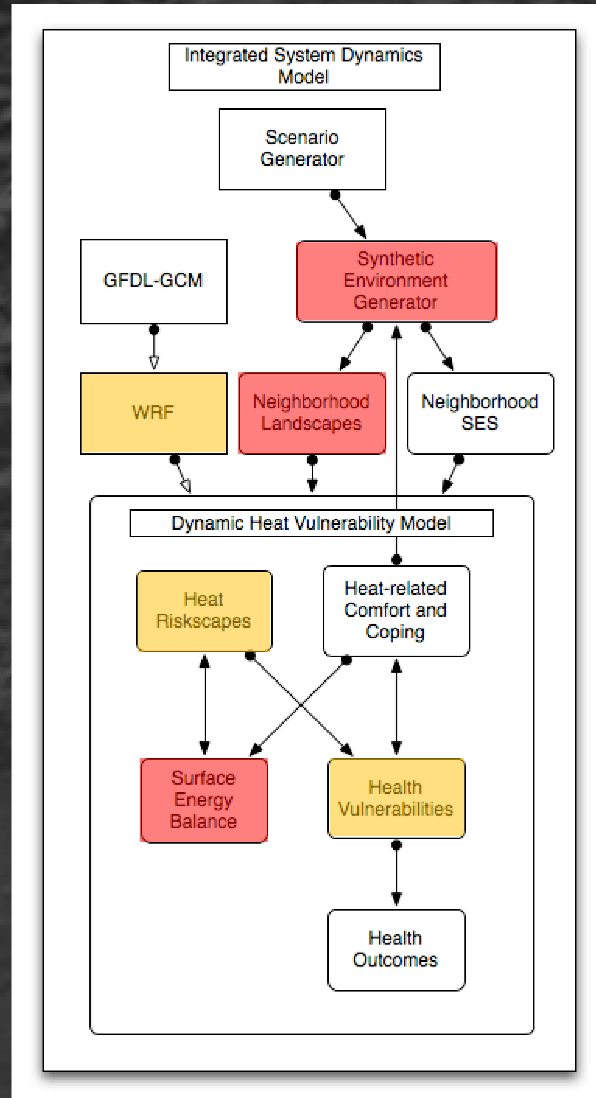
- 1) How does the spatial structure of heat “riskscapes” change through time and how are “riskscapes” related to changes in urban landscape cover characteristics, seasonal variations in local climate, global climate, and residential segregation?

- 2) How have residentially segregated neighborhoods, increasing environmental and social inequalities, and heterogeneous heat “riskscapes” rendered low-income and racial/ethnic minority populations disproportionately vulnerable to heat-related health hazards?

- 3) How will heat-related health vulnerabilities be distributed across particular places and population subgroups in the future?

System Dynamics approach





Critical input: data and/or value-added products required for model component

Supporting input: data and/or value-added products useful for context or constraints on other variables within model component

UVCC Remote Sensing Research Questions and Goals

- Are vegetation cover, surface temperature, and/or land cover/land use trends over time (approx. 1970s – present) visible in moderately high-resolution Landsat data of the Phoenix area? Do they correlate with social demographic trends? Do they correlate with climatic trends?

- Can we observe anomalous (short term) changes in the above parameters using change detection approaches, and if so, can they be correlated with social and/or climatic changes?

- Can we derive very high resolution land cover classifications of study neighborhoods using Object Based Image Analysis and NAIP data?

- Can we improve urban and regional climate models using improved land cover, vegetation, and surface temperature data derived from various satellite and airborne sensors? What are the appropriate LULC classes, spatial scales needed for input into climate and system dynamics models?

Crew
Earth
Observations
Experiment

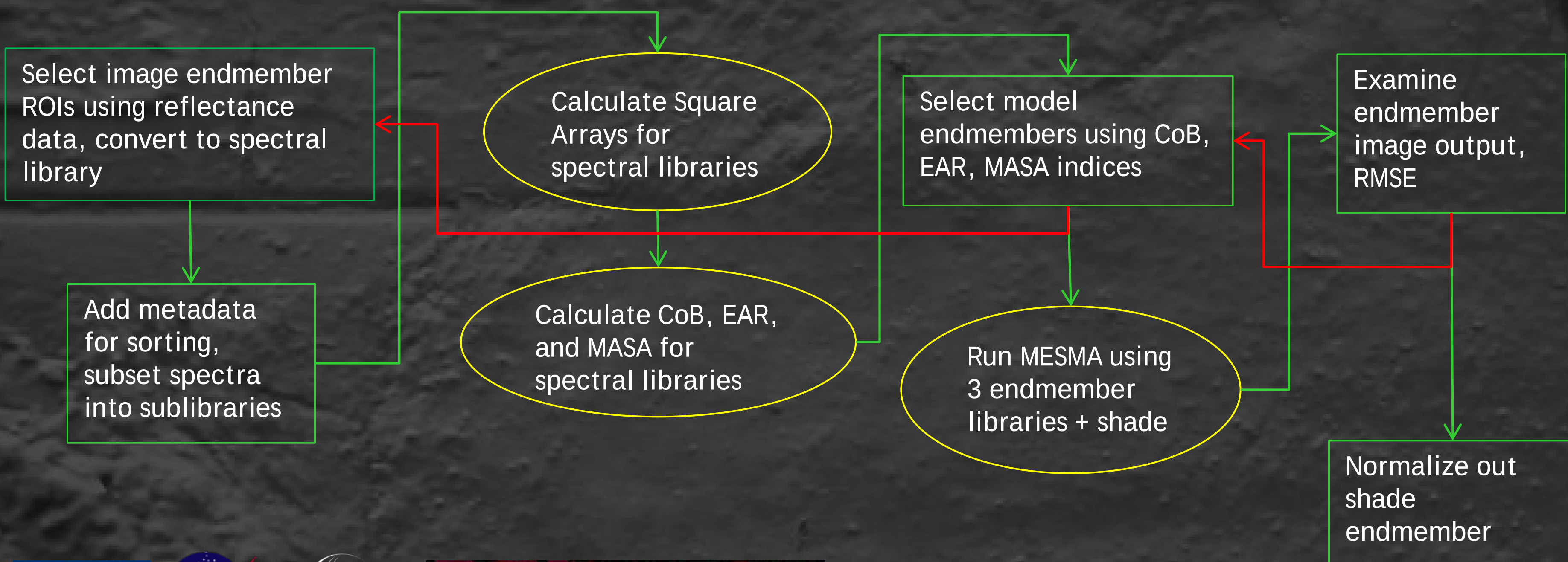
ARIZONA STATE UNIVERSITY

Multiple Endmember Spectral Mixing Analysis (MESMA)

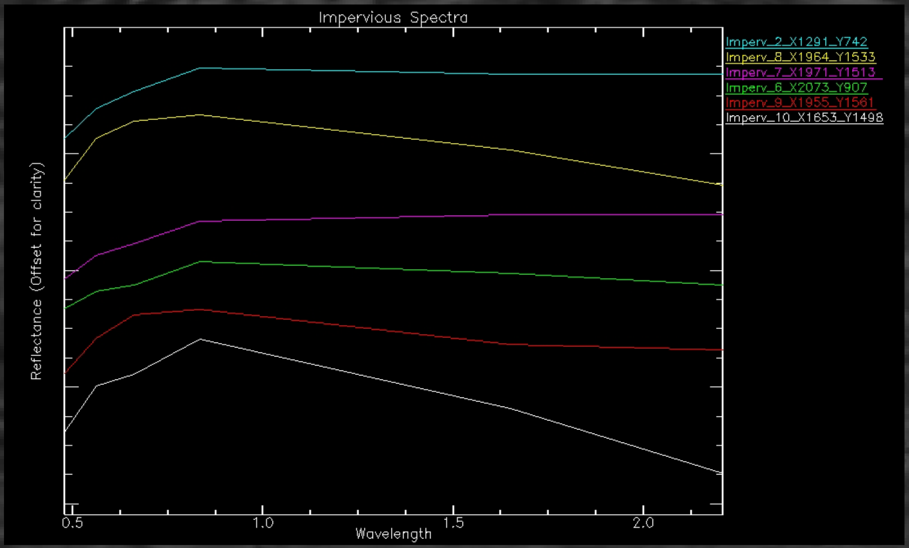
- Per-pixel percentages of vegetation, pervious, and impervious materials desirable for input to climate models, preferable to hard-classified LULC classifications

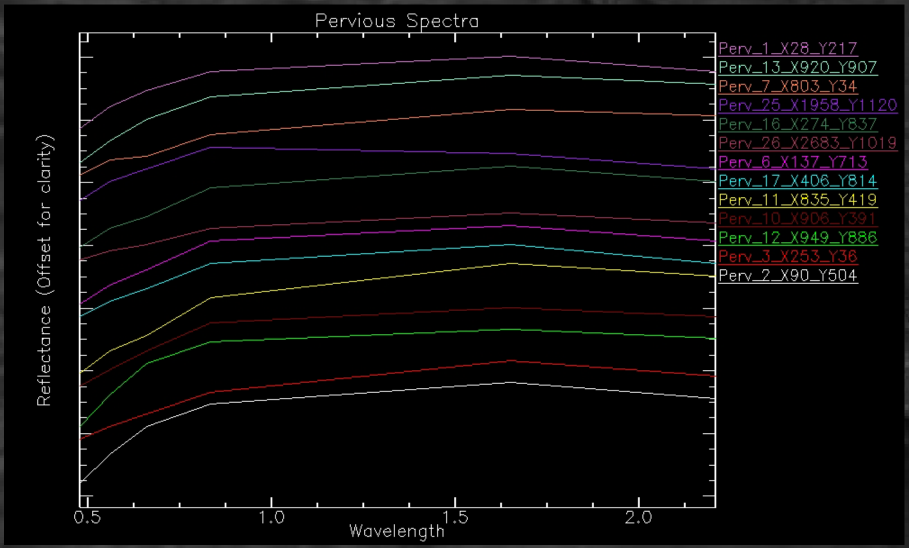
- MESMA approach developed by D. Roberts and colleagues at UCSB, allows for variation of spectral endmembers on a per-pixel basis – helps to overcome band limitations of multispectral data and limits of classical SMA

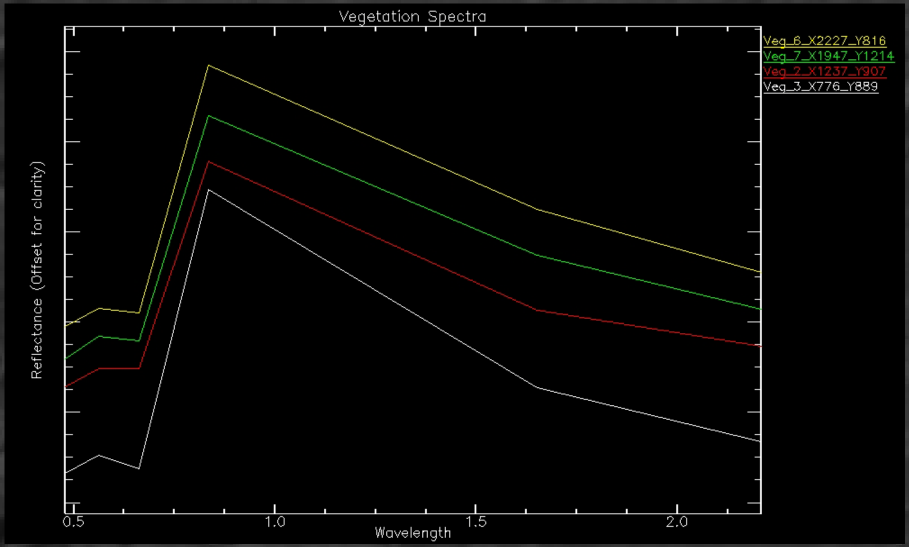
- General workflow as implemented in ENVI/VIPER Tools (Roberts, D., Halligan, K., and Dennison, P., 2007. VIPER Tools User Manual, Version 1.5.):



MESMA – Model Image Spectra





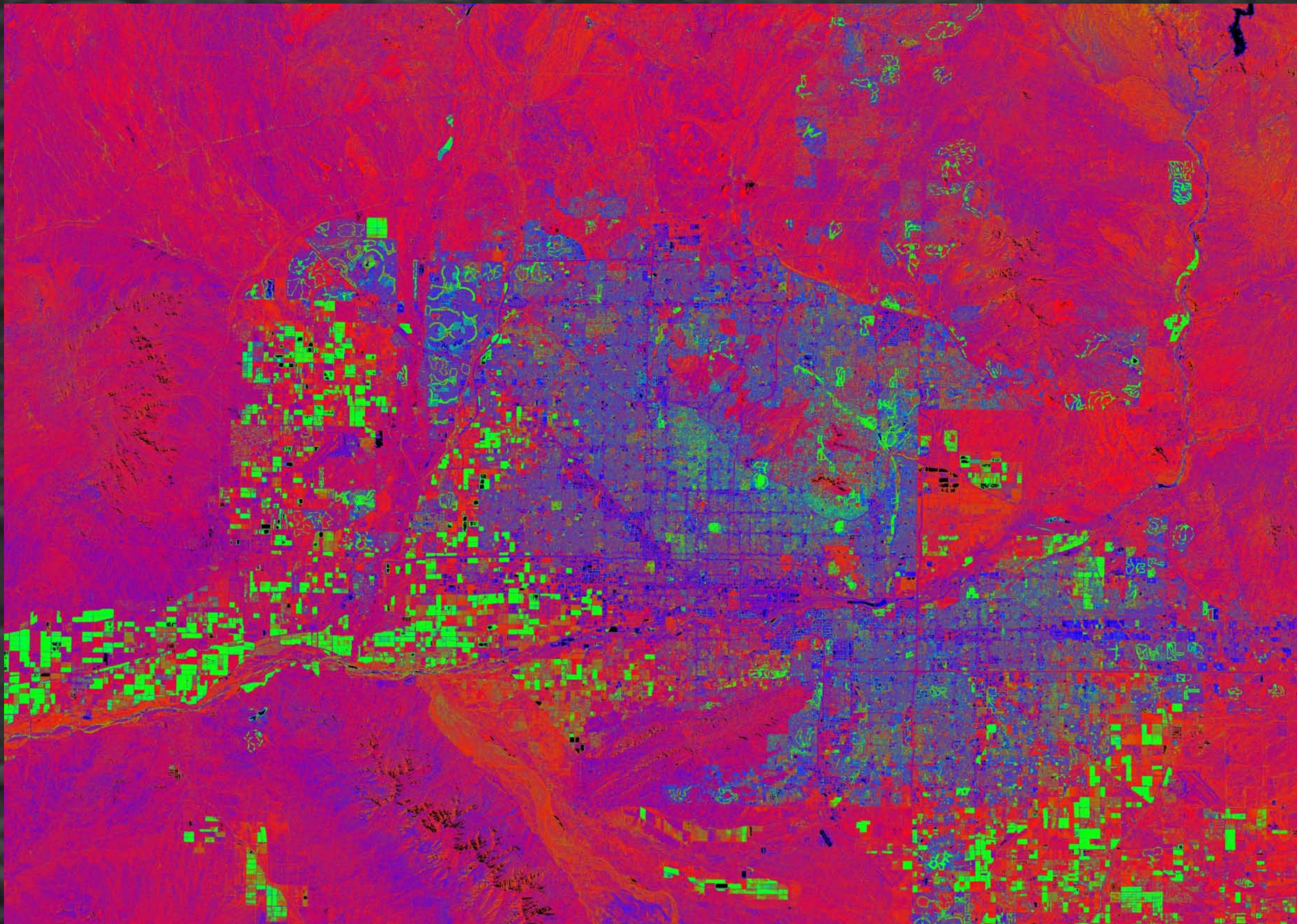


- model spectra selected from pool of 2478 image spectra using In_CoB, EAR, and MASA indices

- results in 312 spectral mixing models (+ shade endmember) applied to image

Data provided by the United States Geological Survey EROS Data Center, Sioux Falls, S.D. This material is based upon work supported by the National Science Foundation (NSF) under Grant No. GEO-0816168, "Urban Vulnerability to Climate Change." Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

Shade-Normalized MESMA Result



Red
- Pervious

Green
- Vegetation

Blue
- Impervious

Pixel color indicates % of endmembers

Less than 1% of pixels not modeled

Landsat ETM+, 3/02/2000

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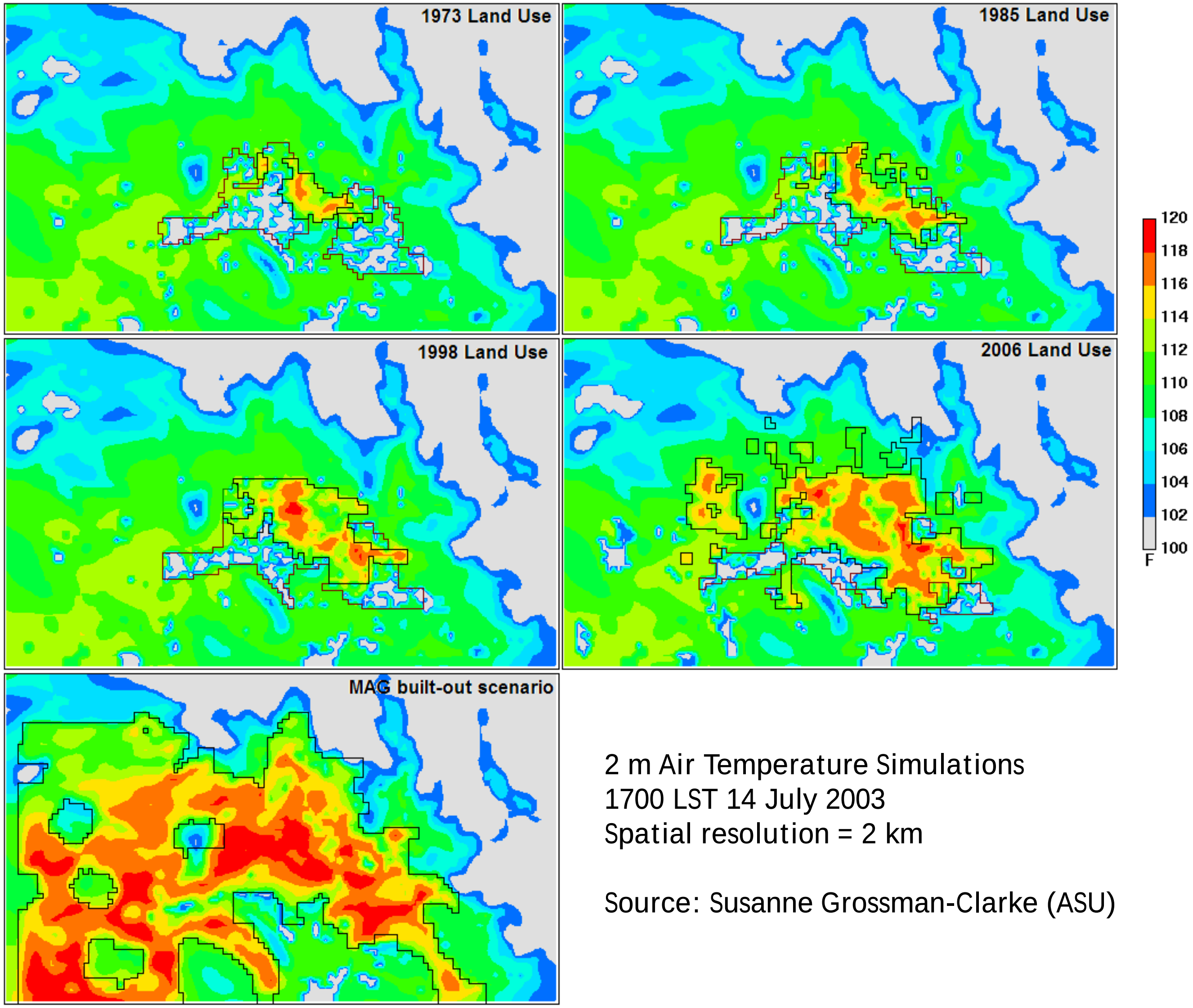
Phoenix Urban Heat Island Expansion



2 m Air Temperature Simulations
1700 LST 14 July 2003
Spatial resolution = 2 km

Source: Susanne Grossman-Clarke (ASU)

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Change Detection Analysis

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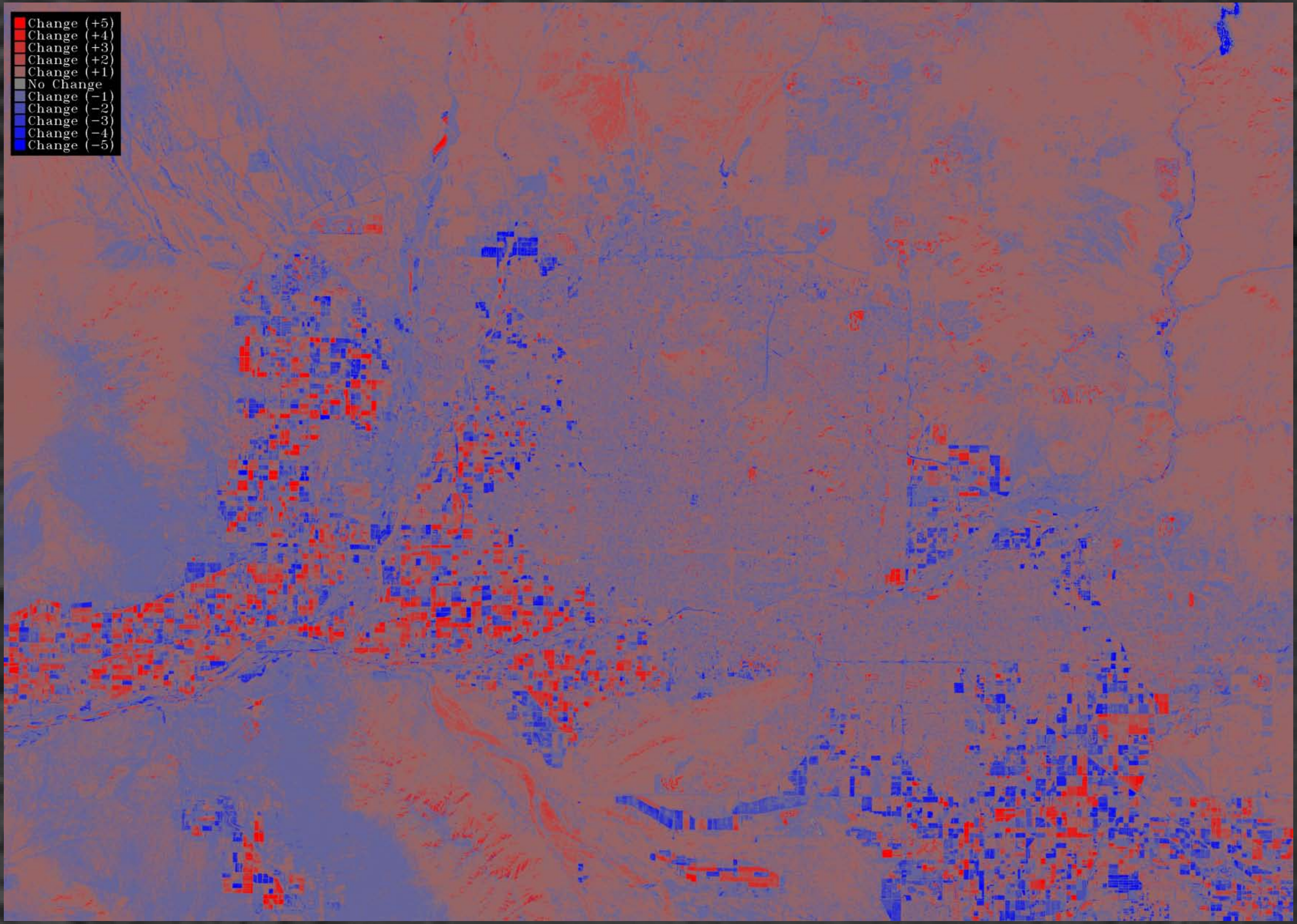

Difference image calculated for NDVI with Tf = 11/13/2000 and Ti = 10/09/1990. The majority of change in the Phoenix metropolitan area (as measured by changes in pixel brightness) is minor over the approximately 10 year period (values of -1 to 1)

Normalized Difference Vegetation Index (NDVI)

- calculated using visible red (ETM+ Band 3) and near-infrared (ETM+ Band 4) wavelength brightness:

$$NDVI = (B4 - B3)/(B4 + B3)$$

- takes advantage of spectral signature of vegetation where reflectance is low in the visible red and high in the near infrared

- indicates photosynthetically active vegetation, has been used to infer vegetation density, biomass, and leaf area index

- values range from +1 (bright) to -1 (dark)

- many types of vegetation indices, but NDVI is the most widely applied

NDVI mosaic of Houston, TX metro area obtained from Landsat ETM+ data acquired on 7/20/2000, 30 m/pixel

Surface Temperature

Surface temperature data for Phoenix, AZ metro area from the Landsat ETM+ acquired on 7/24/00, 60 m/pixel.

- Landsat ETM+ has two bands in the thermal IR (high and low gain), each 10.4 – 12.5 µm

- Bright pixels are hot, dark pixels are cool (relatively); brightness values are in ˚C

- only the surface, or “skin” temperature is measured by the sensor; not air temperature or temp t depth!

UVCC Selected References

Grossman-Clarke, S., Stefanov, W.L., and Zehnder, J.A. Urban weather, climate, and air quality modeling: Increasing resolution and accuracy using improved urban morphology. In Yang, X. (ed.), Urban Remote Sensing: Monitoring, Synthesis and Modeling in the Urban Environment. Wiley-Blackwell, New York (accepted, expected publication date 2010).

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