A Thermodynamic Paradigm For Using Satellite Based Geophysical Measurements For Public Health Applications

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2017 Decadal Survey

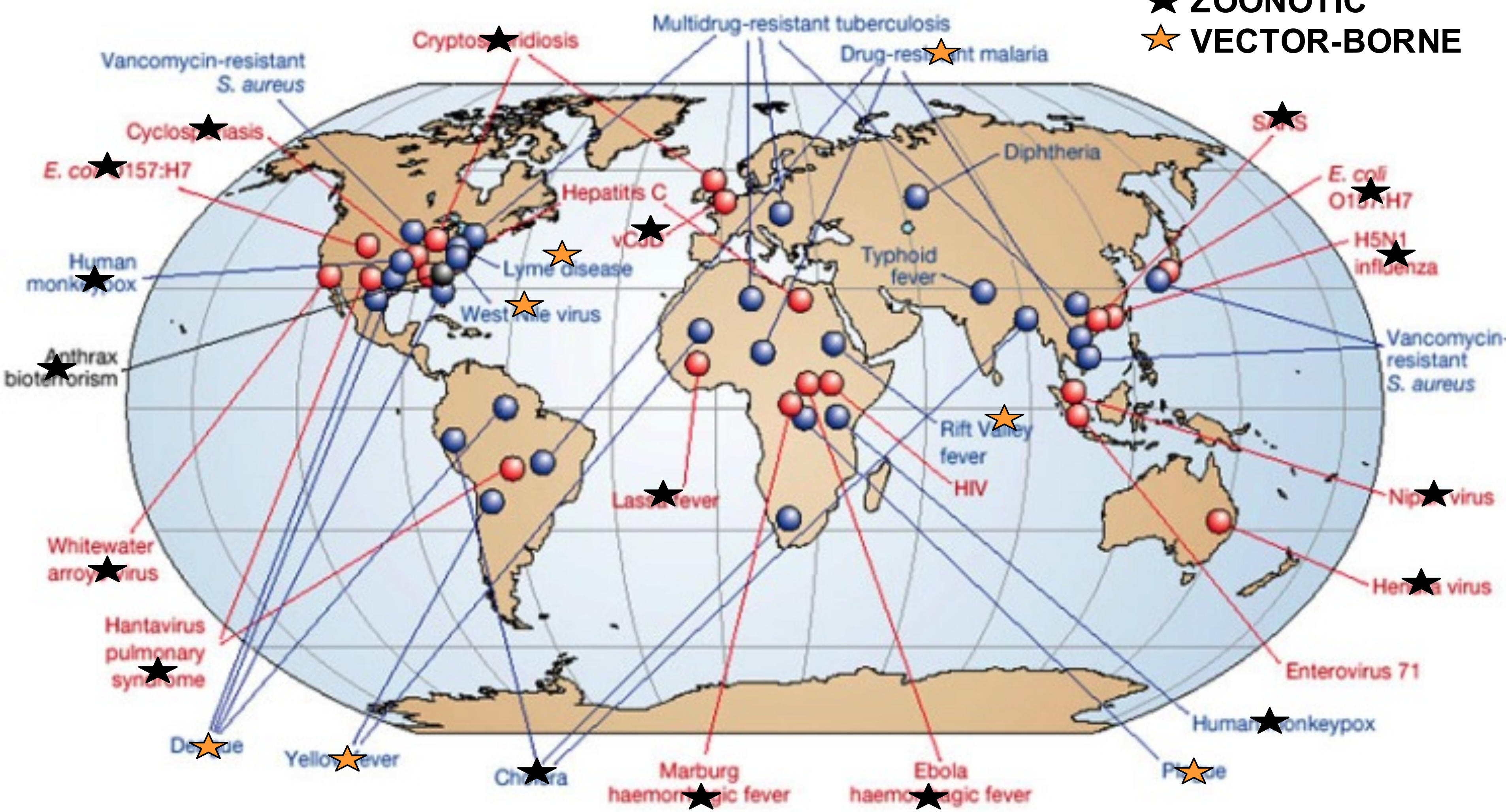
RFI #2 seeks specific input from the community regarding science and applications targets (i.e., objectives) and associated measurements that promise to substantially advance understanding in one or more of the Earth System Science themes associated with the survey's study panels.

This response (#2) falls within the purview of one of the five Earth science themes defined in the Request for Information for ESAS2017:

- (III) Marine and Terrestrial Ecosystems and Natural Resource Management Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services:
  - ✓ *Disease Vector's Habitats and Life Cycles*
  - ✓ *Urban Heat Island - Impacts on Environmental Public Health*
  - ✓ *Harmful Algal Blooms (HABS)*

Global Emerging Diseases*

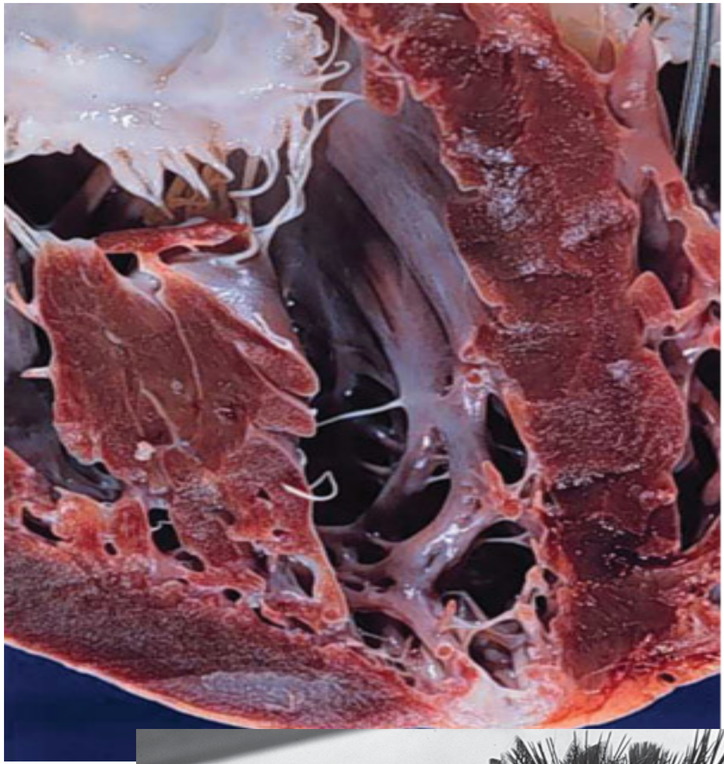
★ ZOONOTIC
☆ VECTOR-BORNE



EMERGING
RE-EMERGING

* Modified from Morens et al. 2004 *Nature* 430:242

a



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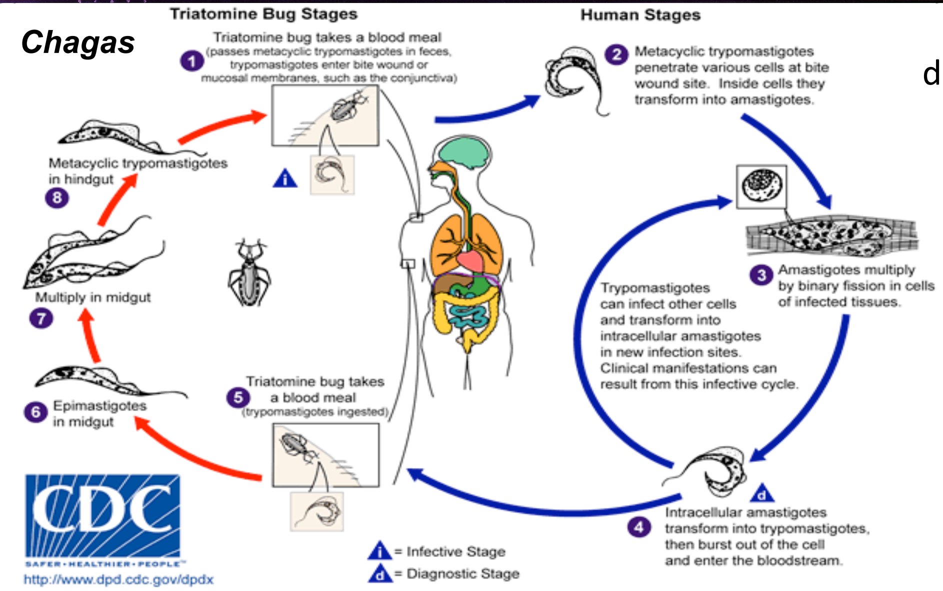
1

3

b



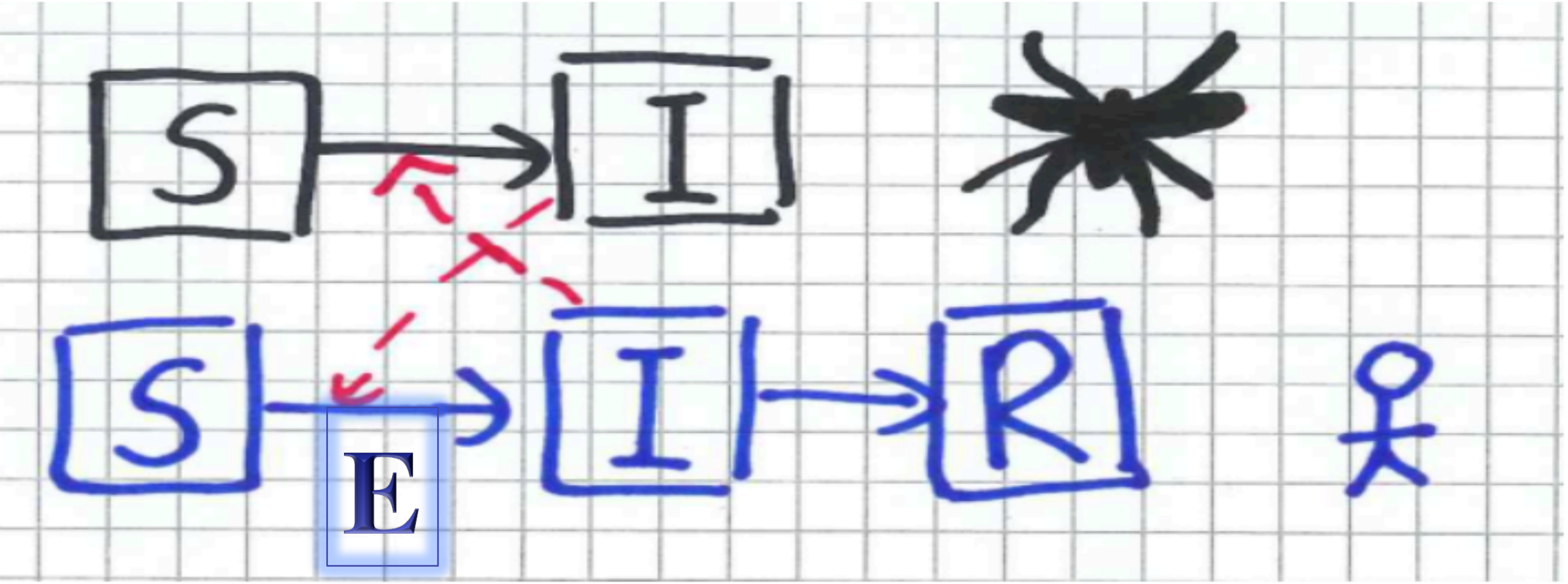
Chagas
Triatomine Bug Stages
Human Stages
Triatomine bug takes a blood meal (passes metacyclic trypomastigotes in feces, trypomastigotes enter bite wound or mucosal membranes, such as the conjunctiva)
Metacyclic trypomastigotes penetrate various cells at bite wound site. Inside cells they transform into amastigotes.
Amastigotes multiply by binary fission in cells of infected tissues.
Trypomastigotes can infect other cells and transform into intracellular amastigotes in new infection sites. Clinical manifestations can result from this infective cycle.
Intracellular amastigotes transform into trypomastigotes, then burst out of the cell and enter the bloodstream.
Triatomine bug takes a blood meal (trypomastigotes ingested)
Epimastigotes in midgut
Multiply in midgut
Metacyclic trypomastigotes in hindgut
1
2
3
4
5
6
7
8
i = Infective Stage
d = Diagnostic Stage
CDC
SAFER·HEALTHIER·PEOPLE
http://www.dpd.cdc.gov/dpdx

d

c

2

1915 Ross Model For Vector-borne Malaria Transmission



$$\frac{dI_h}{dt} = \alpha \lambda \omega I_m (1 - I_h) - \gamma I_h$$

$$\frac{dI_m}{dt} = \alpha v I_h (1 - I_m) - m I_m$$

Ross, Ronald. "Some a priori pathometric equations." British Medical Journal 1.2830 (1915): 546 http://equationsofdisease.wordpress.com

Strengths Of Satellite Observations

Measures environmental state functions important to vector & disease life cycles (within vector)

Precipitation, soil moisture, temperature, vapor pressure deficits, wet/dry edges, solar radiation….

***But also the interfaces as process functions*:**

Land use/cover mapping; Ecological functions/structure, species, canopy - cover species, phenology, chemistry; aquatic plant coverage…..

And provides a Spatial Context

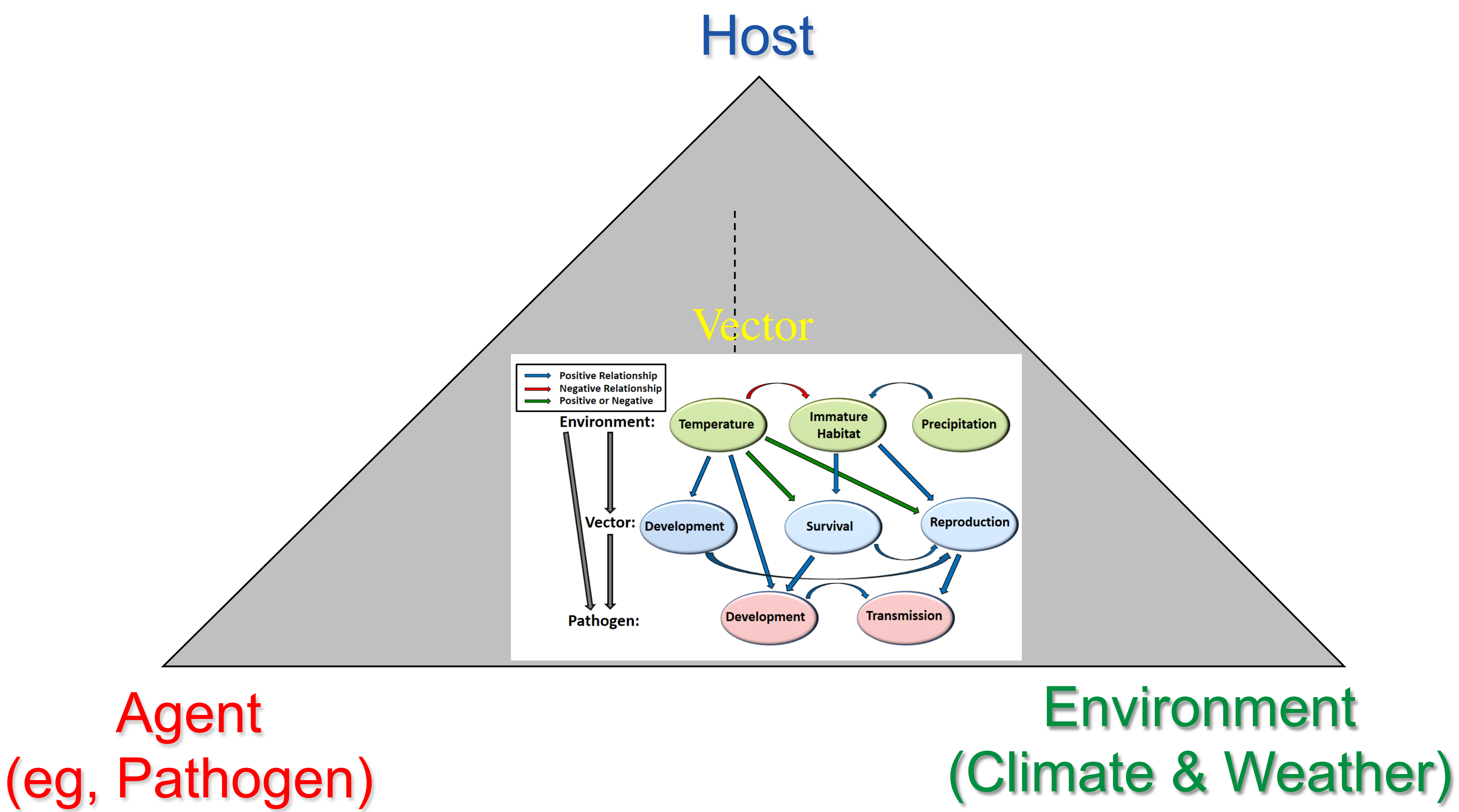
Spatial coverage & topography – local, regional & global…

Lastly, but perhaps the greatest strength:

Provides a time series of measurements

Epidemiologic Triangle of Disease (Vector-borne Diseases)

A multi-factorial relationship between hosts, agents, vectors and environment



Morin 2014

A Ecological Thermodynamic Paradigm

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The epidemiological equations (processes) can be adapted and modified to ***explicitly incorporate environmental factors and interfaces***

Remote sensing can be used to measure or evaluate or estimate ***both environment (state functions) and interface (process functions).*** **The products of remote sensing must be expressed in a way they** ***can be integrated directly into the epidemiological equations.*** **The desired logical structures must be consistent with thermodynamic and with probabilistic frameworks.**

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 -)

Thermal Response Number

TRN = Q*/delta T

where:

Q* = net radiation

delta T = change in temperature

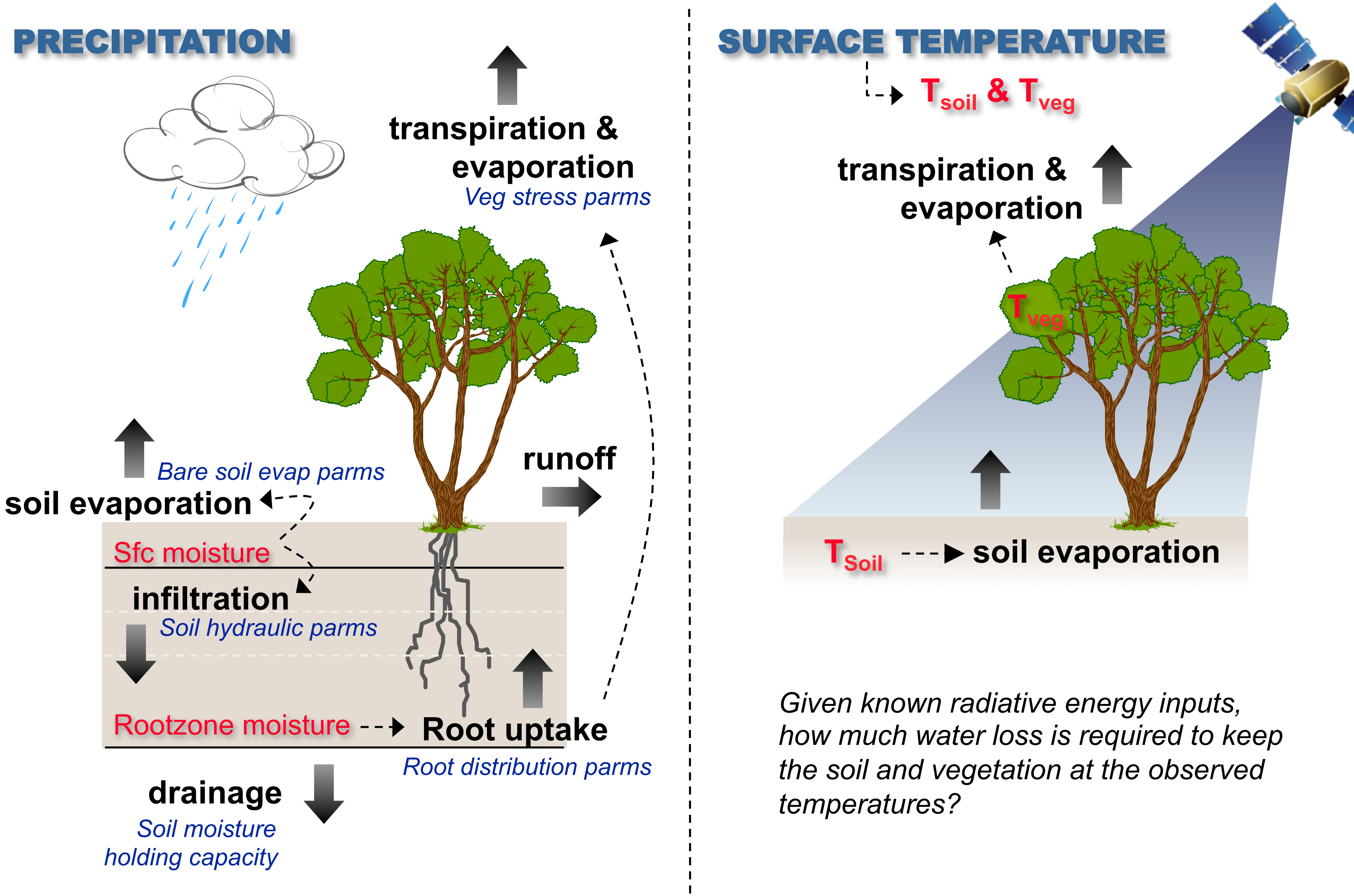
- Uses the change in surface temperature between 2 measurement times
- Uses surface net radiation as amount of energy available the surface for partitioning
- Produces a quantifiable value (kj m-2 oC -1)
- Allows the classification of land use in terms of energy partitioning

Luvall & Hobo 1989

Surface Temperature

$$T_s = T_a + \frac{R_b}{C_\rho}\left(R_n - E\right)$$

Approaches to mapping ET



WATER BALANCE APPROACH
(prognostic modeling)

ENERGY BALANCE APPROACH
(diagnostic modeling)

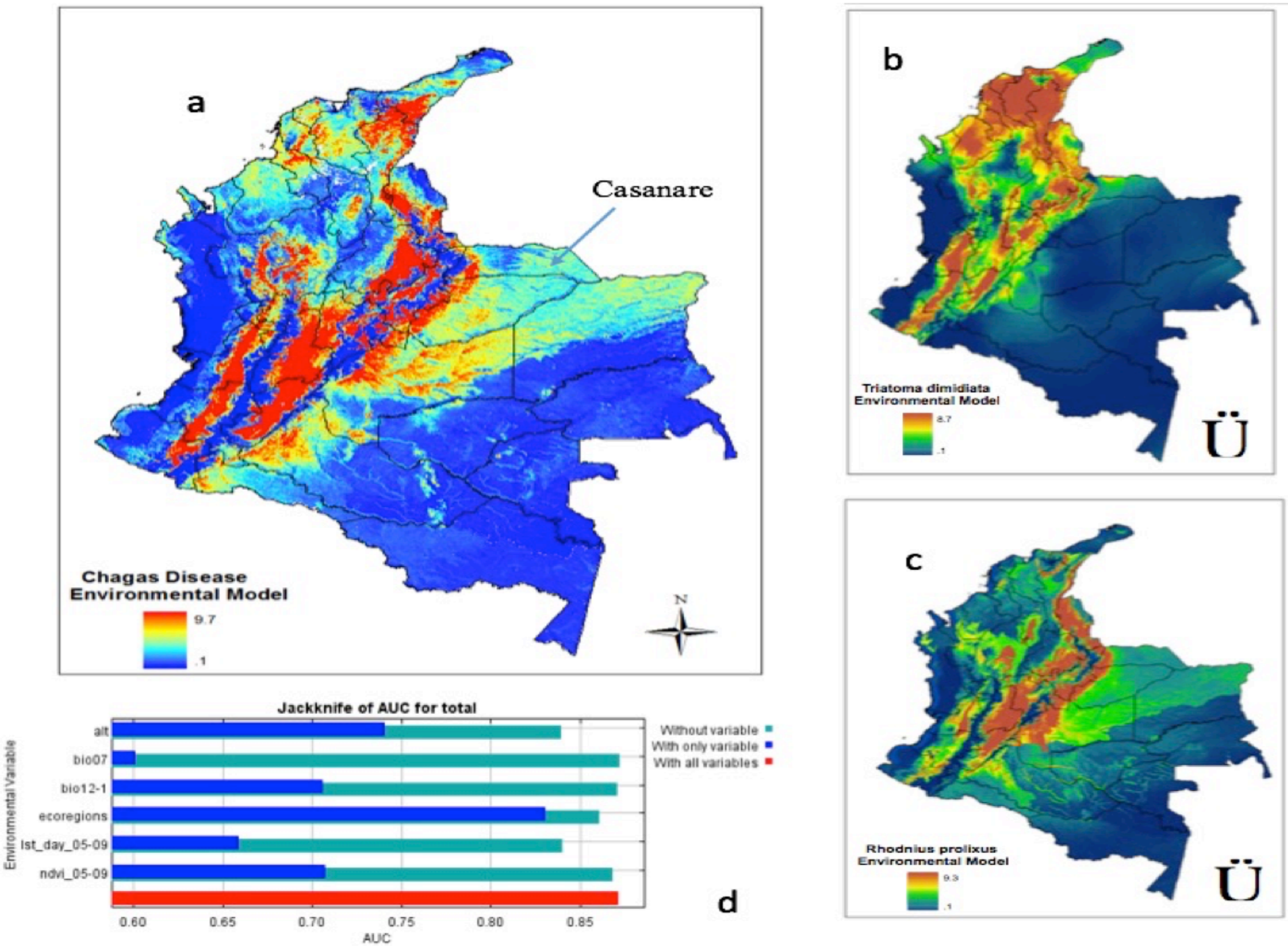


Figure 4. Maxent generated risk surfaces for Colombia generated from national scale data on Chagas disease (a) vector distribution (b, c). Note unique but overlapping geospatial ranges for Triatoma dimidiata and Rhodnius prolixus. Maxent generated Jackknife results (d) show the relative influence of the most significant environmental variables in producing probability map surfaces for Chagas disease.

Malone, J. B. 2005. Biology-based mapping of vector-borne parasites by Geographic Information Systems and Remote Sensing. Parassitologia 47:27–50.

Challenges

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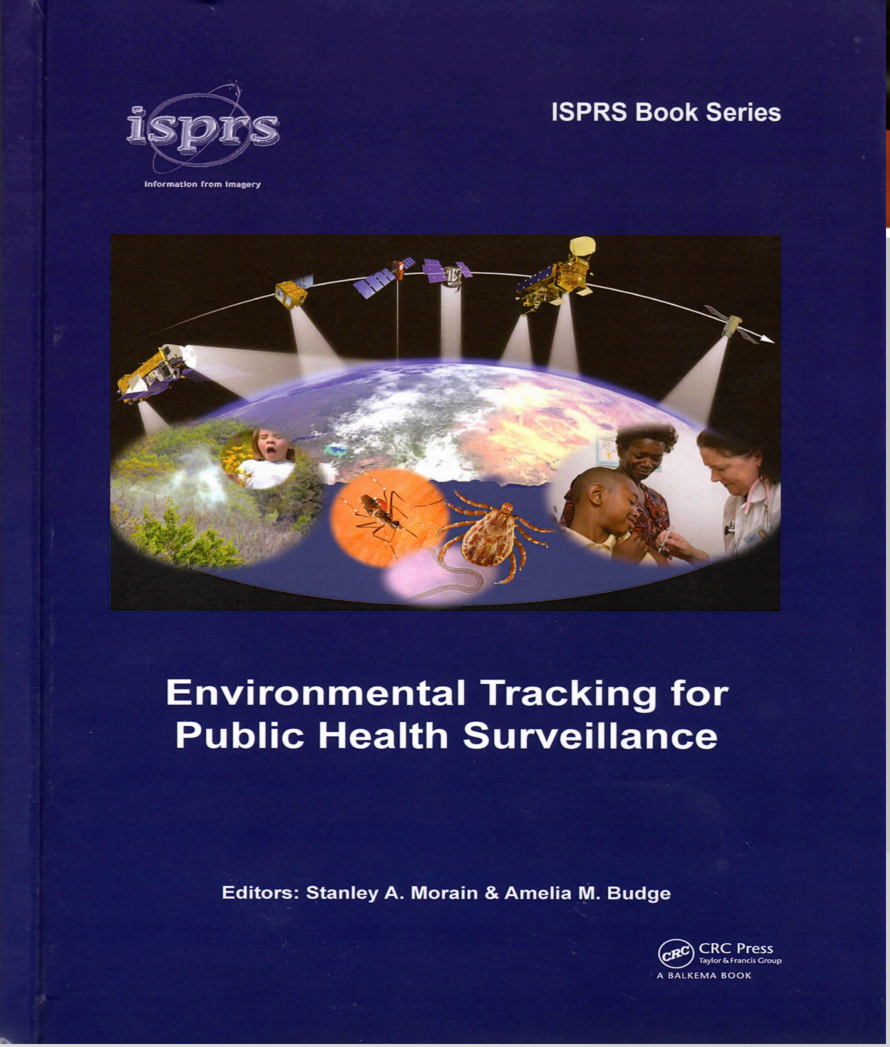
Satellite Data

- repeat frequency & spatial resolution
- spectral bands available
- clouds
- life cycle
- cost
- data availability & timeliness of delivery

Public Health & Epidemiology

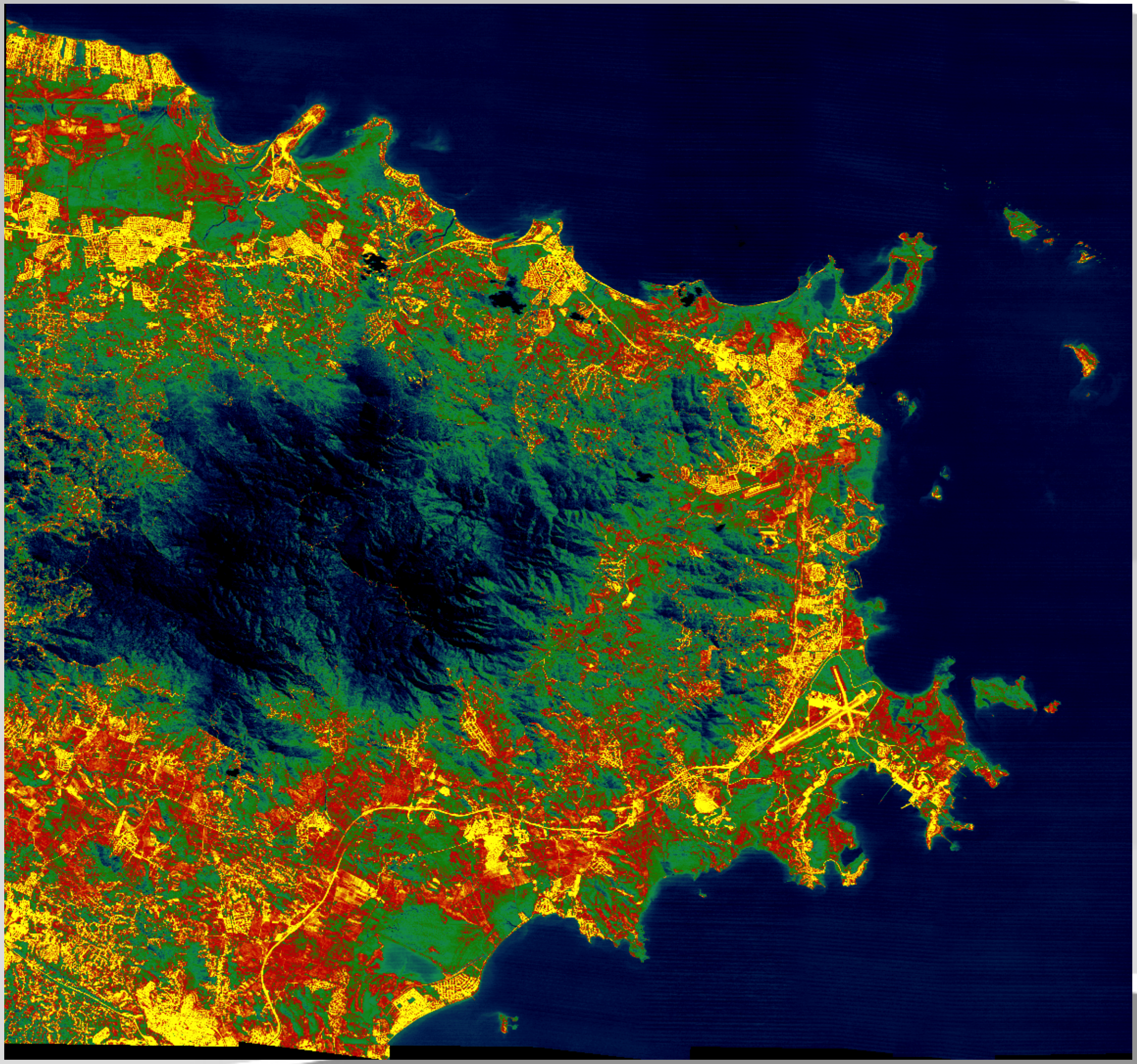
- availability of data & various sampling issues
- difficulty in getting access to sampling areas
- cost
- understanding of the data provided by satellites
- ***Define & quantify the multi-factorial relationships between hosts, agents, vectors and environment***



International Society of Geospatial Health - GnosisGIS

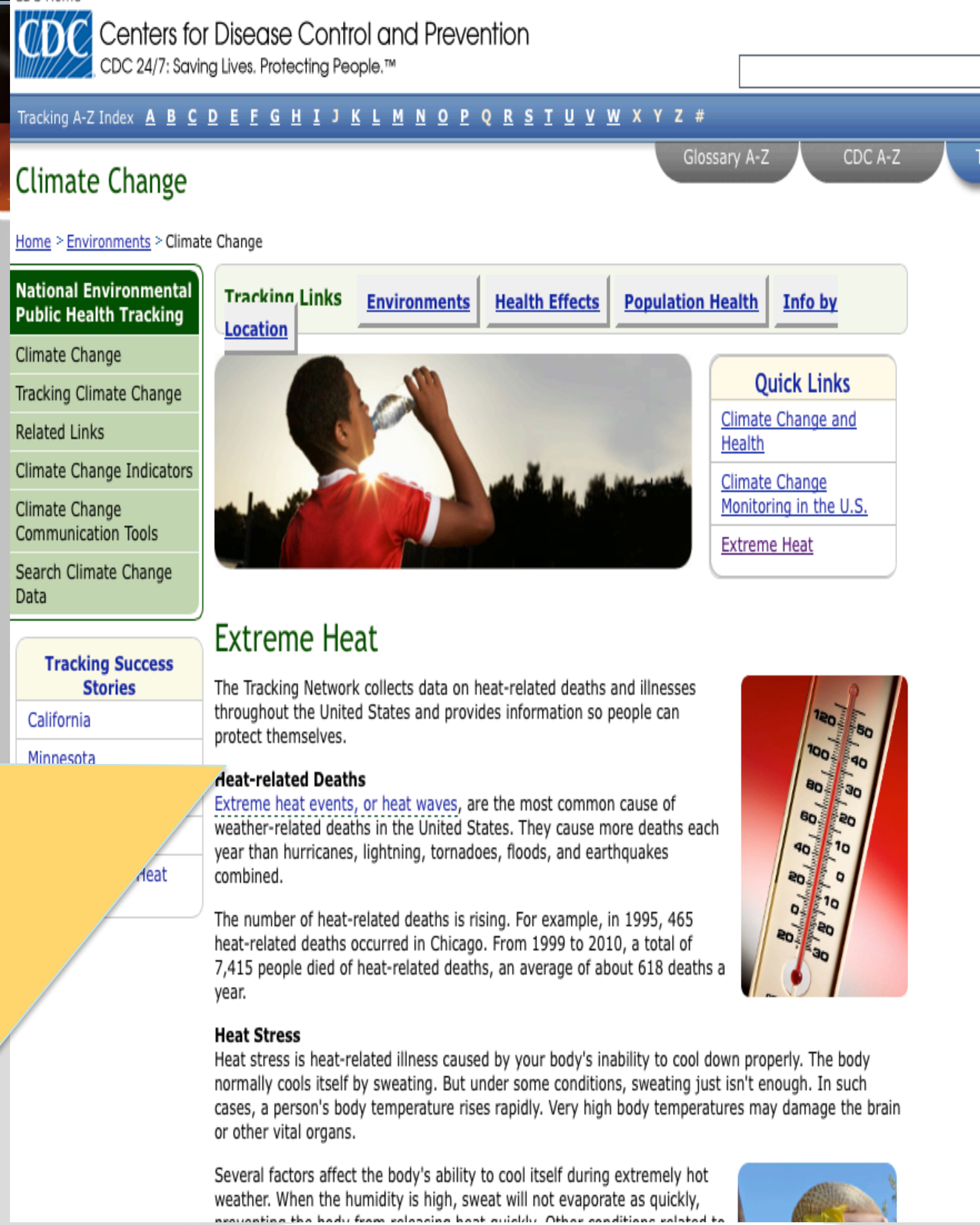
http://www.gnosisgis.org/index.php

Urban Heat Island - Impacts on Environmental Public Health



Extreme heat events, or heat waves, are the most common cause of weather-related deaths in the United States. They cause more deaths each year than hurricanes, lightning, tornadoes, floods, and earthquakes combined.

The number of heat-related deaths is rising. For example, in 1995, 465 heat-related deaths occurred in Chicago. From 1999 to 2010, a total of 7,415 people died of heat-related deaths, an average of about 618 deaths a year.


Centers for Disease Control and Prevention
CDC 24/7: Saving Lives. Protecting People.™

Tracking A-Z Index A B C D E F G H I J K L M N O P Q R S T U V W X Y Z #

Glossary A-Z CDC A-Z

Climate Change

Home > Environments > Climate Change

National Environmental Public Health Tracking
Climate Change
Tracking Climate Change
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Tracking Links Environments Health Effects Population Health Info by Location

Quick Links
Climate Change and Health
Climate Change Monitoring in the U.S.
Extreme Heat

Tracking Success Stories
California
Minnesota

Extreme Heat

The Tracking Network collects data on heat-related deaths and illnesses throughout the United States and provides information so people can protect themselves.

Heat-related Deaths
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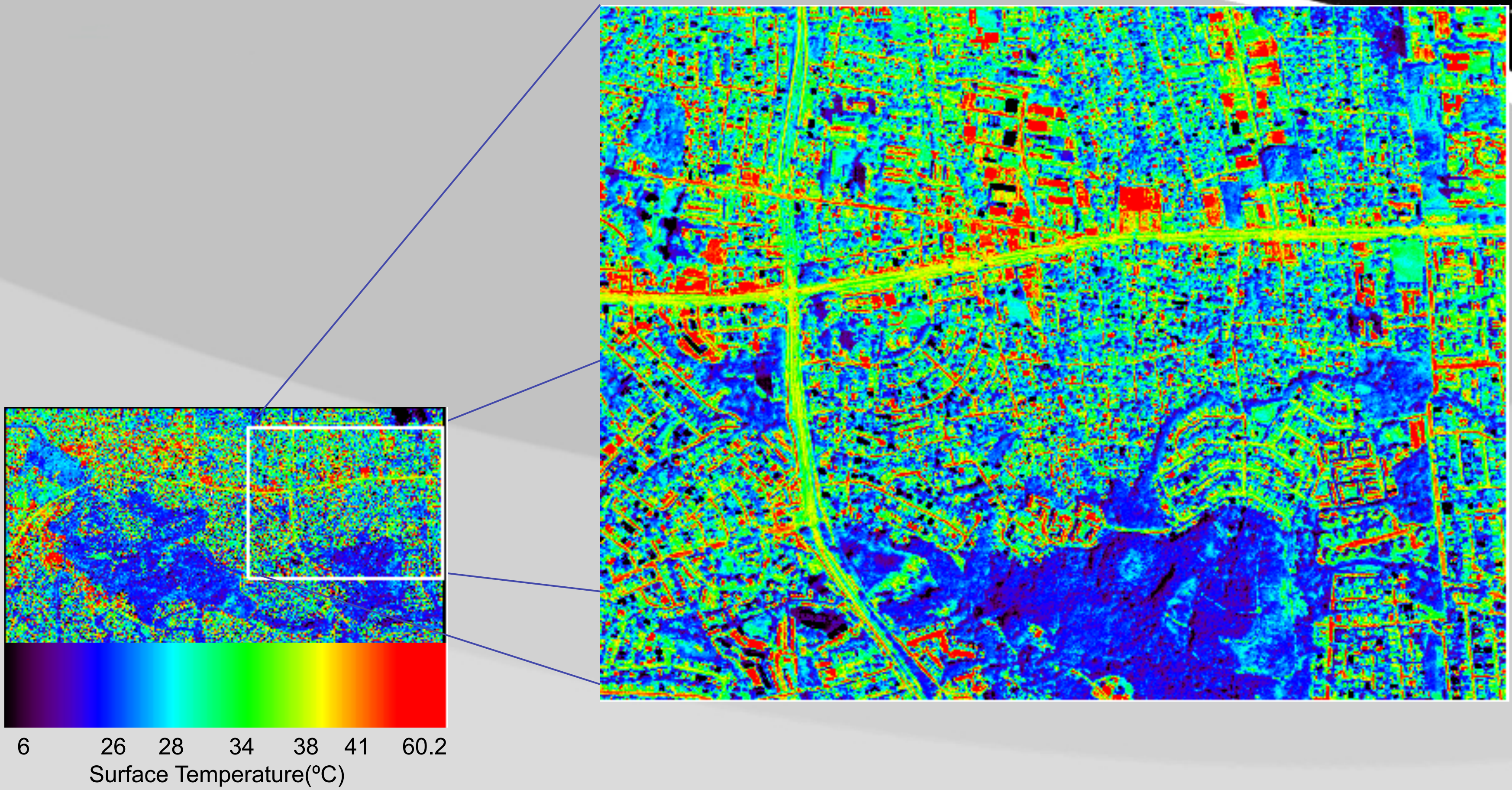
Heat Stress
Heat stress is heat-related illness caused by your body's inability to cool down properly. The body normally cools itself by sweating. But under some conditions, sweating just isn't enough. In such cases, a person's body temperature rises rapidly. Very high body temperatures may damage the brain or other vital organs.

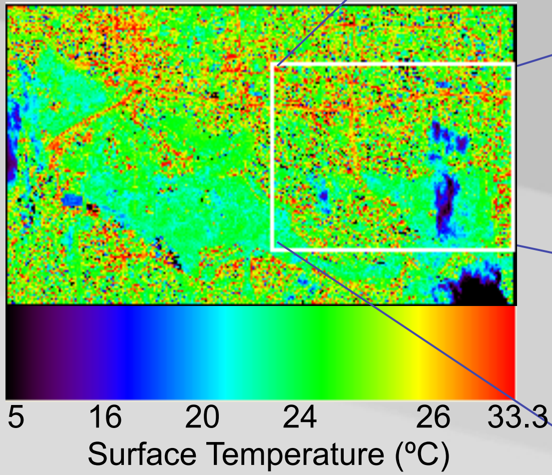
Several factors affect the body's ability to cool itself during extremely hot weather. When the humidity is high, sweat will not evaporate as quickly,

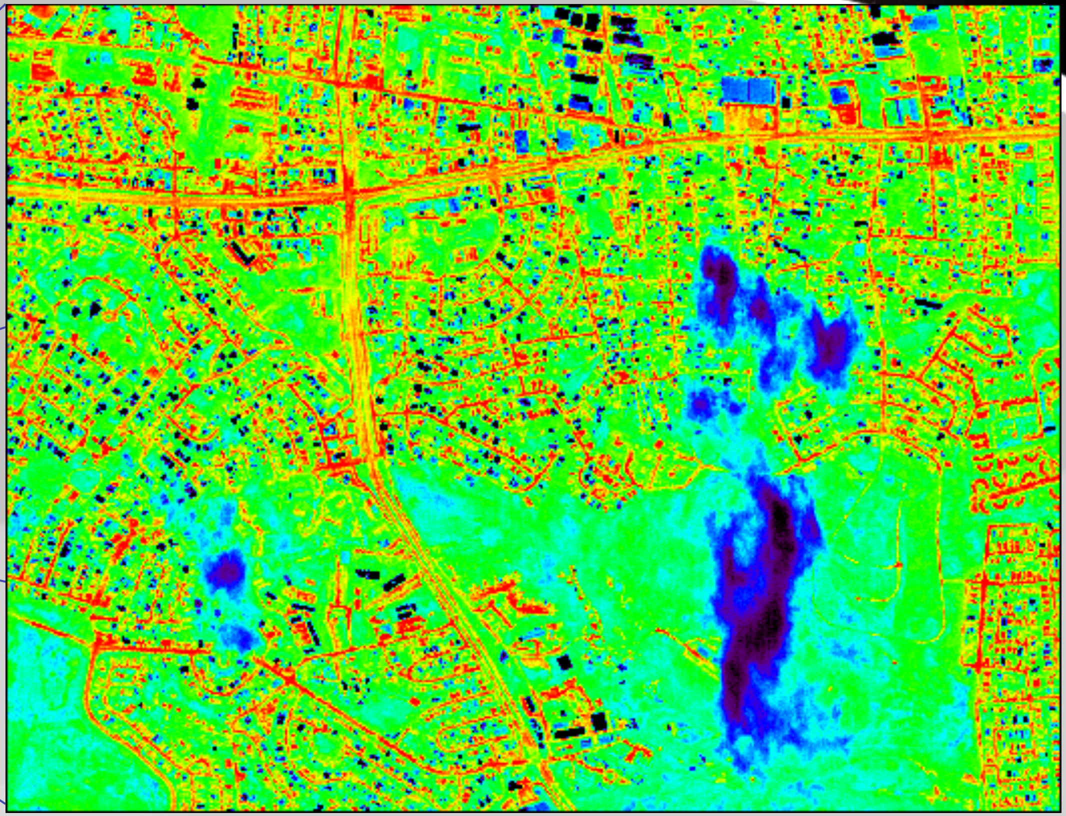
- **European heat wave caused 35,000 deaths 2003**
- **Over 15,000 likely dead in Russian 2010 heat wave; Asian monsoon floods kill hundreds more**
- **Heat wave death toll in NYC rises to 8 NYDN 7/23/13**
- **UK Heat wave death toll: Up to 760 killed and total may double as temperatures above 30º c continue 7/18/13**
- **Chicago July 1995 more than 700 died**

Surface Temperature Day: Flight 1 Line 23 Hato Rey

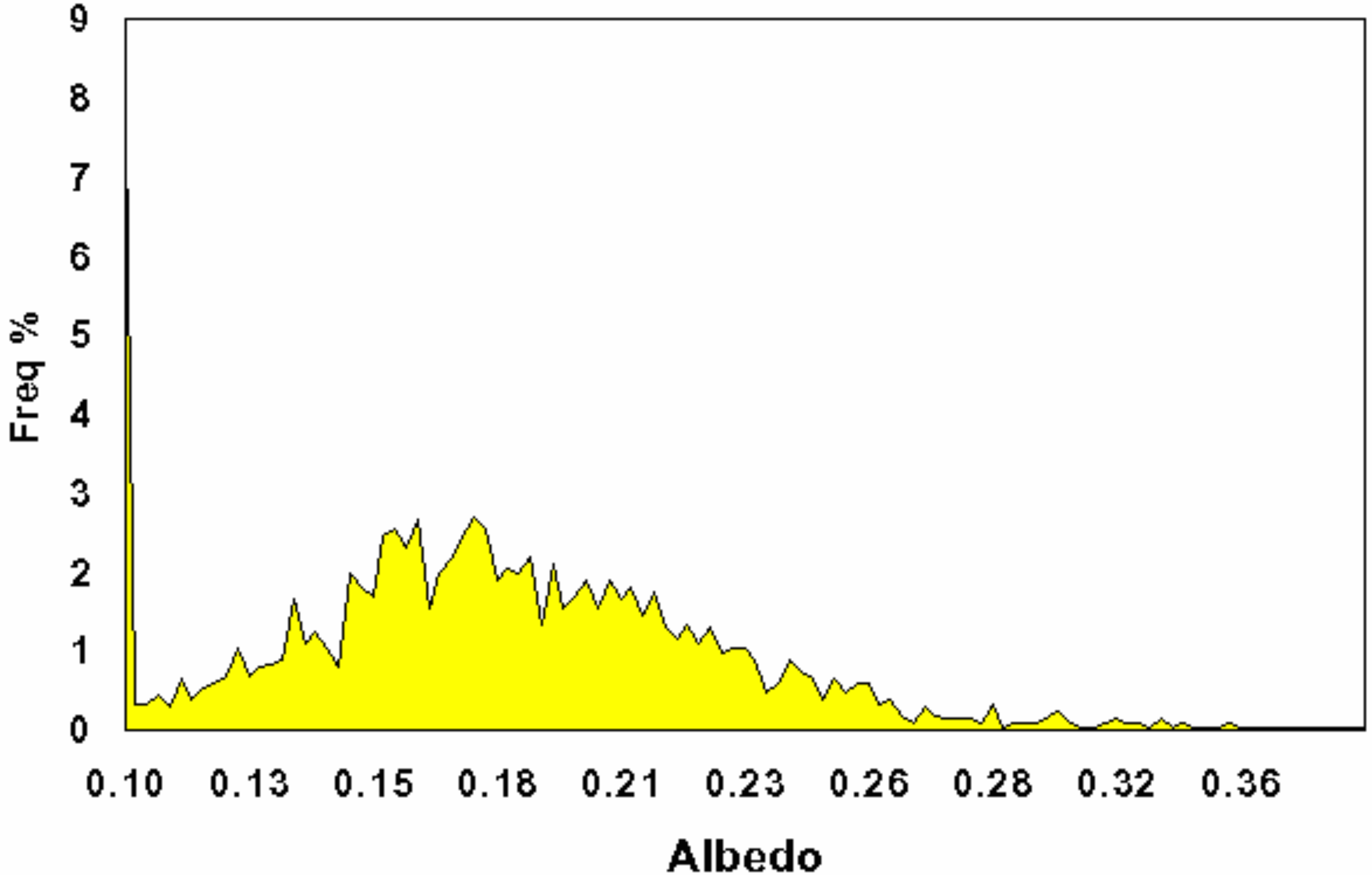


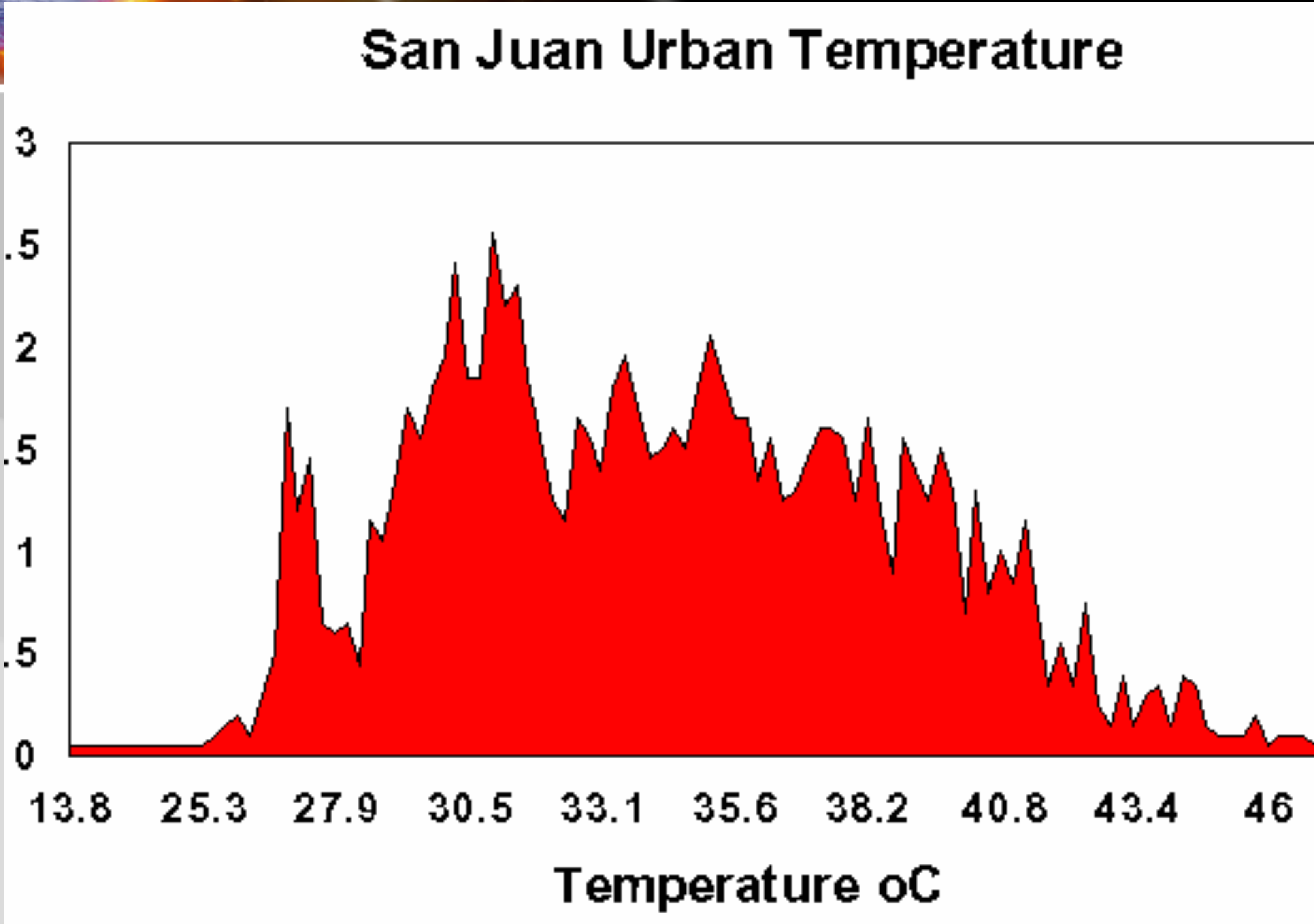
Surface Temperature at Night: Flight 2 Line 23 Hato Rey



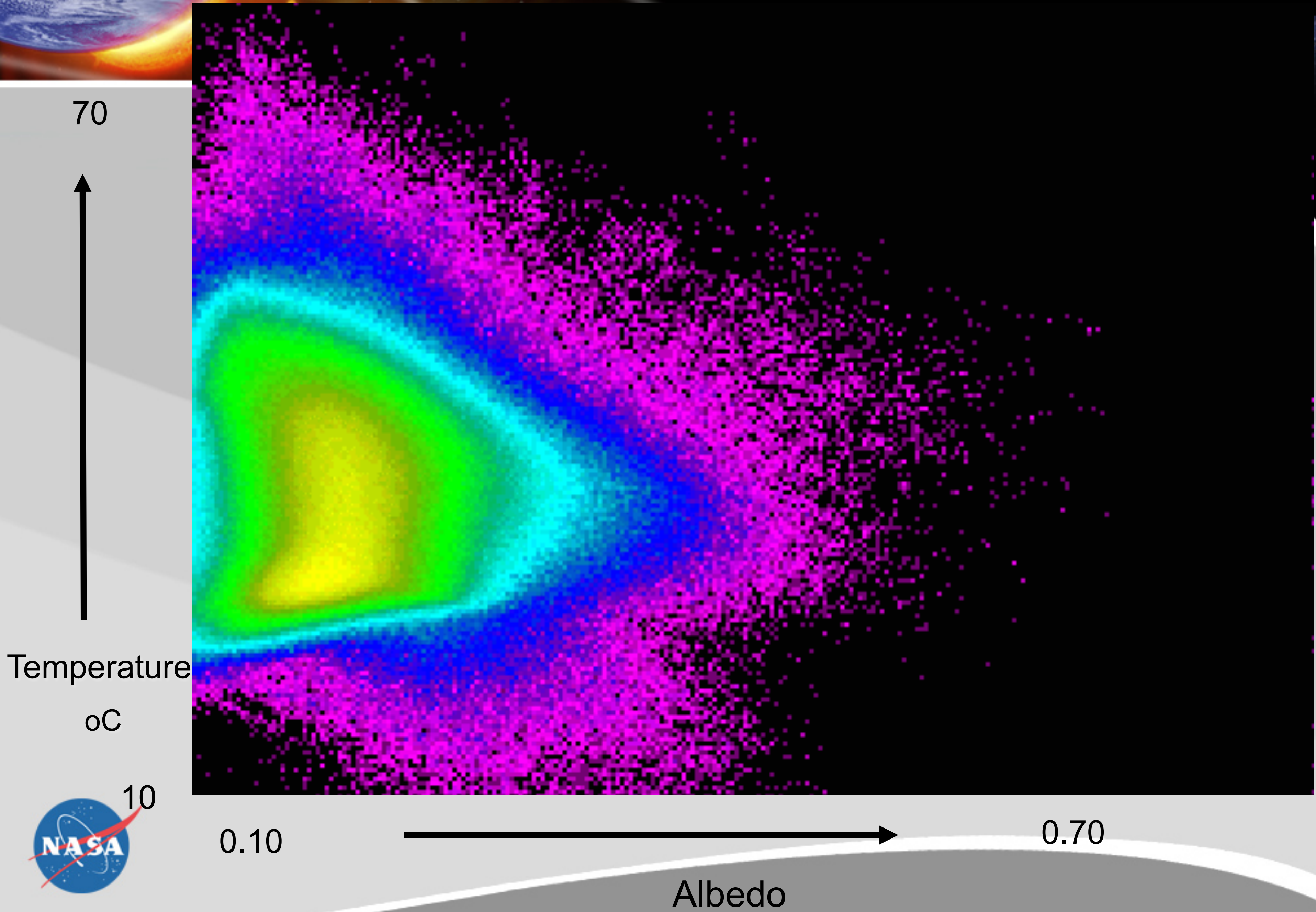


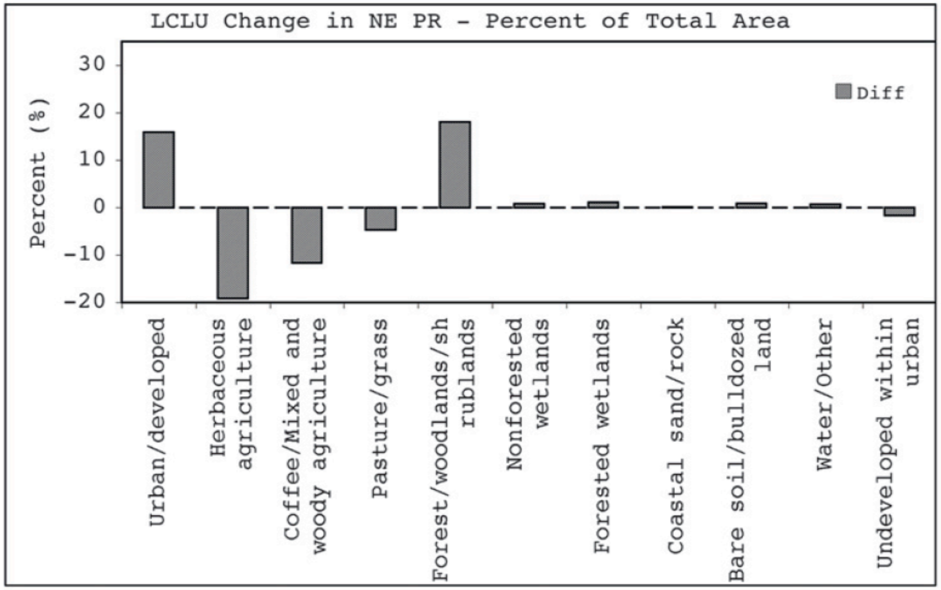
San Juan Urban Albedo

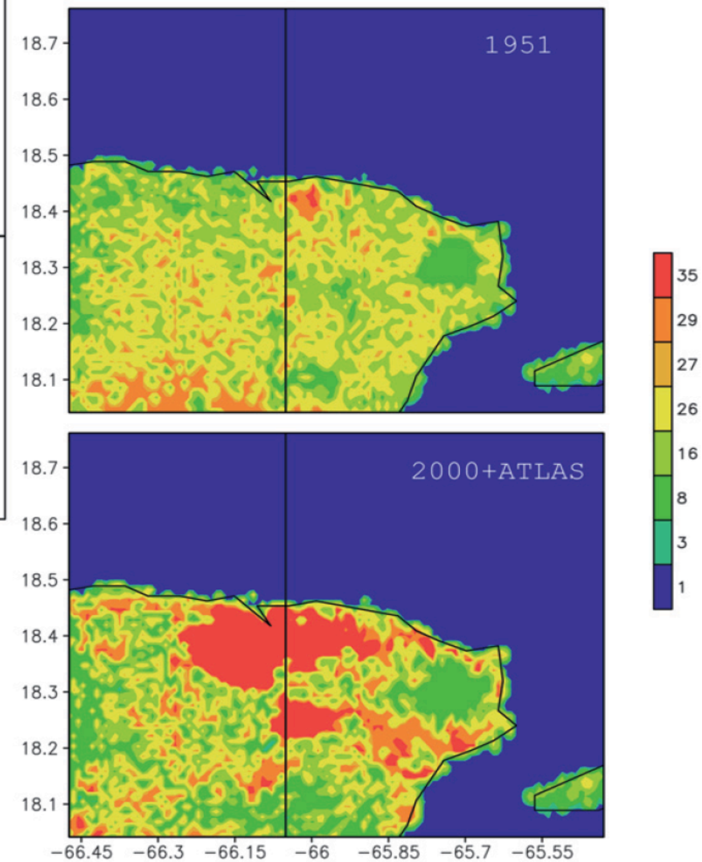



San Juan Urban Temperature
3
.5
2
.5
1
.5
0
13.8
25.3
27.9
30.5
33.1
35.6
38.2
40.8
43.4
46
Temperature oC

San Juan
Albedo vs Te







Northeastern Puerto Rico

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	29	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

FIG. 3. (right) Map showing the LCLU specifications in northeastern Puerto Rico for (top) 1951 and (bottom) 2000; 2000 information is complemented with remote sensing data obtained from the ATLAS sensor. The thick solid vertical line represents the location of the north–south vertical cross section in Figs. 8 and 9. (left) (top) Histogram of historical LCLU changes in percent of total area covered from 1951 to 2000 and (bottom) description of the most relevant vegetation and land classes with percent change and conversion rates.

Comarazamy, Daniel E, Jorge E Gonz‡lez, Jeffrey C Luvall, Douglas L Rickman, and Robert D Bornstein. 2013. “Climate Impacts of Land-Cover and Land-Use Changes in Tropical Islands Under Conditions of Global Climate Change.”Journal of Climate 26 (5): 1535–50. doi:10.1175/JCLI-D-12-00087.

Harmful Algal Blooms (HABS)

Western Basin CyanoHAB during the 2014 Toledo Water Shutdown (1-3 Aug 2014)

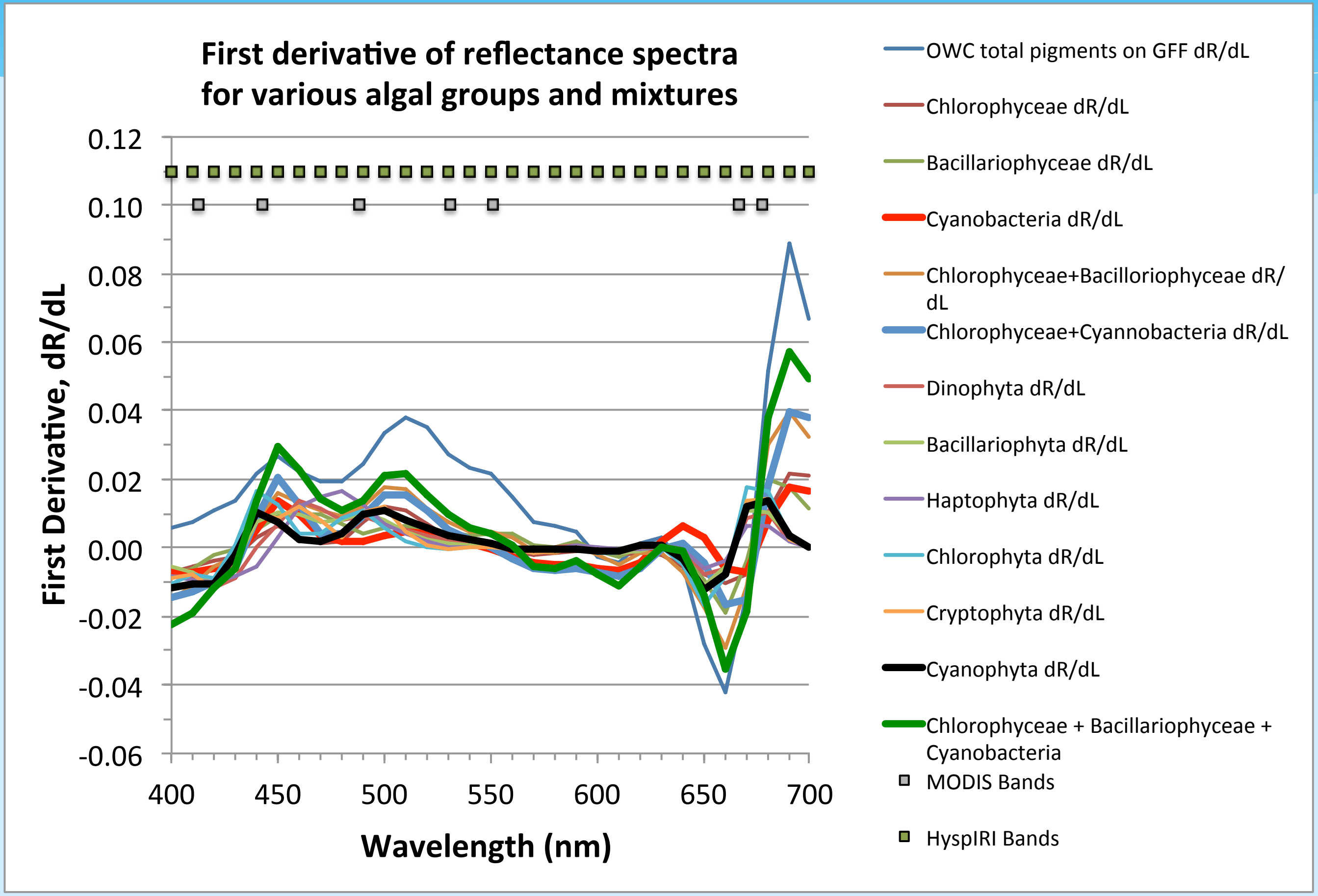
Algae surrounds Toledo's intake facility on Lake Erie on August 3.

Source: Photos- P. Essick, National Geographic;
Related article: J.J. Lee, Aug 4, 2014 National Geographic News

Ortiz et al., (HyspIRI 2016)

1st derivative

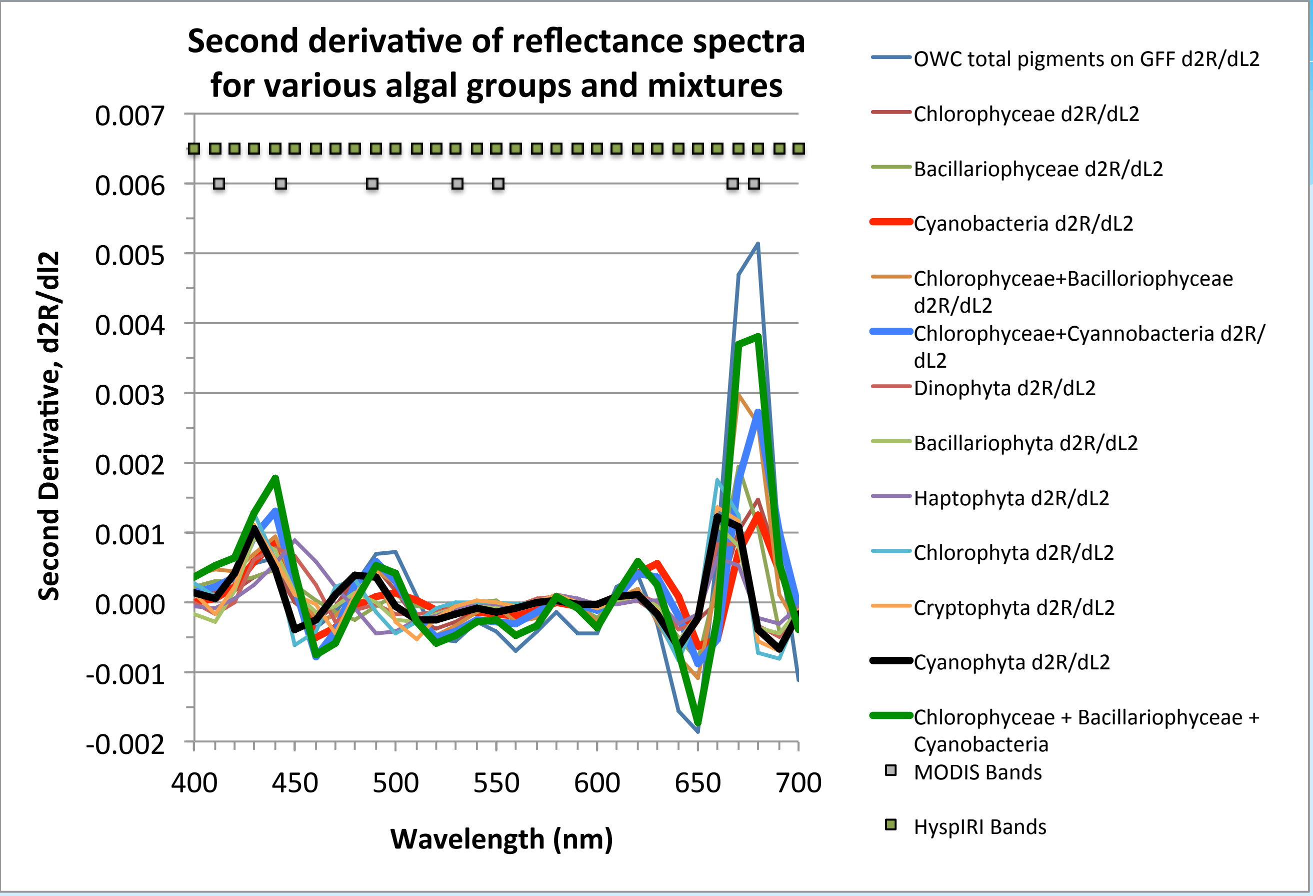
Provides information on different pigments and thus algal and cyanophyte composition



Ortiz et al., (HyspIRI 2016)

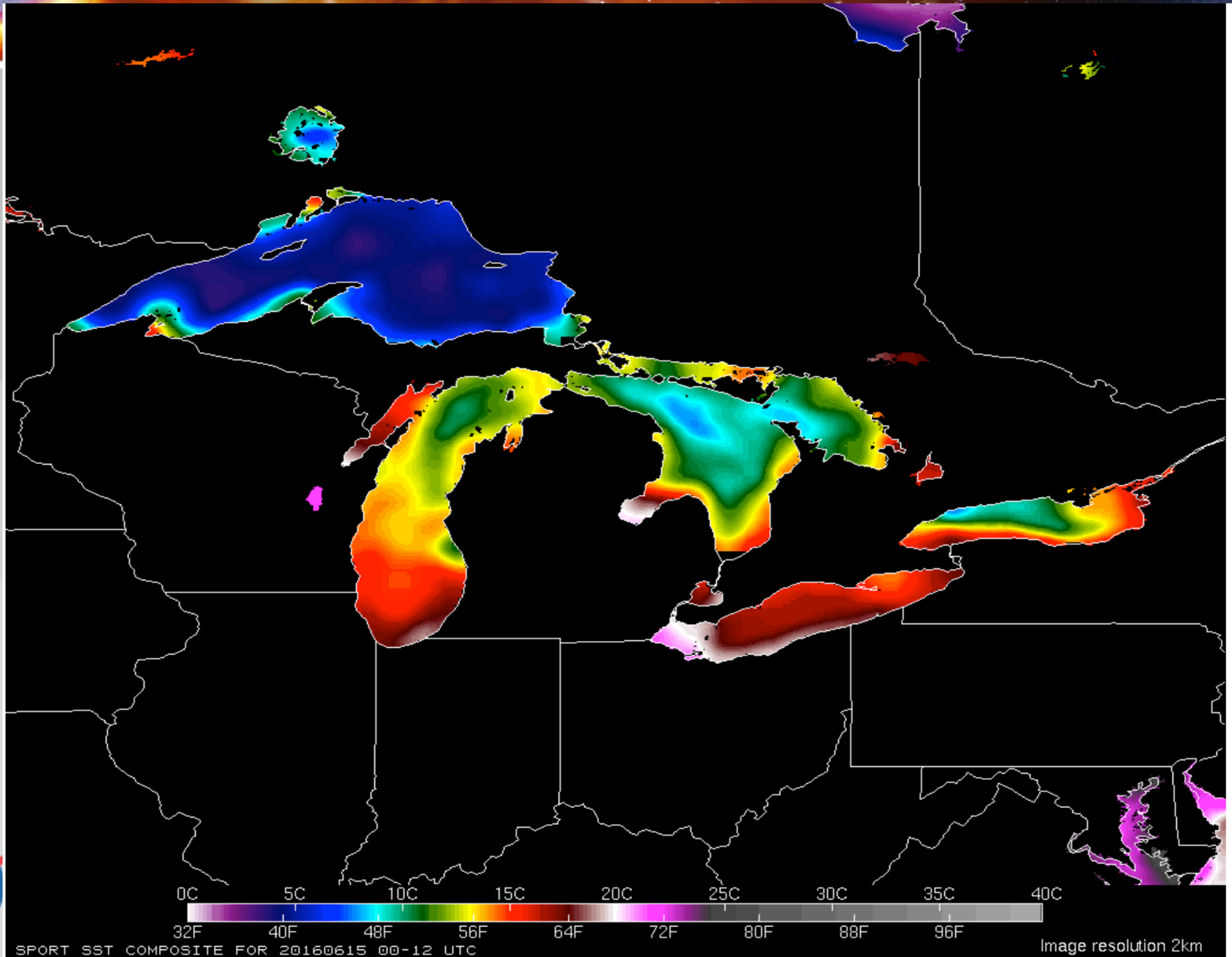
2nd derivative

Red Edge 2nd derivative provides information on algal and cyanophyte concentration and thus bloom intensity

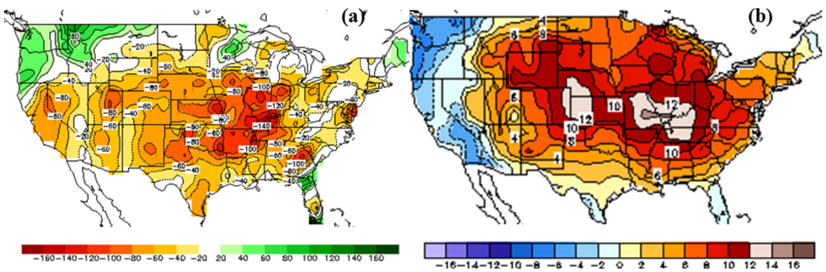


Ortiz et al., (HyspIRI 2016)

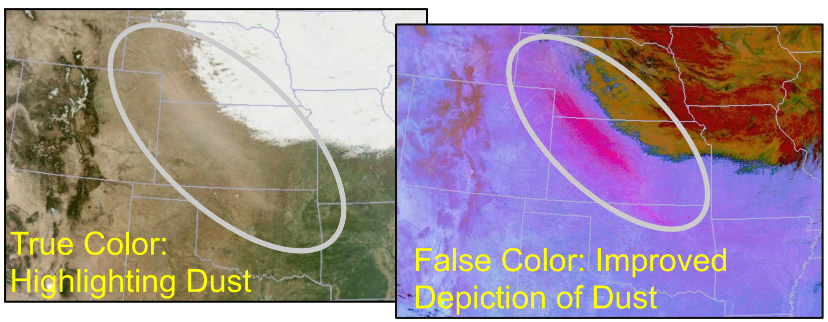
SPoRT SST composite MODIS 2 km



NASA's Short-term Prediction Research and Transition (SPoRT) Center



Temperature and soil moisture anomalies for public health (extreme heat and cold) or environmental applications favorable for disease vectors



Multispectral remote sensing from VIIRS and MODIS for air quality and vegetation applications.

- The SPoRT Center focuses on the transition of "research to applications" for unique NASA, NOAA, and other-agency capabilities
- Current focus is on the use of land surface modeling and remote sensing for a variety of applications
  - Weather Analysis and Forecasting
  - Numerical Weather Prediction
  - Remote Sensing
  - Disasters
- SPoRT is well-suited to combine multiple products to support Public Health applications, through combination of satellite-derived and model-derived information.

Combined, modeling and remote sensing capabilities can support the generation of new Public Health products, alerts, and end training for end users.