NASA's Contributions in Detecting UHI Coastal Cities

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Outline

- URBAN HEAT ISLAND (UHI): DEFINITION AND BACKGROUND
- UHI IN COASTAL CITIES AROUND THE WORLD
- OBSERVATIONAL MEASUREMENTS AND ANALYSES PR & CAL
  - Airborne Images
  - Modeling Experiments
- SUMMARY AND CONCLUSIONS

What is the Urban Heat Island Effect?

Primitive Scenario

Vegetation

Soil

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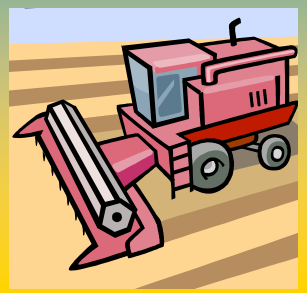
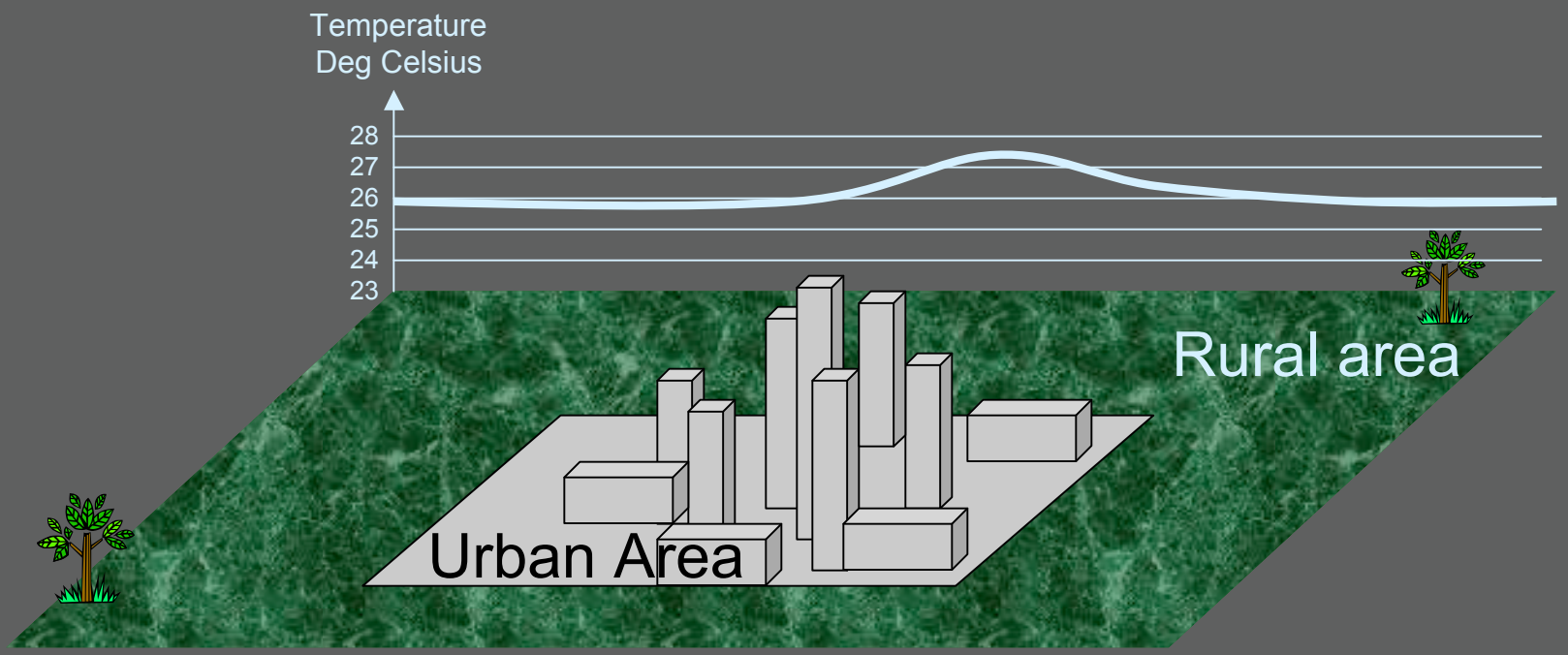


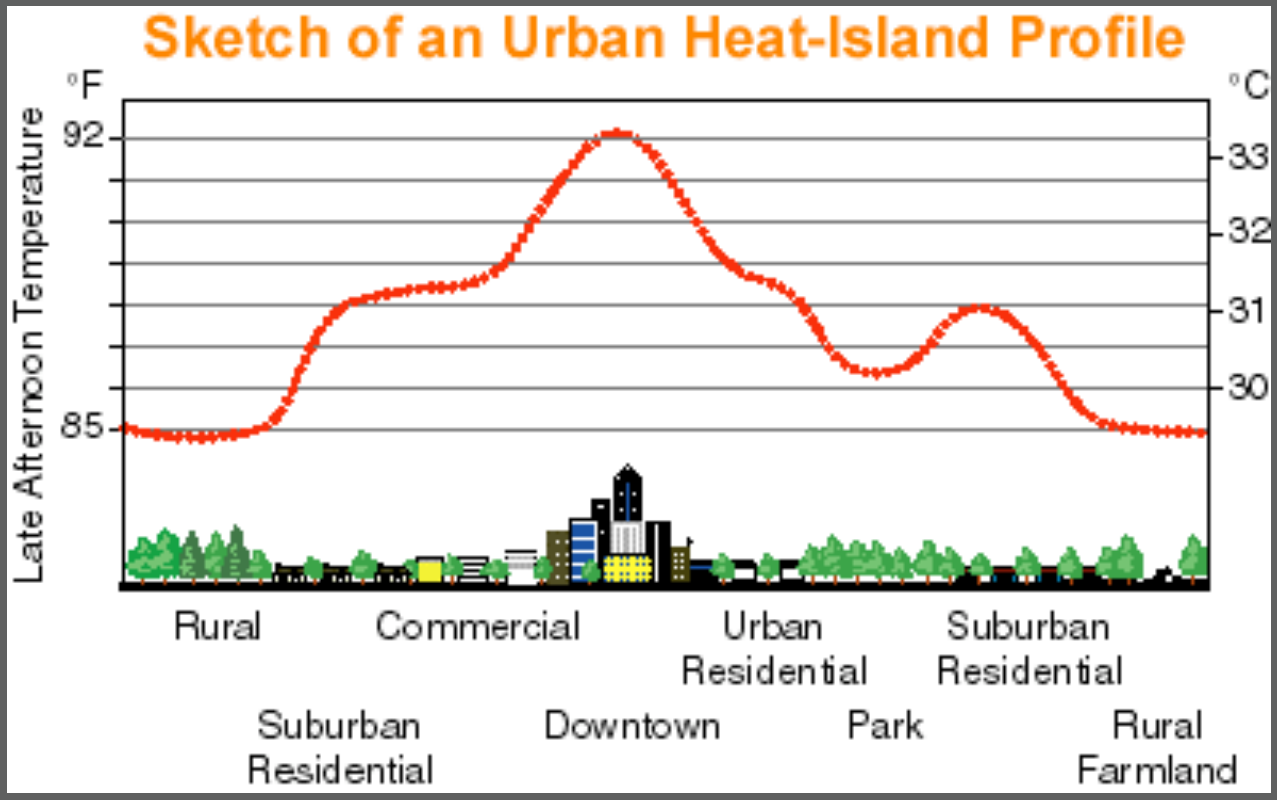
Urban Scenario

Buildings

Concrete



Urban Heat-Island Effect



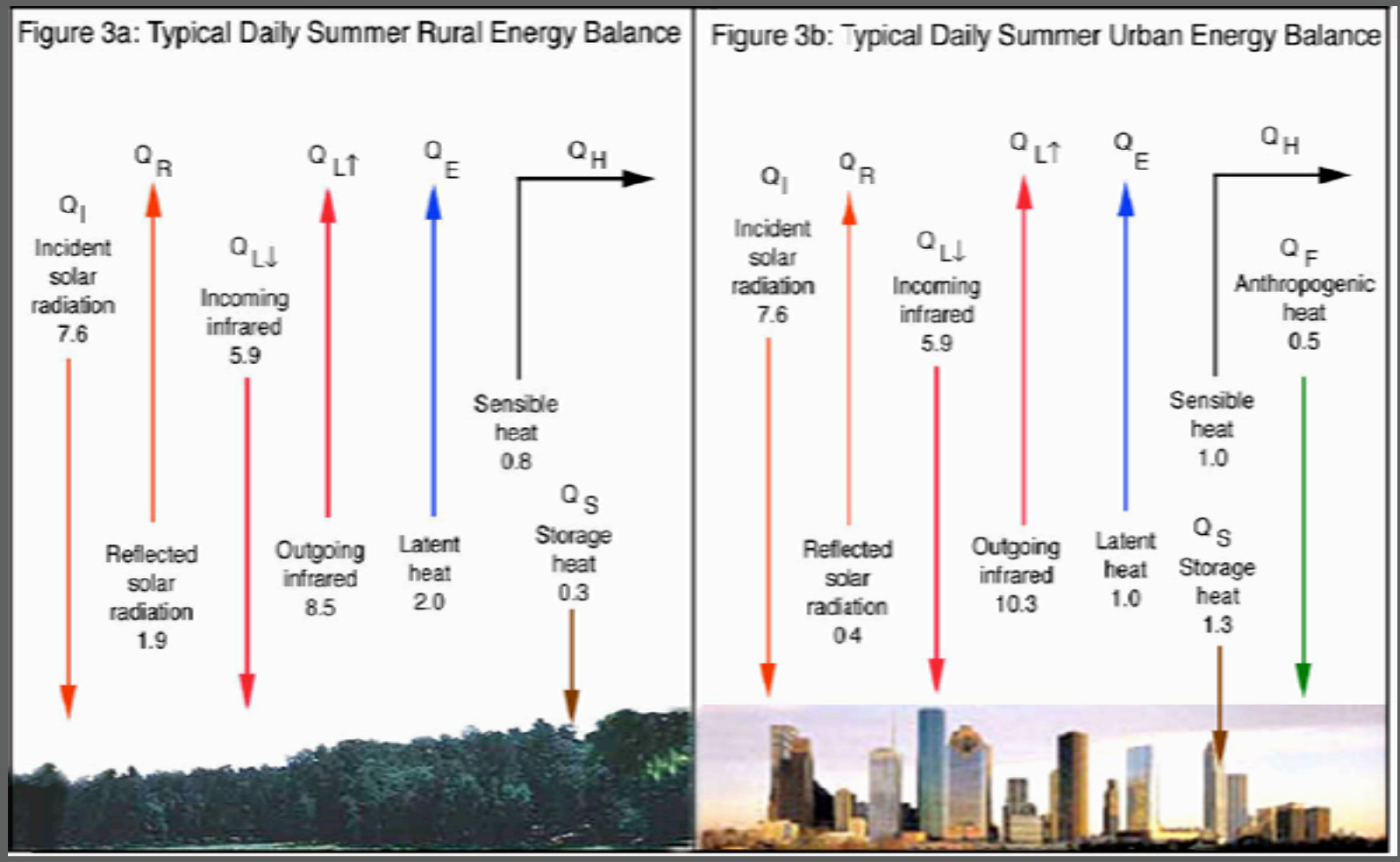
Courtesy of LBNL

Can be defined as the dome of elevated air temperatures that presides over cities in contrast to their cooler rural surroundings.

What leads to the formation of an UHI?

- **Paved urban surfaces.**
  - These make the penetration of precipitation on the soil virtually impossible.
  - Higher water runoff leads to small flash floods over the few vegetated surfaces available.
  - Situation provides little water for evaporation, and thereby, expends little net radiation on evaporation.
- **Cities have large vertical surfaces of different geometric shapes.**
  - They function like canyons affecting radiation and wind patterns.
  - Radiation is reflected back and forth off the walls of buildings resulting in entrapped energy and higher temperatures. Buildings also disrupt wind flow creating less heat loss.

Urban Heat Island Effects on the Energy Balance



Courtesy of Dr. Marshall Shepherd, GSFC

Urban Heat Island Induced Problems & Hazards

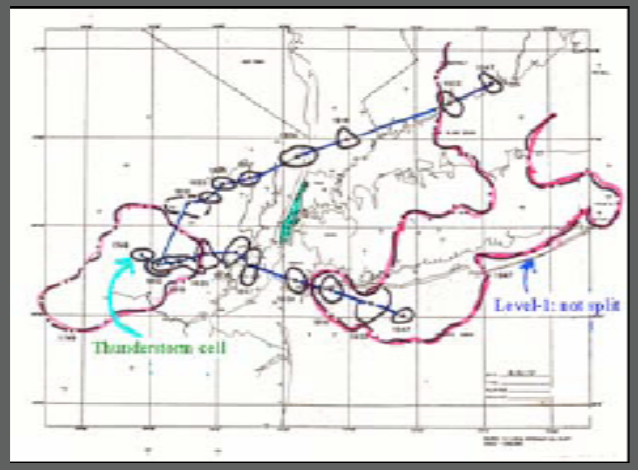
- Poor Air Quality
  - Hotter air in cities increases both the frequency and intensity of ground-level ozone.
- Risks To Public Health
  - The UHI Effect prolongs and intensifies heat waves in cities, making residents and workers uncomfortable and putting them at increased risk for heat exhaustion and heat stroke.
- High Energy Use
  - Hotter temperatures increase demand for air conditioning. This contributes to power shortages and raises energy expenditures.
- Global Warming
  - Urban Heat Islands contribute to global warming by increasing the demand for electricity to cool our buildings.
  - Each kilowatt hour of electricity consumed can produce up to 2.3 pounds of carbon dioxide (CO2), the main greenhouse gas contributing to global warming.
- Urban Heat Island – Induced Precipitation

Urban Heat Island Effects on Precipitation

Previous research has suggested three main factors as possible causes for urban-induced anomalies in precipitation patterns:

- Mechanical mixing and turbulence resulting from increased surface roughness due to the urban landscape (skyline)
- The addition of sensible heat from the urban warm air (UHI_PCP animation from GSFC)
- The anthropogenic cloud condensation nuclei floating in the urban air

Studies in New York City have shown that the building barrier effect tend to split approaching rainfall systems.



From Dr. Robert Bornstein, SJSU

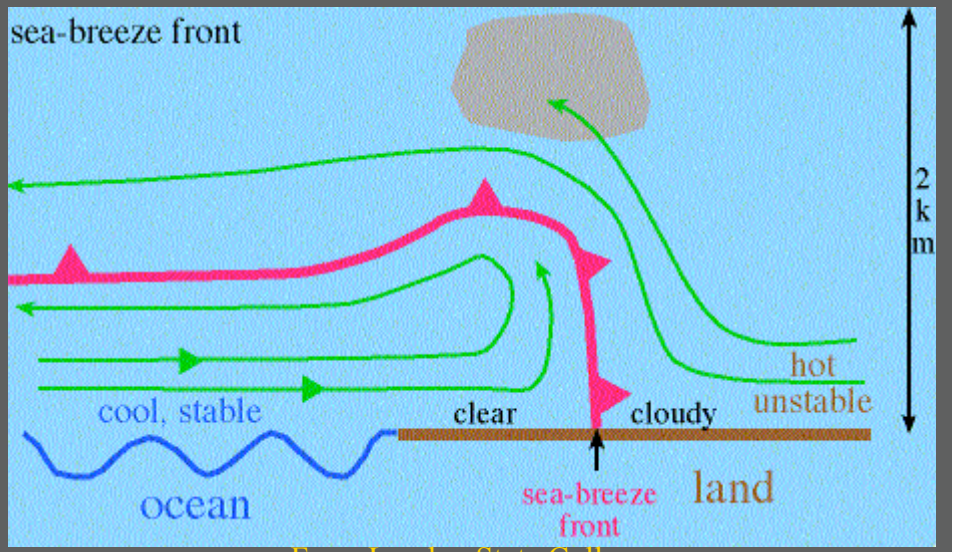
Urban Heat Island and the Sea Breeze

The sea/land breeze is a mesoscale circulation induced by difference in temperature and air density:

- Warm air over land rises
- Sea Breeze moves inland
- Cumuli develop aloft and move seaward
- Upper level return land breeze
- Cool air aloft sinks over water
- Sea Breeze (meso-cold) Front

In coastal Cities:

- Is the sea/land breeze blocked by the buildings?
- Is the sea breeze enhanced by urban-induced convection?
- Does it "wash" away the UHI
- What is the effect…

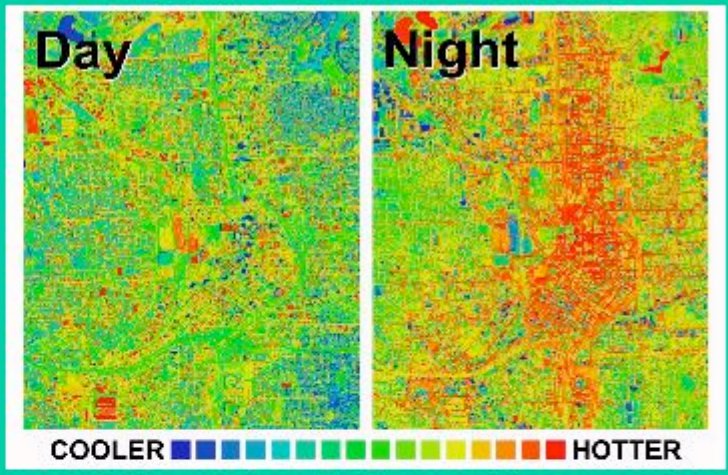


From Lyndon State College

NASA URBAN HEAT ISLAND RESEARCH

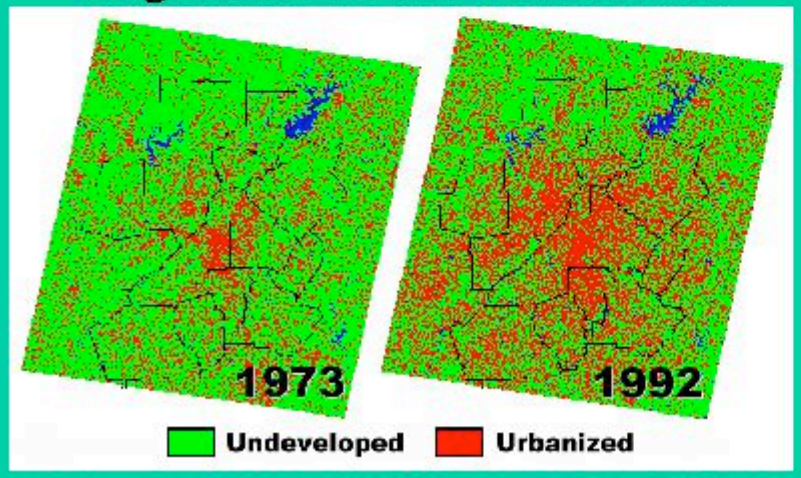
- The urban heat island is a dome of higher air temperatures above a city. The heat island is a major contributor to ozone production and affects local and regional weather.
- Using Atlanta, Georgia as a study area, this research provides a better understanding of how urbanization affects local and regional meteorology, and air quality.

High Resolution Thermal Data For Surface Heat Detection



Thermal infrared aircraft data provide comparison of daytime and nighttime surface temperatures in downtown Atlanta

Land Use Change Affects the Magnitude of the Heat Island

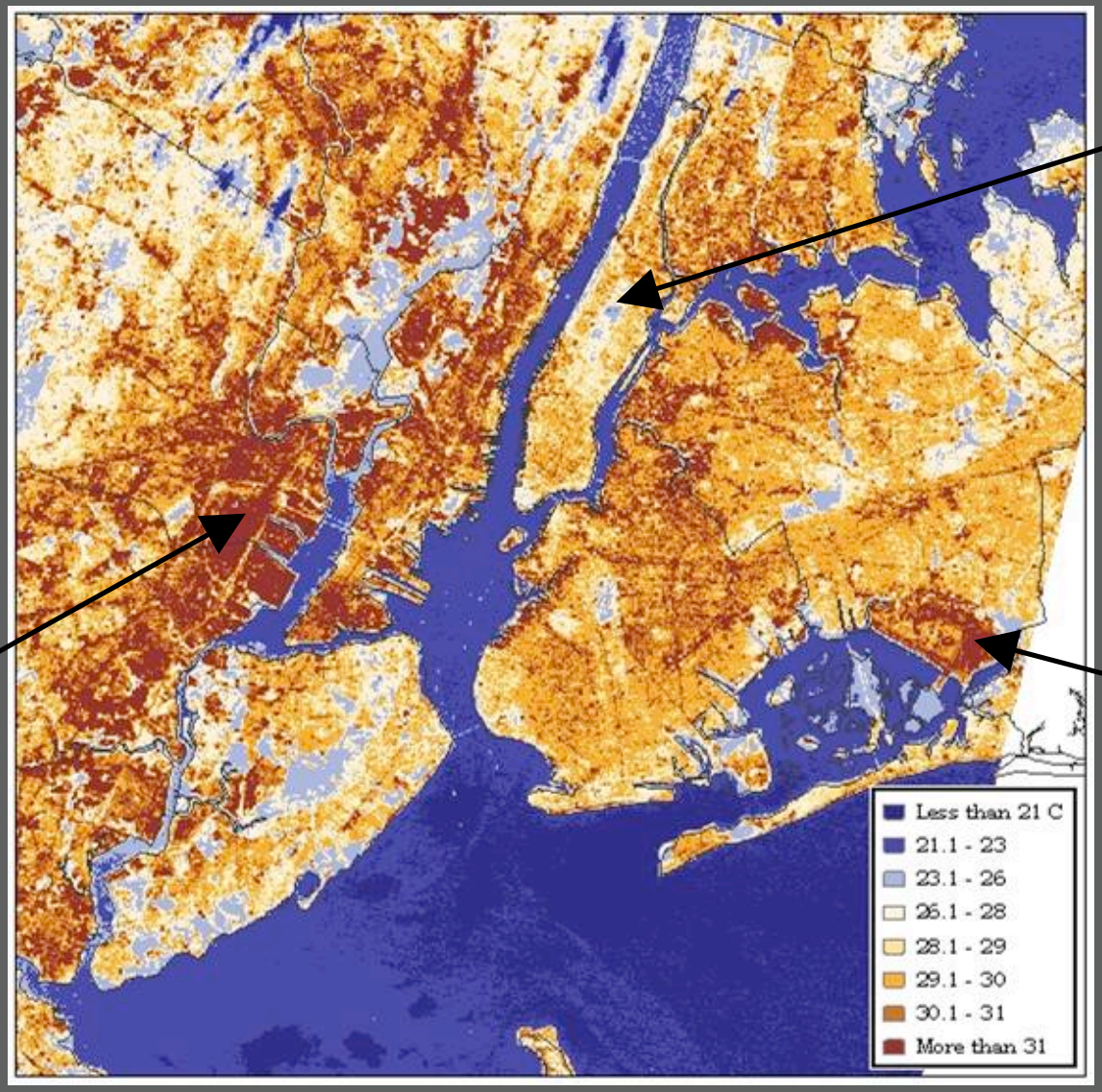


Forest land decreases 380,000 acres. Residential land increases by 370,000 acres. (NASA Landsat data)

BENEFITS TO PEOPLE

- Translation of project's science results to Atlanta urban planners and decision-makers
- Development of Cool Community measures to mitigate heat island effects by planting trees and increasing reflectivity of urban surfaces
- Lessen impact of heat effects on humans

UHI: Case Studies in USA



New York City is one of the most urbanized areas in the world.

From Jennifer Cox, Hunter College SUNY.

UHI: The Case of SJU PR

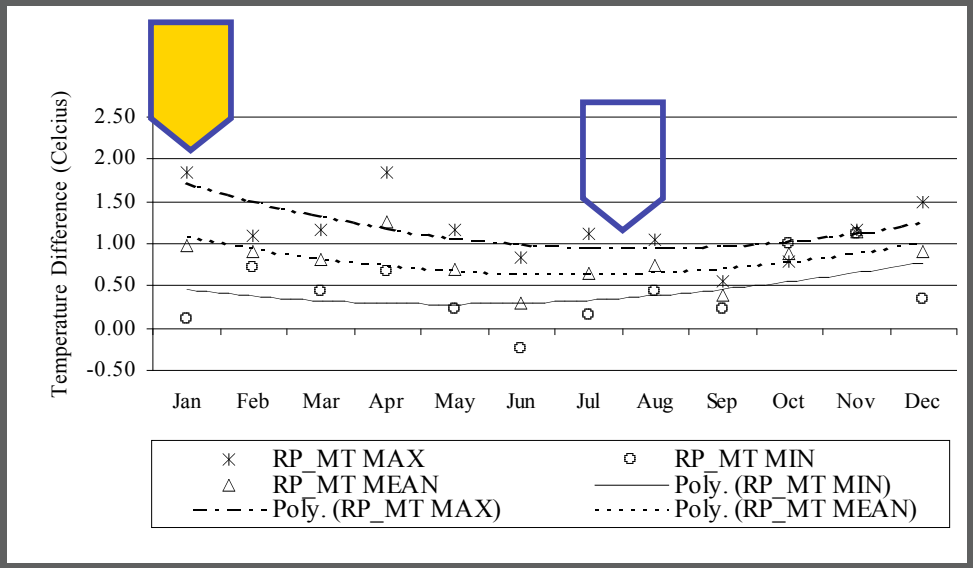
Airborne Images

Size of the
Urbanized
Area
of San Juan
308 km^2

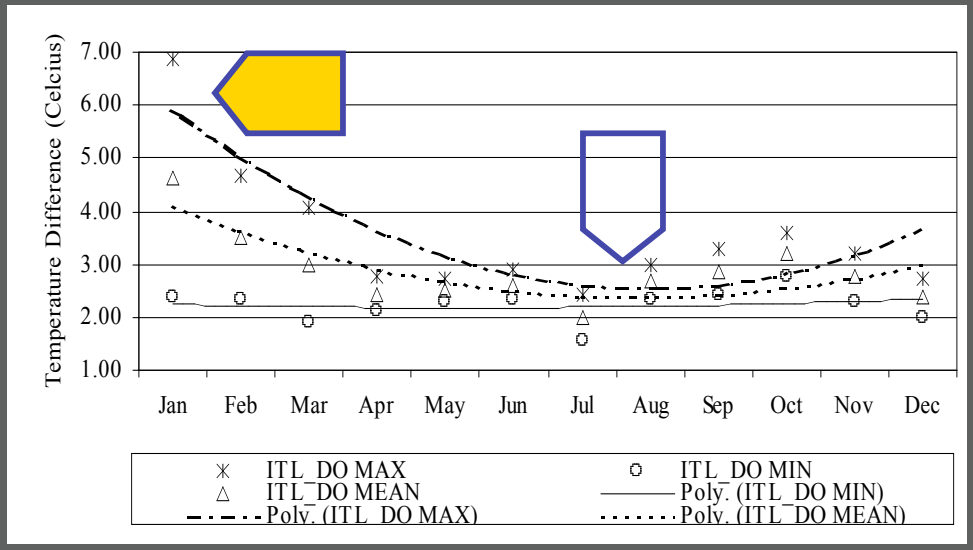
Sensor - Airborne-Ocean-Color-Imager
Time - December 11, 1993
Altitude - 19.8 km altitude
Performed by - NASA-Ames Research Center

Climatological Analysis of UHI For SJU Coop Surface Weather Station

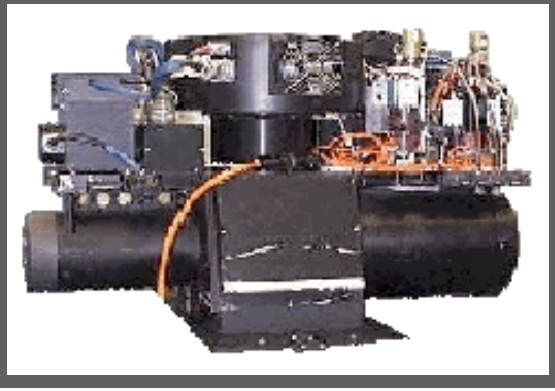
Inland

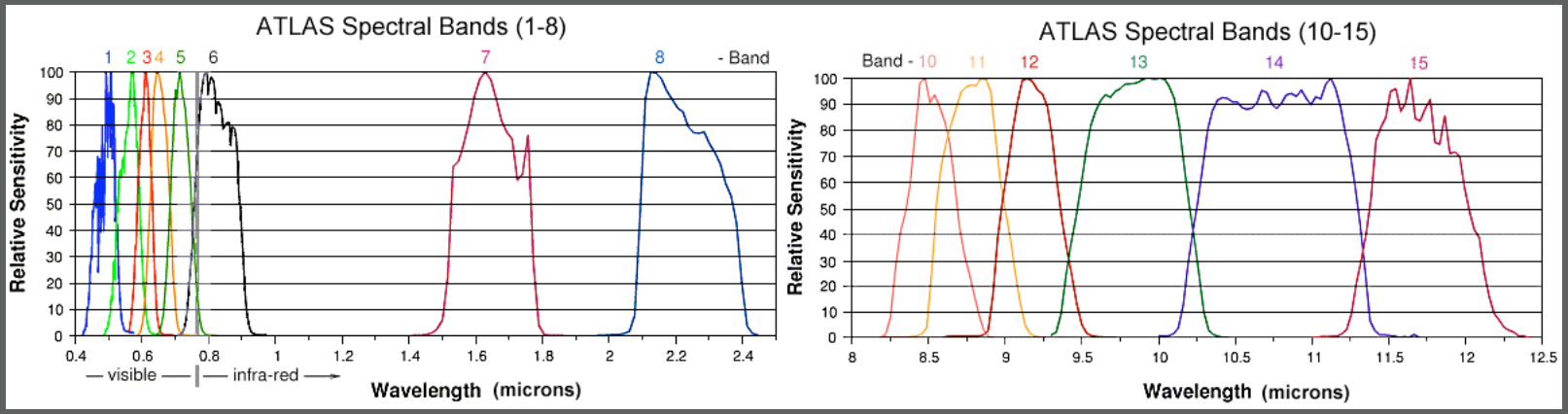


Coastal



RS-ATLAS Campaign

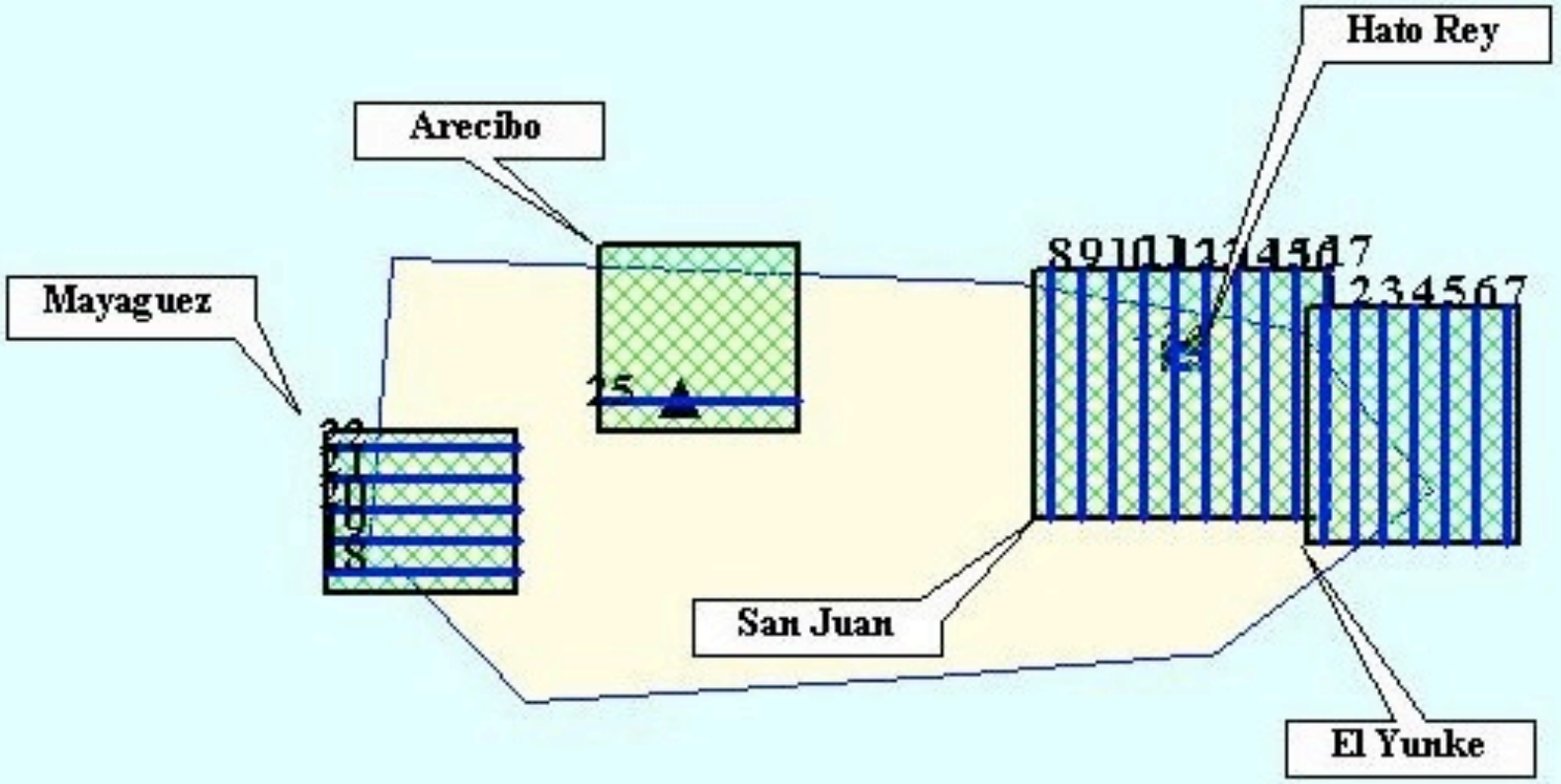




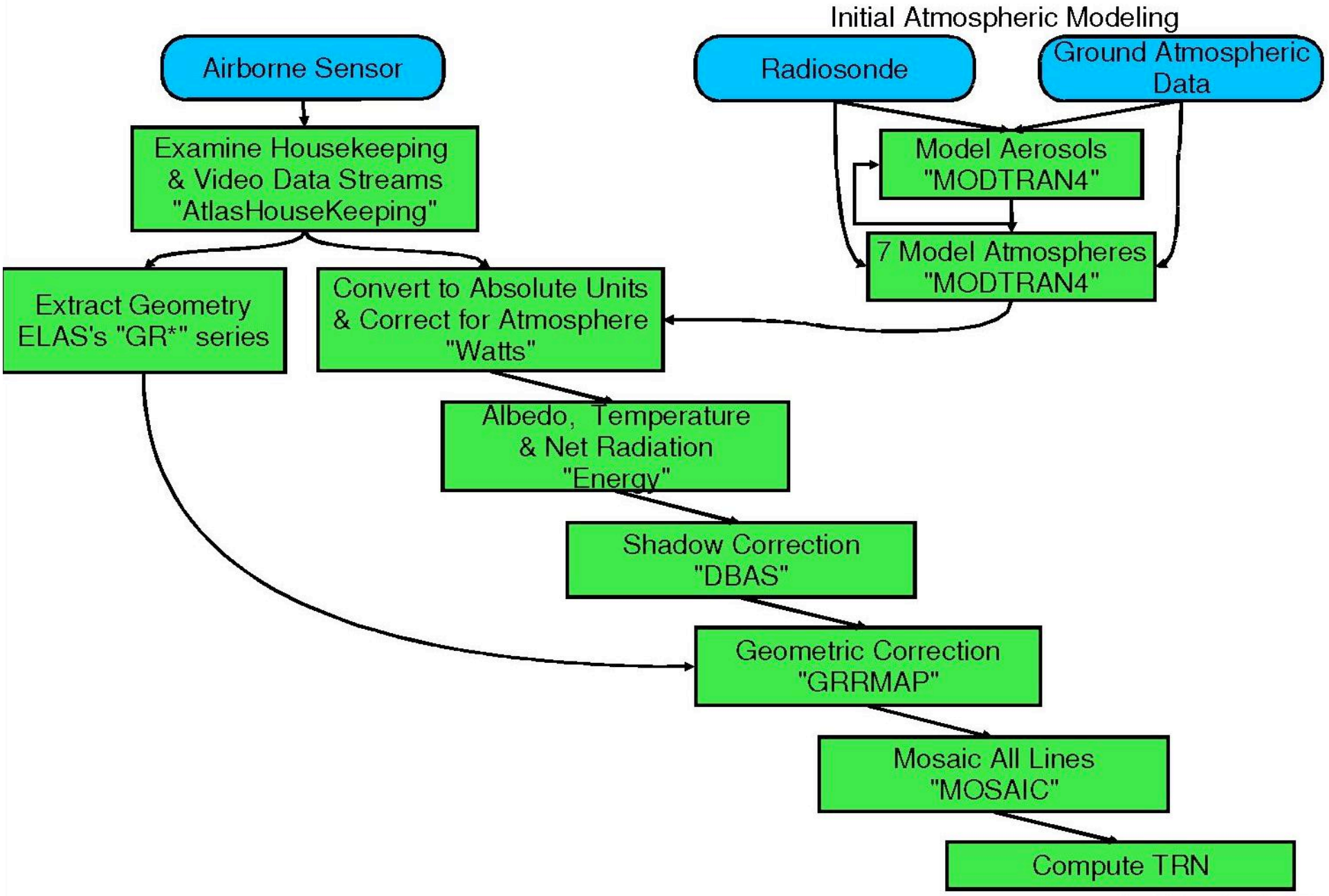
The Airborne Thermal and Land Applications Sensor (ATLAS) from NASA/Stennis operates in the visual and IR bands. It flies on a Lear 23 jet for flexibility and produces high resolution images.

ATLAS visual and IR spectrum. The mission also operated a 9 inch Zeiss camera for high resolution photographic work.

Flight Plan

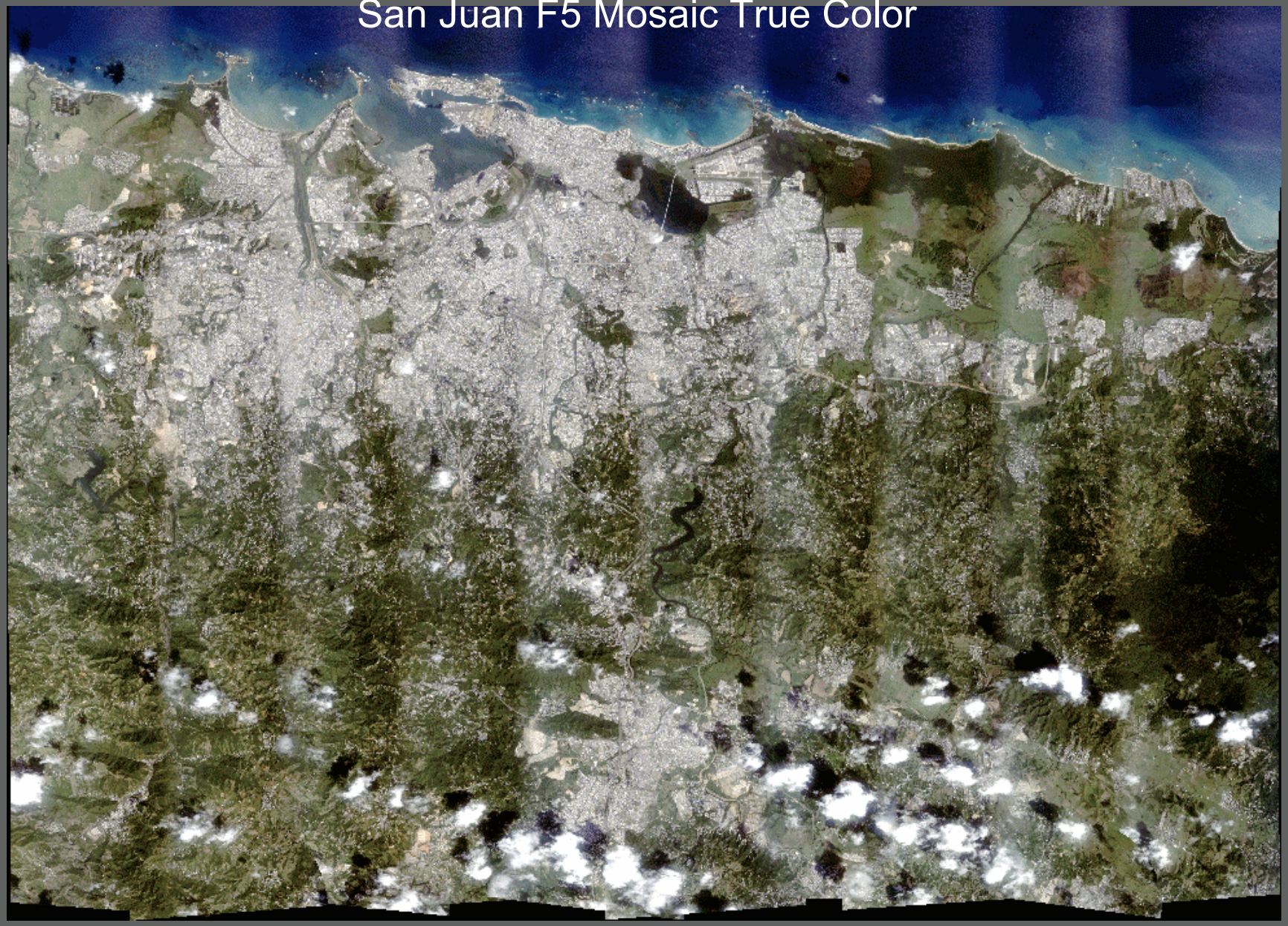


Overall Process Flow

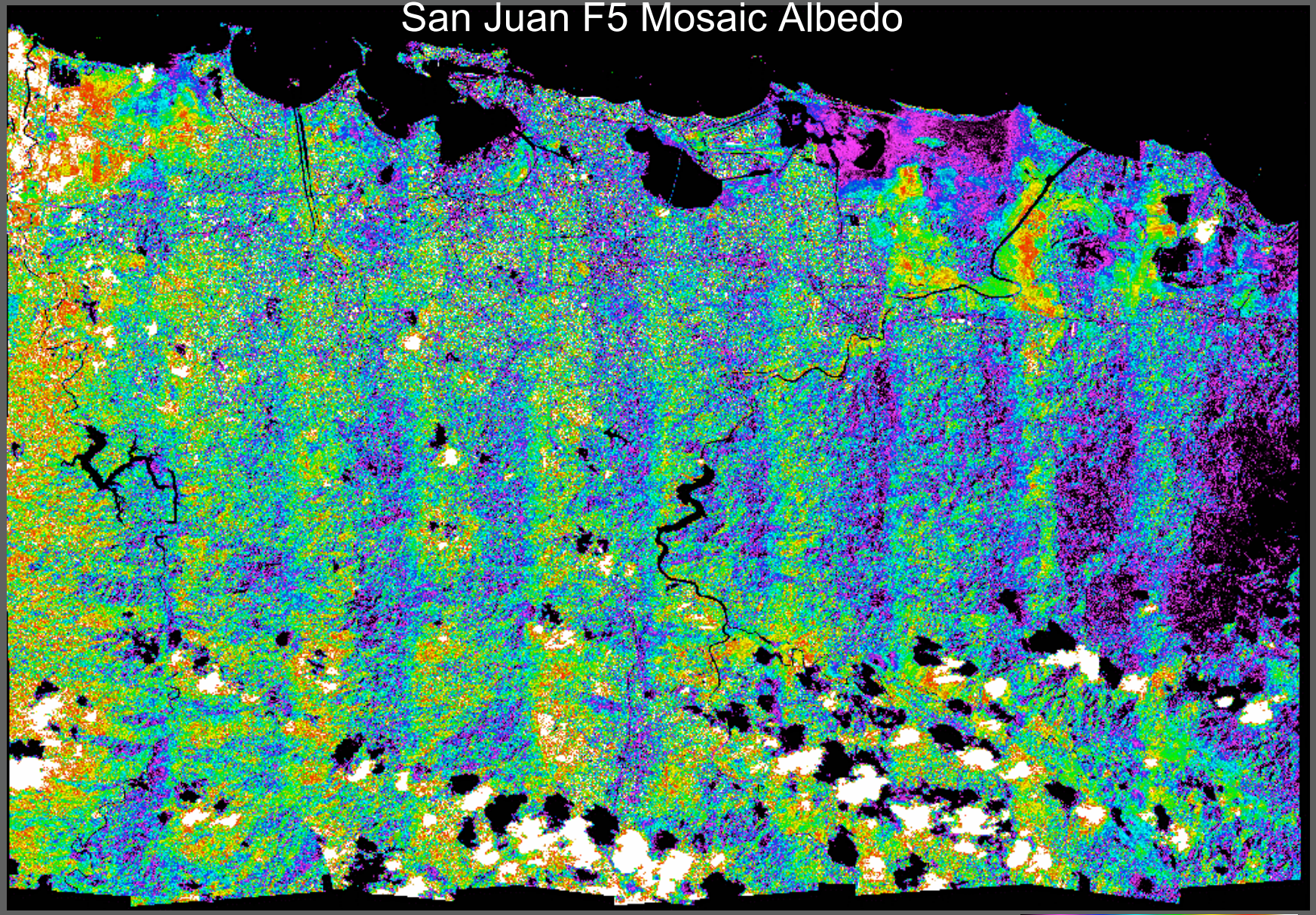


Doug Rickman, June 11, 2001

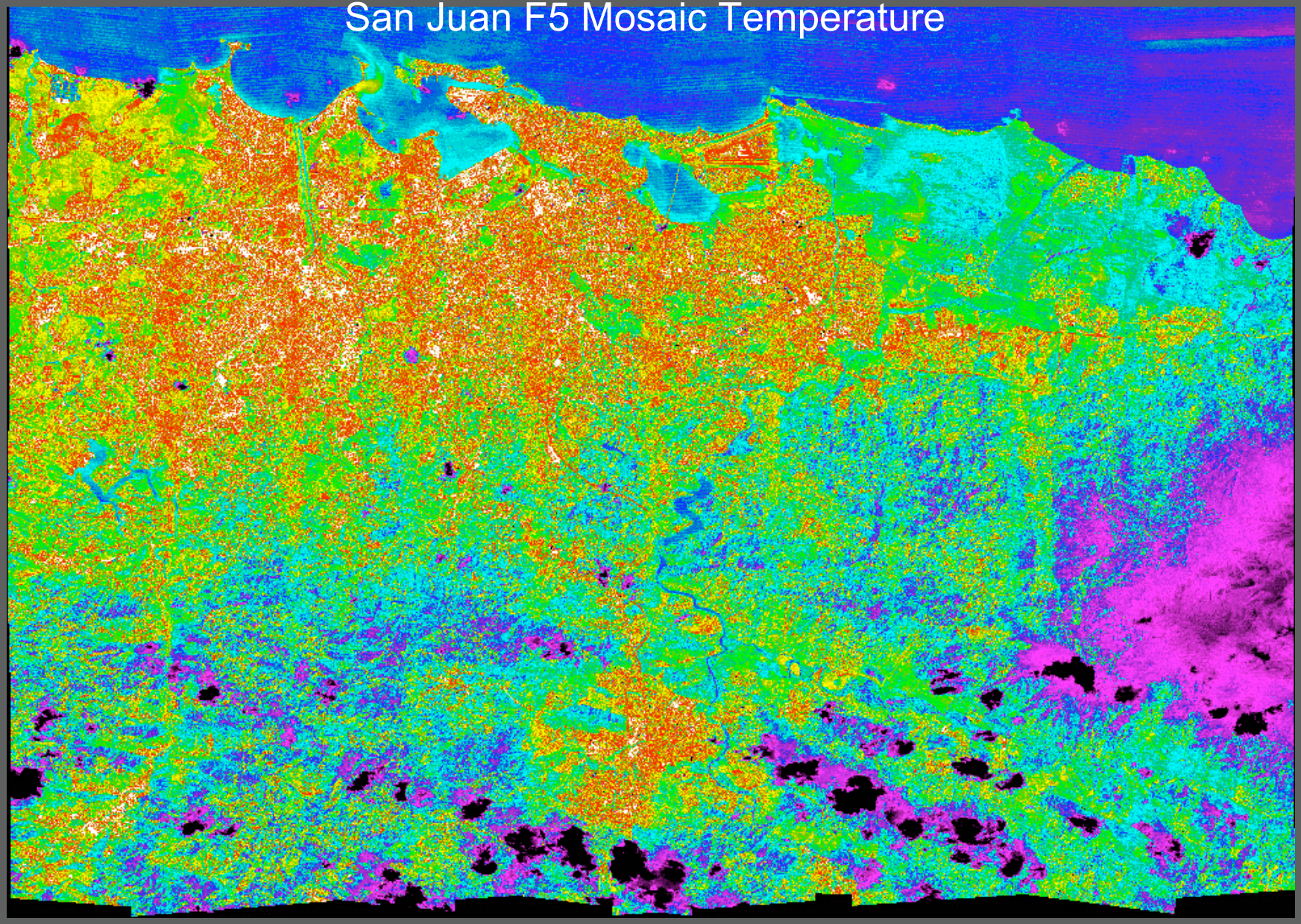
San Juan F5 Mosaic True Color



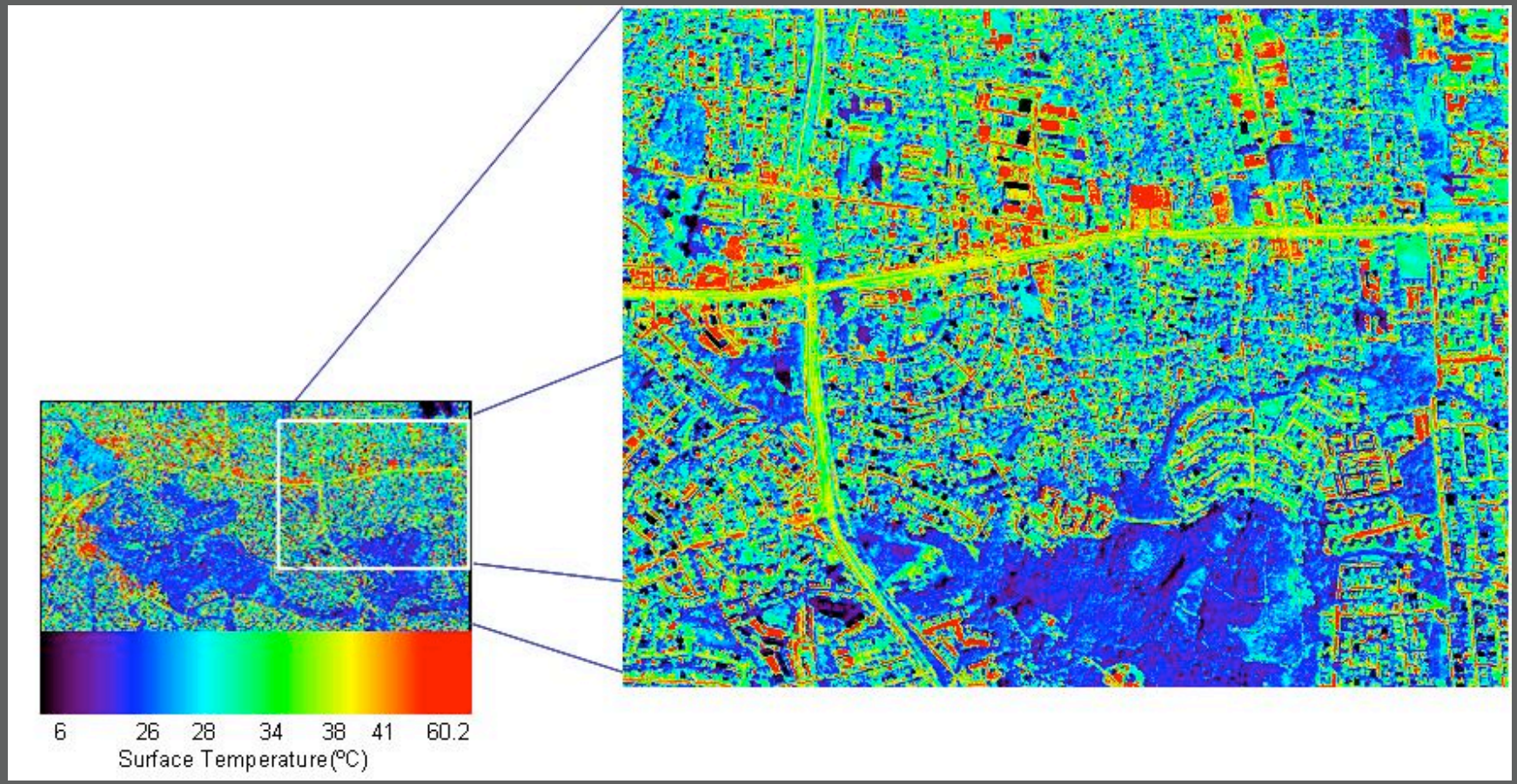
San Juan F5 Mosaic Albedo



San Juan F5 Mosaic Temperature

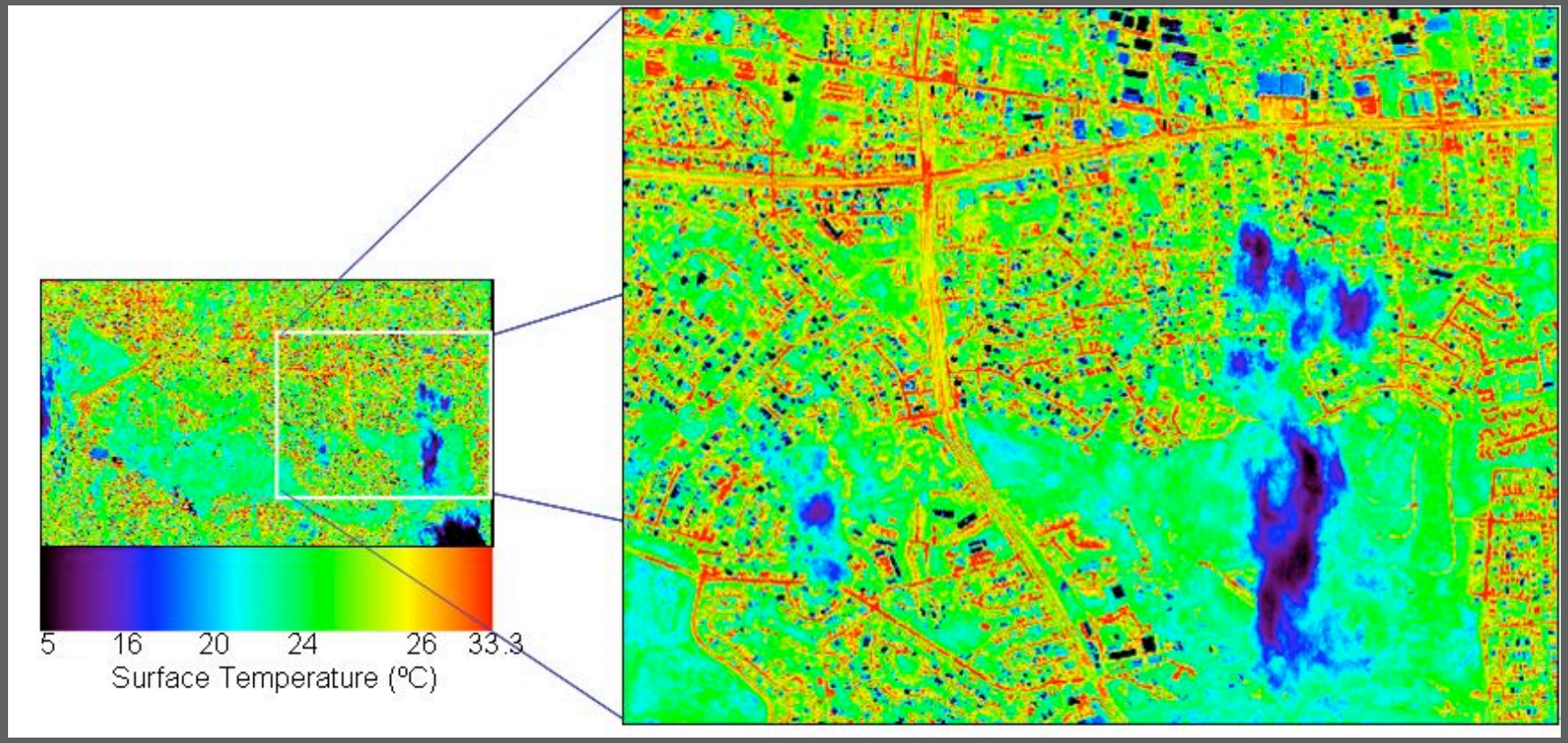


Sample of ATLAS images for San Juan

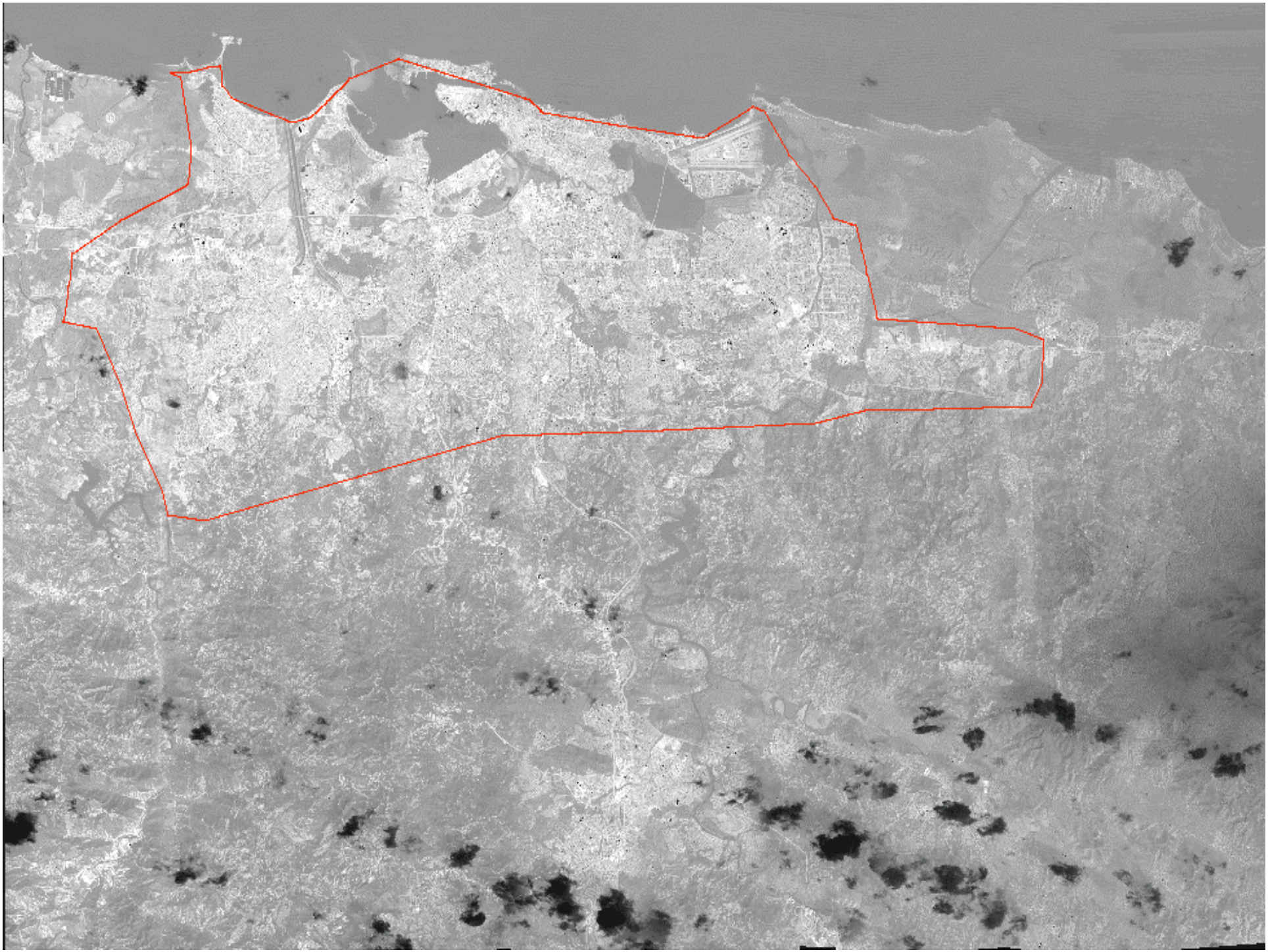


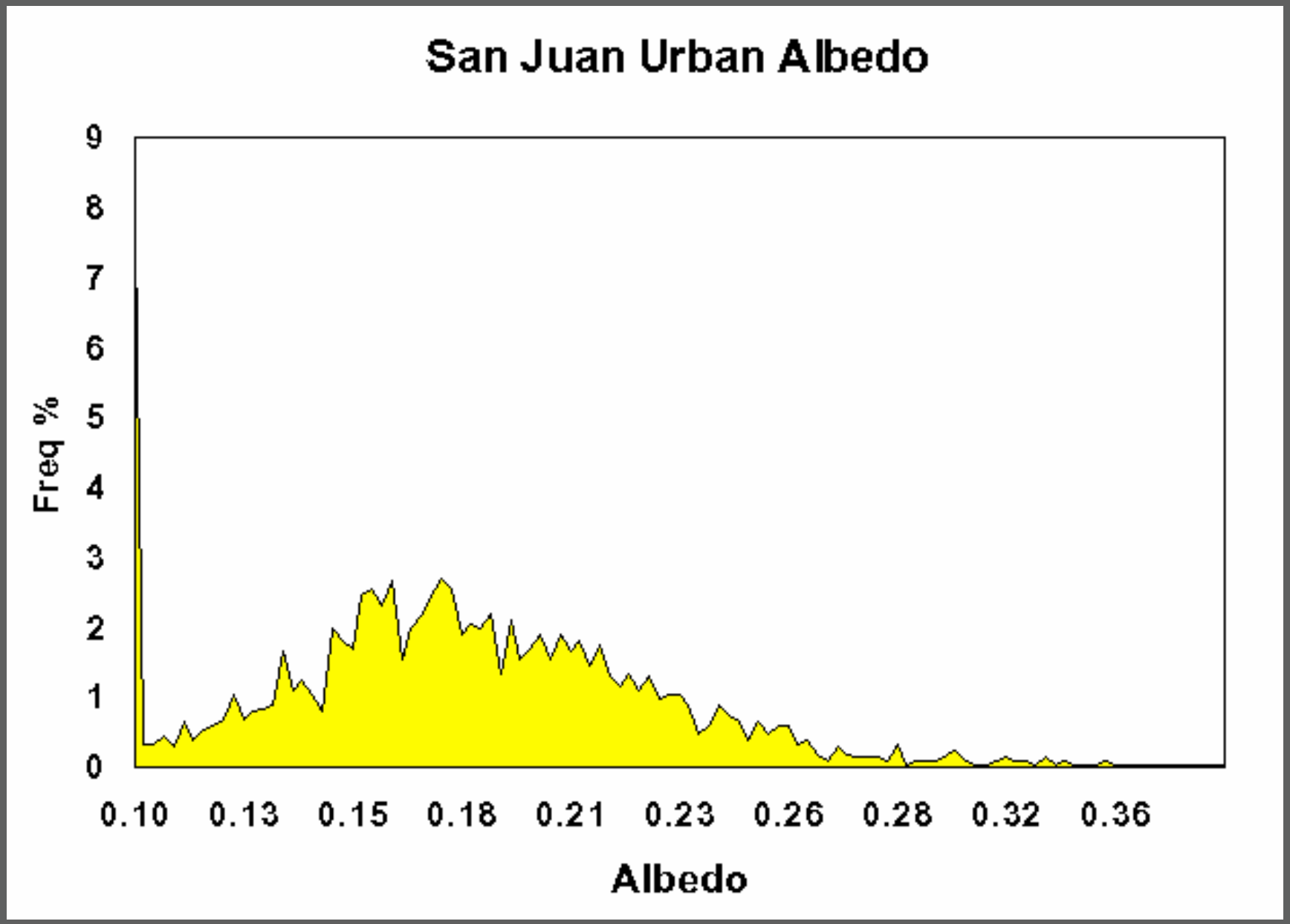
Daytime image of the ATLAS sensor taken at 10 meters. February 16, 2004. (f1.231)

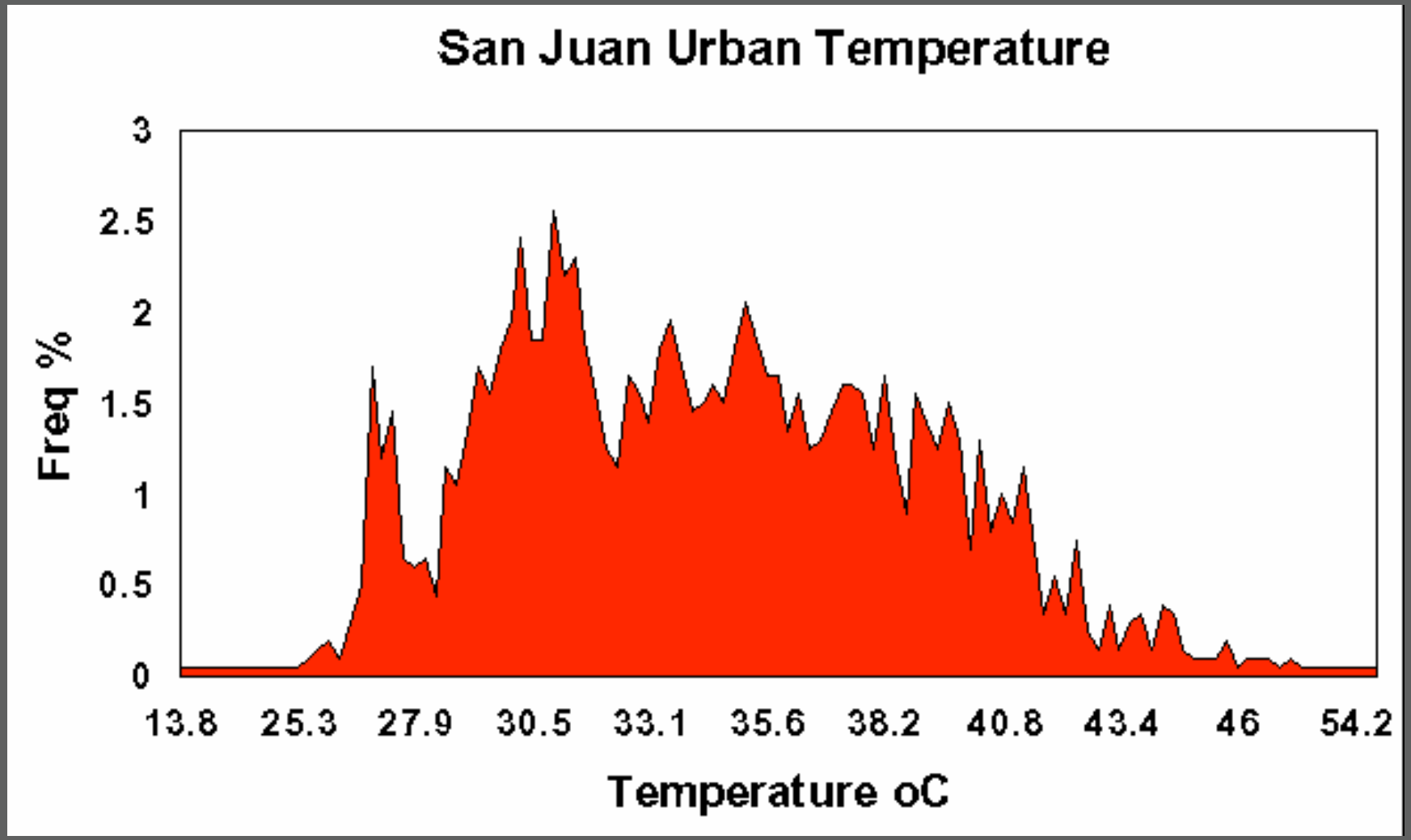
Sample of ATLAS images for San Juan

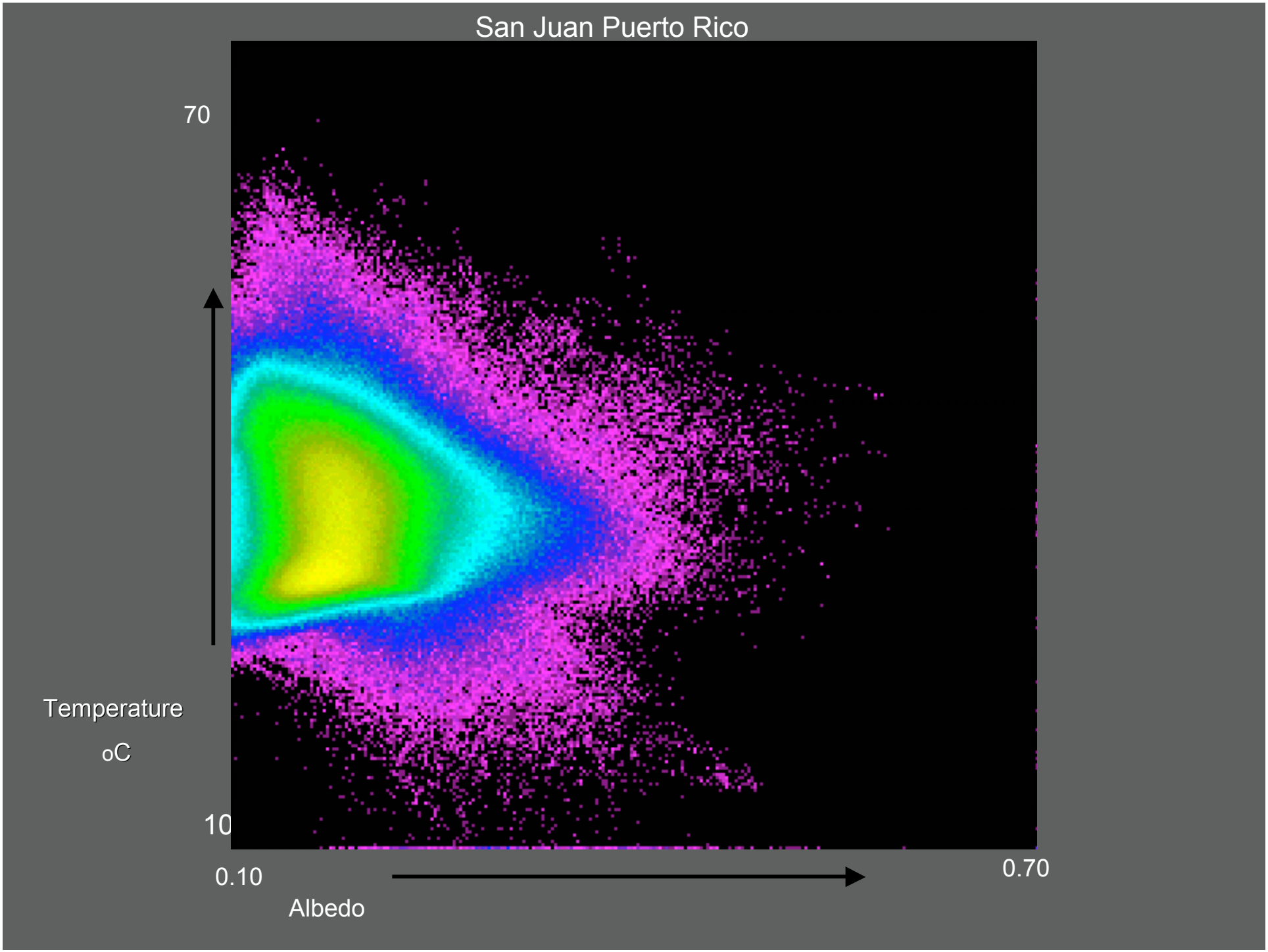


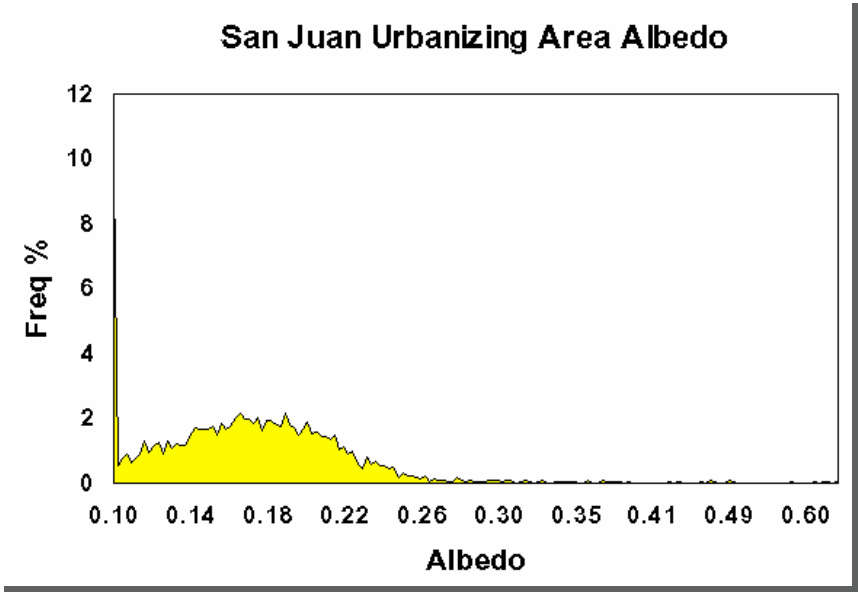
Nighttime image of the ATLAS sensor taken at 10 meters. February 16, 2004. (f2.231)

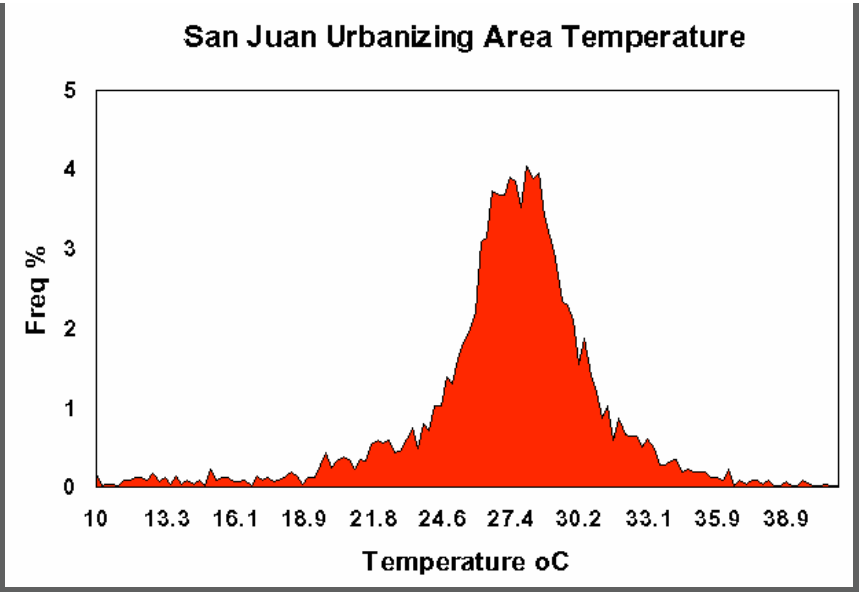


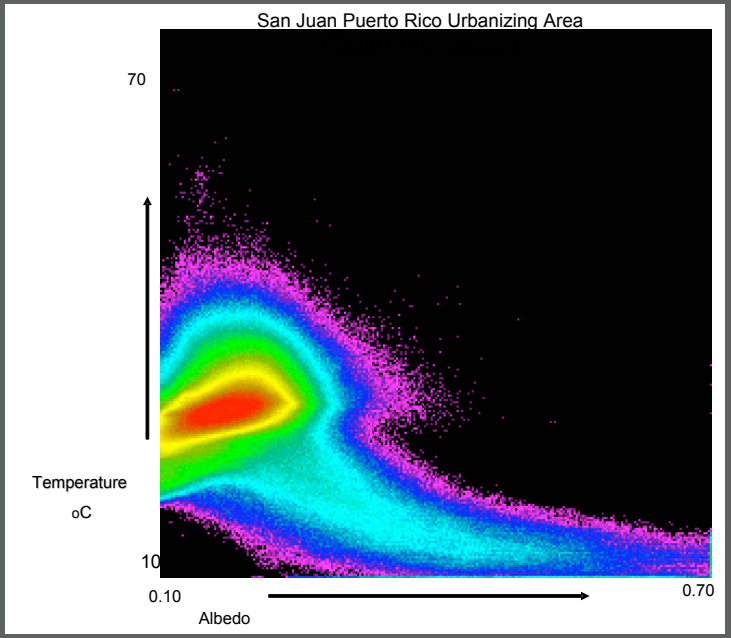

San Juan Urban Albedo
Freq %
9
8
7
6
5
4
3
2
1
0
0.10
0.13
0.15
0.18
0.21
0.23
0.26
0.28
0.32
0.36
Albedo

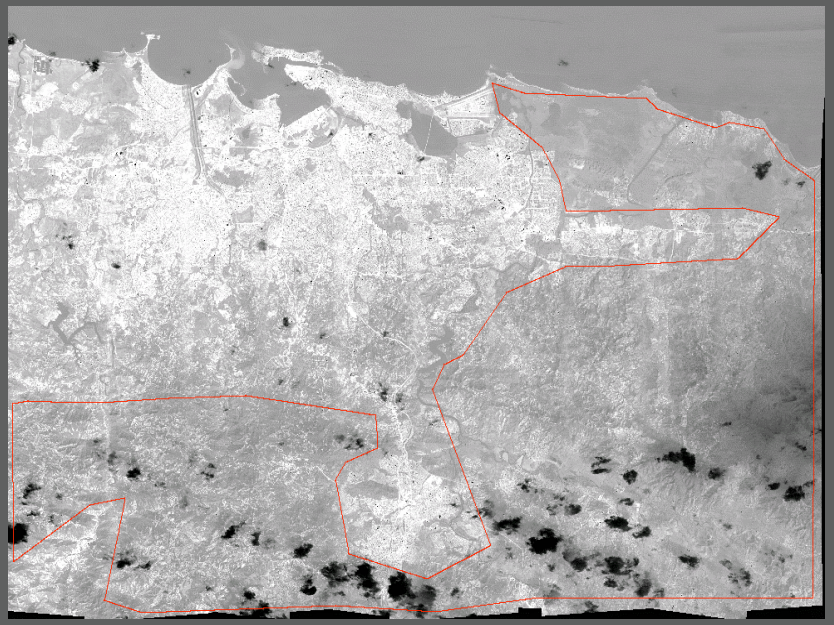

San Juan Urban Temperature
Freq %
3
2.5
2
1.5
1
0.5
0
13.8
25.3
27.9
30.5
33.1
35.6
38.2
40.8
43.4
46
54.2
Temperature oC


San Juan Puerto Rico
70
Temperature
oC
10
0.10
0.70
Albedo

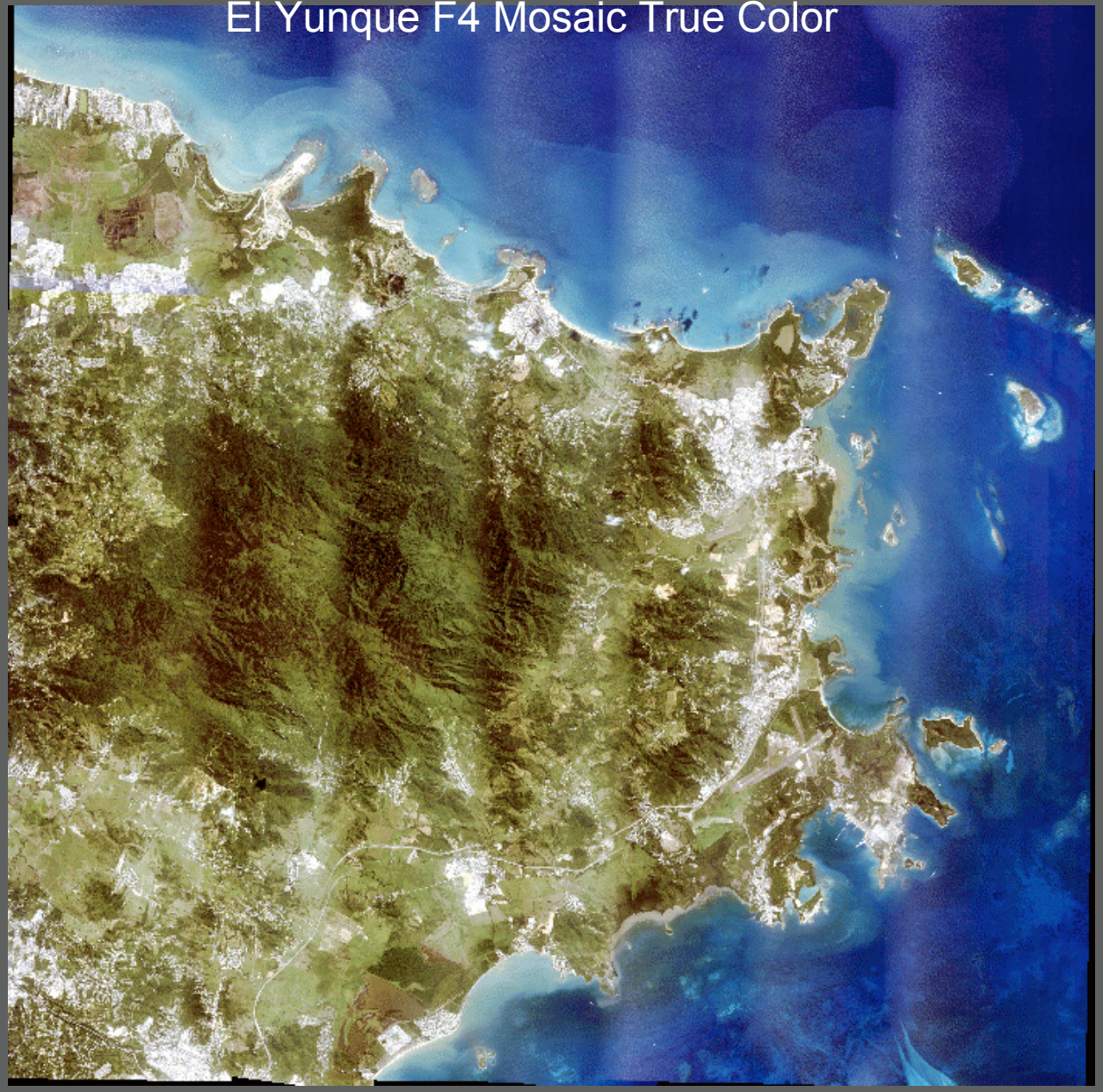

San Juan Urbanizing Area Albedo
Freq %
12
10
8
6
4
2
0
0.10 0.14 0.18 0.22 0.26 0.30 0.35 0.41 0.49 0.60
Albedo

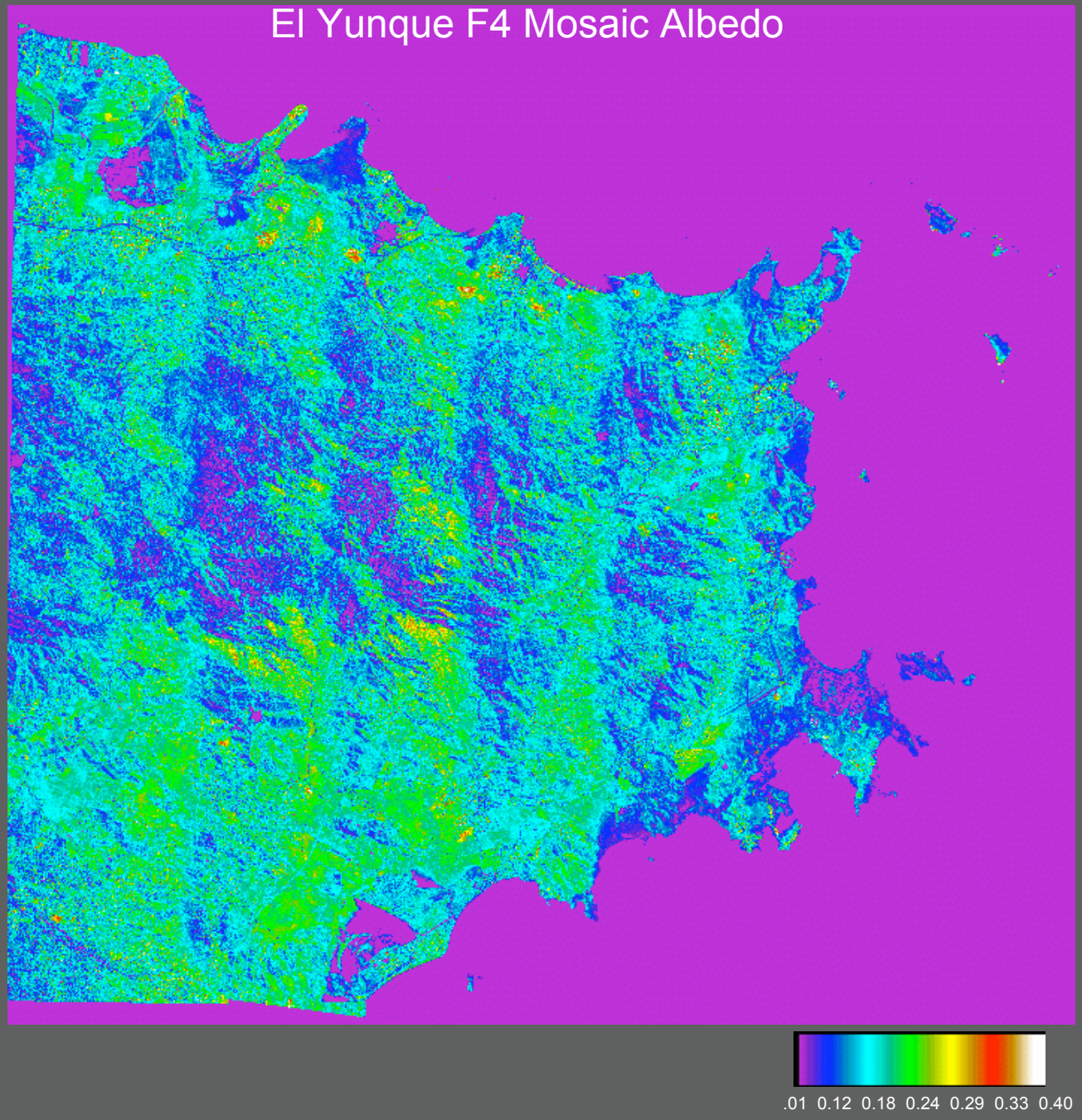

San Juan Urbanizing Area Temperature
Freq %
5
4
3
2
1
0
10 13.3 16.1 18.9 21.8 24.6 27.4 30.2 33.1 35.9 38.9
Temperature oC


San Juan Puerto Rico Urbanizing Area
70
Temperature
oC
10
0.10
0.70
Albedo

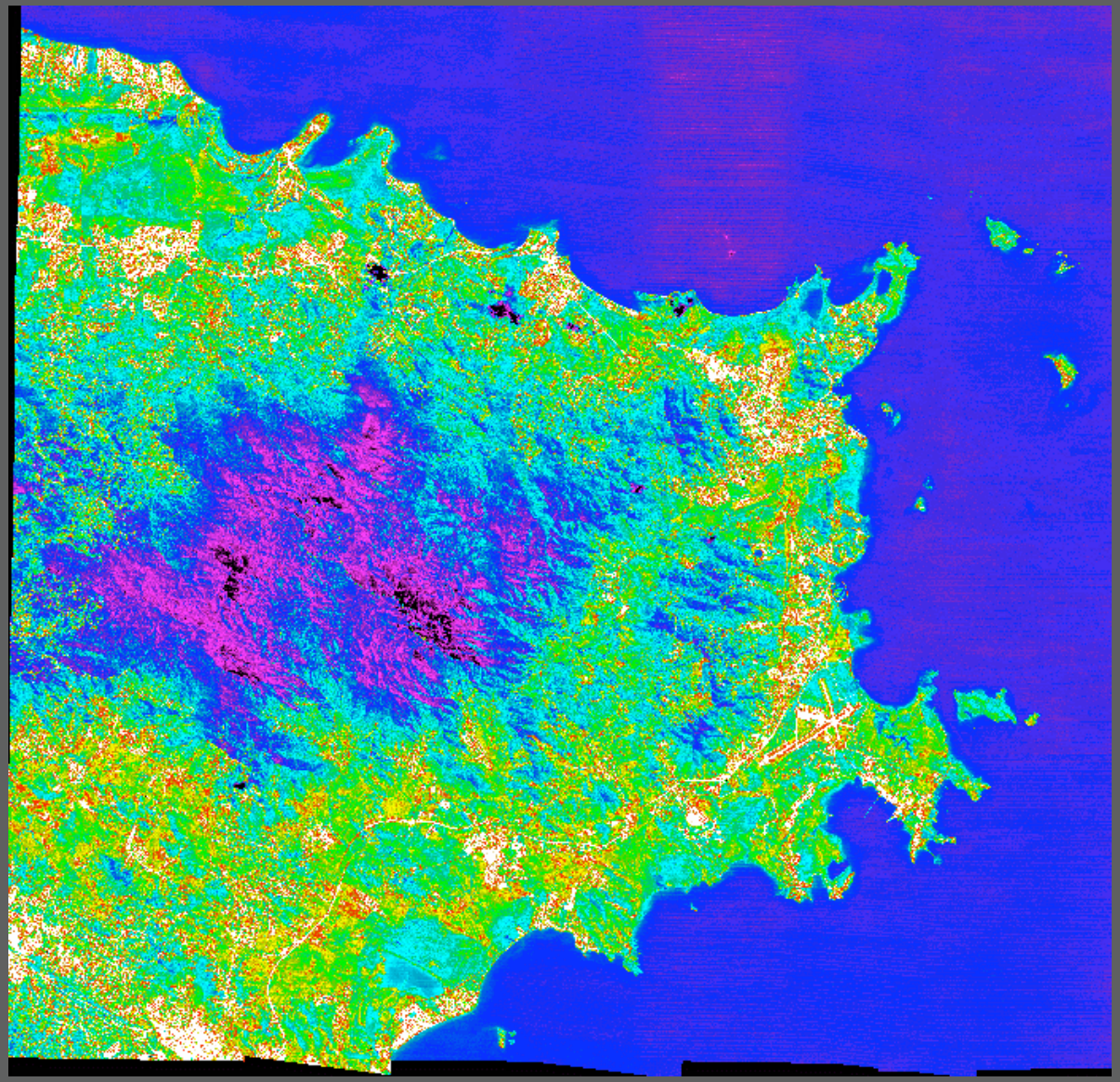


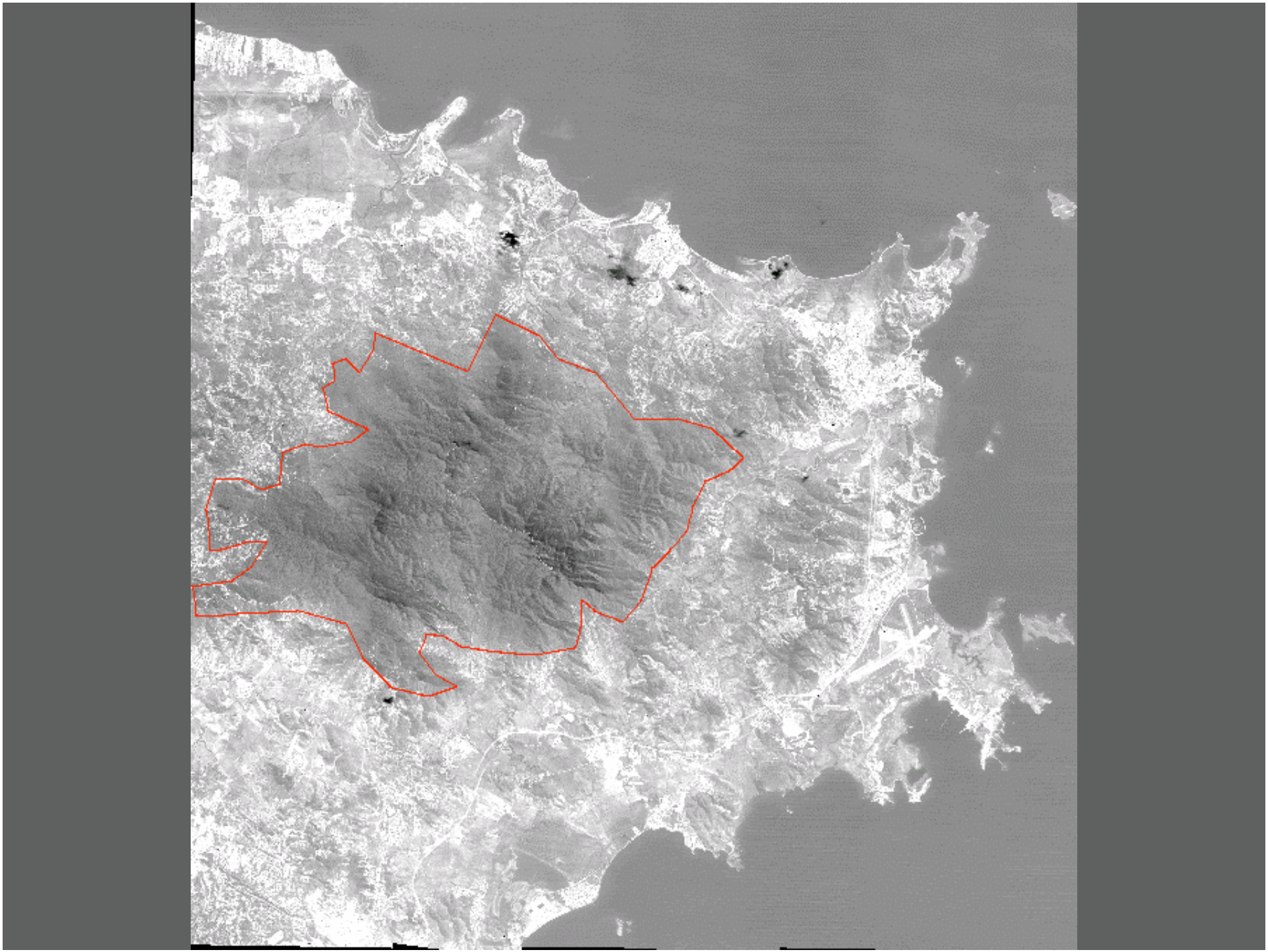
El Yunque F4 Mosaic True Color

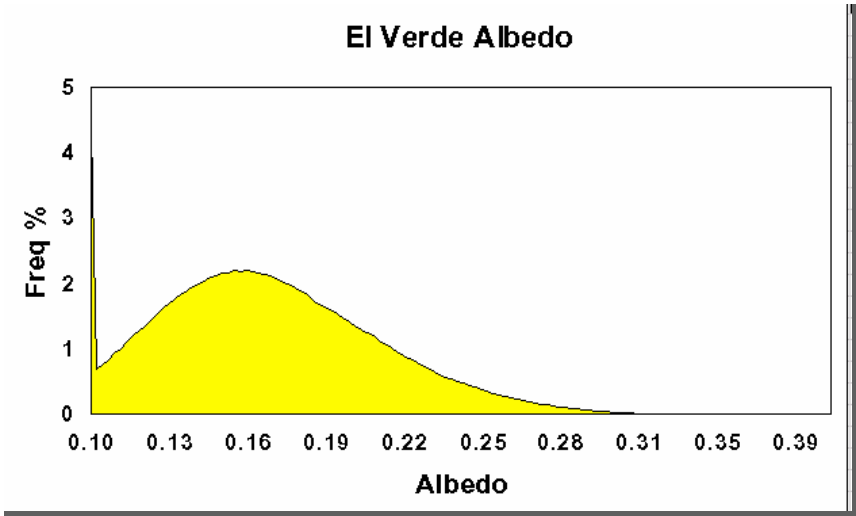


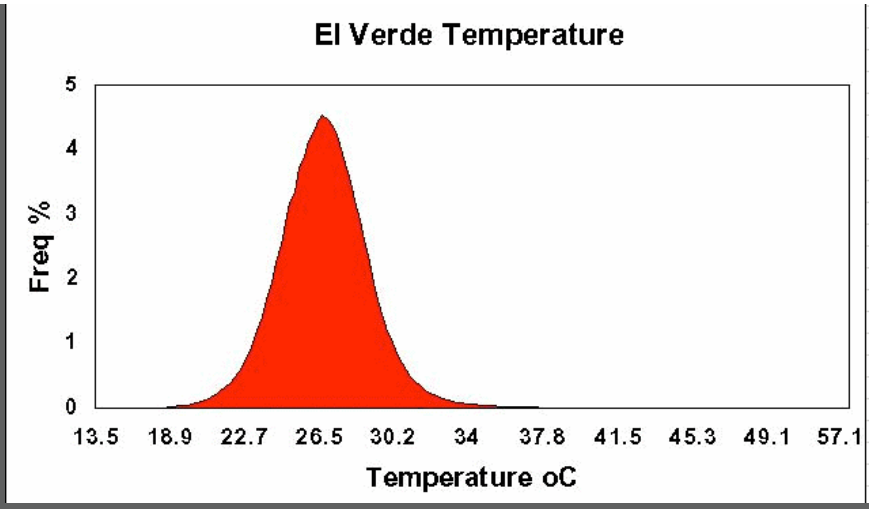

El Yunque F4 Mosaic Albedo
.01 0.12 0.18 0.24 0.29 0.33 0.40

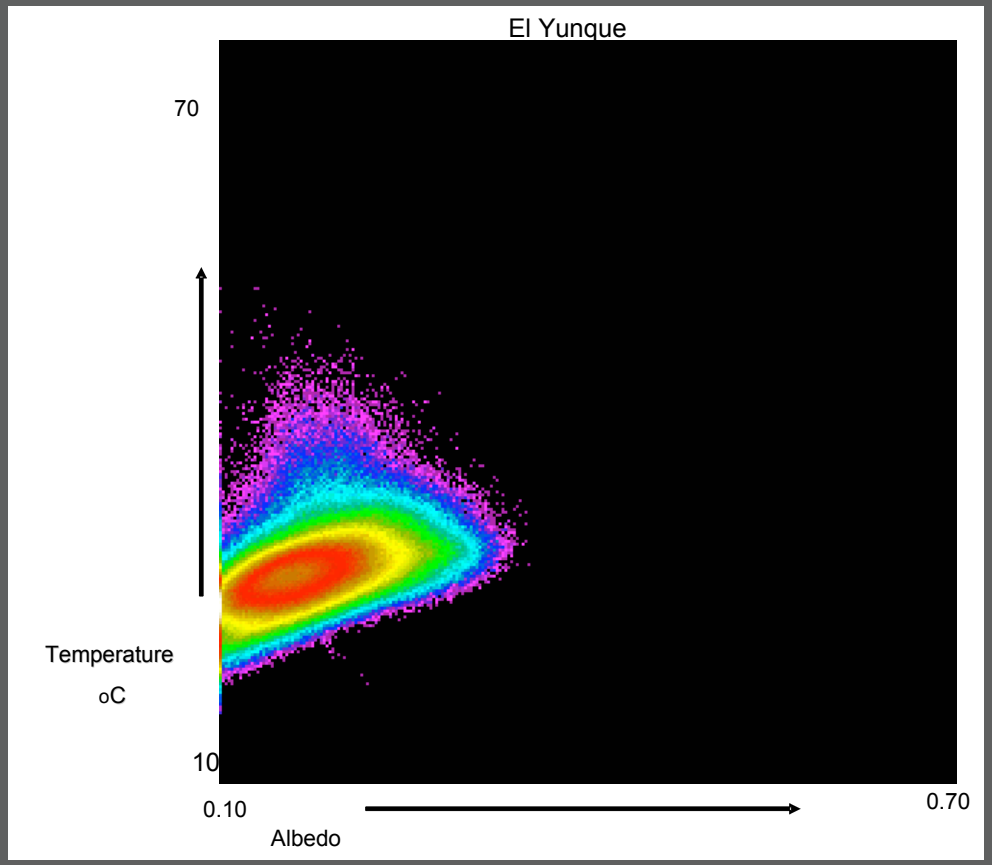
El Yunque F4 Mosaic Temperature



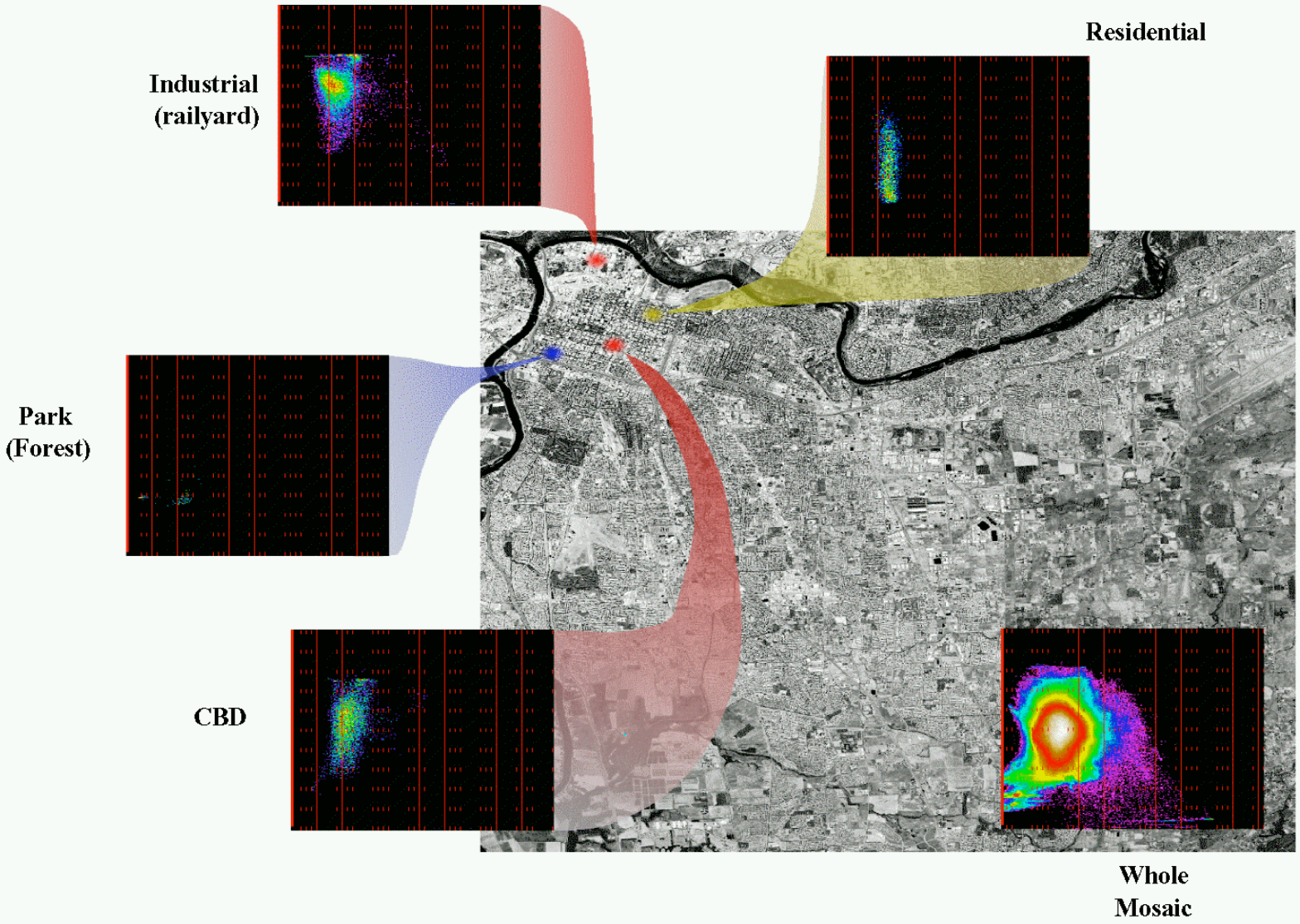


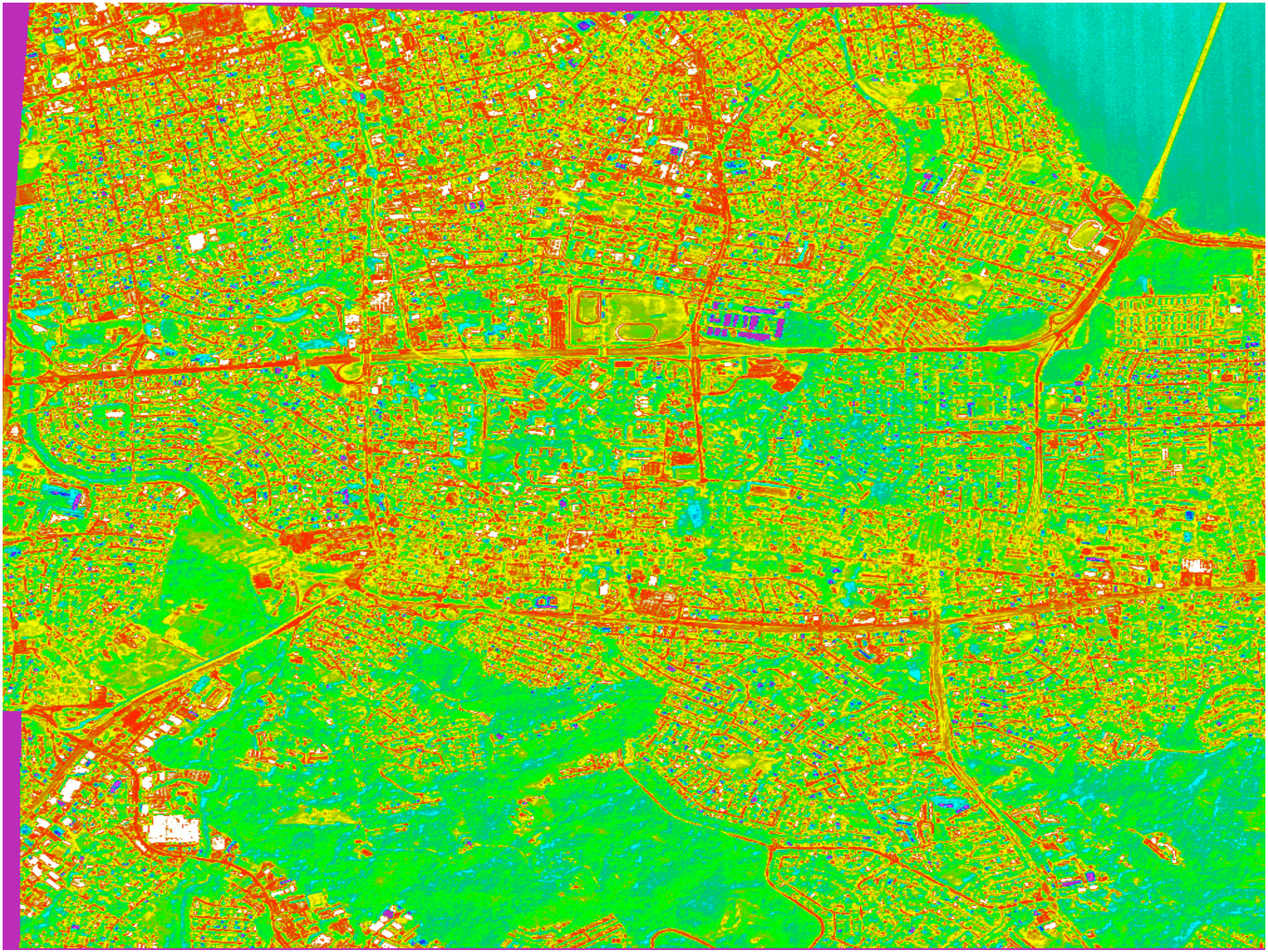

El Verde Albedo
Freq %
0
1
2
3
4
5
0.10
0.13
0.16
0.19
0.22
0.25
0.28
0.31
0.35
0.39
Albedo


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


El Yunque
70
Temperature
oC
10
0.10
0.70
Albedo

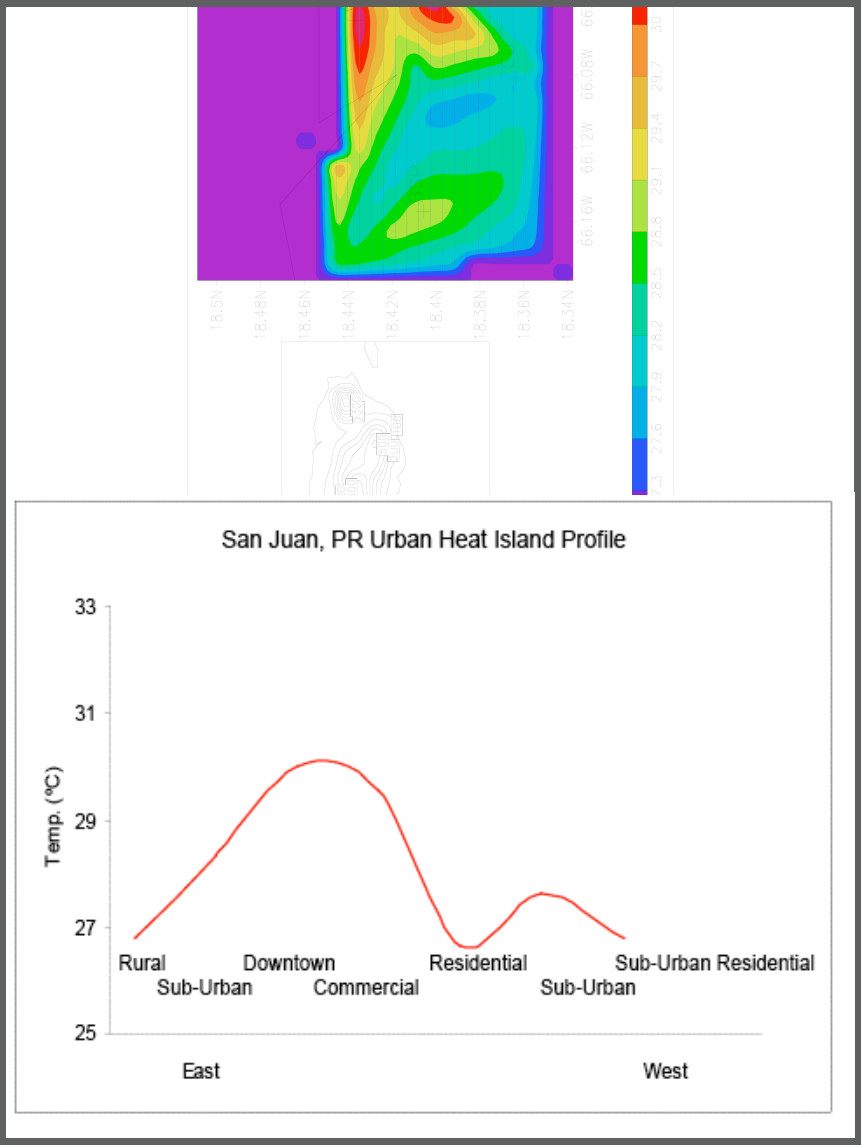
Sacramento Skattergrams
Albedo vs Temperature





Observational Analysis

- Urban Heat Island Studies in San Juan

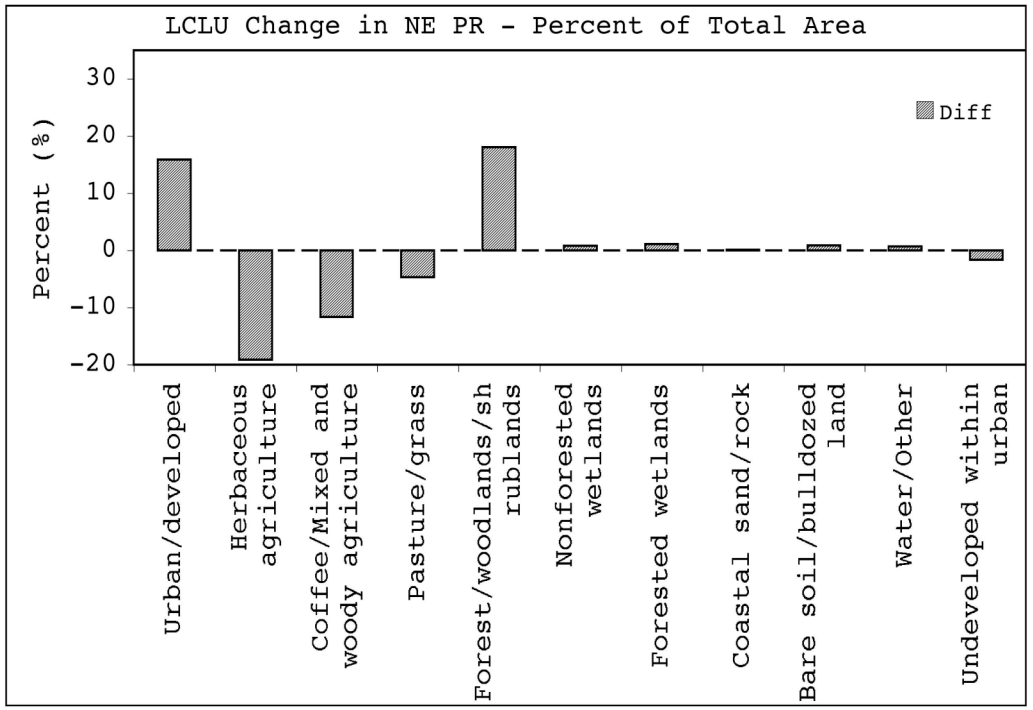


Weather stations and temperature sensors were deployed in the metropolitan area of San Juan, P.R. and its surroundings, the data show strong indications of an Urban Heat Island.

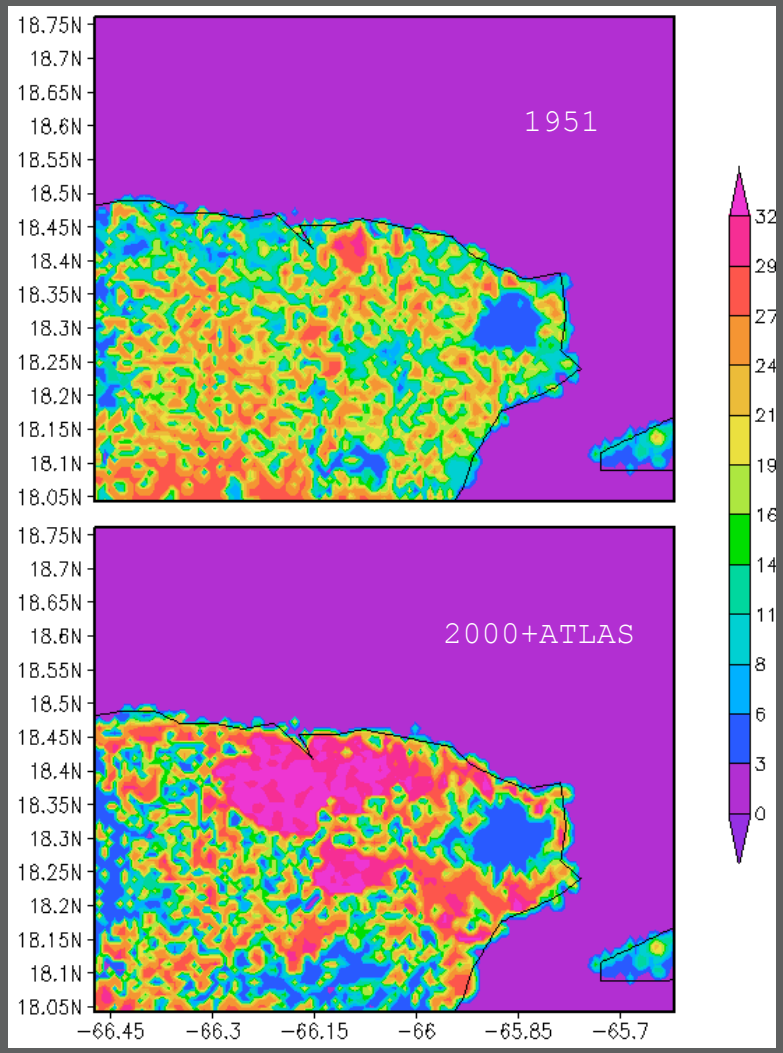
Land Use Impact Analysis & Numerical Model for SJU

- Validation of the Numerical Model (Regional Atmospheric Modeling System [RAMS]).
- Quantify the impact of the urban LCLU in the local climate.
- Study the reaction of the atmosphere to the presence of the urban LCLU.

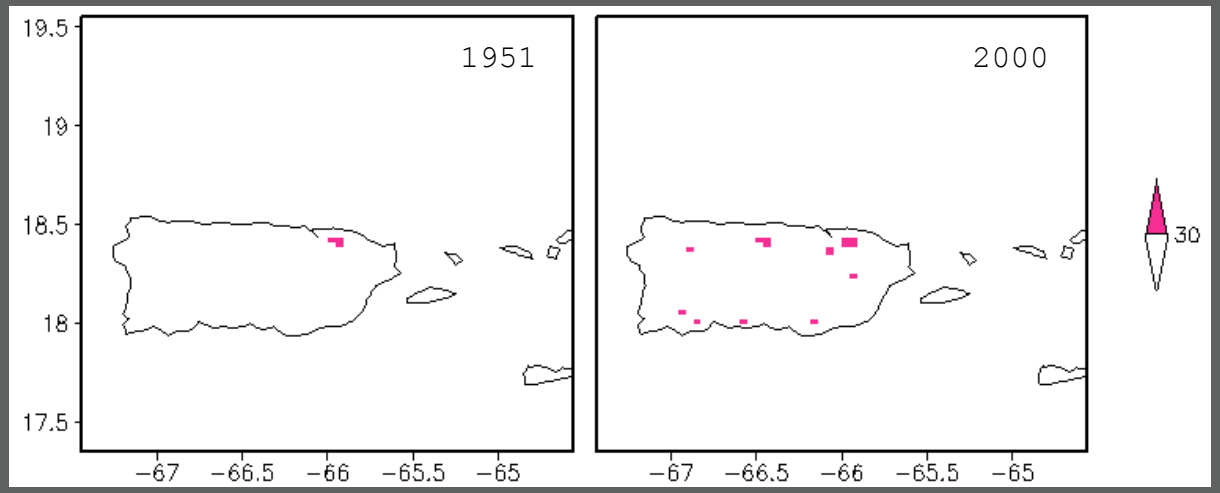
LCLU Specifications - Northeast PR

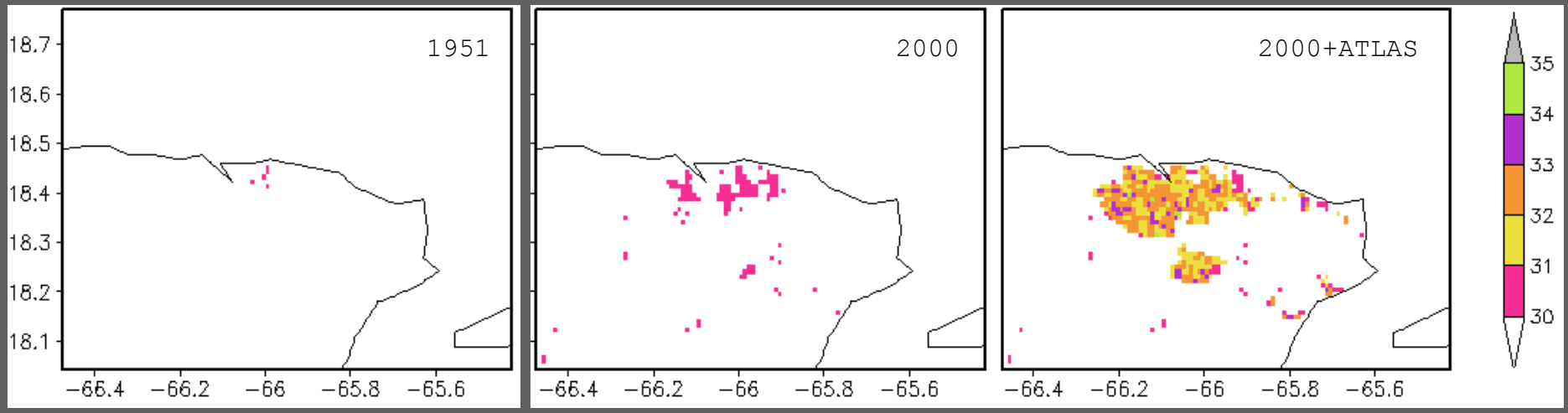


Description	class	1951	2000	Diff
Background/water	0			
Urban/developed	30	1.92	17.81	15.89
Herbaceous agriculture	8	19.19	0.09	-19.10
Coffee/Mixed and woody agriculture	12	12.38	0.76	-11.62
Pasture/grass	27	33.73	28.99	-4.74
Forest/woodlands/shrublands	3	9.37	27.43	18.06
Nonforested wetlands	16	0.00	0.76	0.76
Forested wetlands	19	0.00	1.08	1.08
Coastal sand/rock	26	0.00	0.14	0.14
Bare soil/bulldozed land	27	0.00	0.91	0.91
Water/Other	1	0.23	0.93	0.70
Undeveloped within urban	7	1.71	0.00	-1.71



LCLU Specifications
Urban Comparison (1951 vs. 2000)

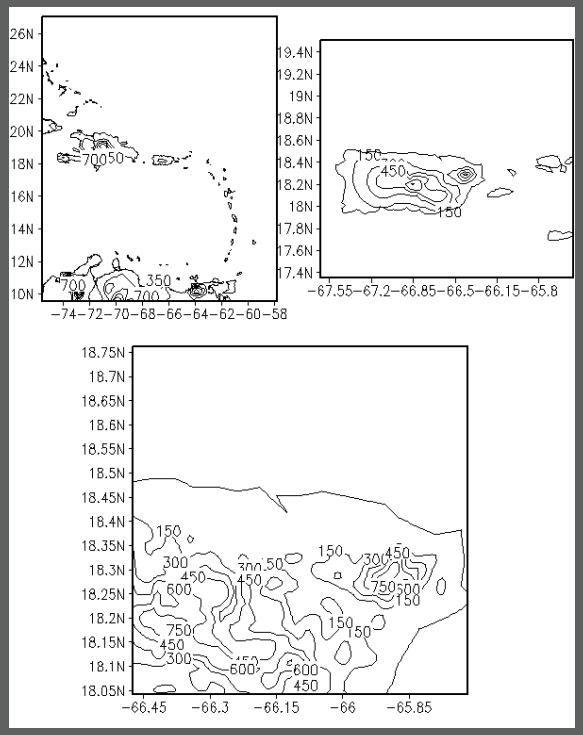


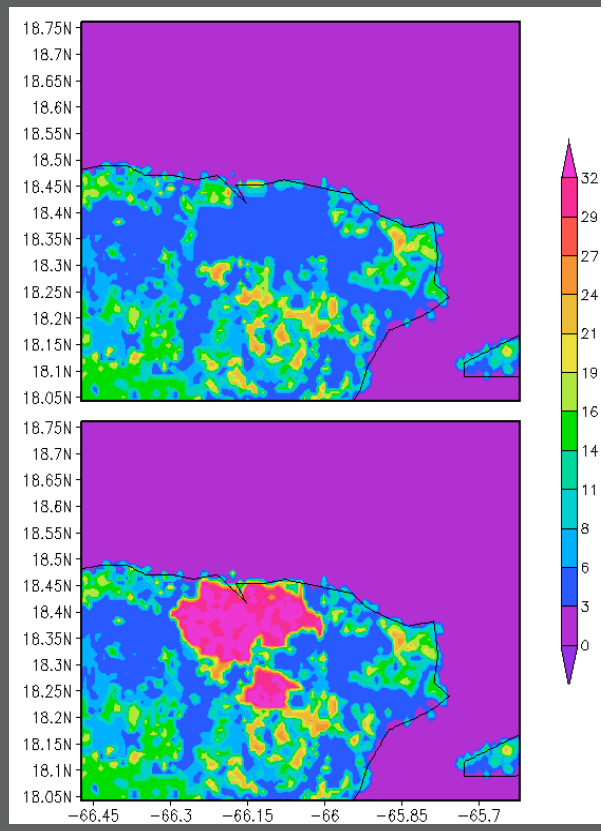


Methodology / Numerical Experiments

In order to answer this question, a series of numerical atmospheric simulations is proposed to separate the signal of LCLU change. The Regional Atmospheric Modeling System (RAMS) will serve as the main research tool.

General Model Configuration			
	Grid 1	Grid 2	Grid 3
$\Delta x = \Delta y$	25km	5km	1km
vertical	σ-coordinate $\Delta\sigma$ = 30mts near sfc until $\Delta\sigma$ = 1km, model top at ~25km		
CPU time	Approximately 5 to 6 days for a 30-day simulation		

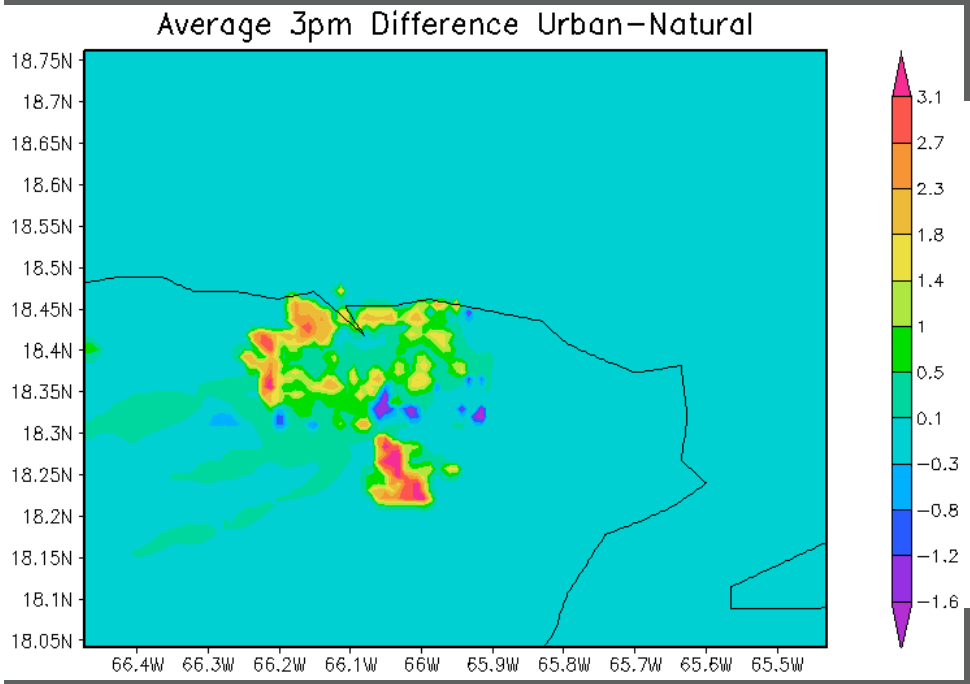


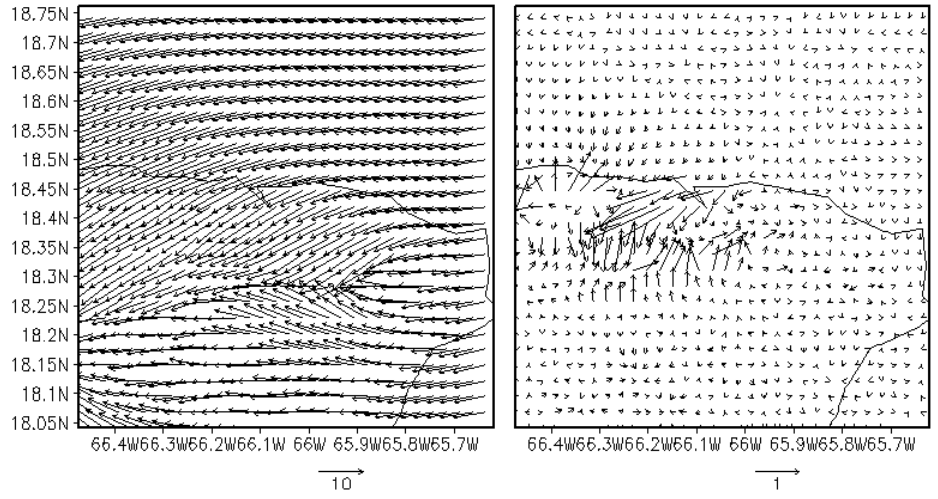


Model grids w/ topography and surface characteristics for the two scenarios analyzed

Urban Effects on Boundary Layer

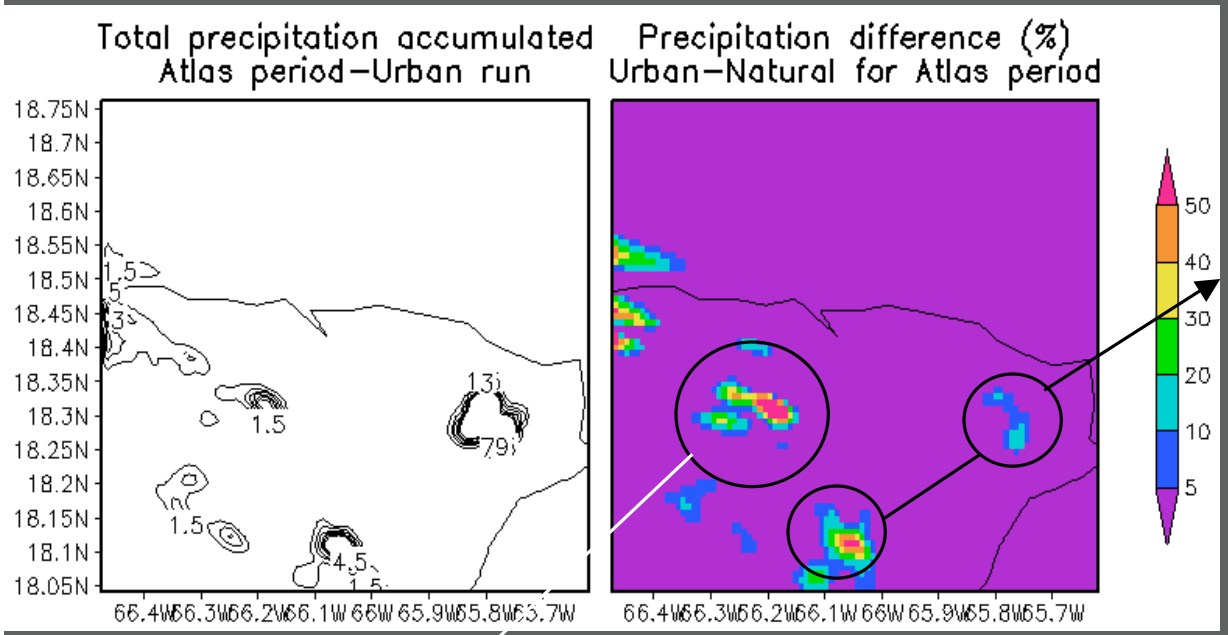
Preliminary impact study of LCLU changes on the local climate of northeastern Puerto Rico (10-day period of the ATLAS Mission)





Environmental Change Impact on Local/Regional Climate

- Effect of the SJMA on precipitation



- What causes this disturbance?
- How is it linked to urban development?
- How large will it be for longer simulations?
- Current research will try to address these issues

- What causes this disturbance?

  Increased warming and latent heat flux over the city.

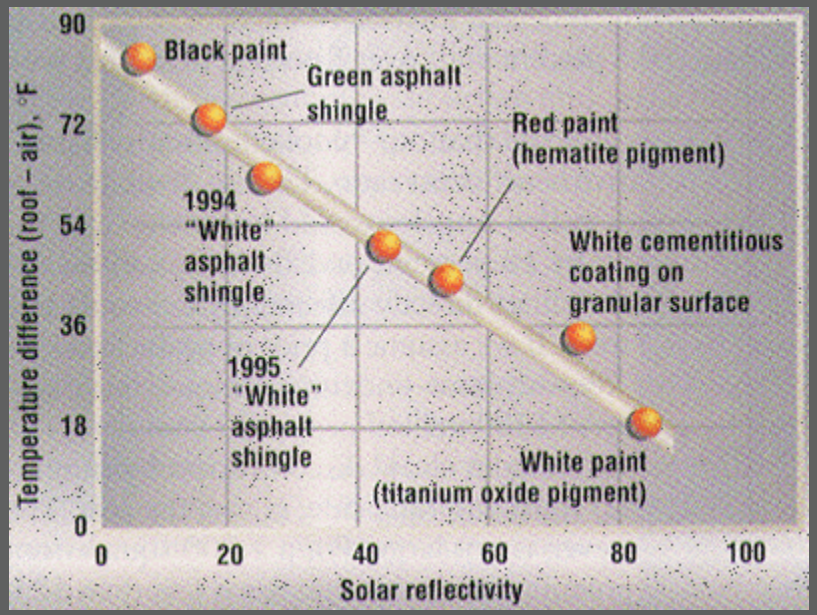
→ Enhanced vertical motions in warm moist air leads to cloud formation over the city, which are advected to the west.

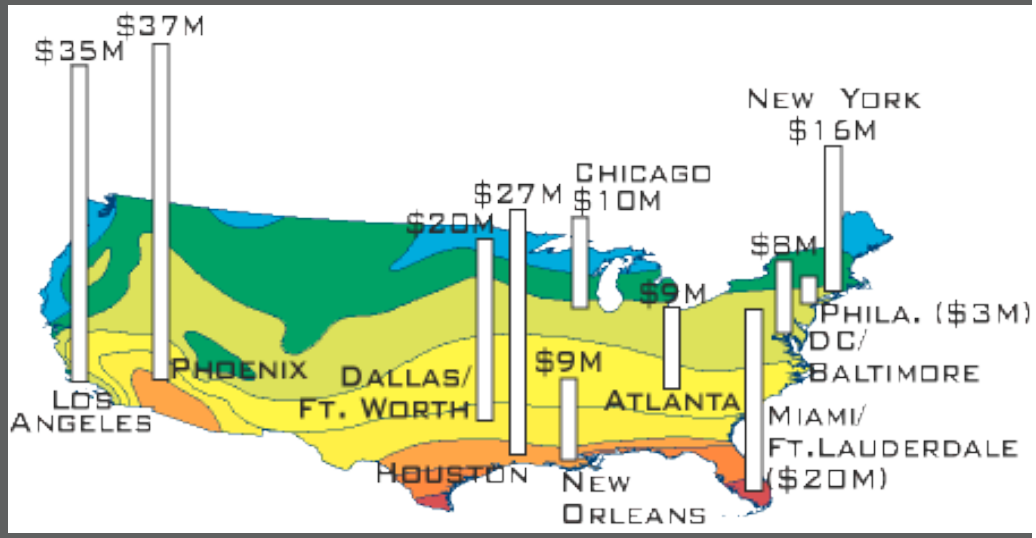
→ The prevailing trade winds transport the clouds leeward of the city, where the model is producing the accumulated rain.

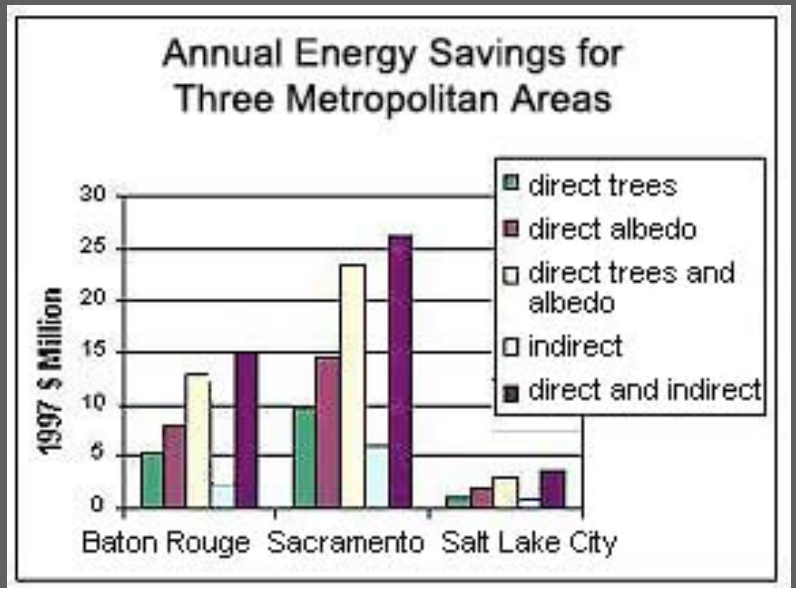
What Can Be Done ?

- Greening the landscape
- Reflecting the sun
- Planning the growth
- Community action

Reflective & Green Roofs







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.

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The Power To Do More.™

SMUD Cool Roof Program

Incentive

- **SMUD provides an incentive of $0.20 per square foot of cool roof surface to roofing contractors, with the intention and agreement that the roofing contractors will pass the incentive to building owners in terms of lower total project cost.**

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Summary

- The UHI is a clear indicator of anthropogenic induced climate change.
- LCLU may induce changes in the regional climate impacting surface temperature, flow patterns, and the hydrological cycle.
- Remote sensors (HR & LR) can be combined with climate data & modeling tools to analyze UHI impacts over coastal metropolitan areas.
- Mitigation alternatives have demonstrated to be effective tools in reducing UHI.

Acknowledgments

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  - NASA, NOAA, UPR, CCNY, and SCU