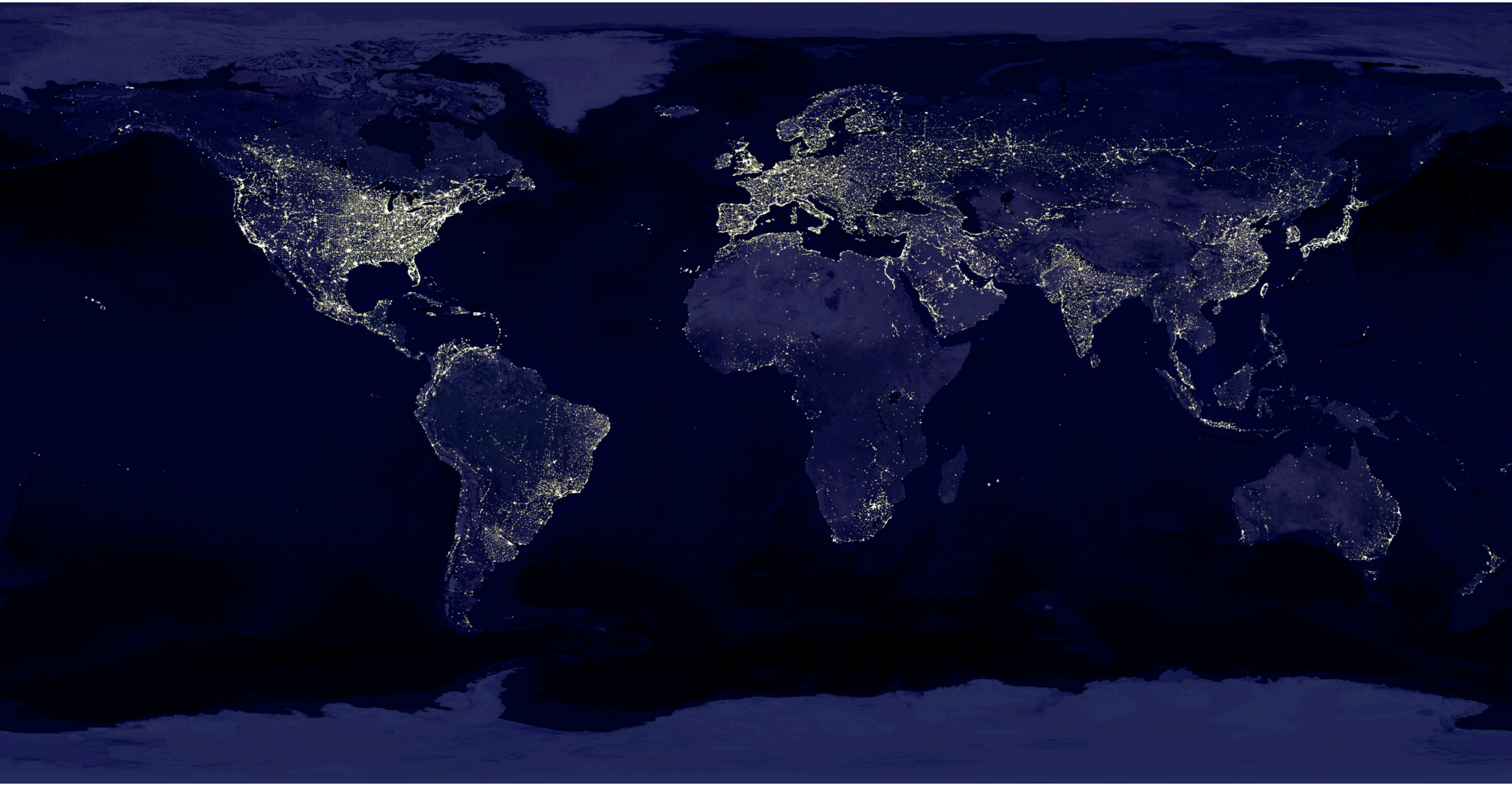
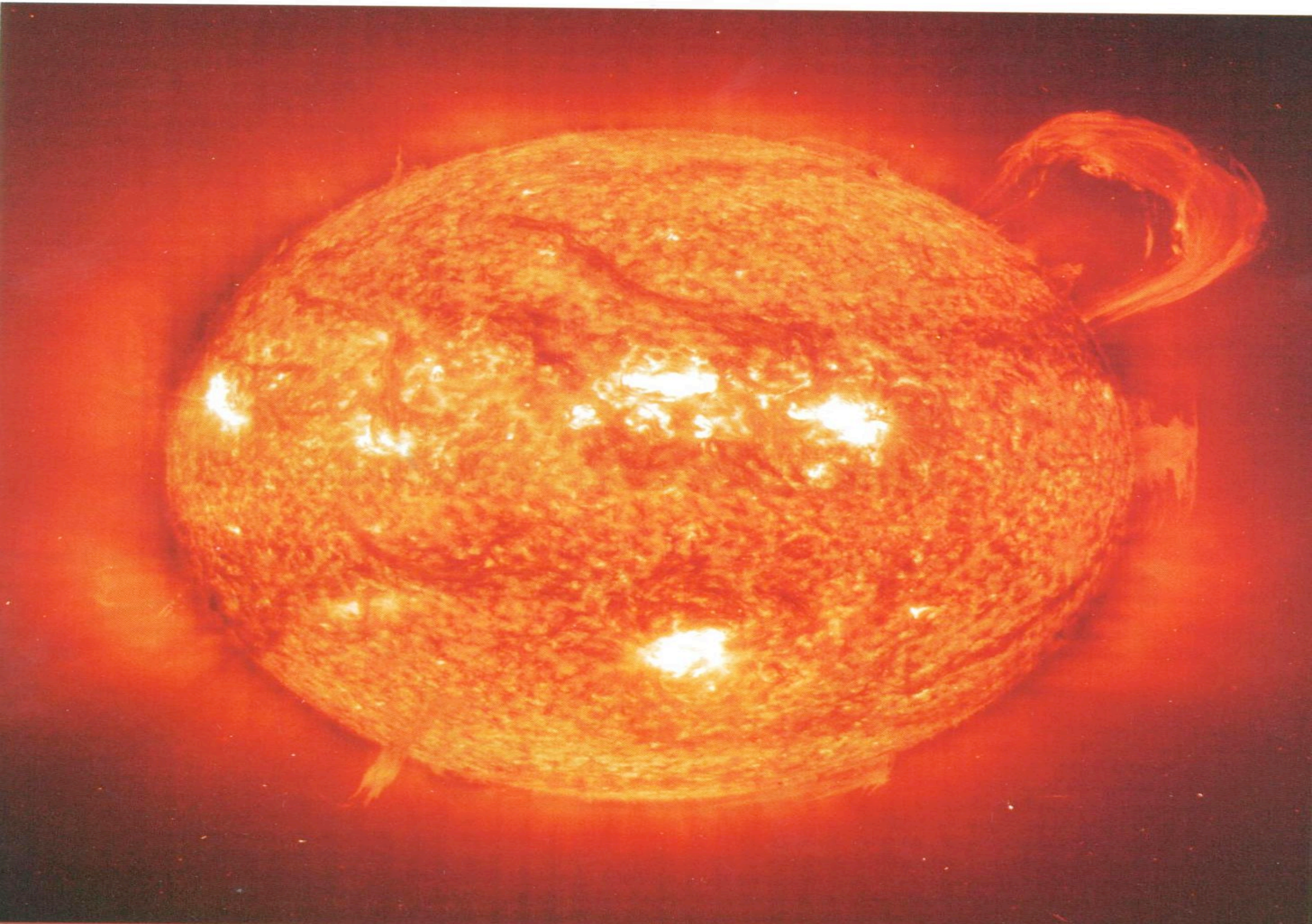
Analysis of the urban surface radiative budget and urban heat islands: How can HyspIRI data be used?

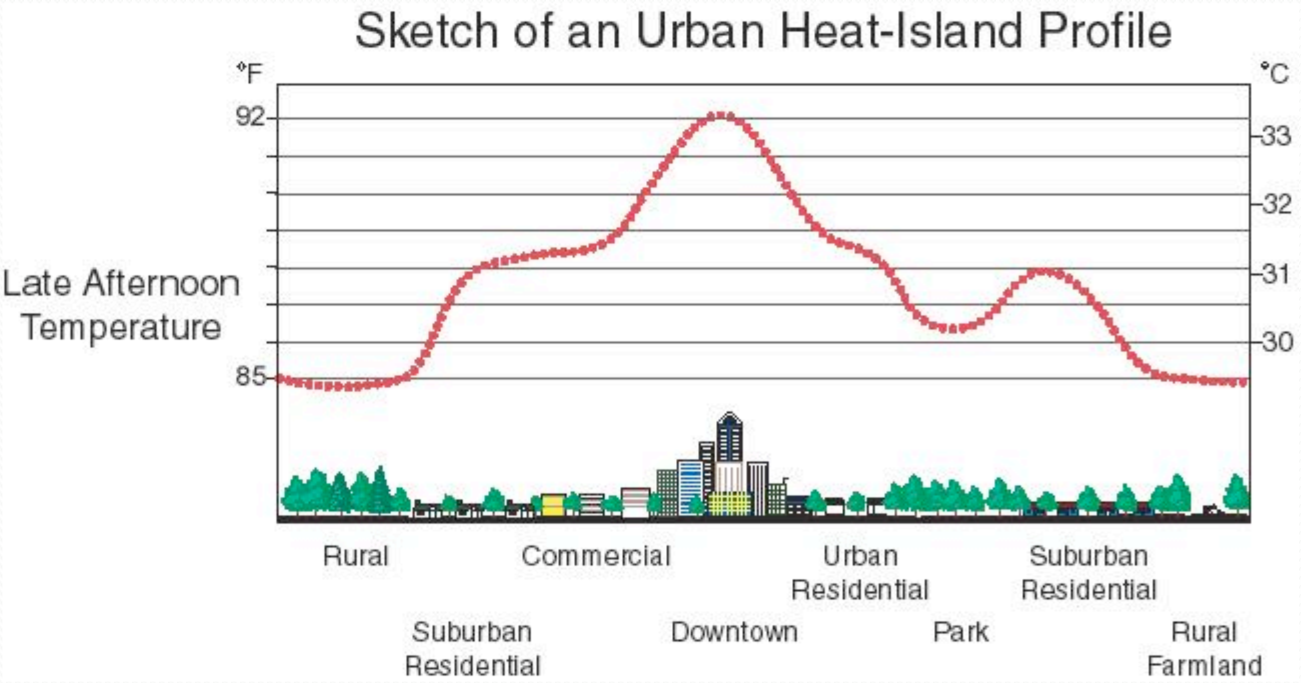


Jeffrey C. Luvall
NASA Marshall Space Flight Center

Solar and Heliospheric Observatory (SOHO) EIT Image of the Sun Obtained on September 14, 1999



What Happens to the Sun's Energy ?



Sketch of an Urban Heat-Island Profile
°F
°C
92
85
33
32
31
30
Late Afternoon Temperature
Rural
Suburban Residential
Commercial
Downtown
Urban Residential
Park
Suburban Residential
Rural Farmland

ion to Planet Earth
nal Aeronautics and Space Administration

Urban Remote Sensing and Air Quality Models

Volatile Organic Compounds
+ Nitrogen Oxides
+ Sunlight

→ Ozone

- Air pollution remains a National issue.
- Temperature increases the ozone levels.
- Urban heat island has major effect on temperature and height of mixing layer.
- Measurement program is defining land use patterns and relationship to heat production.
- Remote sensing data are being used to improve air quality modeling.

TRMM Precipitation Radar Study of Urban-Induced Rainfall Featured in August 11th, 2003 Issue of TIME magazine

AUGUST 11, 2003

TIME

M E T E O R O L O G Y

How Cities Make Their Own Weather

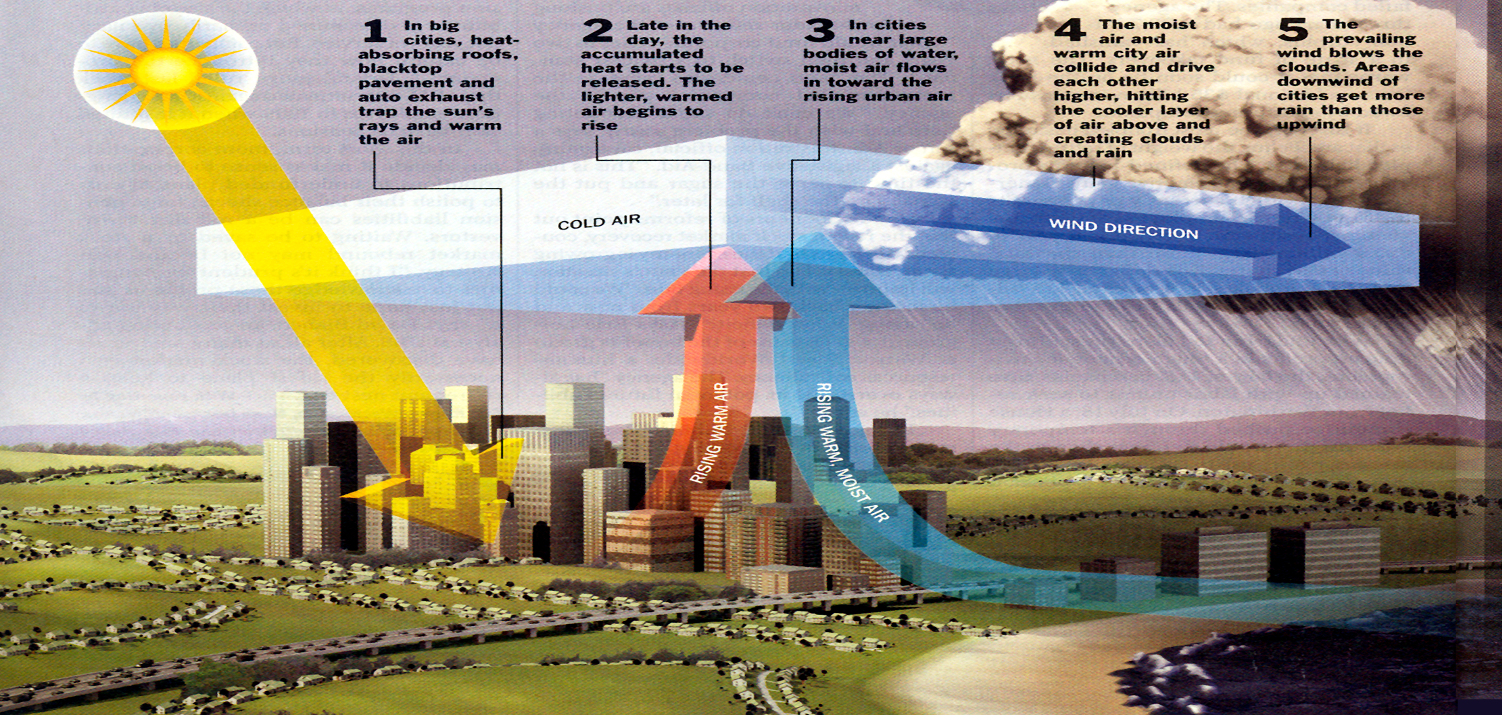
When Houston is hit by a sudden storm, the city may be partly to blame. Increasingly, urban centers don't merely endure bad weather; they help create it. Researchers believe the phenomenon may be more common now than ever before.

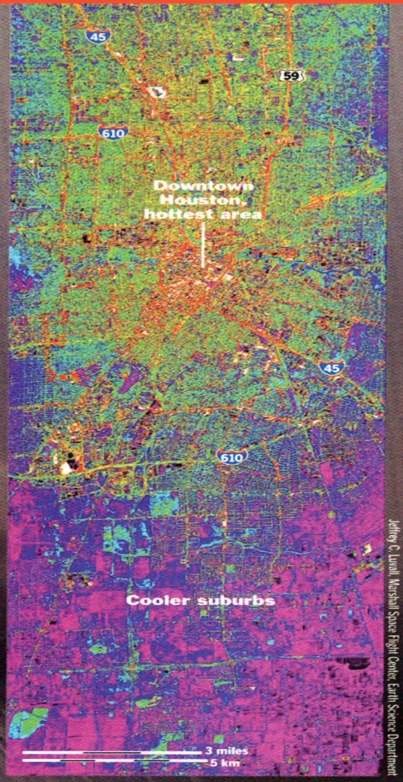
Scientists have known for 200 years that the temperature in a city can be higher than that in its environs—something they learned when an amateur weather watcher detected a 1.58°F temperature difference between London and its suburbs. Modern cities, with their cars and heat-trapping buildings, can create an even bigger temperature gap, sometimes as much as 10°F.

Islands of urban heat can do funny things with weather. Hot city air, like hot air anywhere else, rises—even more so because of the turbulence caused by tall buildings. When that air is damp enough and collides with colder layers above it, water can condense out as a sudden burst of rain, especially if there are few frontal systems to disrupt the layers, as in summer. In a spot storm above a city or just downwind of it, it's likely that nature alone isn't behind the downpour.

NASA and the University of Arkansas have been using satellite mapping and ground-based temperature readings termine how widespread this phenor is. This spring researchers got a su when they turned their attention to Houston. Because it's near a coast and sea breezes tend to cool and disperse hot air, Houston was thought to be comparatively safe from homemade rain. Now it appears that the opposite may be true. "The sea breeze may exacerbate the rainfall," says research meteorologist Marshall Shepherd of NASA's Goddard Space Flight Center. The warm air and sea air collide, he explains, and "move straight up like the front ends of two cars that hit head on, providing a pump of moist air that helps thunderstorms develop."

Hot, waterlogged cities can be cooled off in the usual ways—by limiting auto exhaust, for example. Using light-colored roofing and paving materials in place of black, heat-absorbing tar will also help. As a bonus, the cooler roof will reduce the need for air conditioning. —*By Jeffrey Kluger*



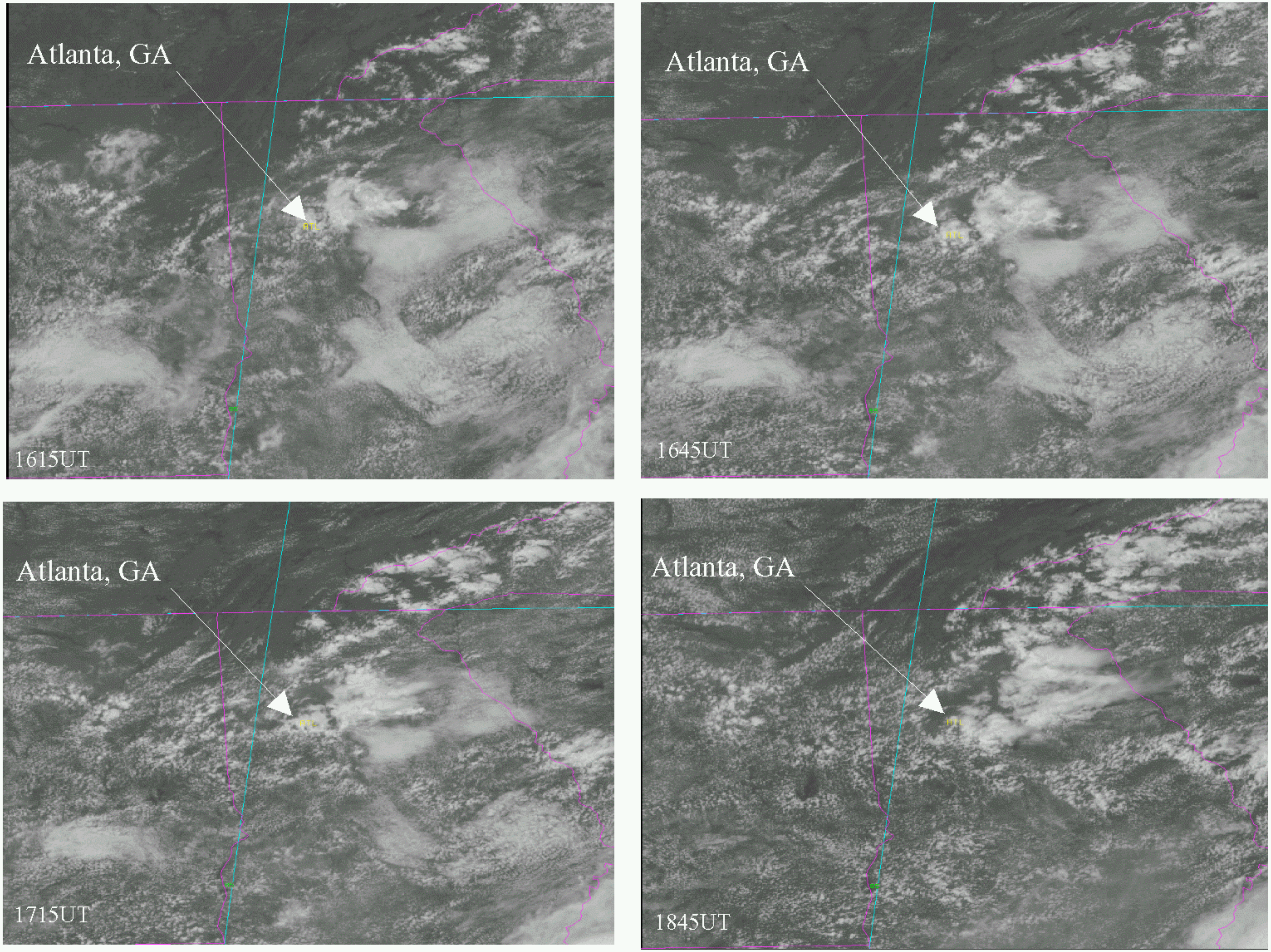


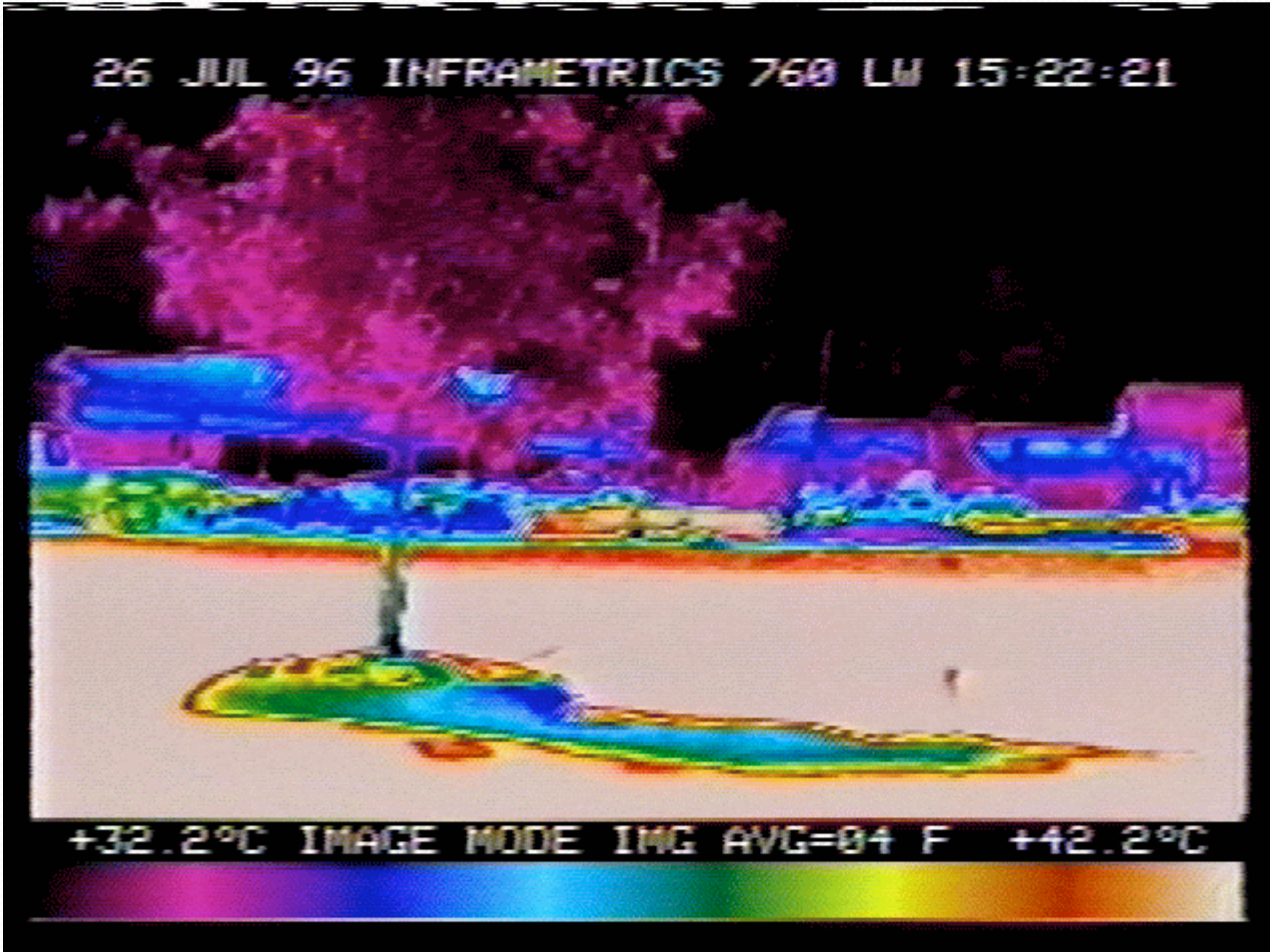
HOT ZONE

High concentrations of buildings, roads and other artificial structures retain heat, leading to warmer temperatures. A NASA snapshot of Houston taken one evening in August 2000 demonstrates this urban heat-island effect: the hot zone downtown stands in sharp contrast to the cooler suburbs to the south

70°F (21°C) — 90°F (32°C)

Source: NASA/Goddard Space Flight Center
TIME diagram by Joe Lertola


Atlanta, GA
1615UT
Atlanta, GA
1645UT
Atlanta, GA
1715UT
Atlanta, GA
1845UT


26 JUL 96 INFRAMETRICS 760 LW 15:22:21
+32.2°C IMAGE MODE IMG AVG=04 F +42.2°C

Surface Radiation Budget

$$Q^* = (K_{in} + K_{out}) + (L_{in} + L_{out})$$

Q^* = Net Radiation

K_{in} = Incoming Solar

K_{out} = Reflected Solar

L_{in} = Incoming Longwave

L_{out} = Emitted Longwave

Surface Energy Budget

$$Q^* = H + LE + G$$

H = Sensible Heat Flux

LE = Latent Heat Flux

G = Storage (maybe + or -)

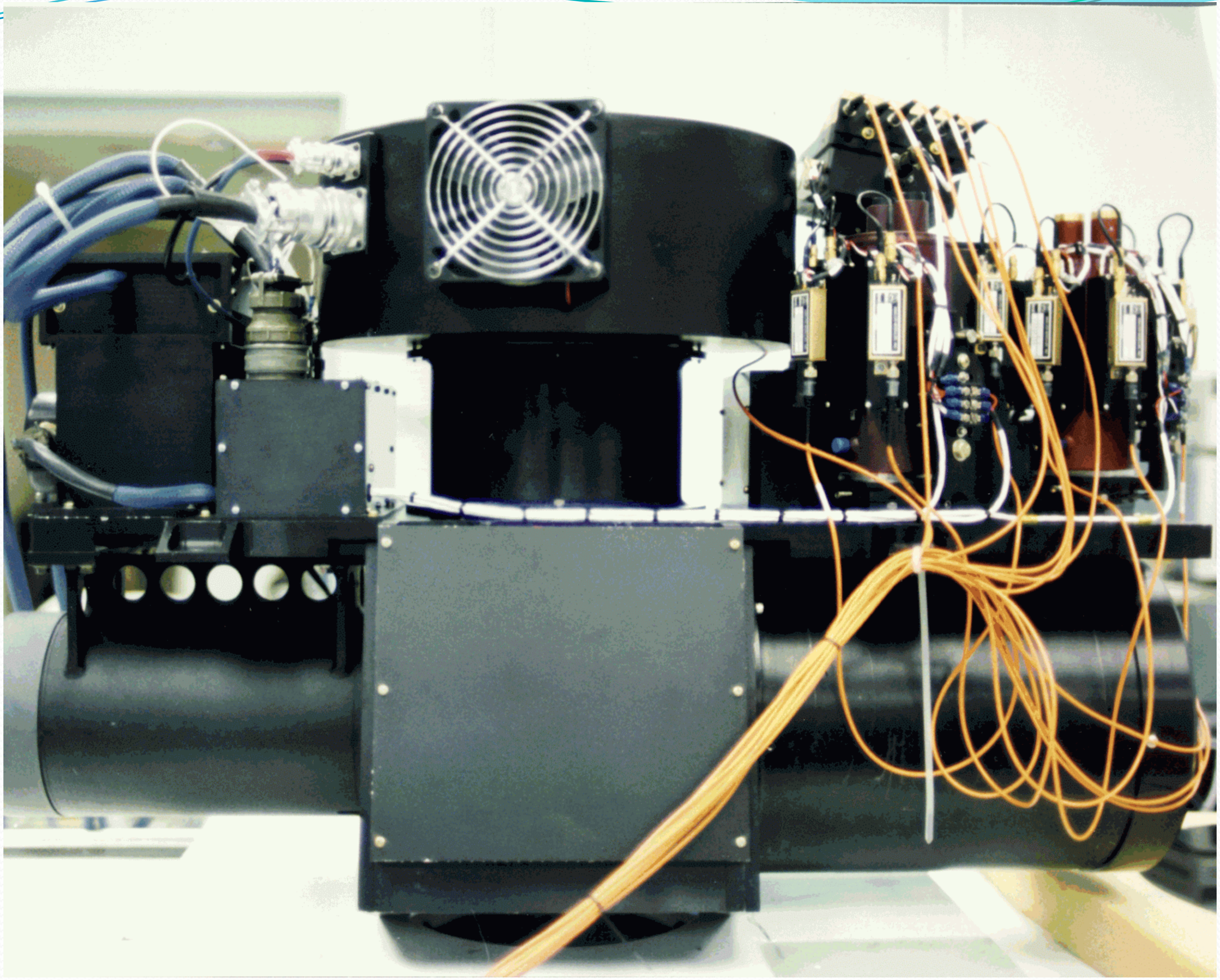
Natural Surface Albedo

Surface	*Albedo*
Soils	0.05-0.40
Desert	0.20-0.45
Grass	0.16-0.26
Crops	0.18-0.25
Forests-deciduous	0.15-0.20
Forests-coniferous	0.05-0.15
Water (small zenith angle)	0.03-0.10
Snow (fresh)	0.40-0.95

Albedo of Typical Urban Mateials & Surfaces

Surface	*Albedo*
Asphalt Roads	0.05-0.20
Concrete	0.10-0.35
Brick	0.20-0.40
Tar & Gravel Roofs	0.08-0.18
Tile Roofs	0.10-0.35
Corrugated Iron Roofs	0.10-0.16
White Membrane	0.64-0.84
Paint-White	0.50-0.90
Paint- Red,Brown,Green	0.20-0.35
Urban Areas	0.10-0.27 (0.15)

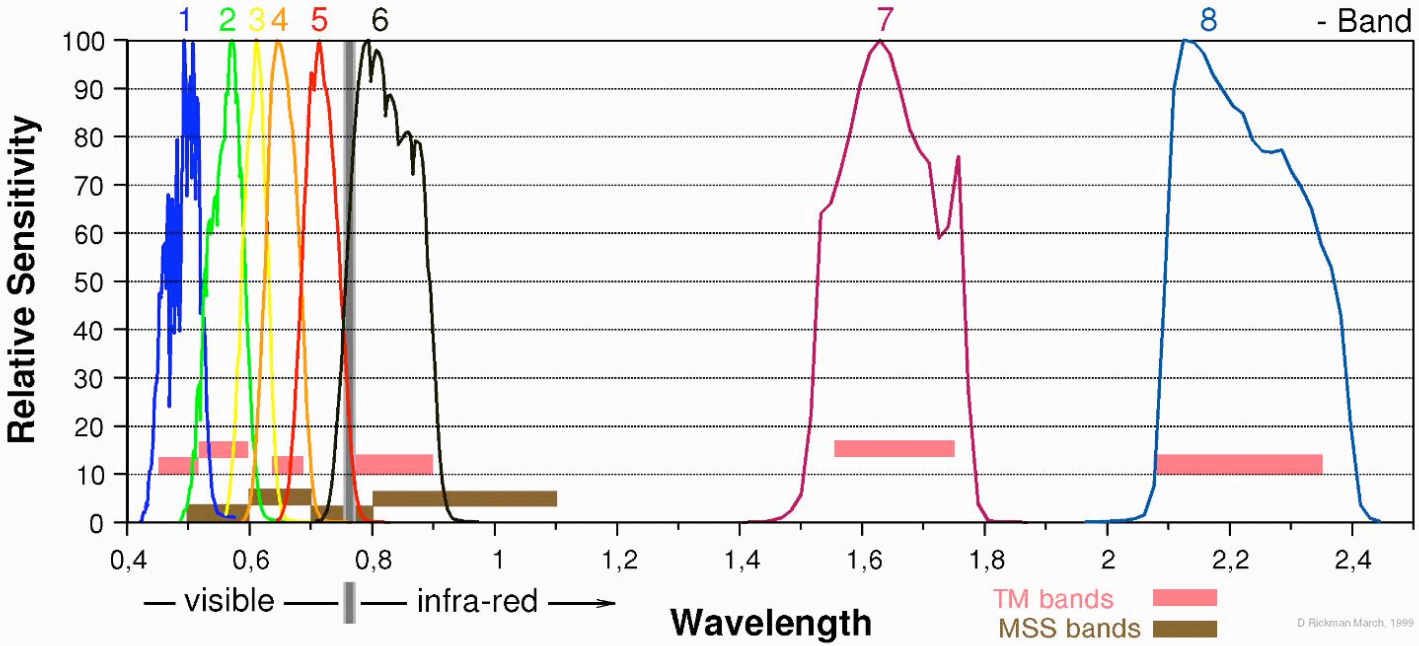

NASA
N933NA



ATLAS

Typical Spectral Response Curves

Reflected Bands

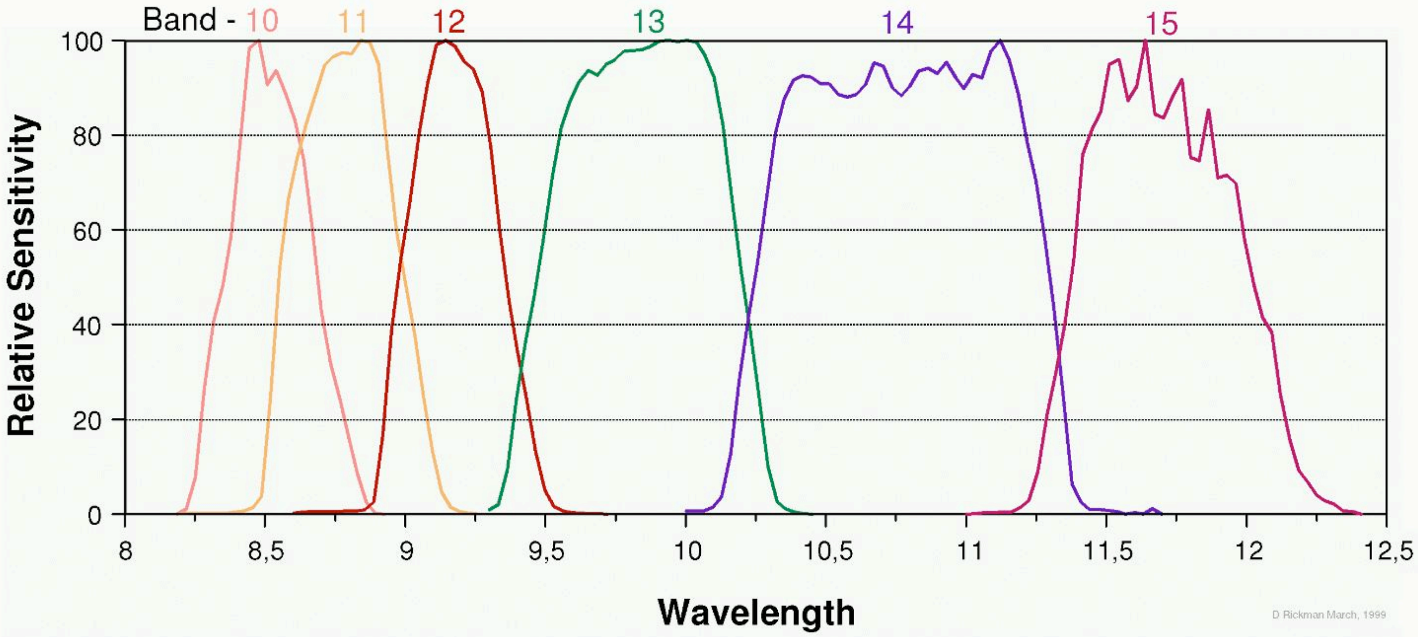


D. Rickman, et al., Nov. 9,1999

ATLAS

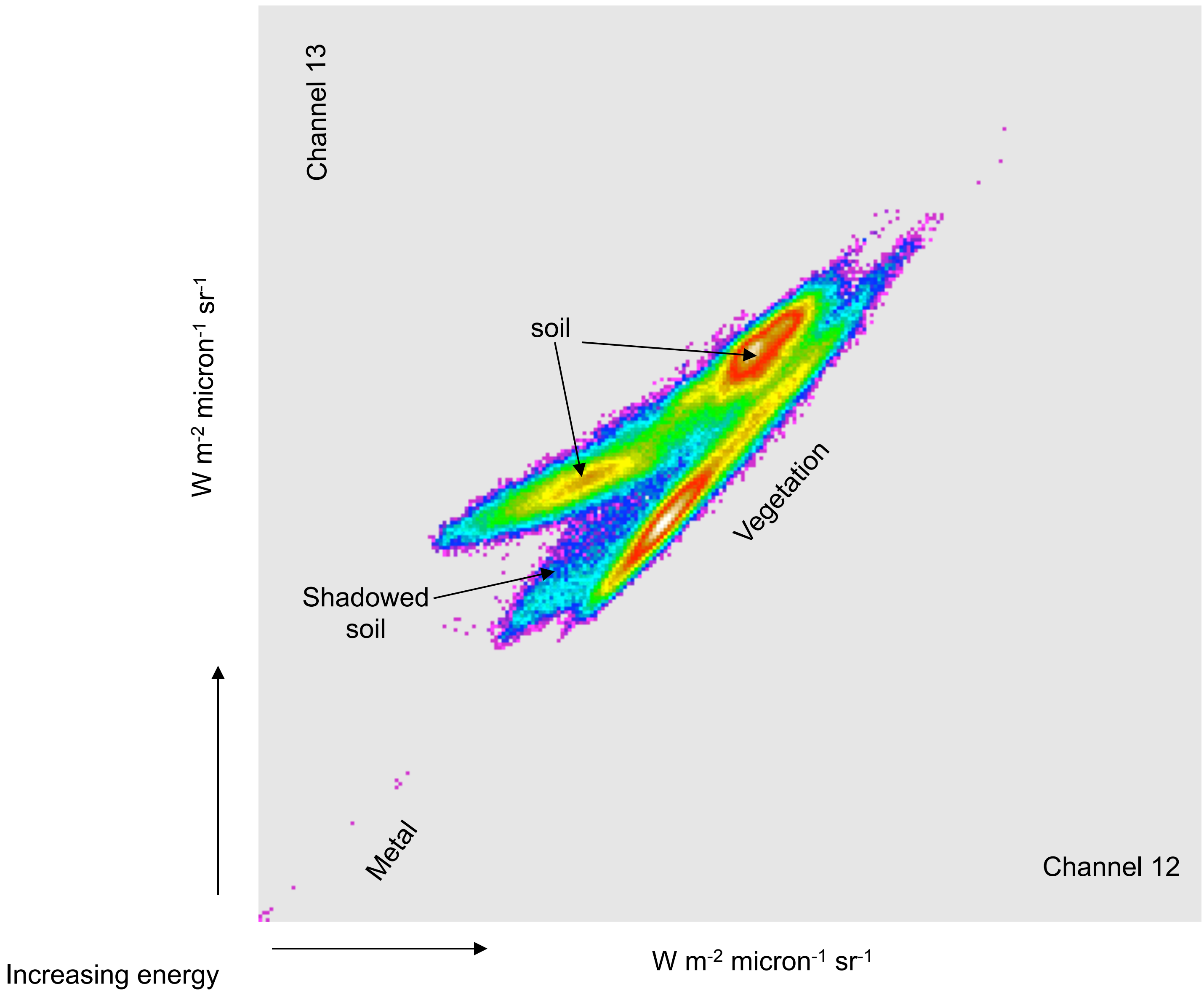
Typical Spectral Response Curves

Thermal Bands



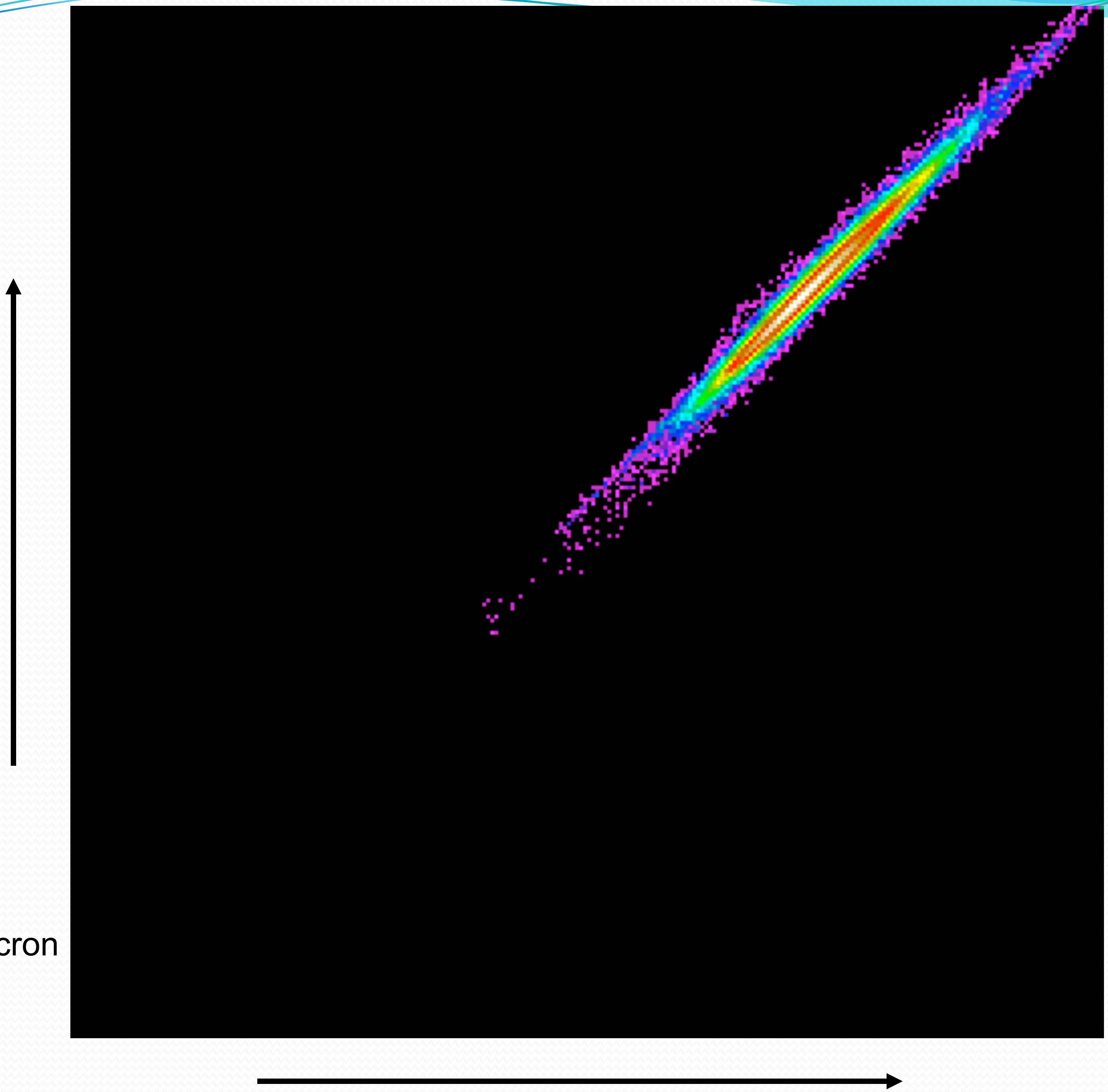
D. Rickman, et al., Nov. 9,1999

Emissivity Differences in Natural Surfaces



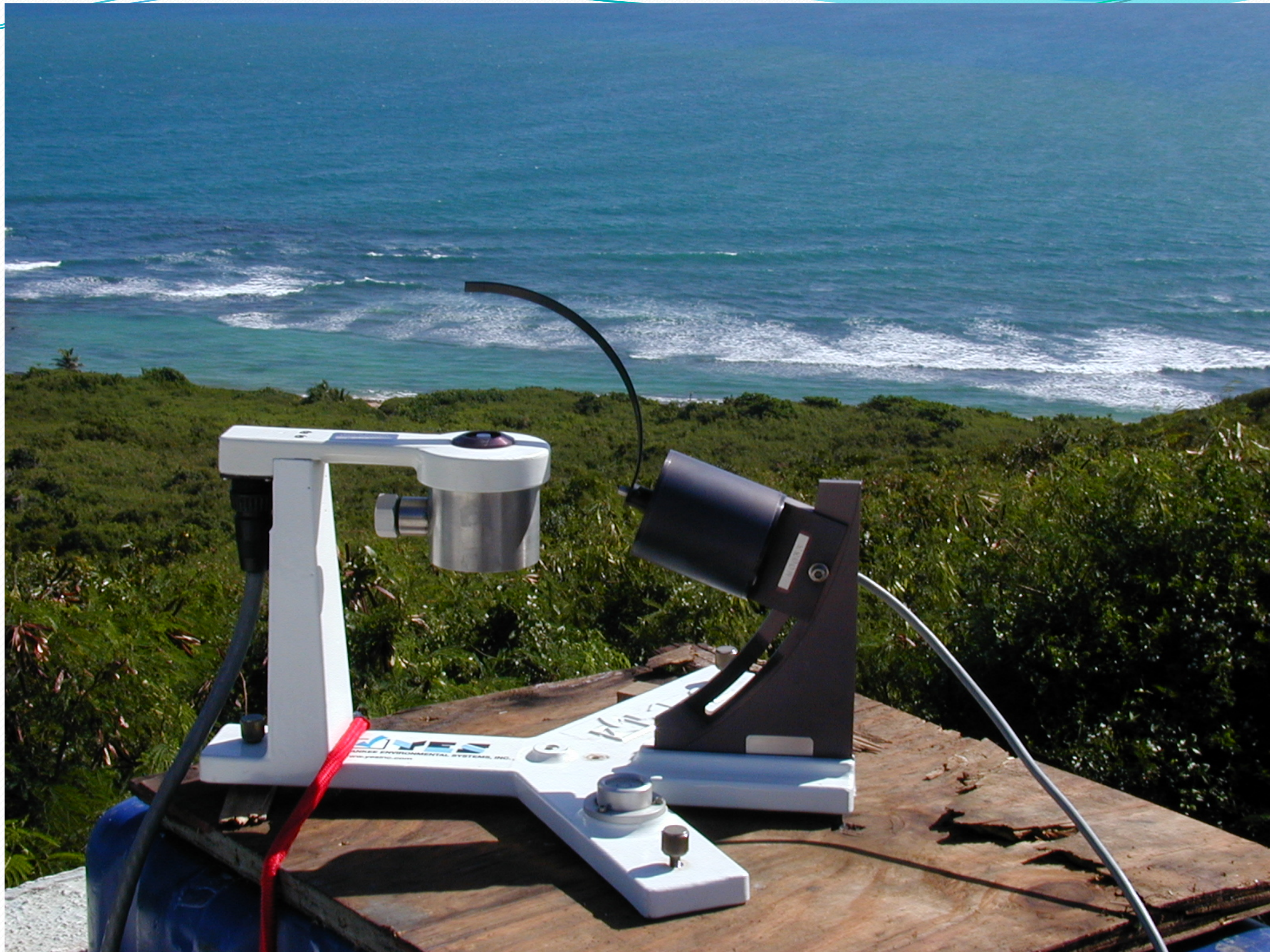
San Juan

CH 10 vs CH 11

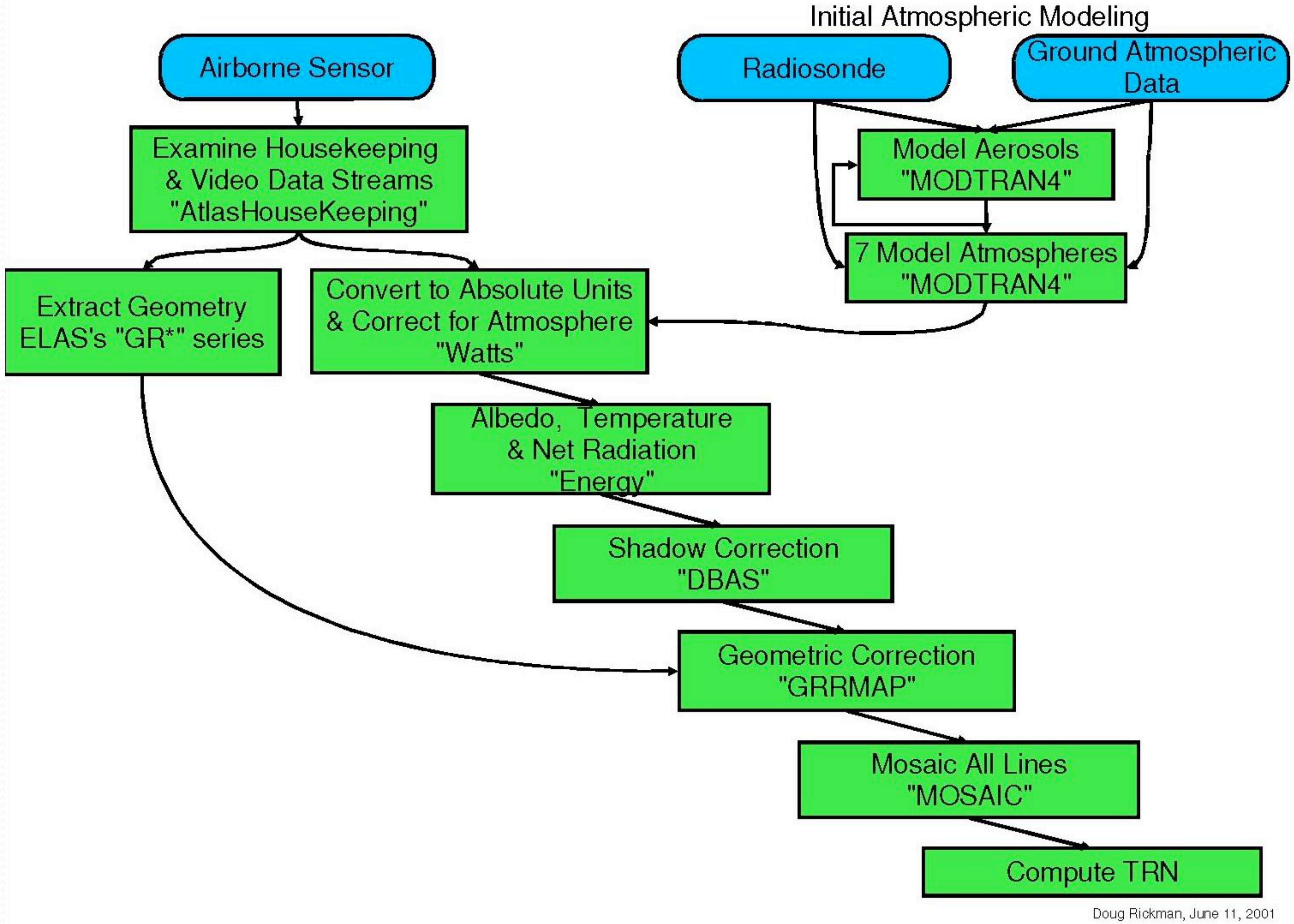


Energy

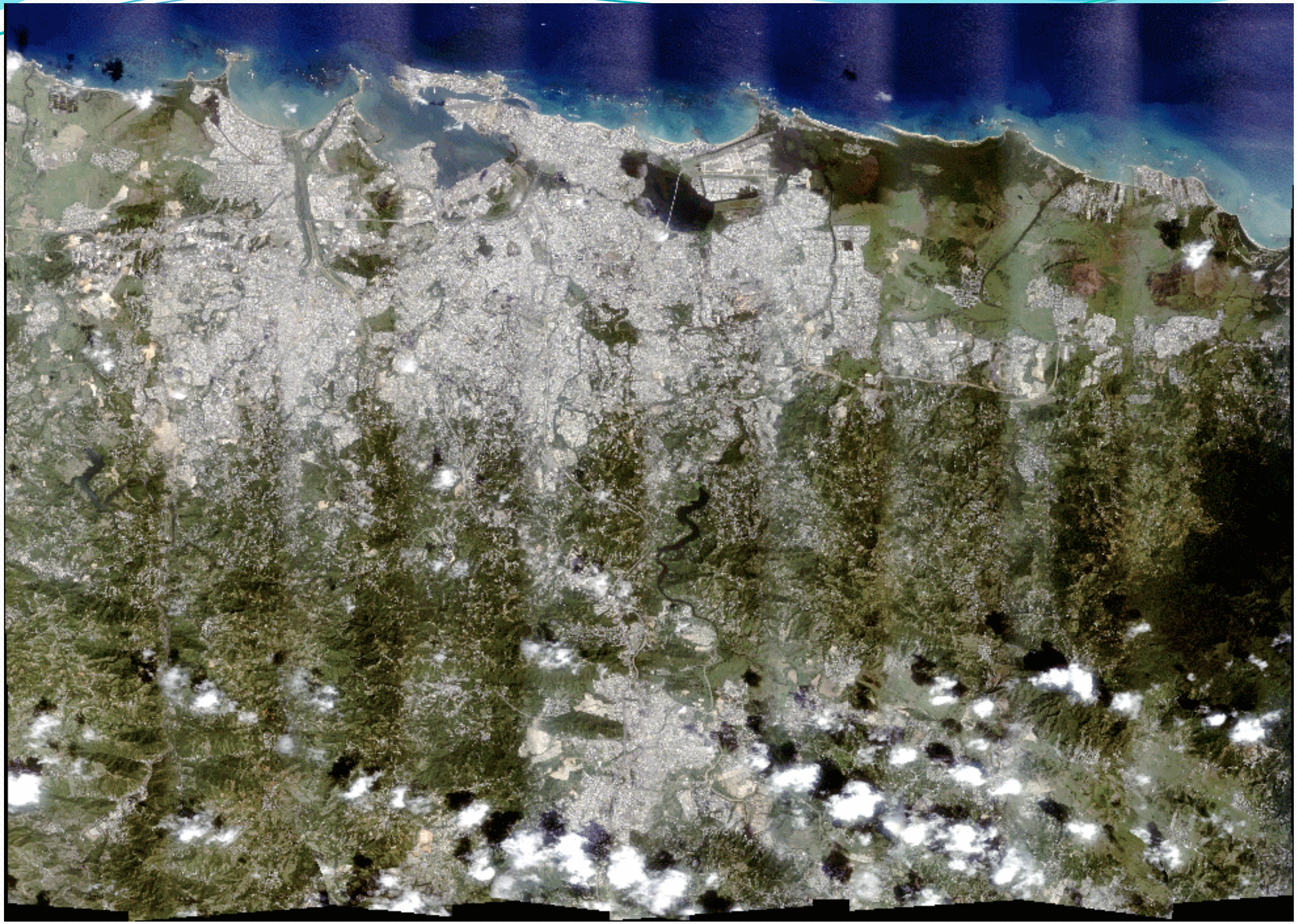
W m-2 sr-1 micron


YES
ENVIRONMENTAL SYSTEMS, INC.

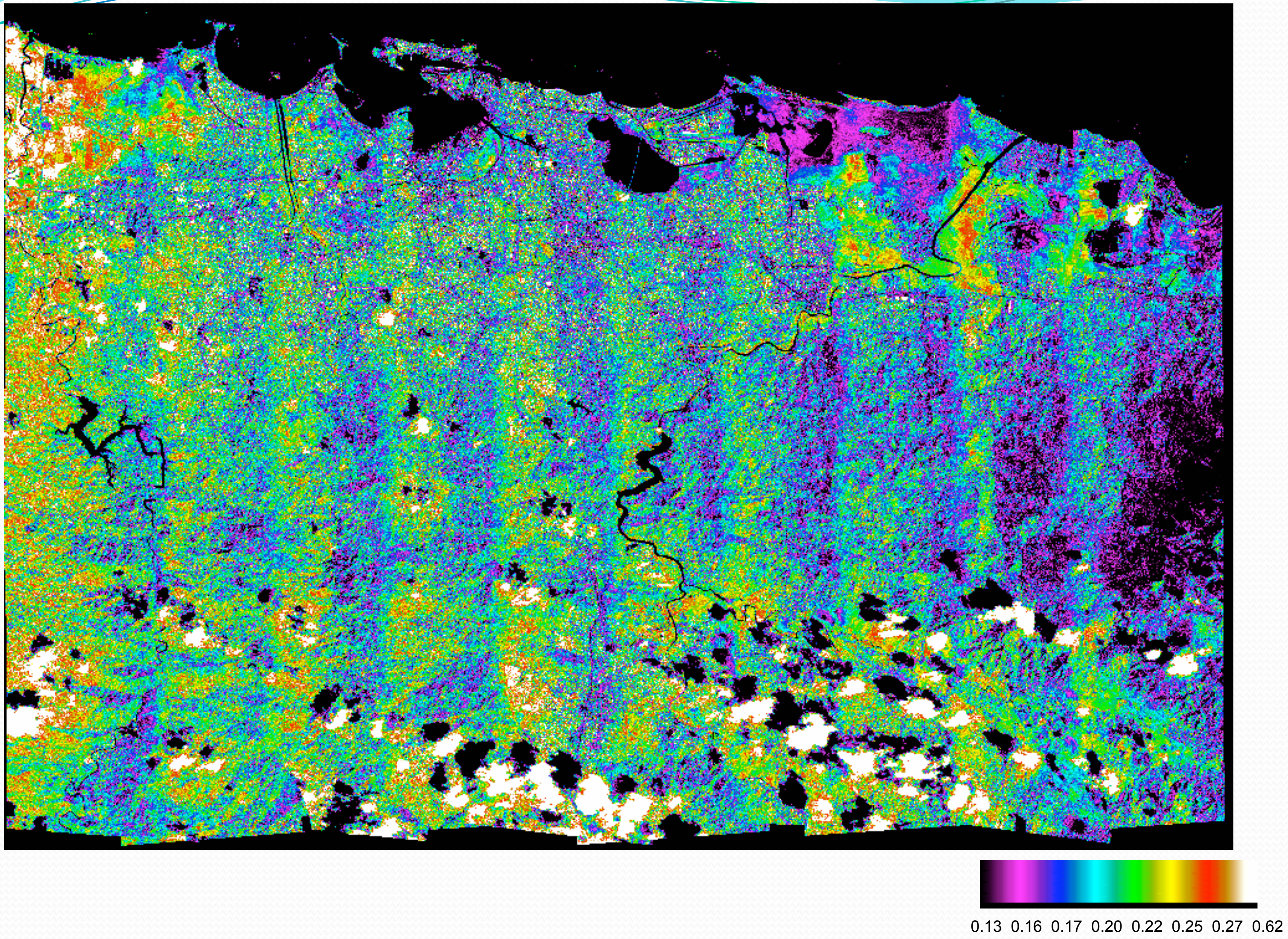
Overall Process Flow



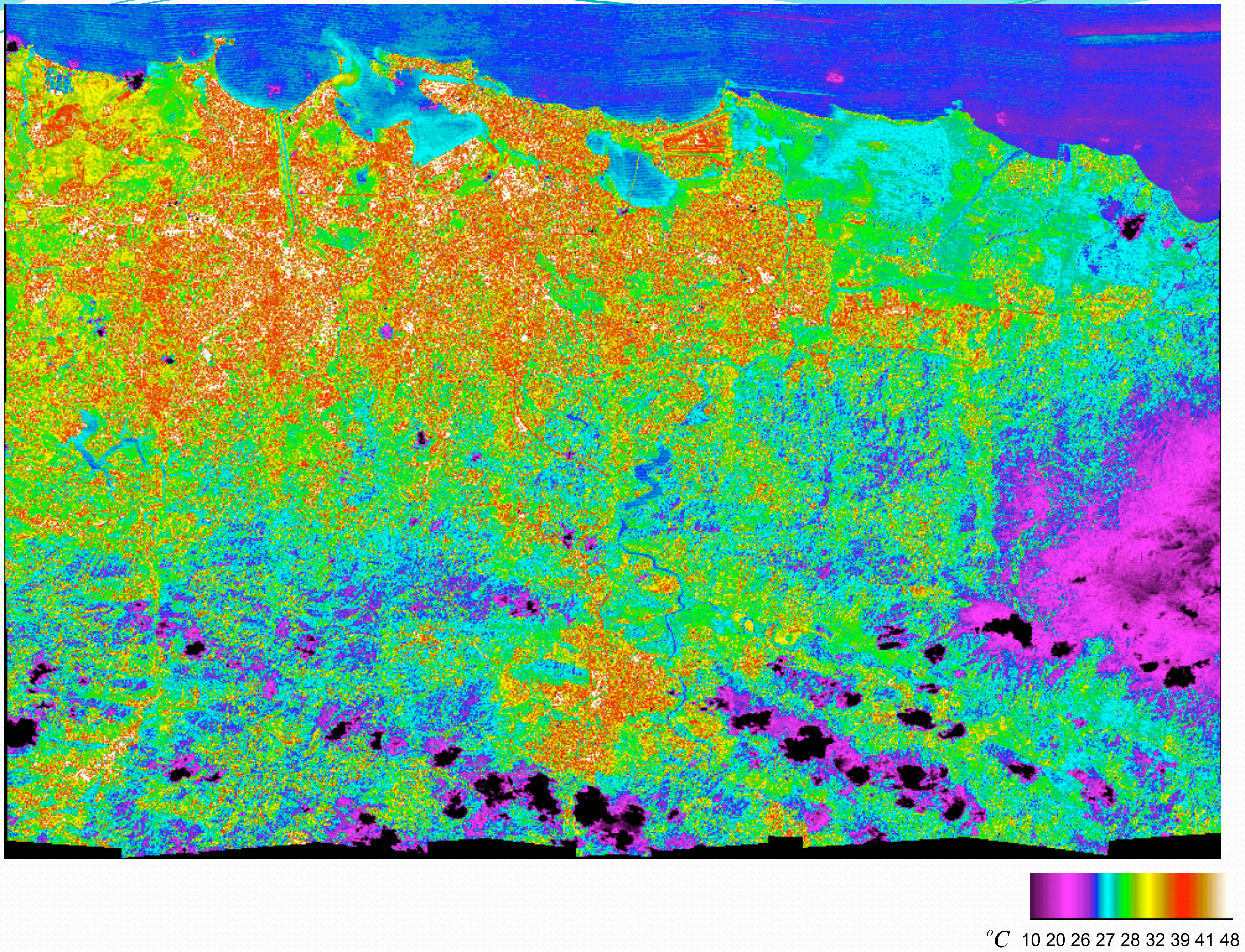
San Juan F5 Mosaic True Color

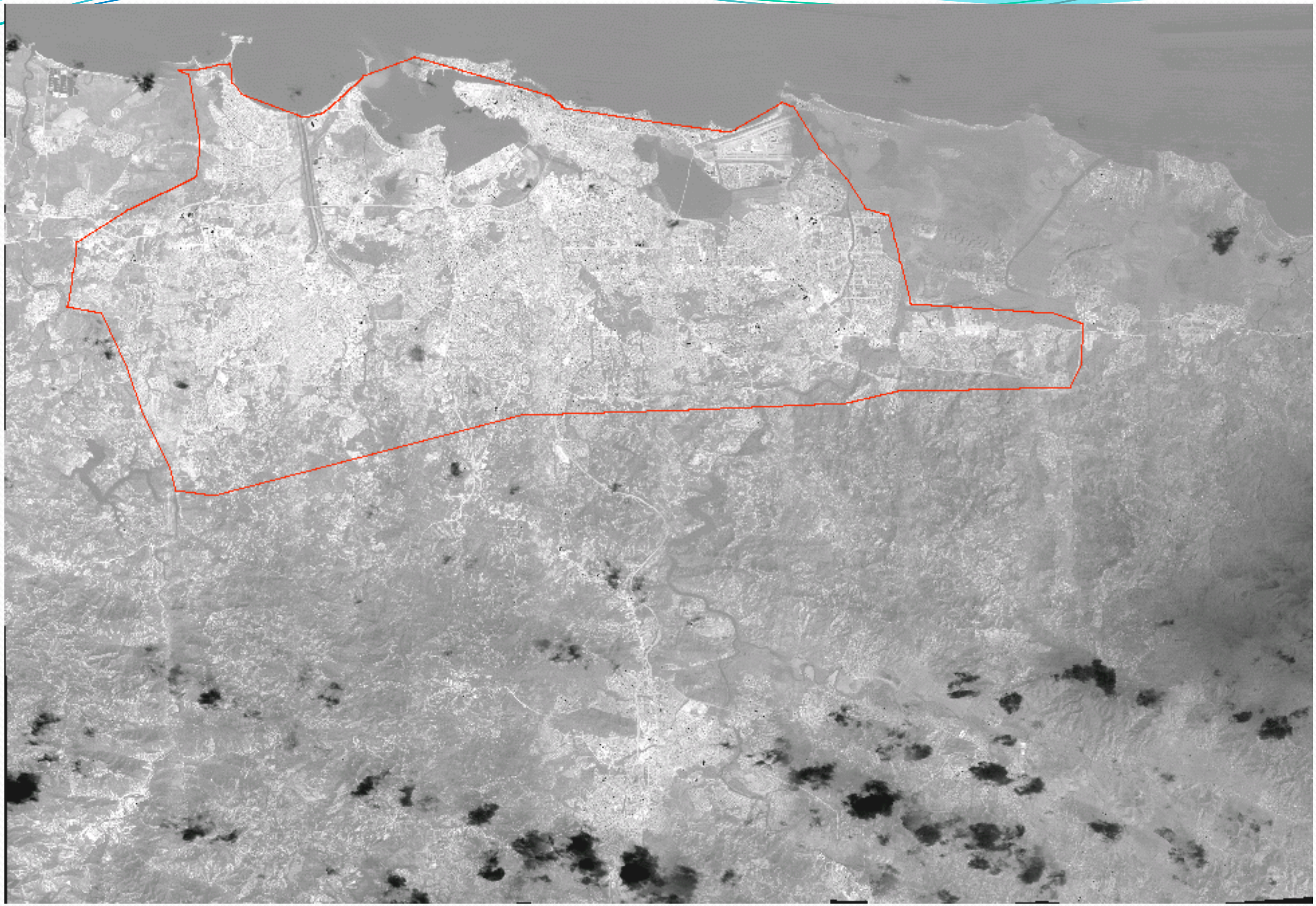


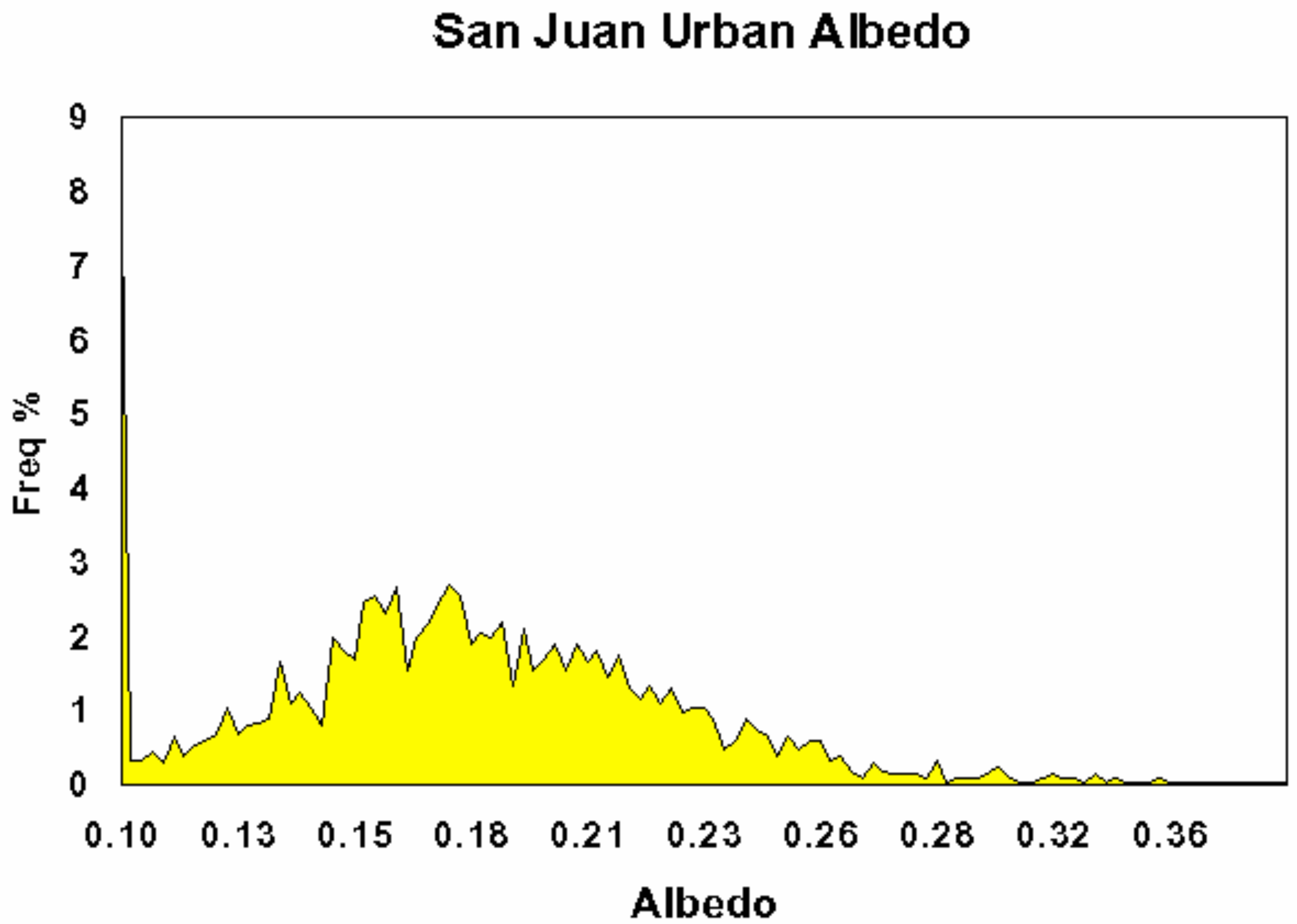
San Juan F5 Mosaic Albedo

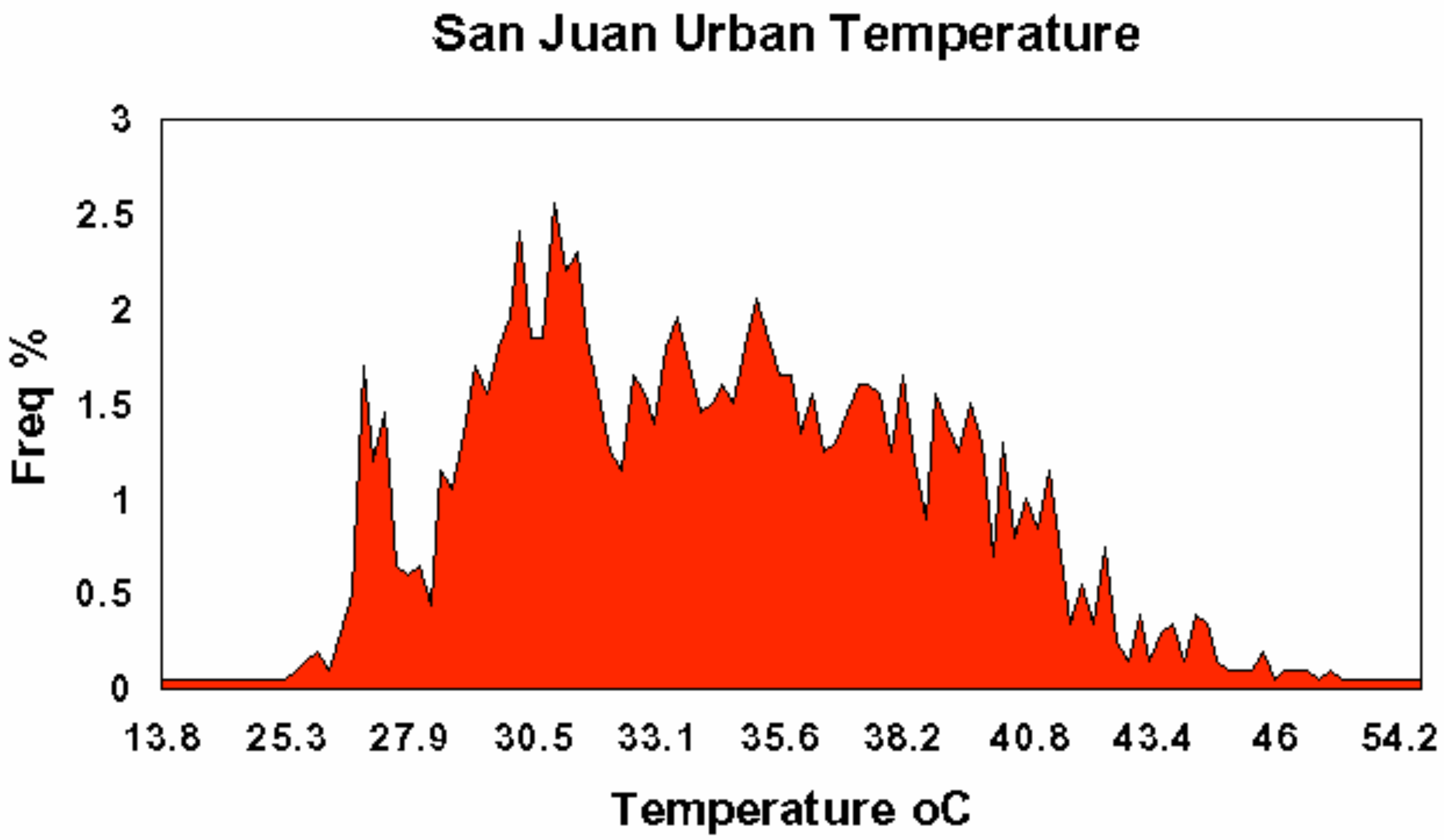


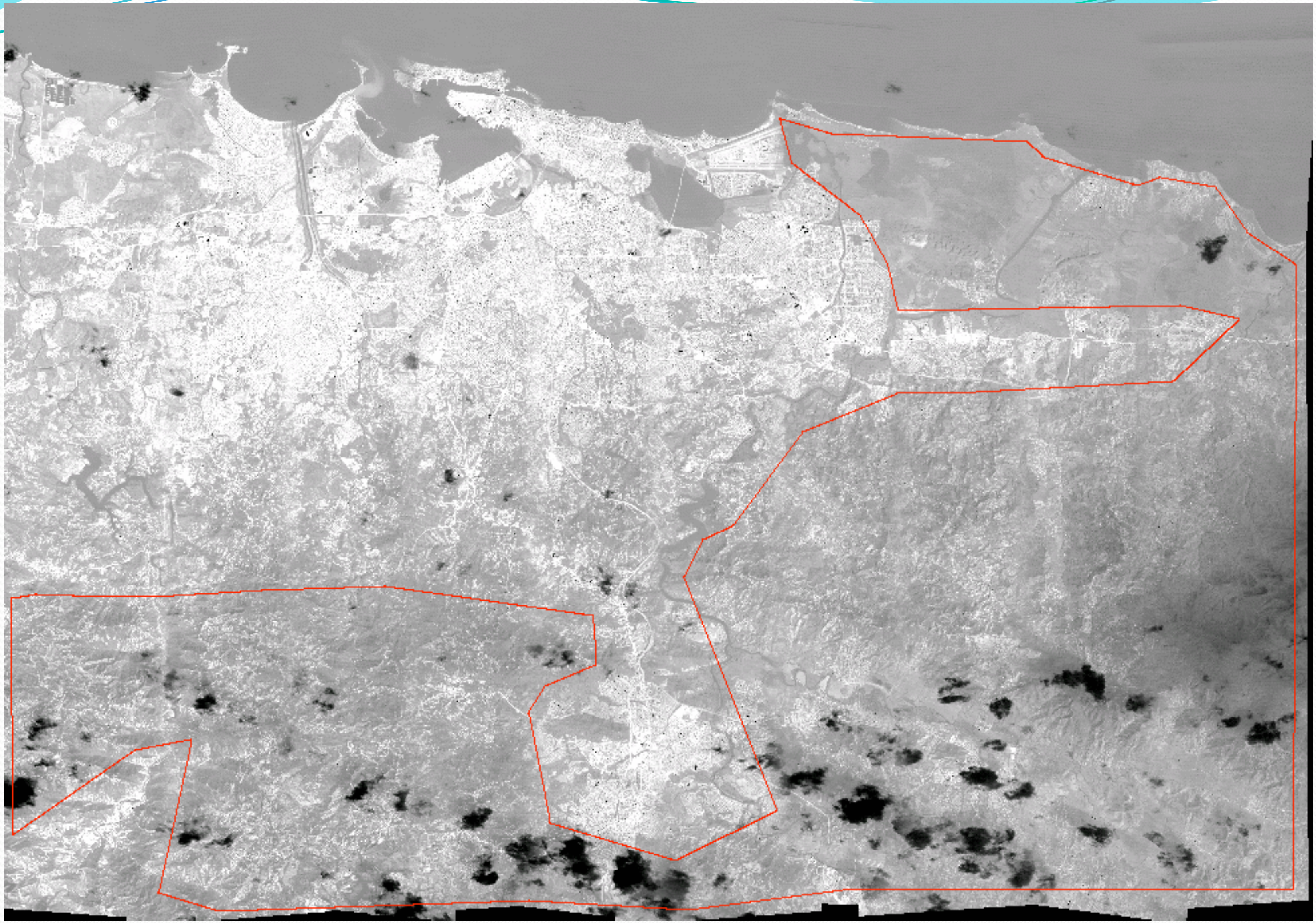
San Juan F5 Mosaic Temperature

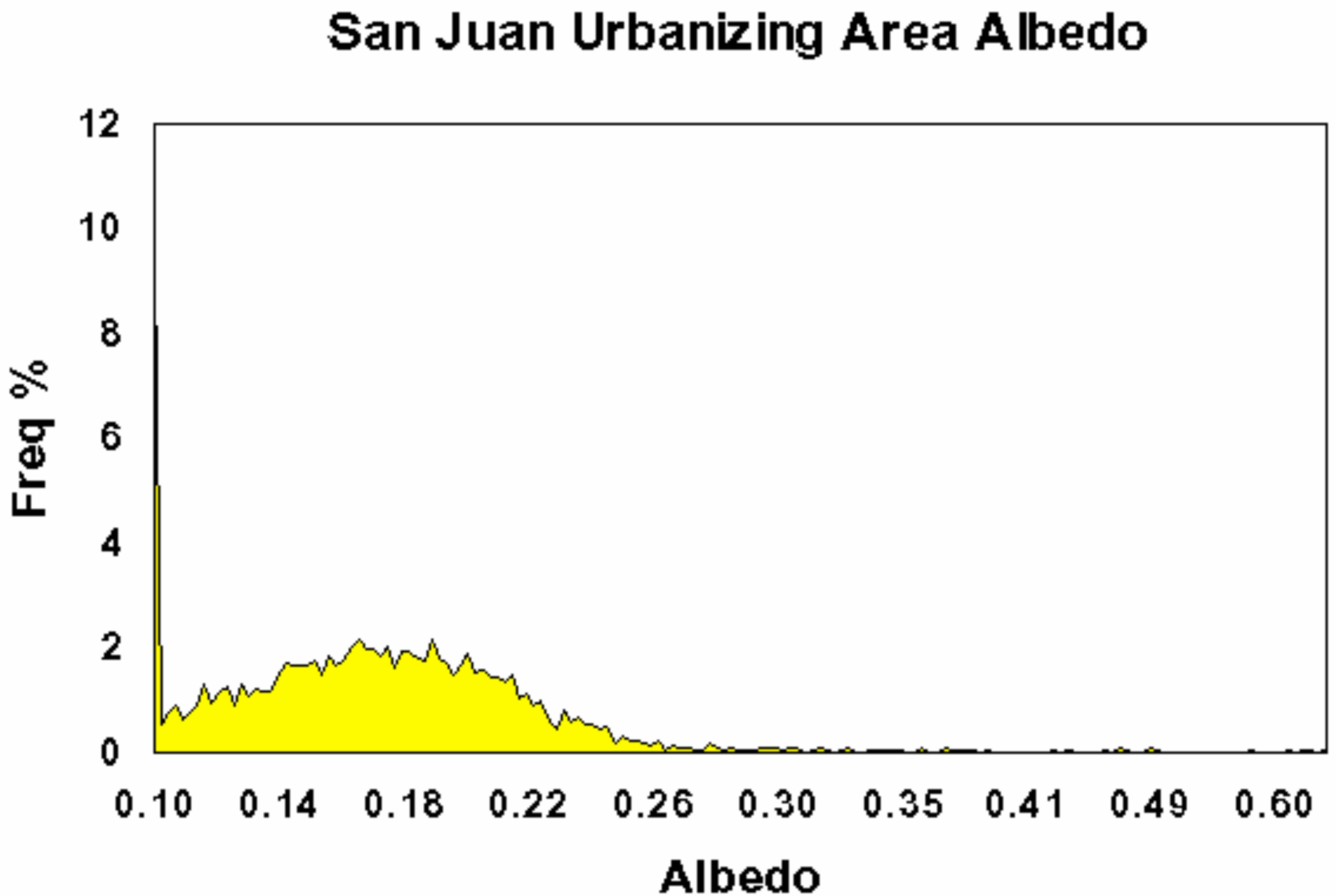


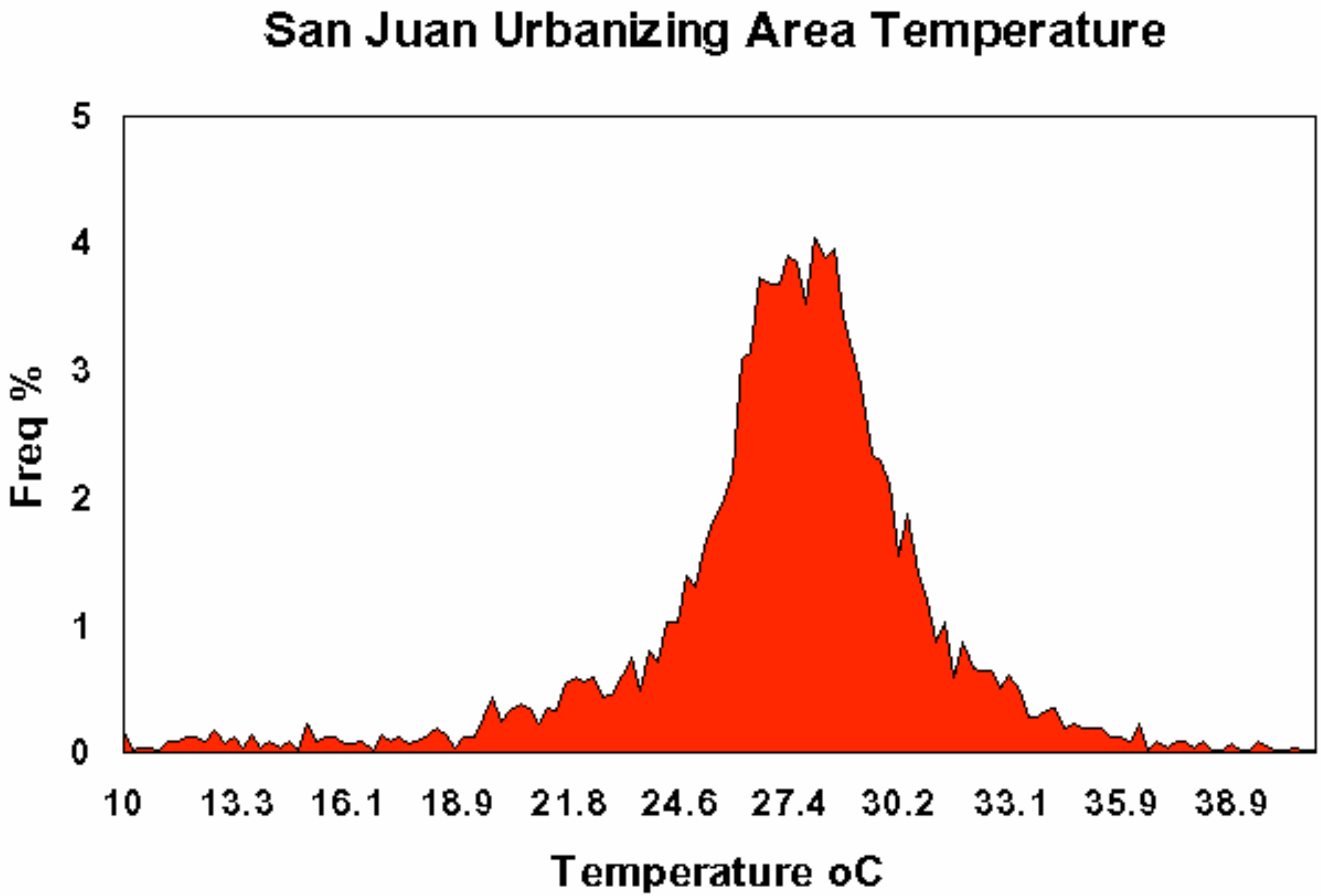



San Juan Urban Albedo
9
8
7
6
5
4
3
2
1
0
Freq %
0.10
0.13
0.15
0.18
0.21
0.23
0.26
0.28
0.32
0.36
Albedo


San Juan Urban Temperature
Freq %
3
2.5
2
1.5
1
0.5
0
13.8
25.3
27.9
30.5
33.1
35.6
38.2
40.8
43.4
46
54.2
Temperature oC

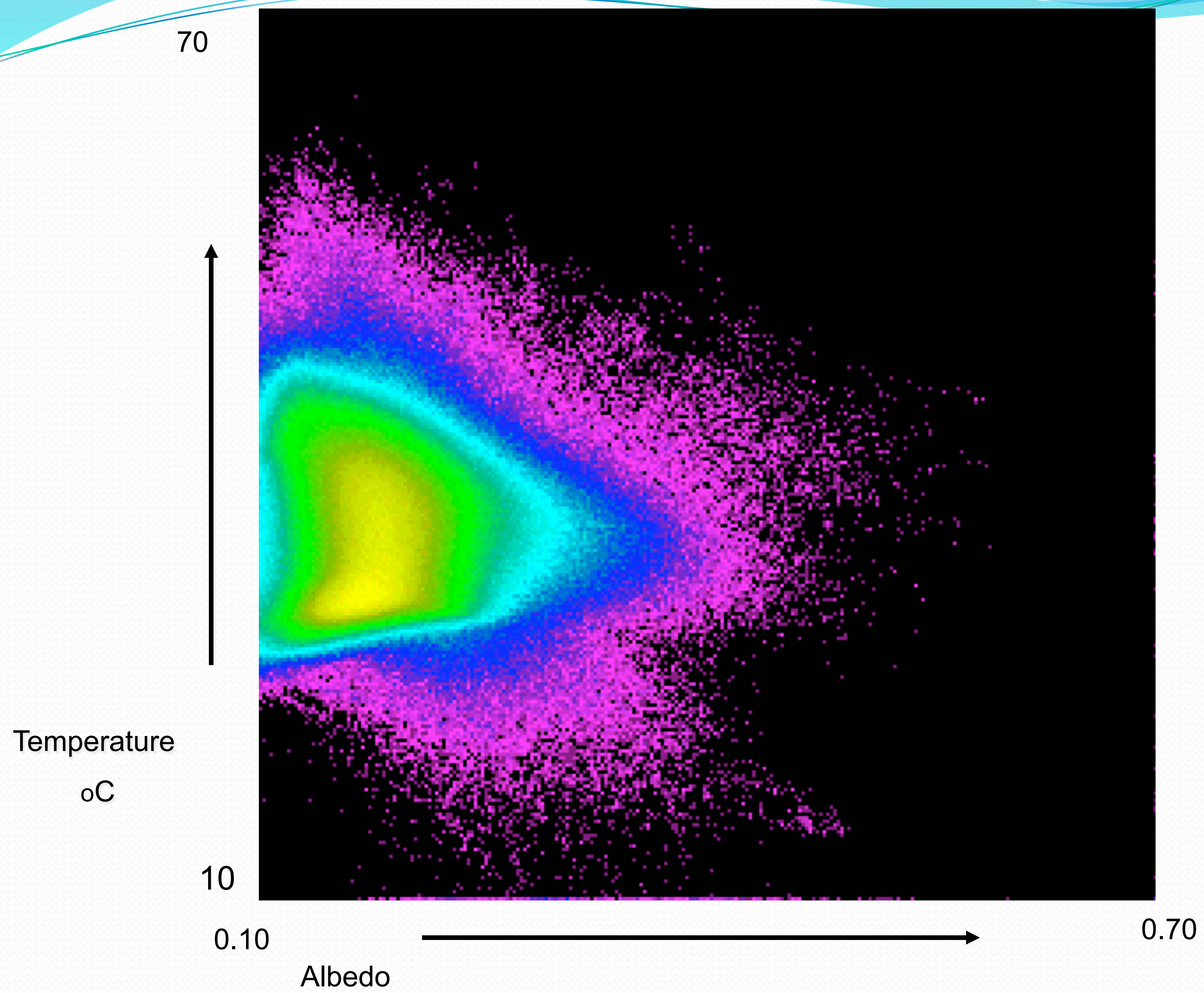



San Juan Urbanizing Area Albedo
12
10
8
6
4
2
0
Freq %
0.10
0.14
0.18
0.22
0.26
0.30
0.35
0.41
0.49
0.60
Albedo

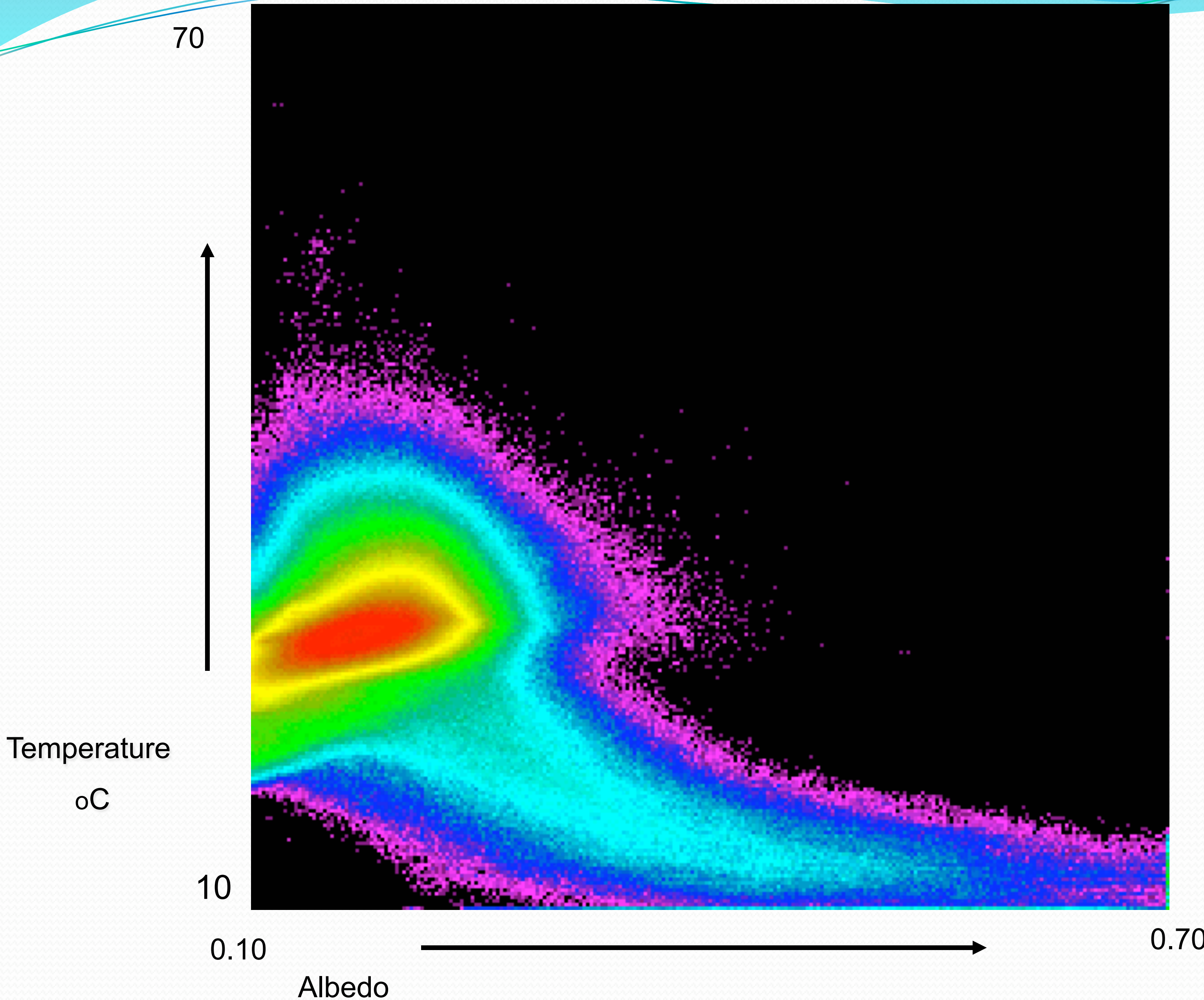


San Juan Urbanizing Area Temperature
5
4
3
2
1
0
Freq %
10
13.3
16.1
18.9
21.8
24.6
27.4
30.2
33.1
35.9
38.9
Temperature oC

San Juan Puerto Rico
Albedo vs Temperature

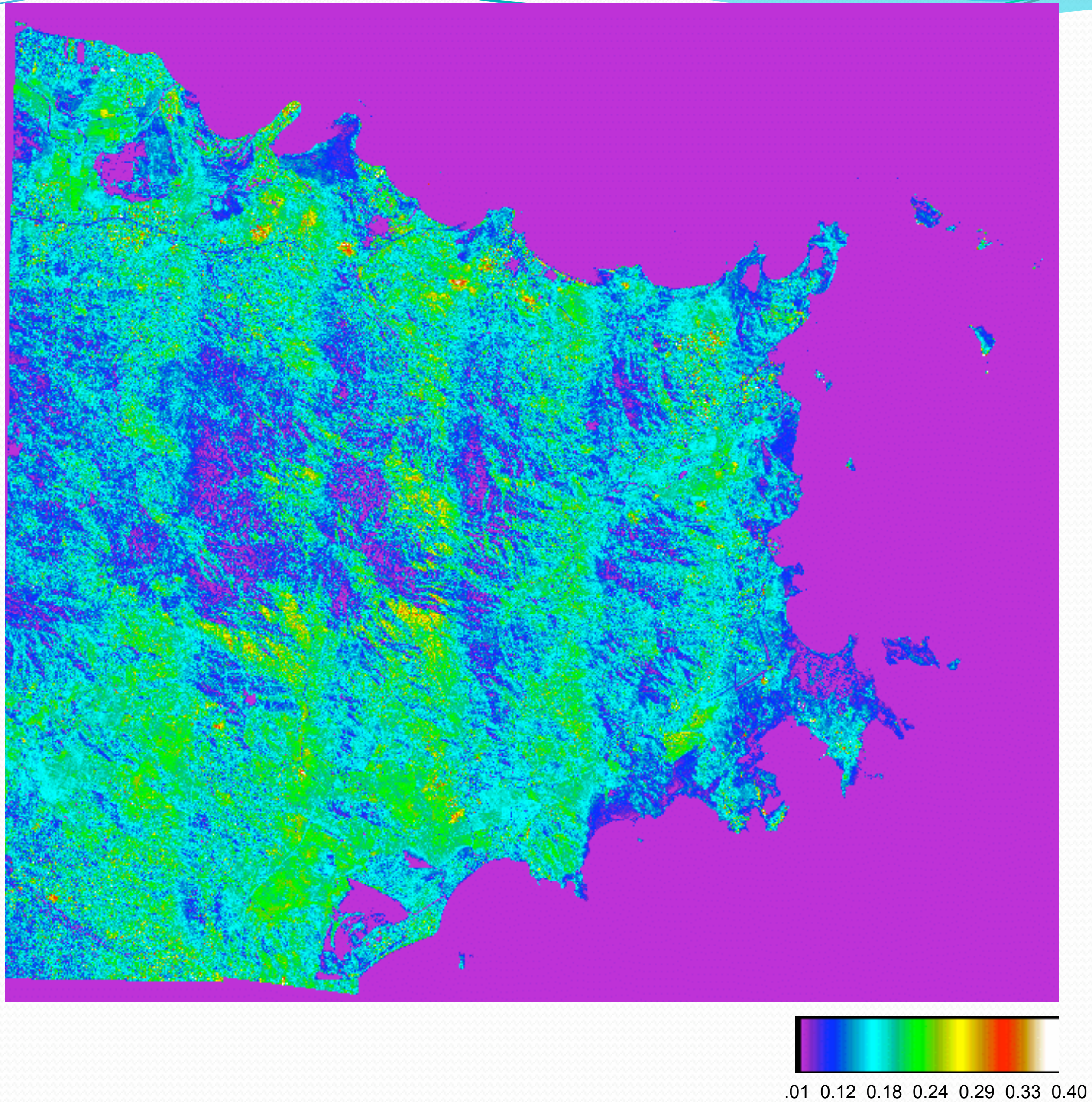


San Juan Puerto Rico Urbanizing Area
Albedo vs Temperature

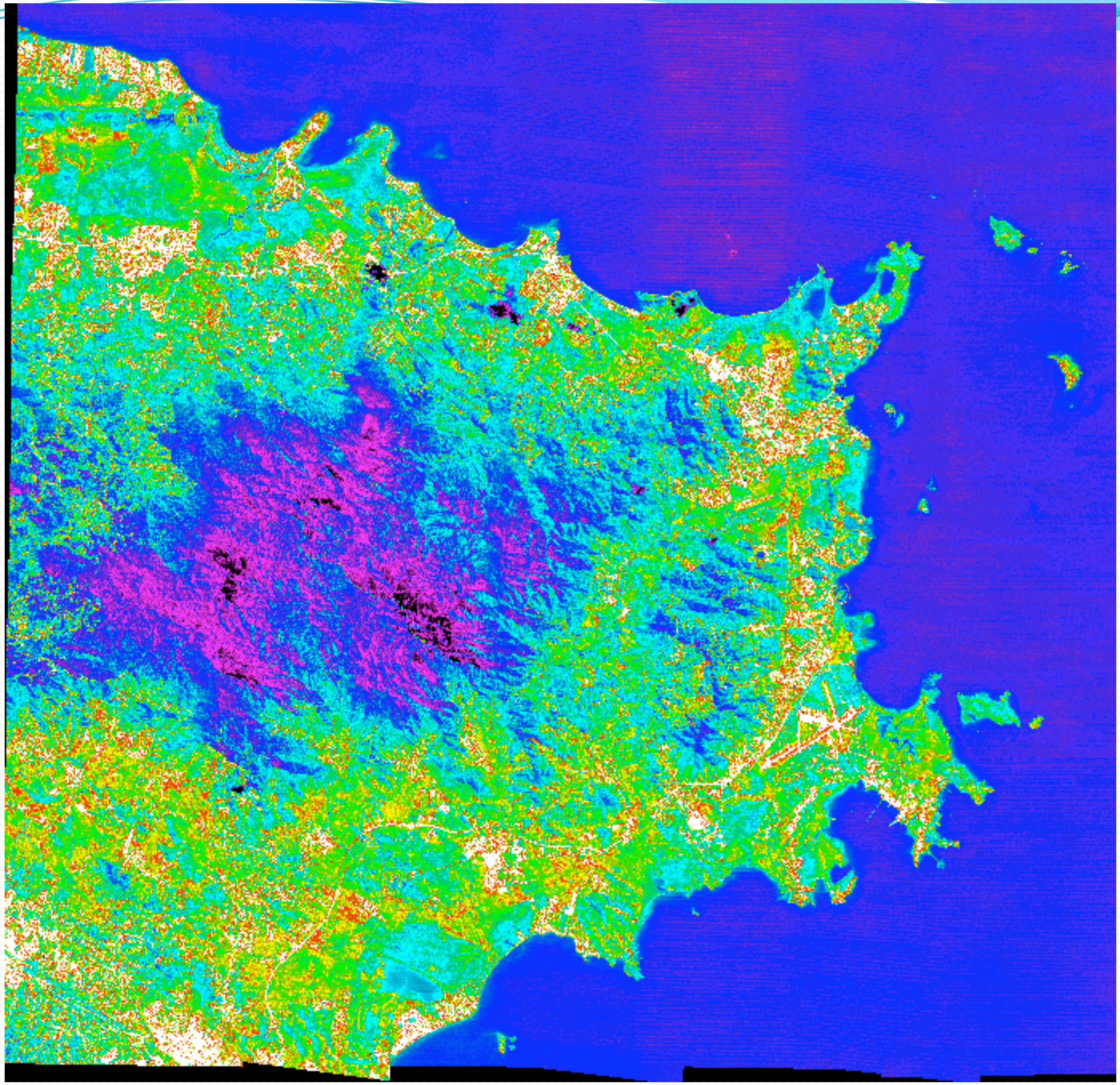


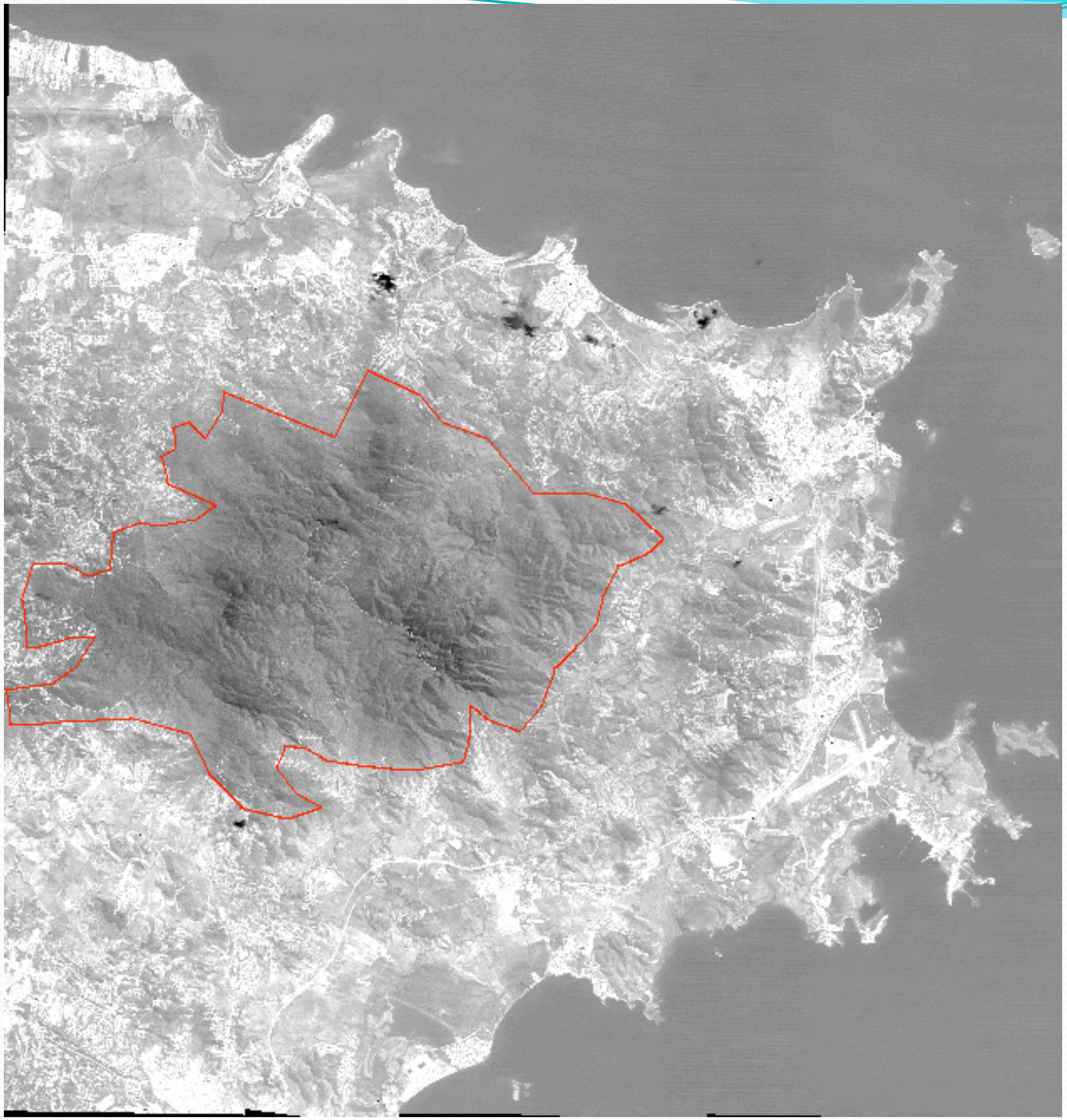
El Yunque F4 Mosaic True Color

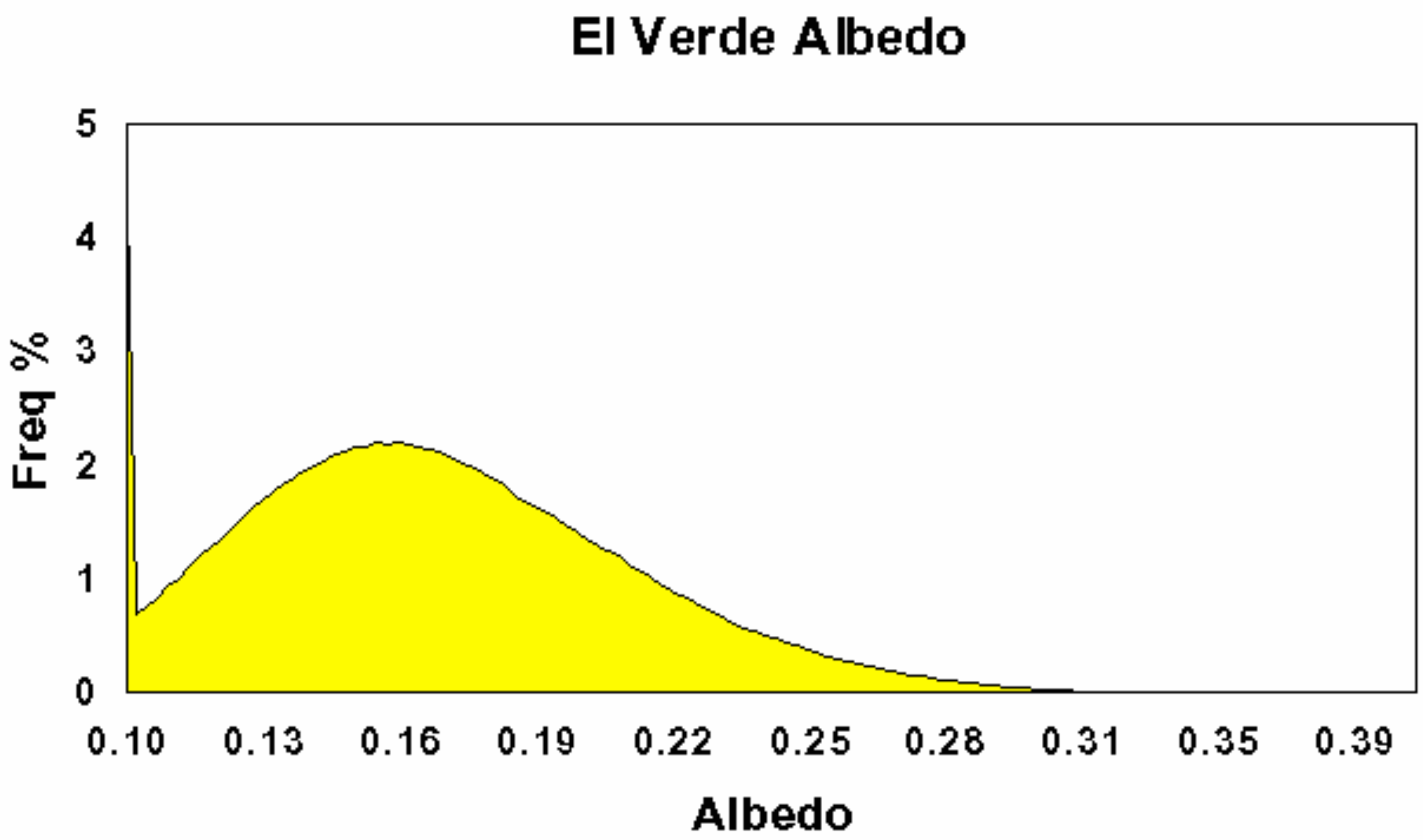
El Yunque F4 Mosaic Albedo



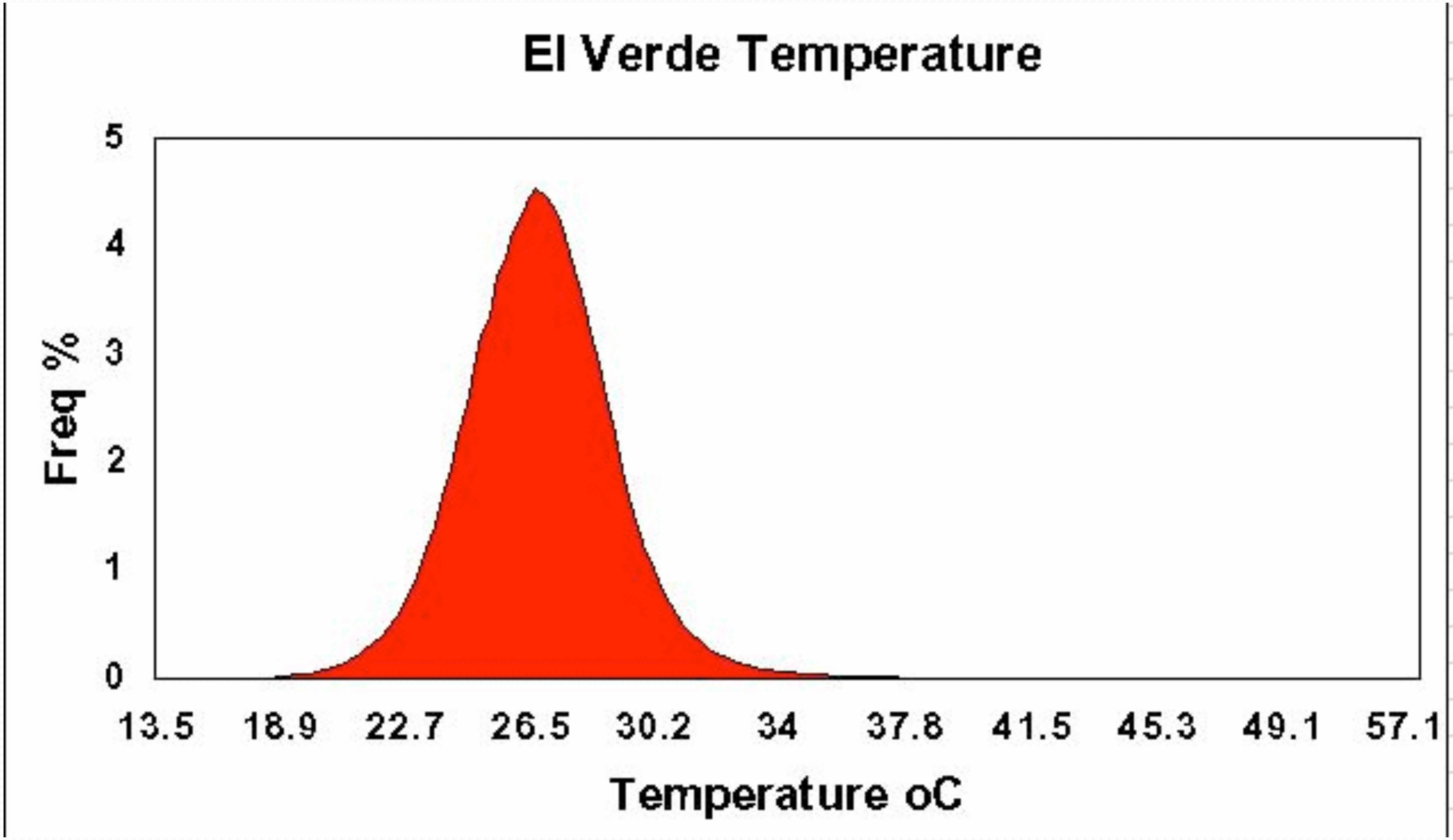
El Yunque F4 Mosaic Temperature

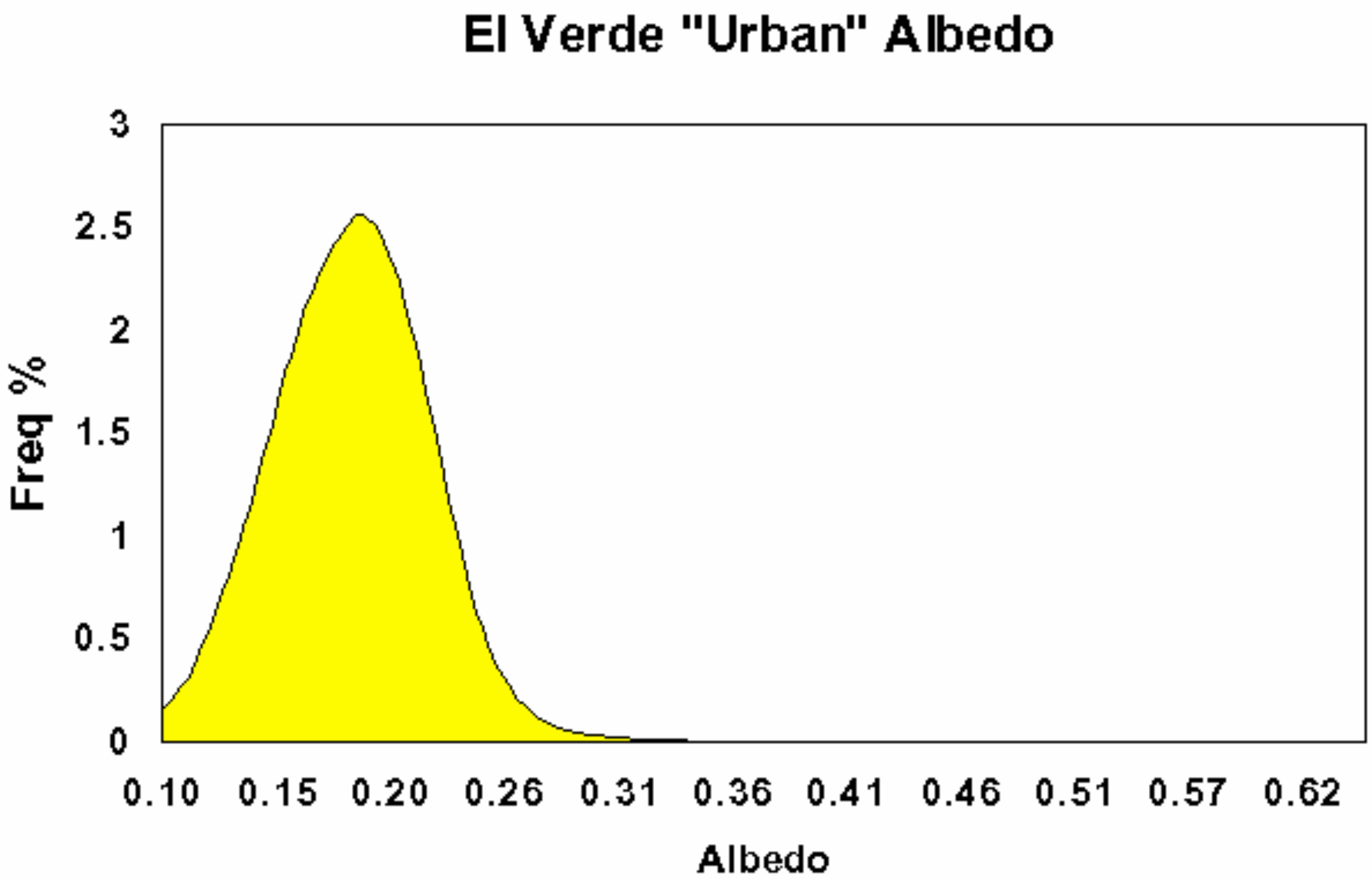


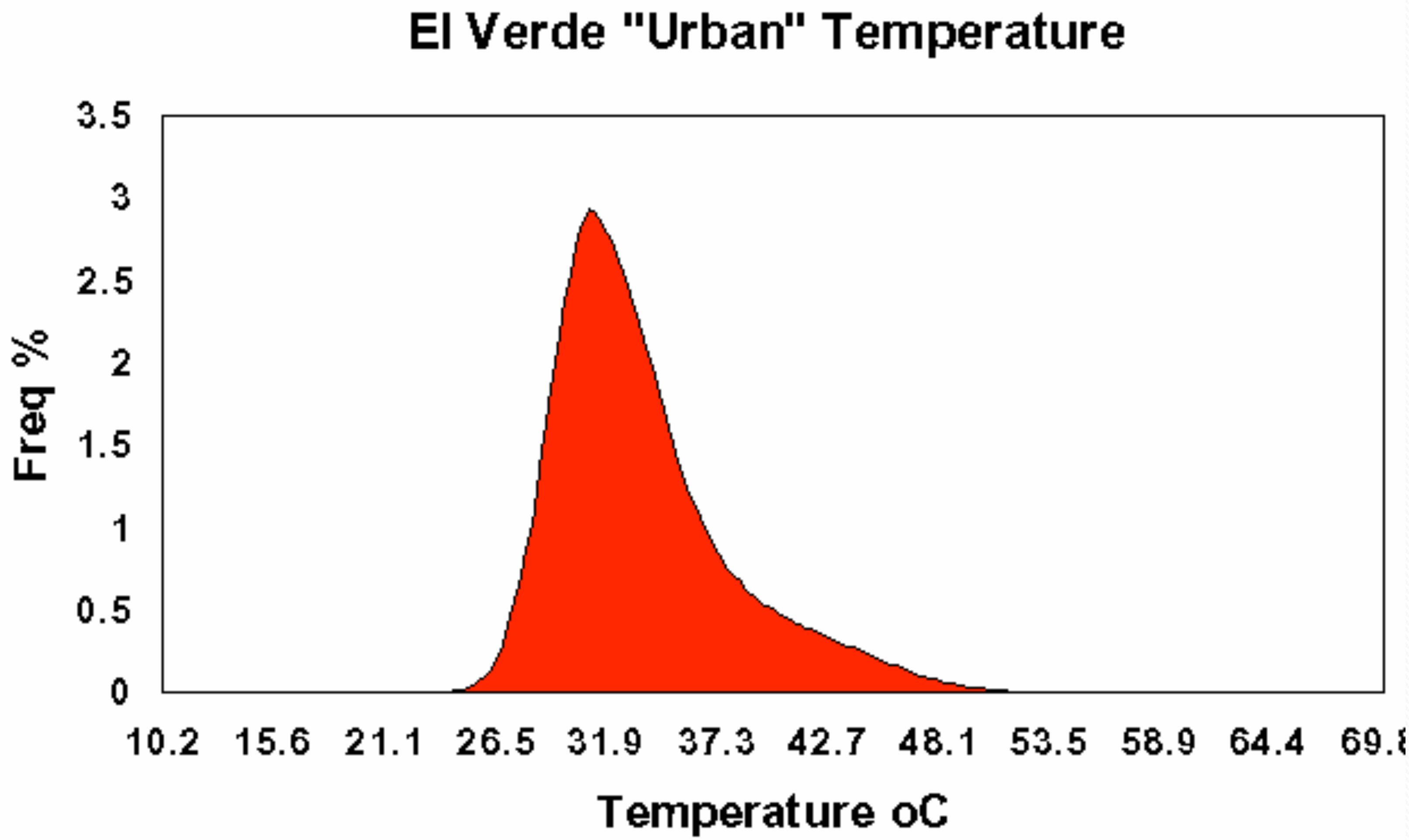




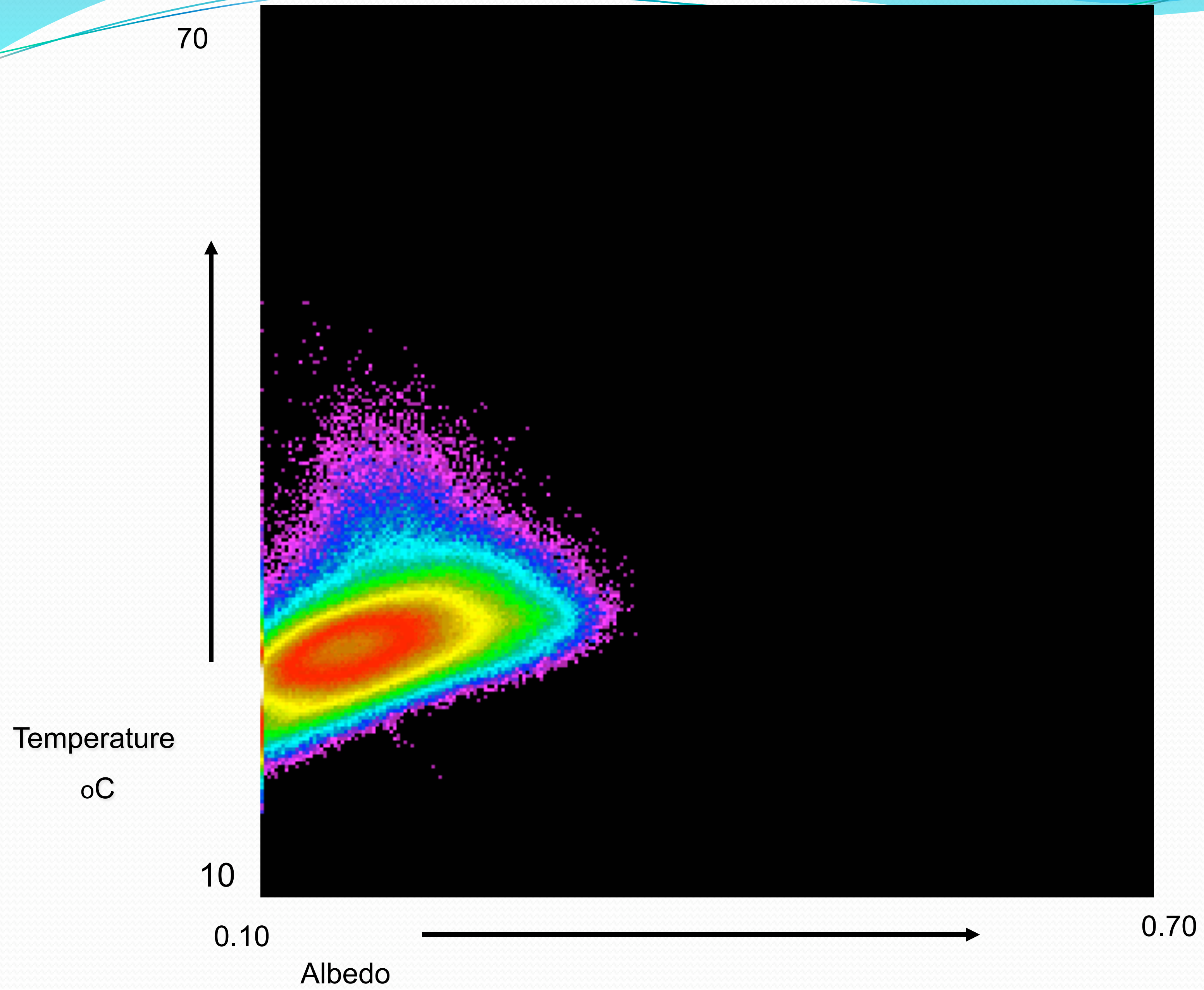
El Verde Albedo
Freq %
5
4
3
2
1
0
0.10
0.13
0.16
0.19
0.22
0.25
0.28
0.31
0.35
0.39
Albedo


El Verde Temperature
Freq %
5
4
3
2
1
0
13.5
18.9
22.7
26.5
30.2
34
37.8
41.5
45.3
49.1
57.1
Temperature oC


El Verde "Urban" Albedo
Freq %
3
2.5
2
1.5
1
0.5
0
0.10
0.15
0.20
0.26
0.31
0.36
0.41
0.46
0.51
0.57
0.62
Albedo


El Verde "Urban" Temperature
3.5
3
2.5
2
1.5
1
0.5
0
Freq %
10.2
15.6
21.1
26.5
31.9
37.3
42.7
48.1
53.5
58.9
64.4
Temperature oC

El Yunque
Albedo vs Temperature



Urban Heat Island Mitigation Pilot Project

EPA/NASA Marshall Space Flight Center

Jeffrey C. Luvall
Dale Quattrochi
Maury Estes
Doug Rickman

Urban Heat Island Mitigation Strategies

- Albedo Modification
  - Lighter colored roofs and pavements
  - New materials/coatings
- Plant trees and increase green space
  - Shade buildings, rooftops, parking lots and roads
  - Cool the air through transpiration
- Rooftop gardens
  - Keep roofs cool by shading and/or transpiration
  - storm water reduction

SMUD's Urban Heat Island mitigation efforts

- ✓ Increased Vegetation– SMUD's Shade Tree program (1990)
- ✓ Increased Roof's Albedo—SMUD's Cool Roof program (2001)
- ❑ Light colored pavements (i.e. Cool Parking Lots)– Sacramento Cool Community Project (1999)

SMUD
SACRAMENTO MUNICIPAL UTILITY DISTRICT
The Power To Do More.℠

SMUD Shade Tree Program

- started in 1990
- implemented in collaboration with the Sacramento Tree Foundation (STF)
- over 100,000 program participants
- approximately 300,000 trees planted
- annual budget over $1.5 million
- over $20 million invested since 1990
- received several national and state awards
- pay-for-performance contract with STF based on observed Present Value Benefits (PVB)

SMUD Shade Tree Program

Estimates of Savings for mature trees

- Average energy cooling load savings are 153 kWh/year/ per tree
- Average demand savings are 0.056 kW
- When 300,000 trees are mature = about 16 MW

SMUD Cool Roof Program

Program Objectives

- **Load Reduction-- reduce electricity peak demand and air conditioning energy load associated with high solar energy absorbed on the surface of roofs and rooftop ducts during the summer months**
- **Urban heat island effect mitigation**
- **Market Transformation-- expand the commercial retrofit and new construction roofing marketplace for highly reflective and emissive roof coatings and materials.**

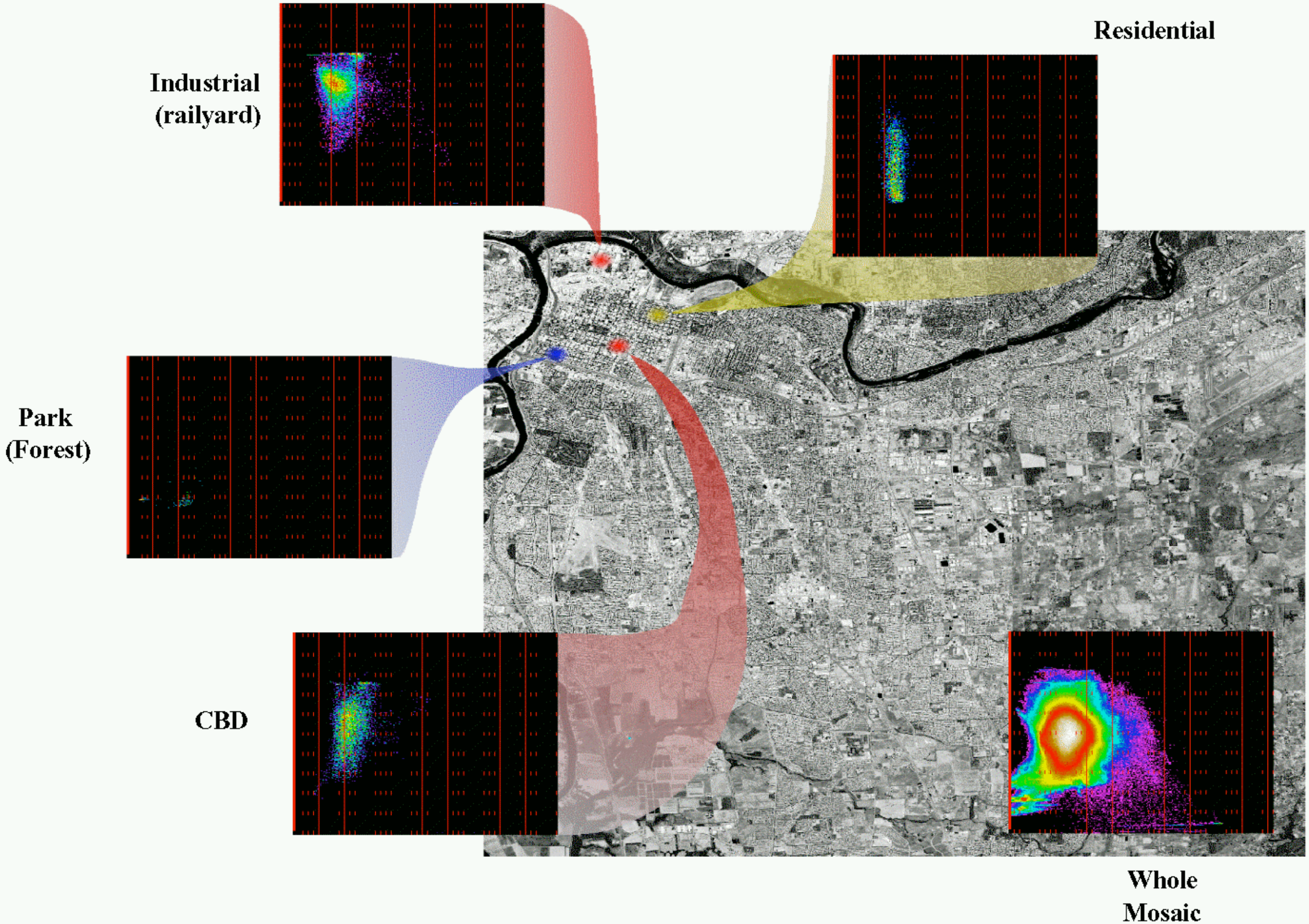
SMUD
SACRAMENTO MUNICIPAL UTILITY DISTRICT
The Power To Do More.℠

SMUD Cool Roof Program

Estimates of Savings

- Average energy cooling load savings of 20%
- Average energy cooling load savings are 0.15 kWh/year/Sq.Ft.
- Average demand savings are 0.25 W/Sq.Ft.

Sacramento Skattergrams
Albedo vs Temperature

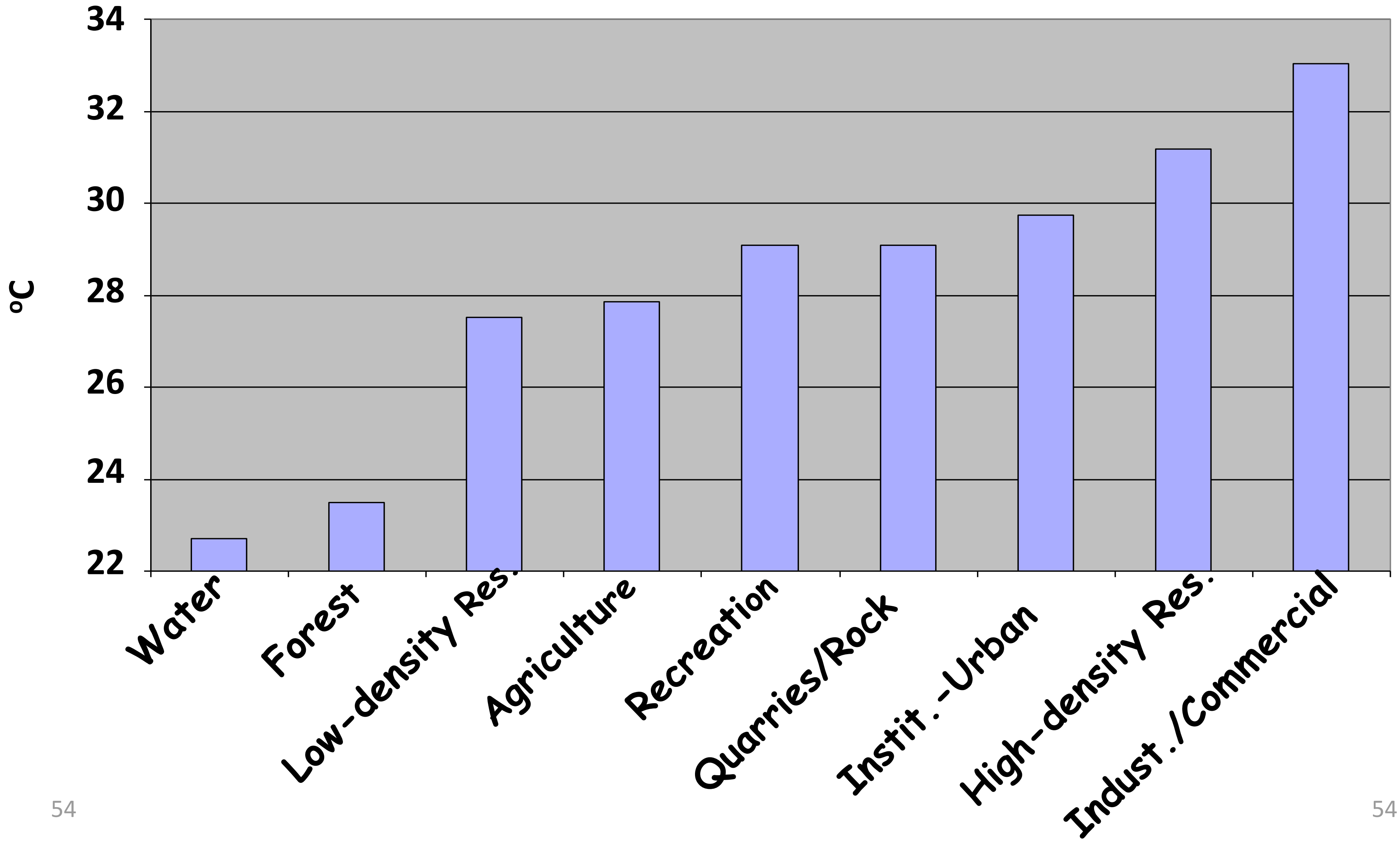


Spatial Growth Models

- Empirical
  - statistically matching temporal trends and/or spatial patterns with a set of predictor variables
- Dynamic Process
  - Interactions between agents/organisms and environment (Cellular Automata, SLEUTH)
  - Cells can represent parcels of land with unique characteristics and each changing as a result of rules on both the cell's state and state of neighbors
- Agent-based
  - Micro-scale behaviors of individuals (farmers, ranchers, etc.) or institutions (industries, gov't, etc. with feedback loops (Research)

Surface Temperature by Land Use Class

Based on ATLAS aircraft data, May 1997



54

Problem description

- Istanbul is the largest city in turkey
  - Population 11 million
- Traffic congestion:
  - 600 cars enter the system every day
- Infrastructure project under consideration includes construction of **a third bridge** across the Bosporus, north of the city
  - How would the proposed infrastructure project affect the ecologically sensitive area located in the north?
  - Answer needed in days!!
  - This project is the **first step** towards a DSS that would provide an answer to such questions


Istanbul, Turkey
Ataturk Airport
20.2 km
Image © 2008 DigitalGlobe
Image © 2008 TerraMetrics
©2006 Google™

Fatih Sultan Mehmet Bridge
Istanbul, Turkey
3.87 km
Image © 2008 DigitalGlobe
© 2006
Google™

1986 LandSat Image

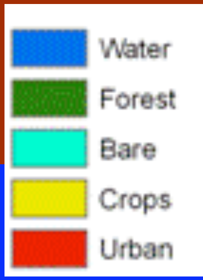
Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

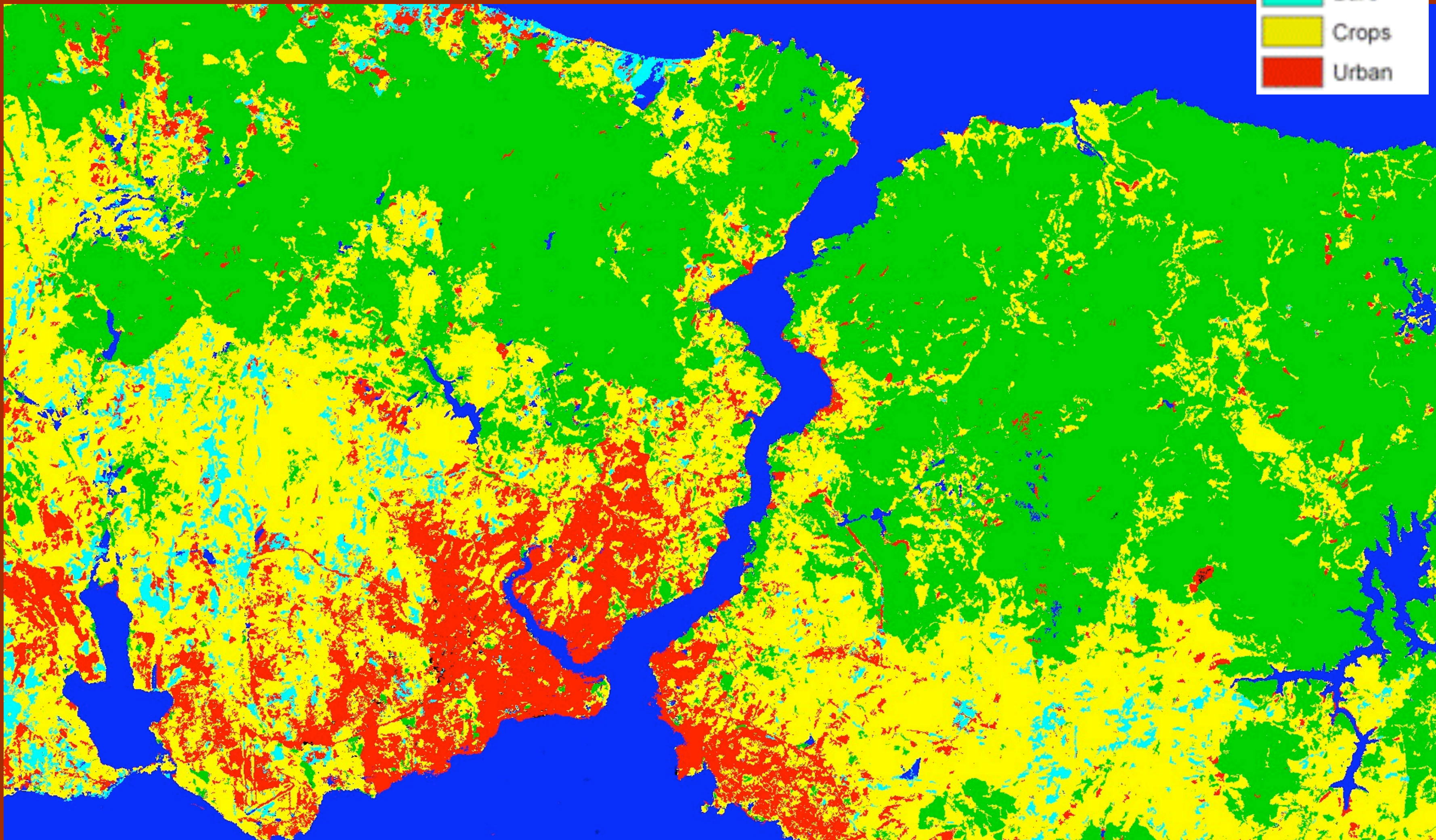
2007 LandSat Image

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

1986 Land Use

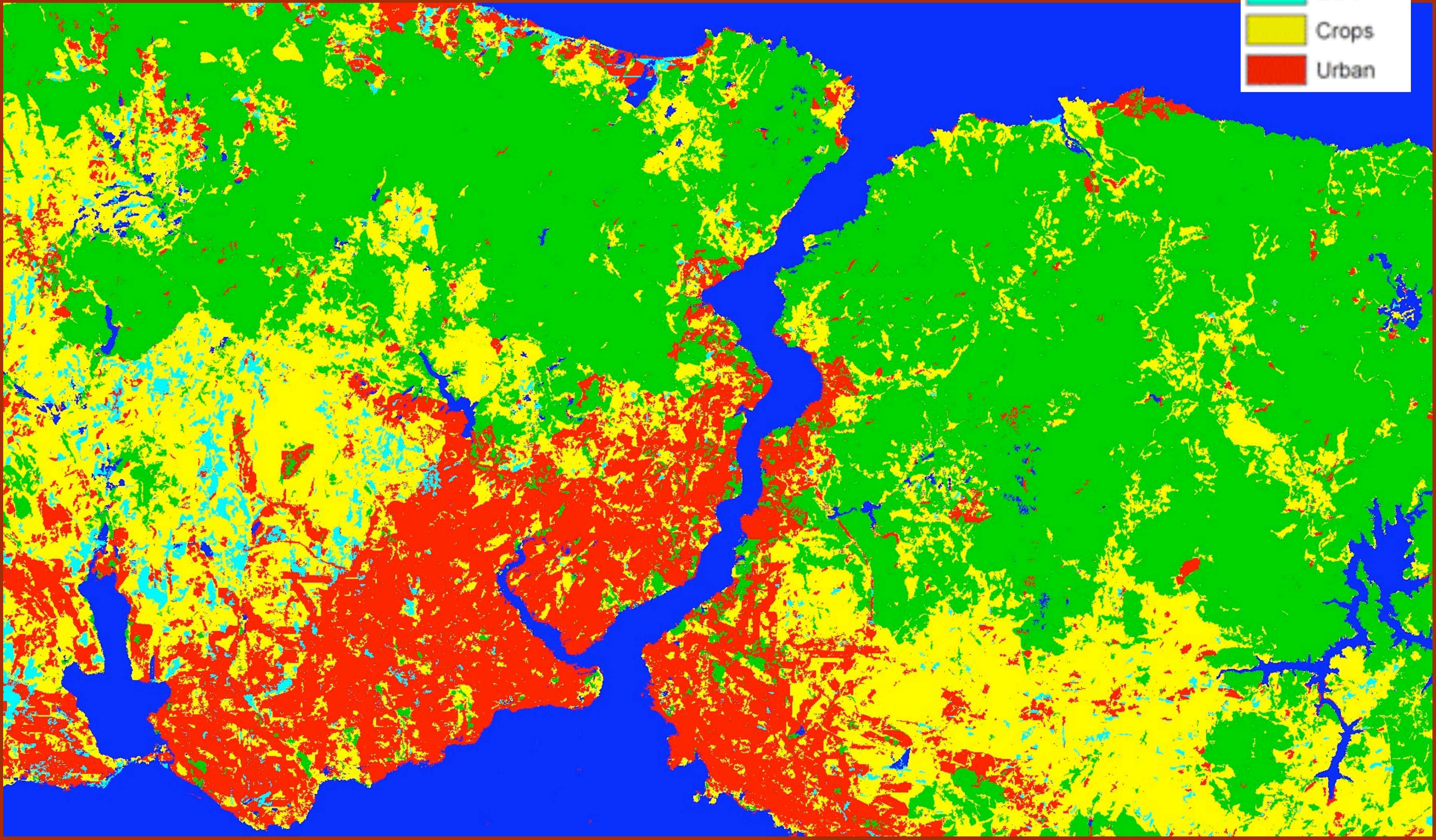




Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

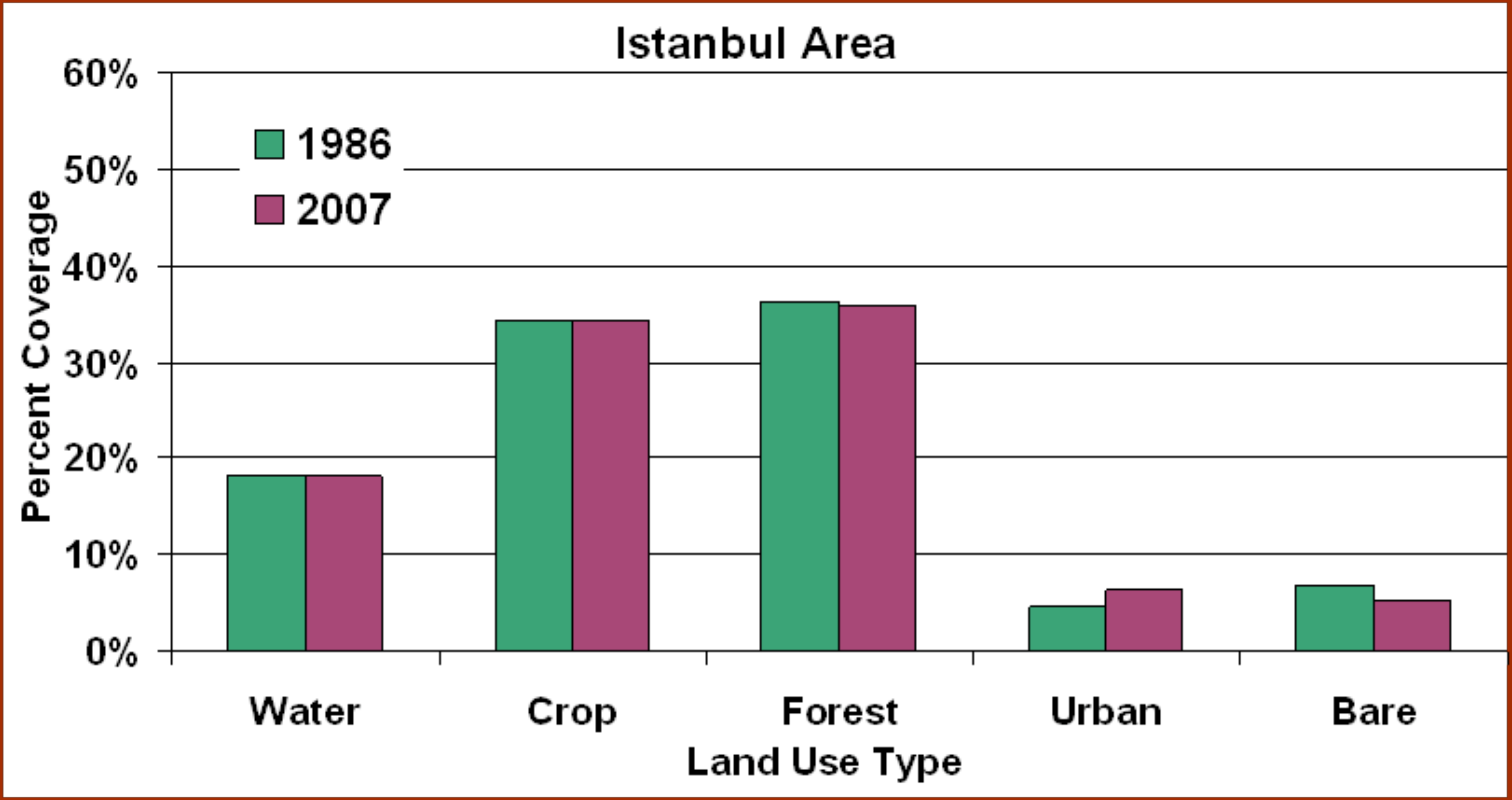
2007 Land Use



Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

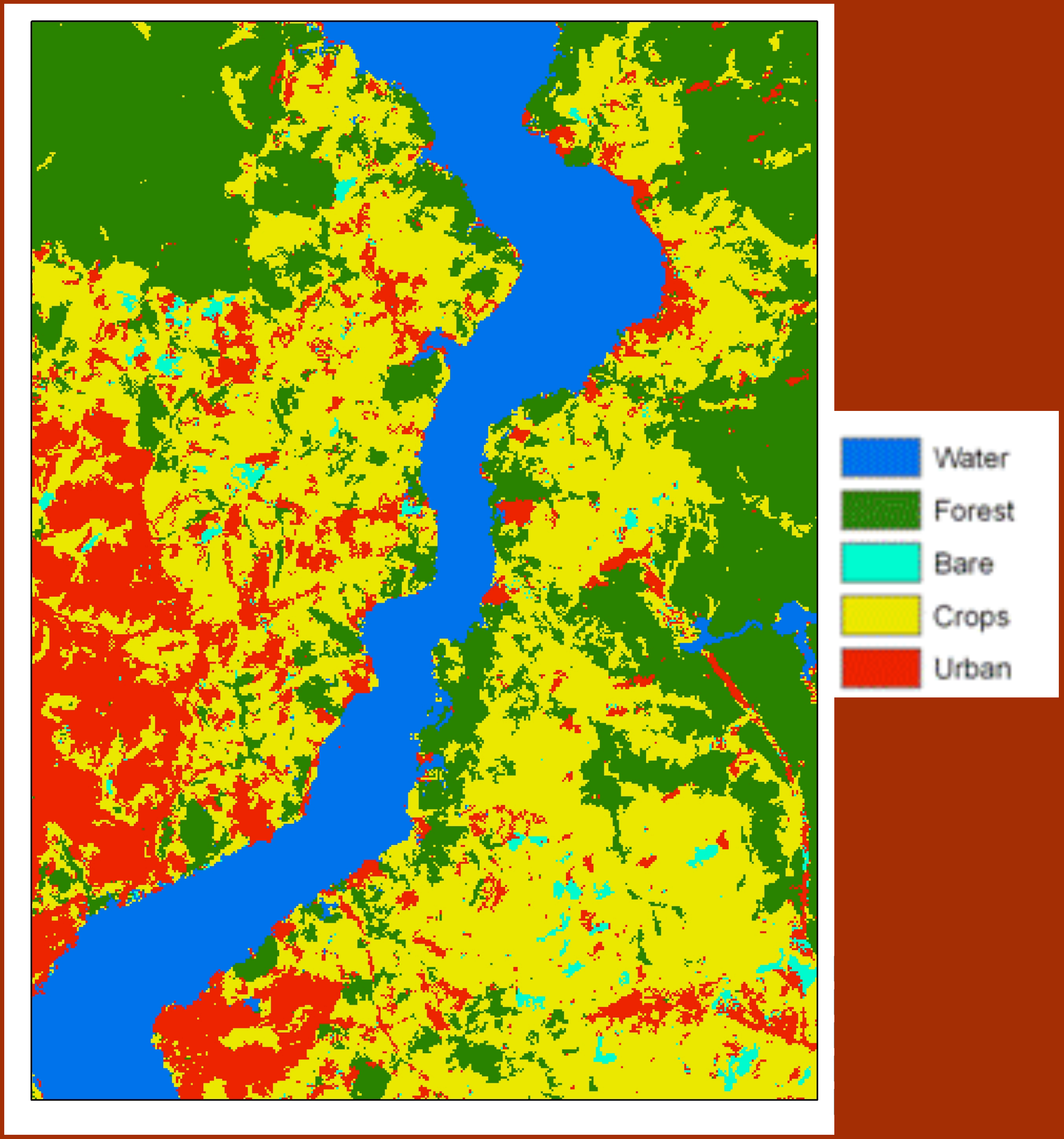
Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

LULC statistics for Istanbul



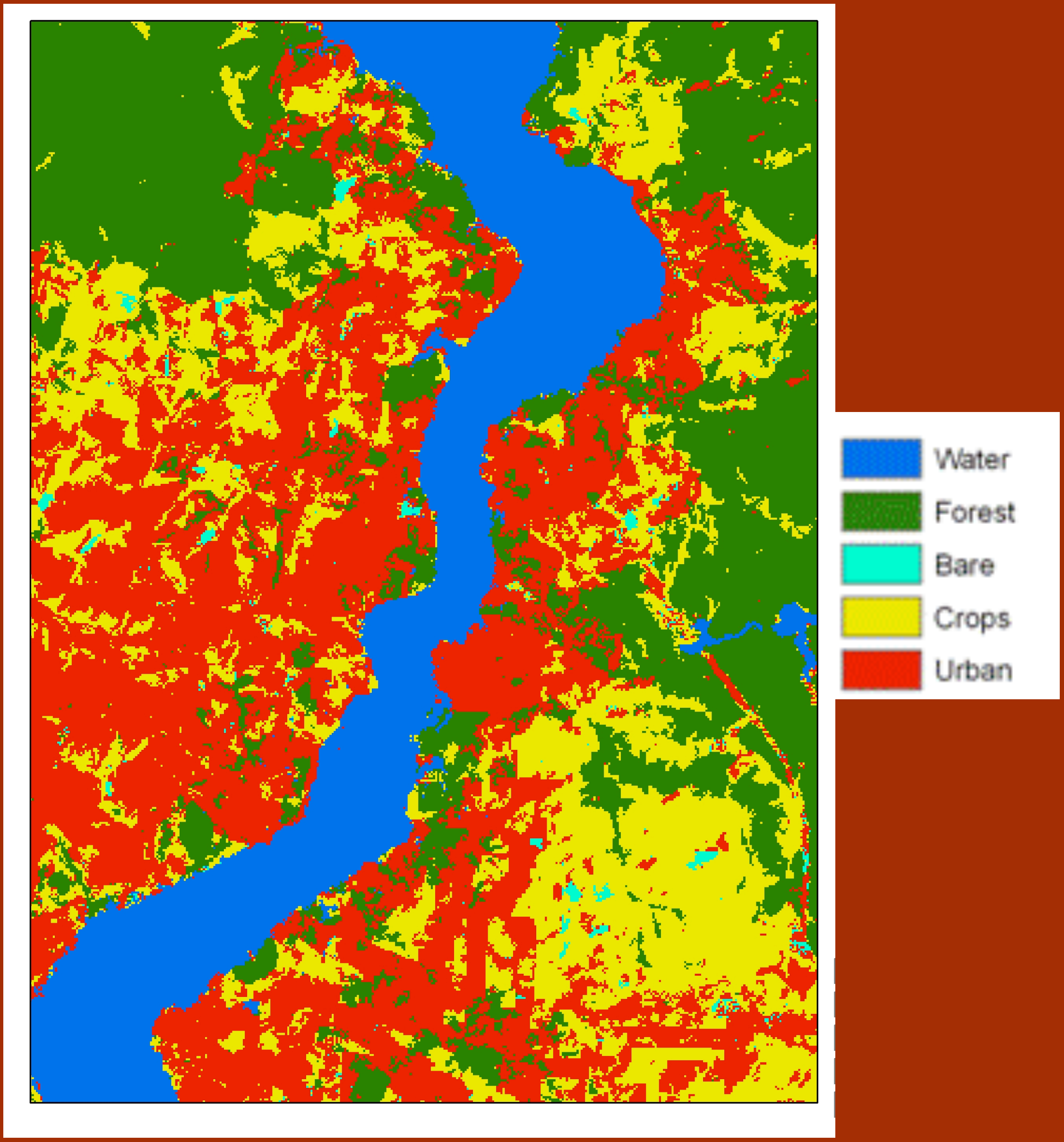
Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

1986 Land Use – Bridge Area



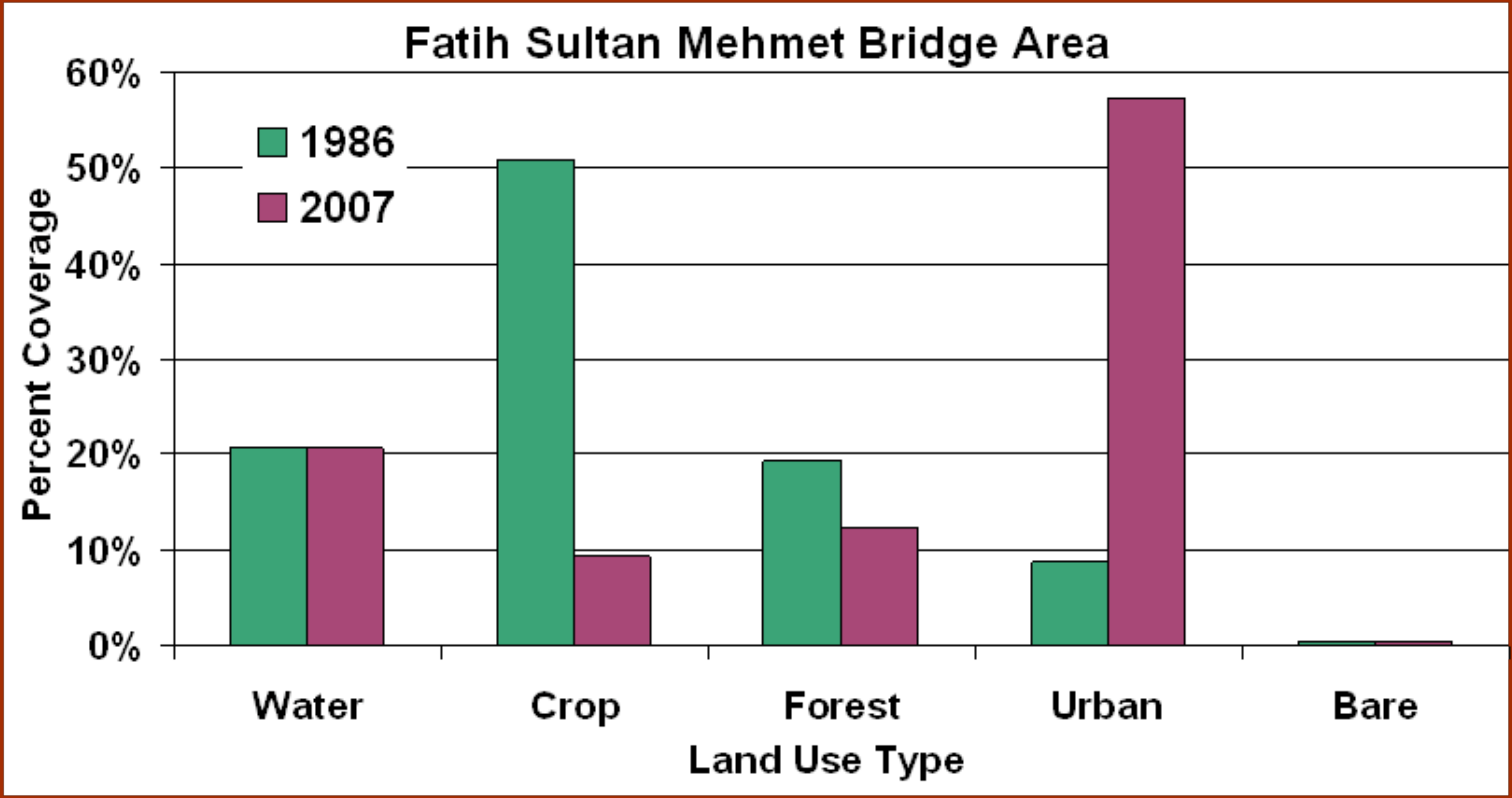
Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

2007 Land Use – Bridge Area

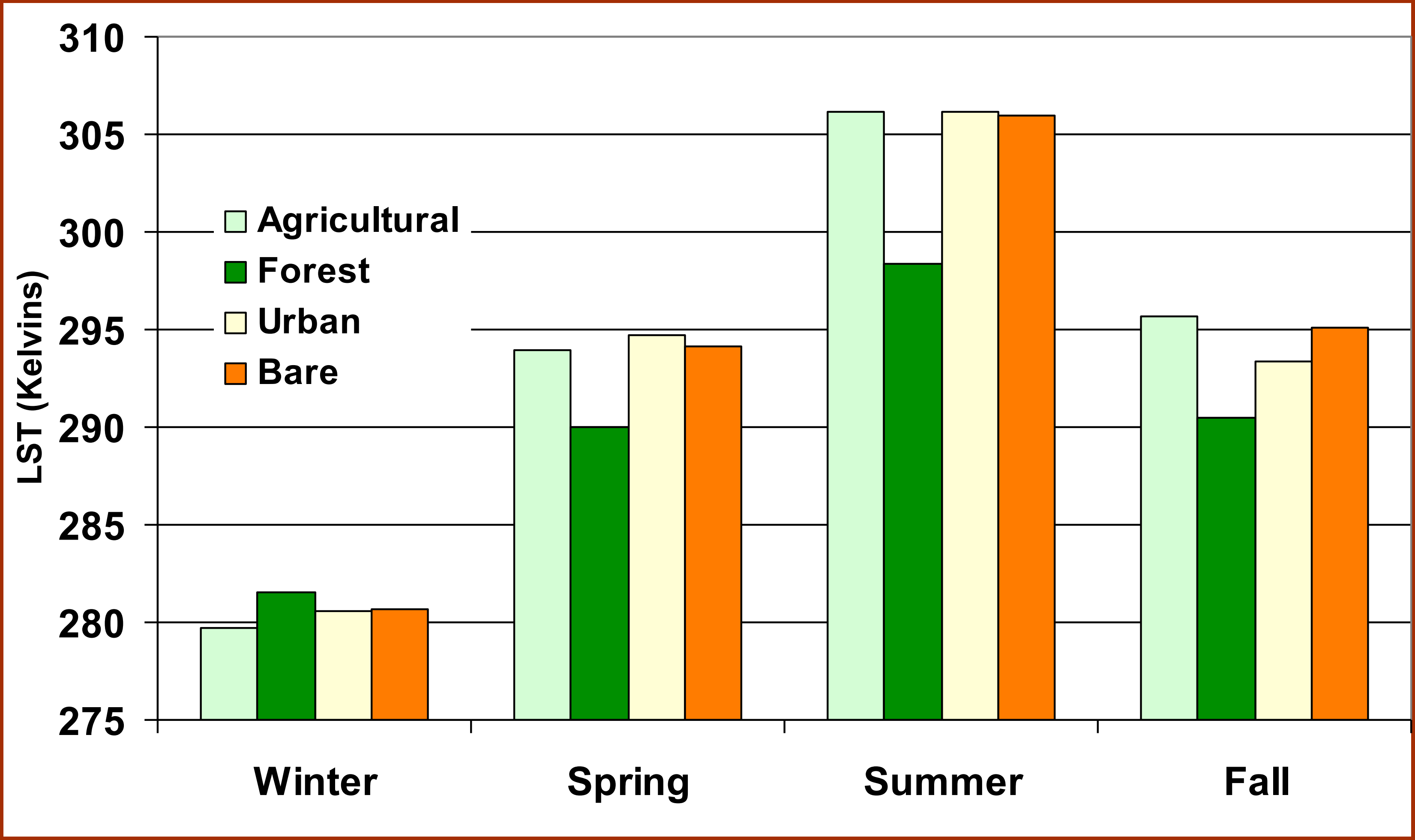


Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

LULC statistics around the bridge



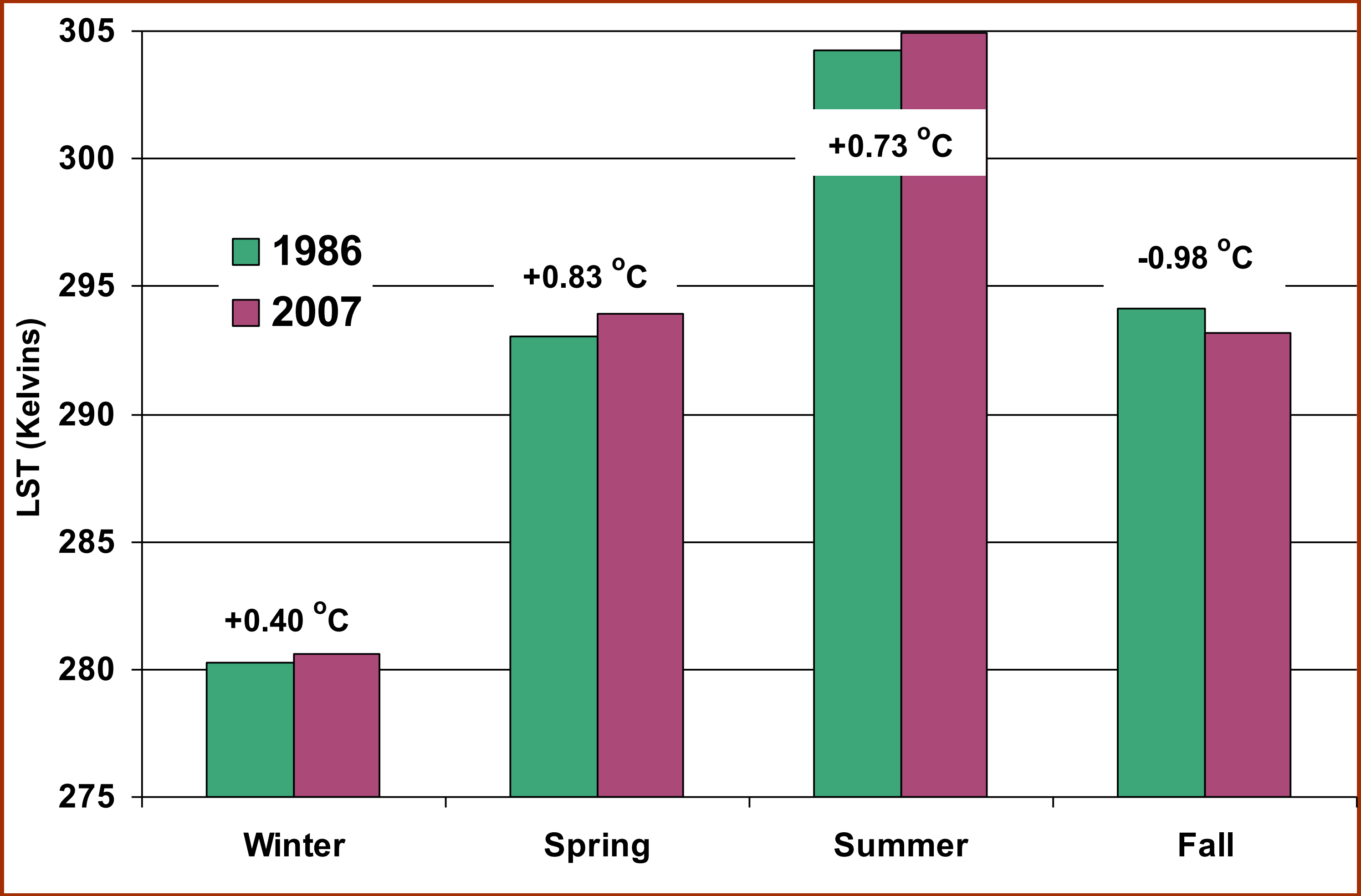
LST as a function of LULC and season



Mean land surface temperature by season and land use type, from all Aqua and Terra MODIS observations, 2003-2006.

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

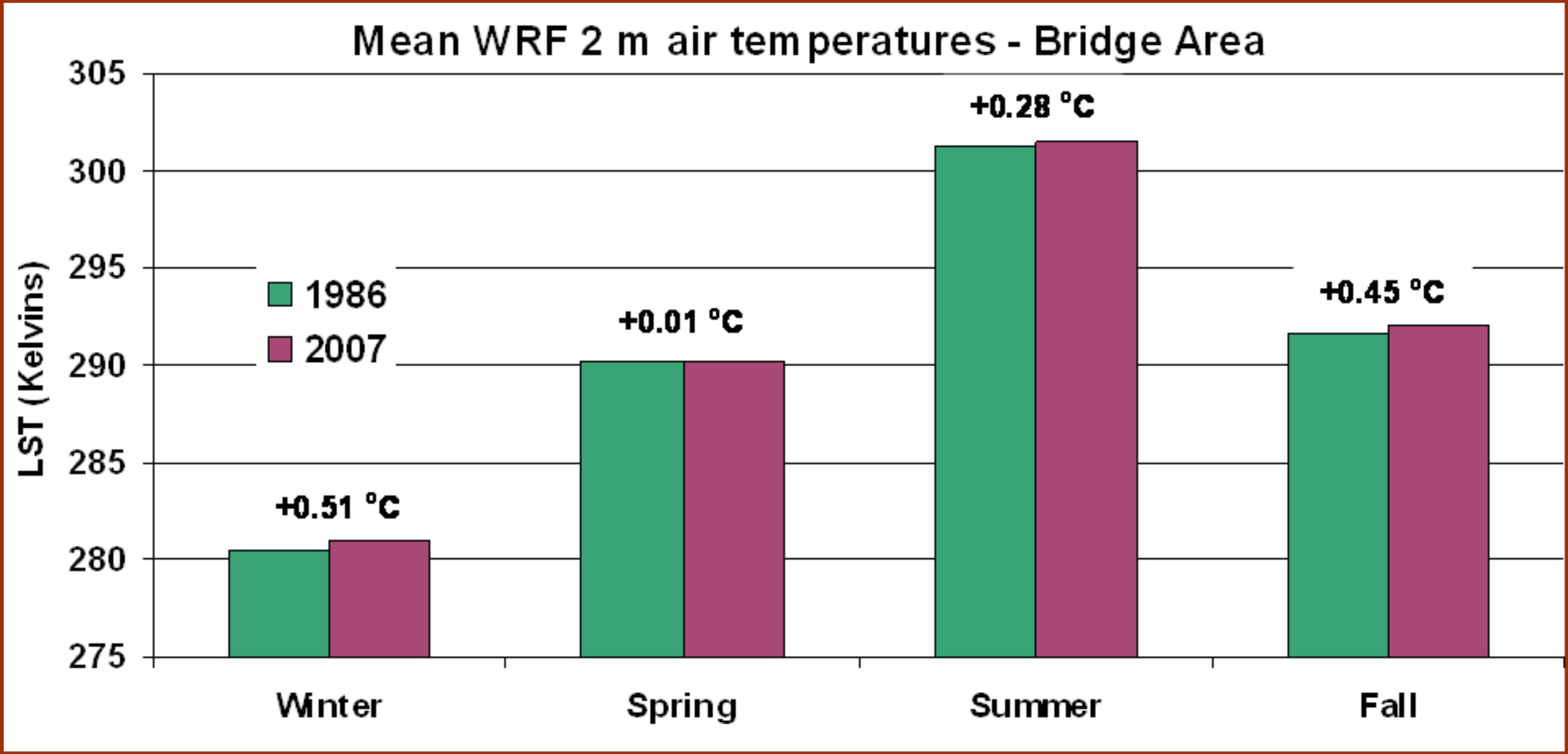
LST differences due to urbanization, 1986-2007



Inferred relative differences in seasonal LST attributed to LULC changes in vicinity of the second bridge between 1986 and 2007.
2007 LST based on 2003-2006 mean MODIS LST for each LULC type and 2007 Landsat LULC.
1986 LST estimated from the different proportions of LULC from the 1986 Landsat LULC.

Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

Modeled 2-m air temperature
Bridge Area



Land Processes Research and Applications Team, NASA Marshall Space Flight Center, Huntsville, AL

What can HyspIRI dsata provide for urban heat island research and applications ?

- Scale consistance with complex urban surfaces
- Well calibrated data allows quantifiable radiative & energy budgets:
    - Analysis of albedo
    - Analysis of surface temperature
    - Analysis of emissivity
- Scale consistant to plan alteration of the urban fabric to mitigate the urban heat island
- Swath width scale for urban climatiolgy studies - urbanization of RAMS.
- Global cities.
- Only mutispectral thermal at 60 m
- 5 day repeat for thermal for short & long term trend analysis
- Allow for functional classification of urban surfaces