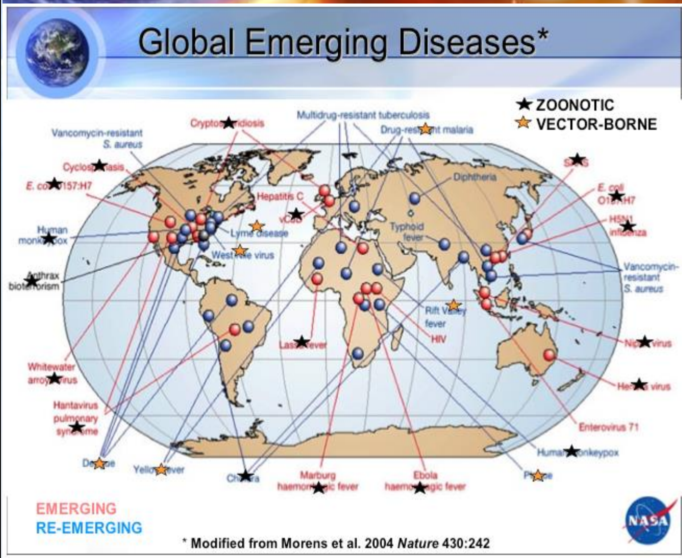
A Thermodynamic Paradigm For Using the Latest Space-based Geophysical Measurements For Public Health Applications

Jeffrey C. Luvall
Marshall Space Flight Center

θΔ ics

Global Public Health Challenges



Vector Borne Diseases

Dust

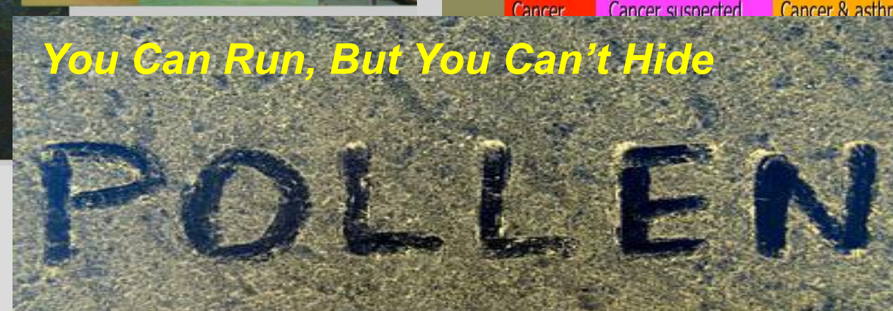
Middle East Dust – Trace Composition

Links between selected elements and some known lung function conditions and diseases

	Desert Dust <10 μm	Desert Dust 20-40 μm
Mn (ppm)	450	331.98
Fe (ppm)	25500	18111.61
Co (ppm)	11.72	8.24
Pb (ppm)	17.22	9.45
Cu (ppm)	220	152.64
Cd (ppm)	1.24	0.70
Mg (ppm)	13230.49	10572.70
Al (ppm)	15912.39	13154.60
Ca (ppm)	139577.64	140250.15
Na (ppm)	1098.28	1476.86
Cr (ppm) [but species critical]	181.32	187.36
Zn (ppm)	105.18	72.30
Ni (ppm)	93.28	60.44
Ti (ppm)	1095.52	539.81

Cancer | Cancer suspected | Cancer & asthma | Emphysema | Asthma

Harmful Algal Blooms

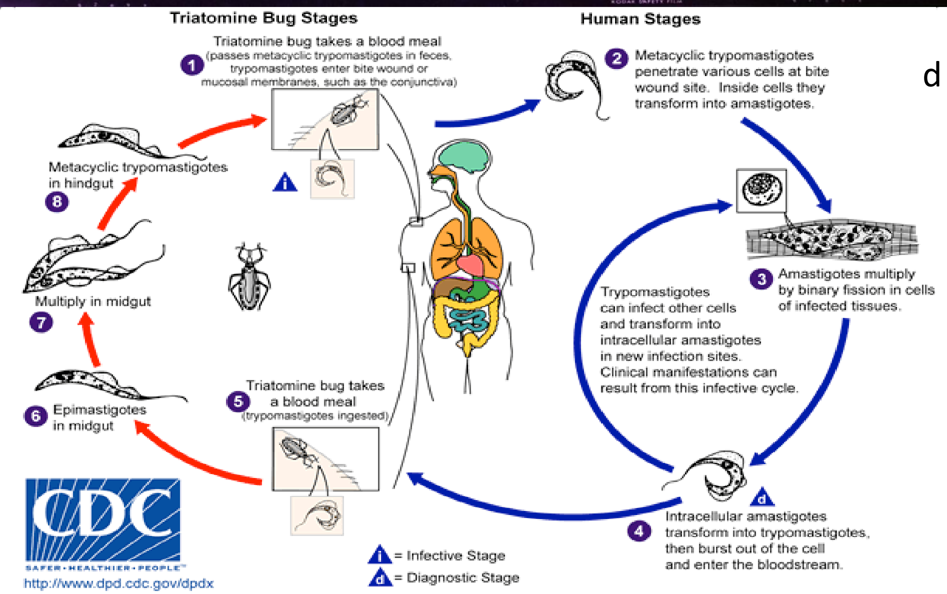


Juniper Pollen Phenology and Dispersal

1

3

b



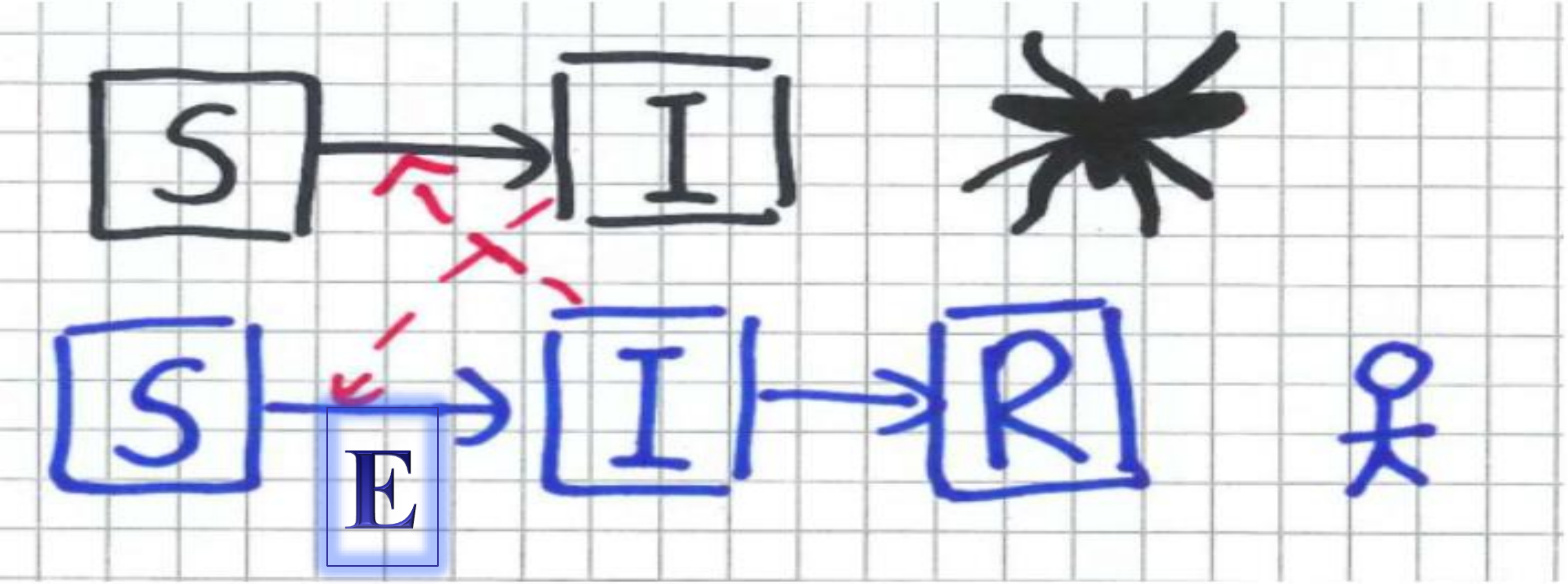
Triatomine Bug Stages
Human Stages
1 Triatomine bug takes a blood meal (passes metacyclic trypomastigotes in feces, trypomastigotes enter bite wound or mucosal membranes, such as the conjunctiva)
2 Metacyclic trypomastigotes penetrate various cells at bite wound site. Inside cells they transform into amastigotes.
3 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.
4 Intracellular amastigotes transform into trypomastigotes, then burst out of the cell and enter the bloodstream.
5 Triatomine bug takes a blood meal (trypomastigotes ingested)
6 Epimastigotes in midgut
7 Multiply in midgut
8 Metacyclic trypomastigotes in hindgut
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, canopy cover, species, phenology, 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

A Ecological Thermodynamic Paradigm

☀ θΔ ics 🌎

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.

Challenges

☀θΔ ics 🌎

Satellite Data

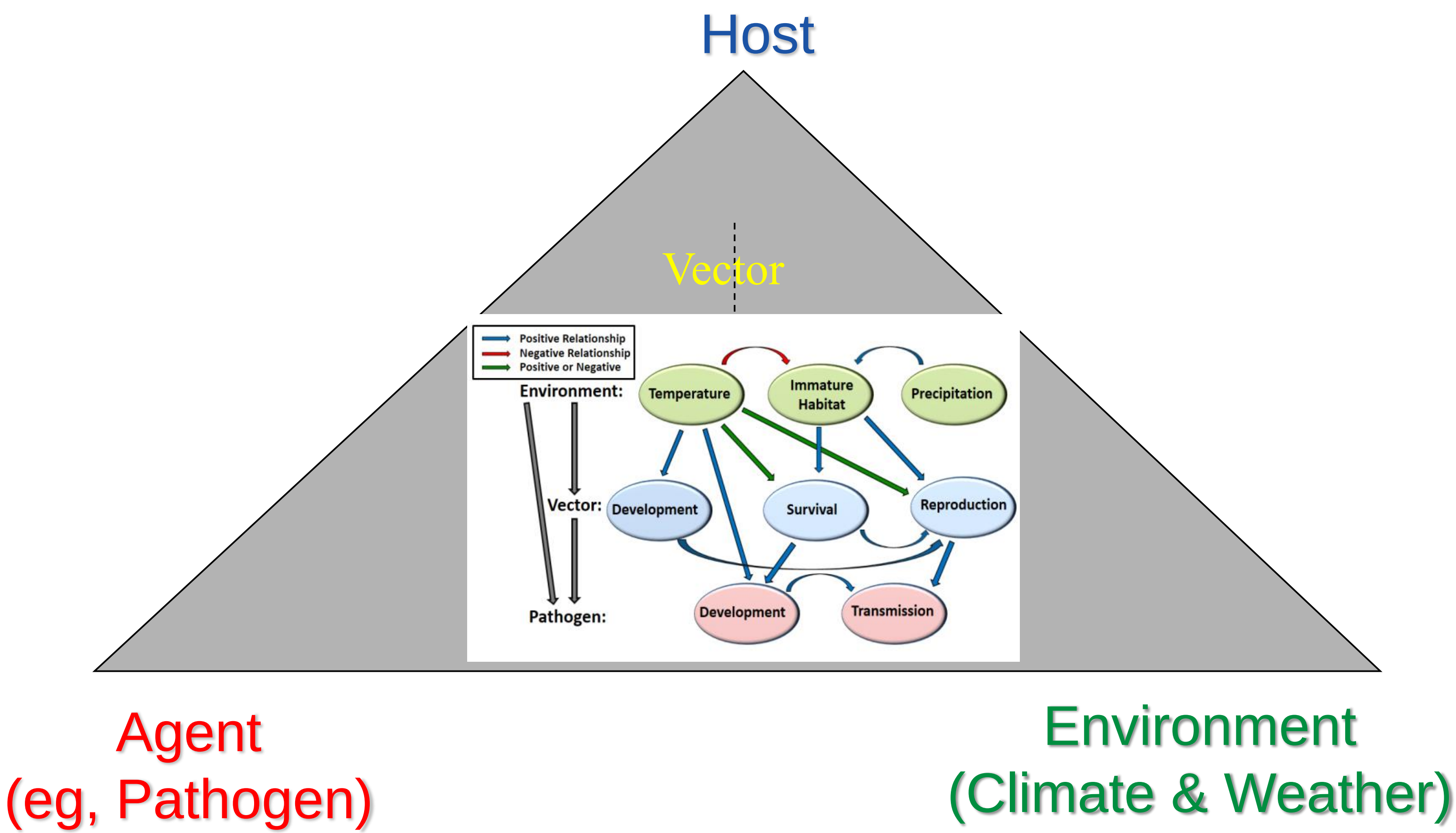
– repeat frequency & spatial resolution
– spectral bands available
– clouds
– life cycle
– cost
– data availability & timeliness of delivery

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***

Epidemiologic Triangle of Disease (Vector-borne Diseases)

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



Morin 2014

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

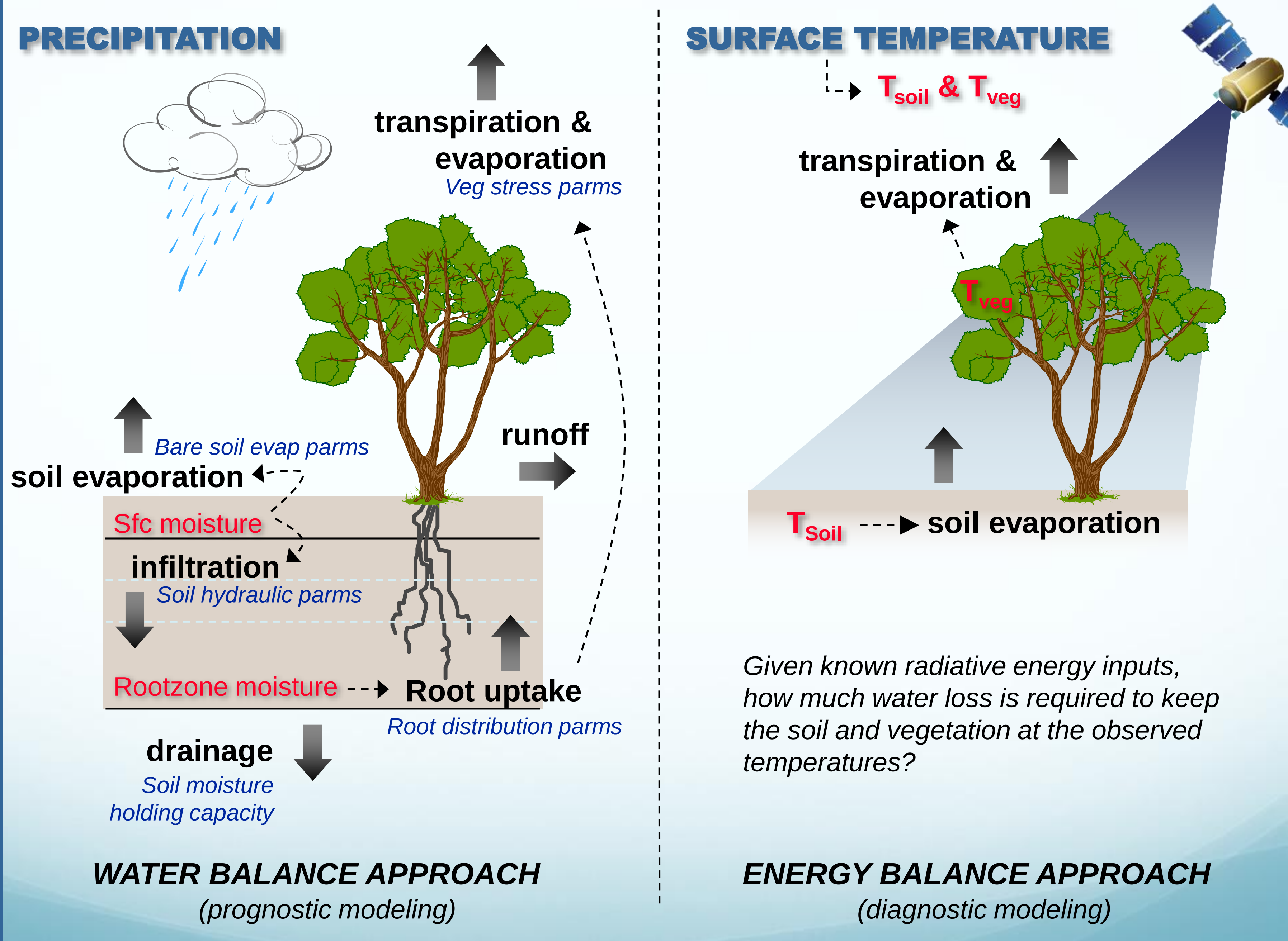
LE = Latent Heat Flux

G = Storage (maybe + or -)

Surface Temperature

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

Approaches to mapping ET



Martha C. Anderson, et al. *USDA-Agricultural Research Service, Hydrology and Remote Sensing Laboratory, Beltsville, MD*

Vectorial Capacity

$$VC = \frac{ma^2bp^N}{-\log(p)}$$

variable	definition
m	Mosquito:vertebrate density
a	Man biting rate of mosquito (alternatively, contact rate)
b	Vector competence (% mosquitoes that will become infectious)
p	Mosquito mortality (average lifespan)
N	EIP (time it takes for virus to be transmitted by a mosquito)

Figure 5: Vectorial Capacity (VC) equation and variable definitions.

Potentially, An Increased Risk of Transmission

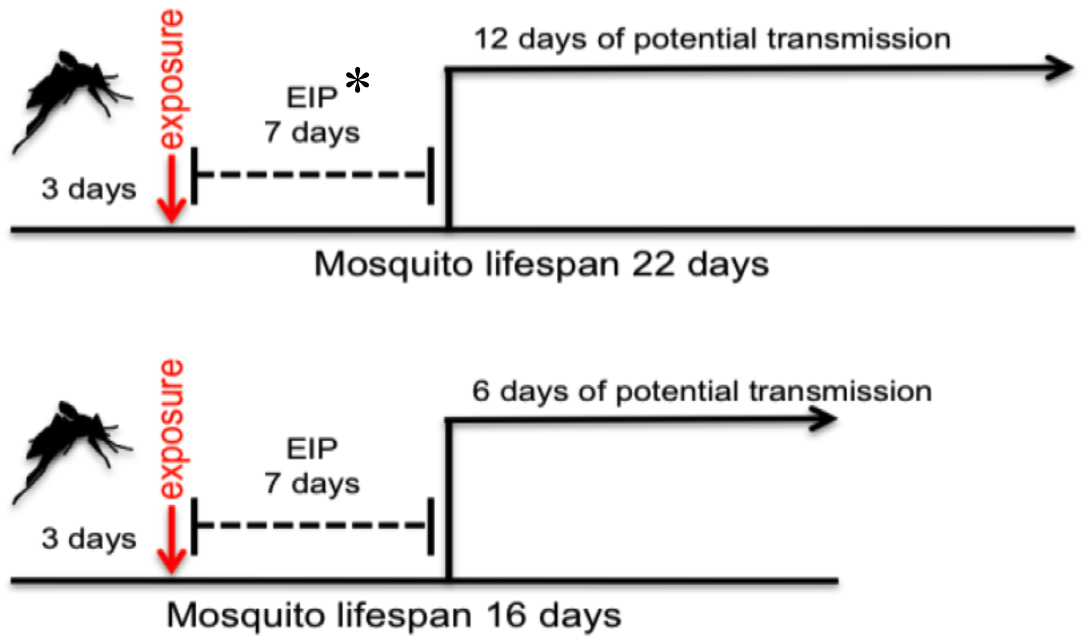
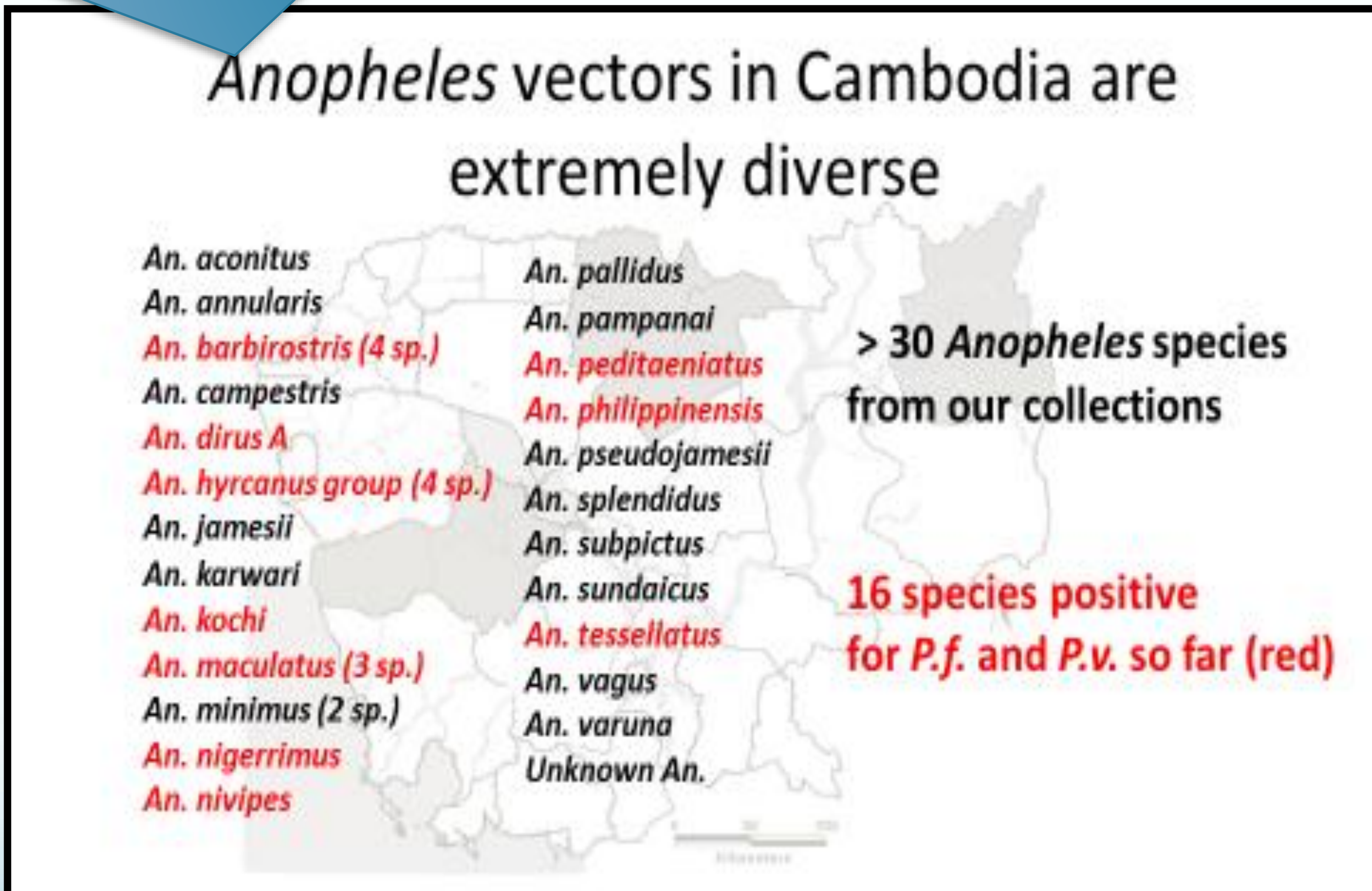


Figure 8 (from Christofferson & Mores 2016): Schematic demonstrating the impact of mosquito mortality on the cumulative transmission potential of an arbovirus.

*Extrinsic Incubation Period (EIP). This process is known to be influenced by both intrinsic (such as viral strain and/or mosquito population) and extrinsic factors (such as temperature and humidity)

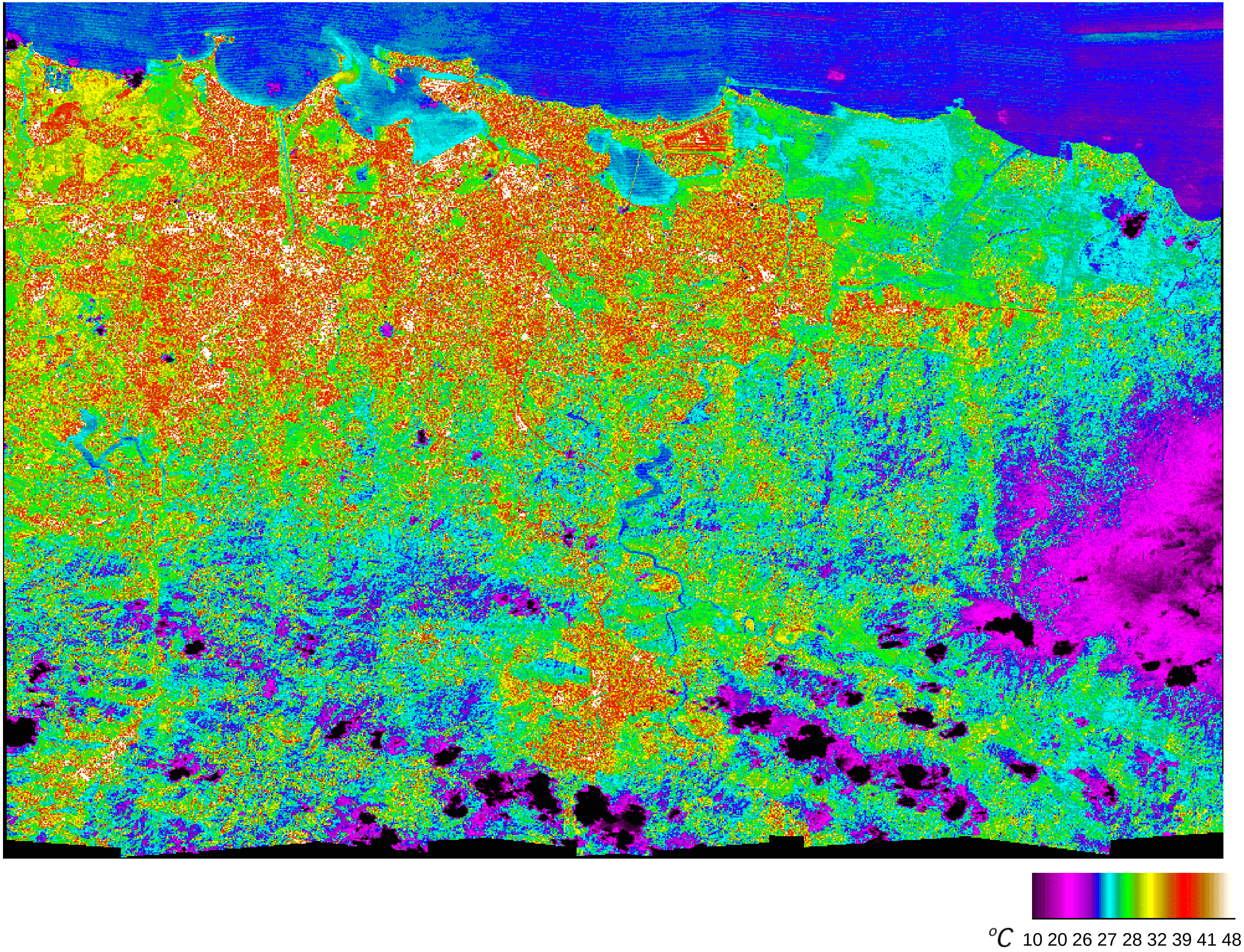
Plasmodium falciparum is a protozoan parasite, one of the species of Plasmodium that cause malaria in humans. (P. vivax was also present in Cambodia)



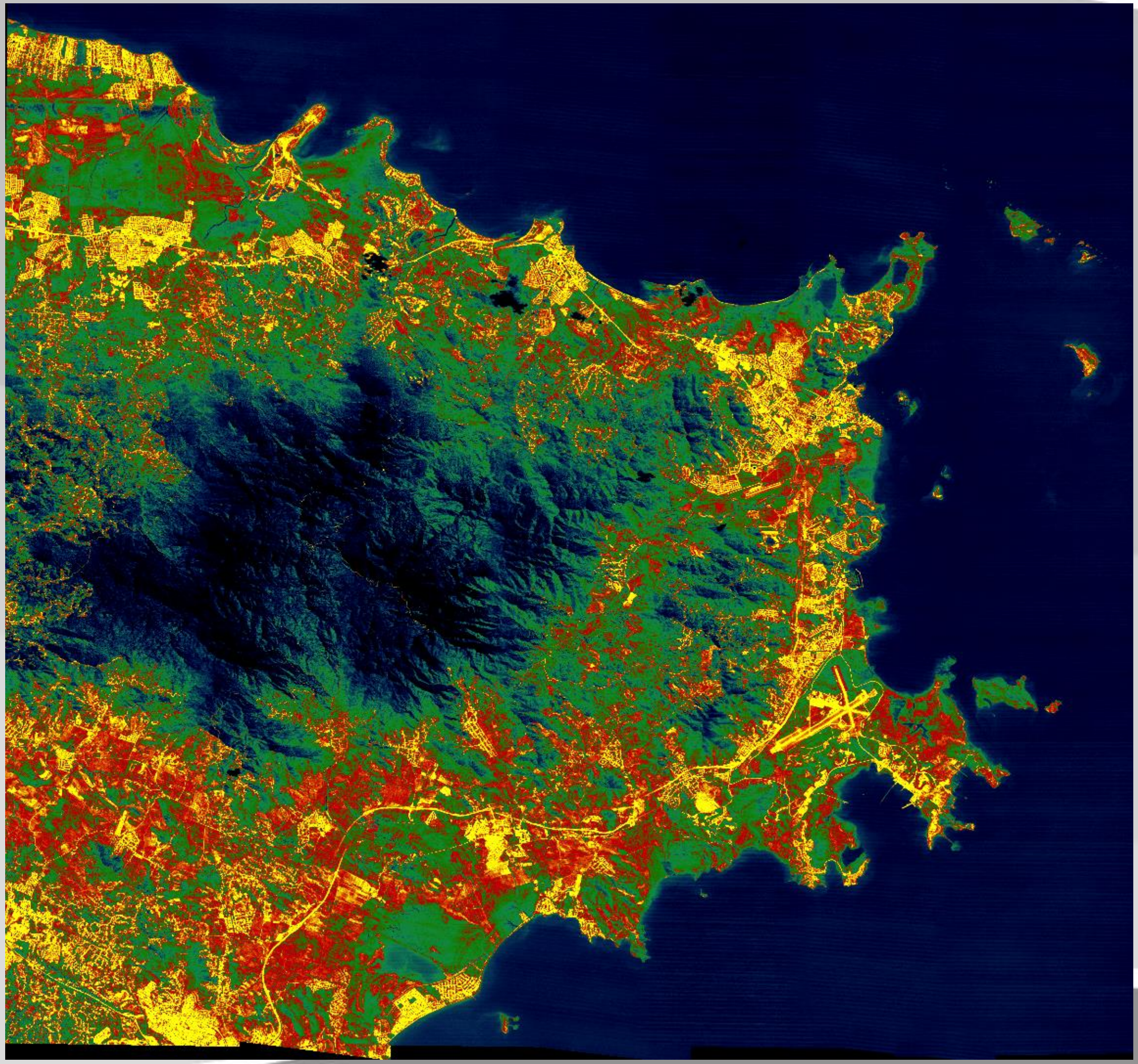
Robert J. Novak, PhD
University of South Florida
College of Public Health
Department of Global Health

Environmental Surveillance and Monitoring System

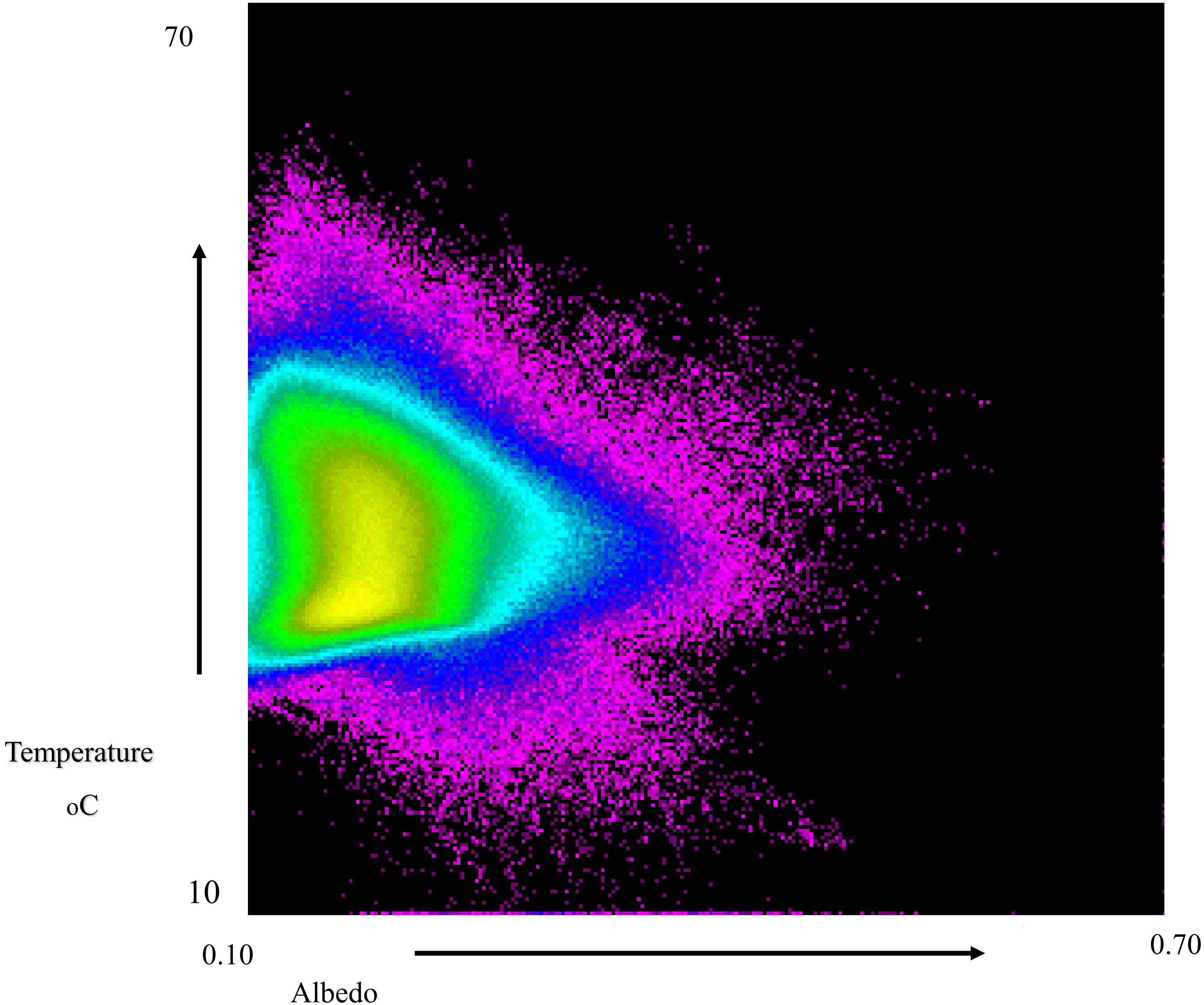
San Juan F5 Mosaic Temperature



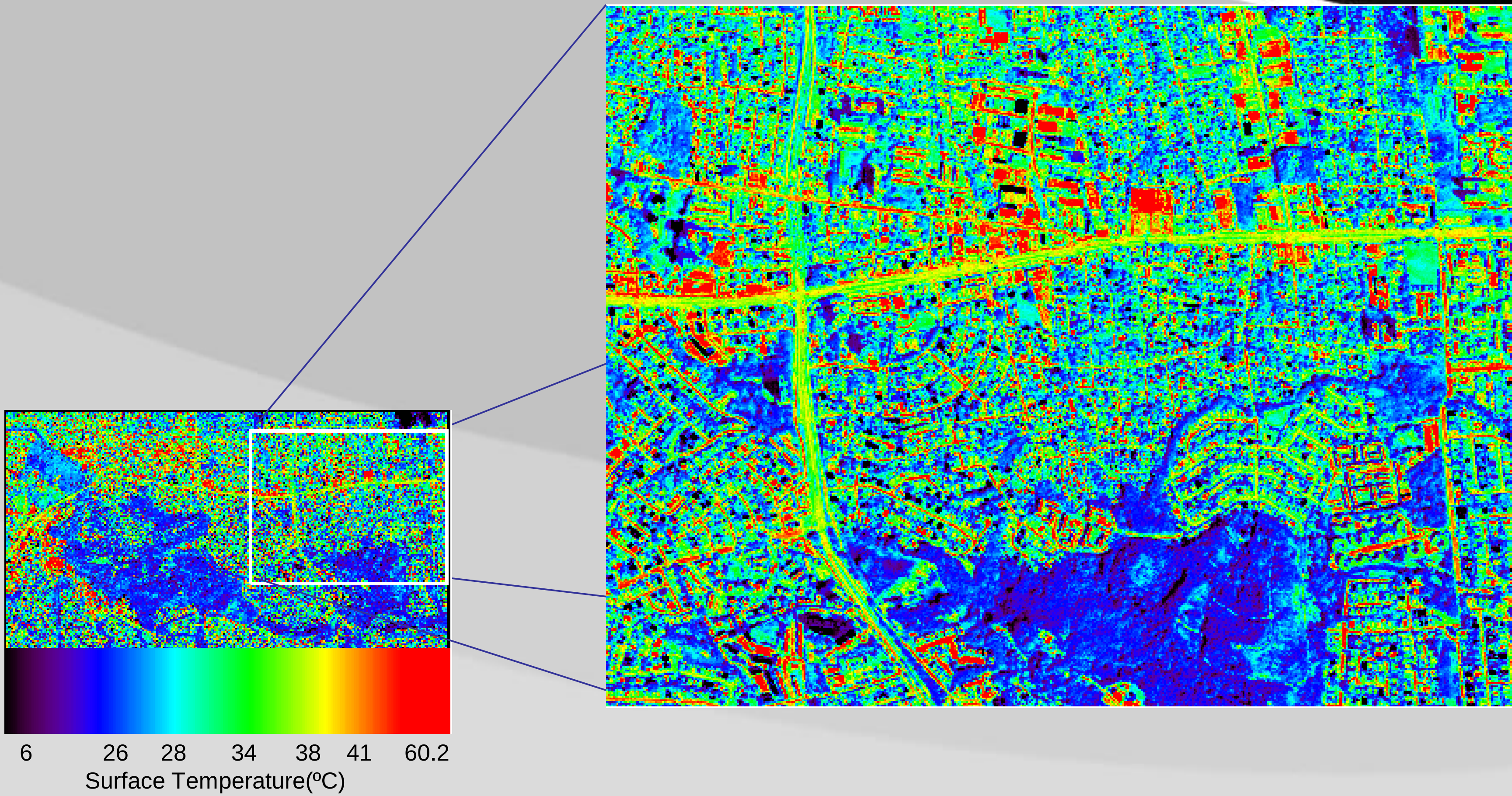
Puerto Rico 10 m ATLAS Thermal Data



San Juan Puerto Rico
Albedo vs Temperature

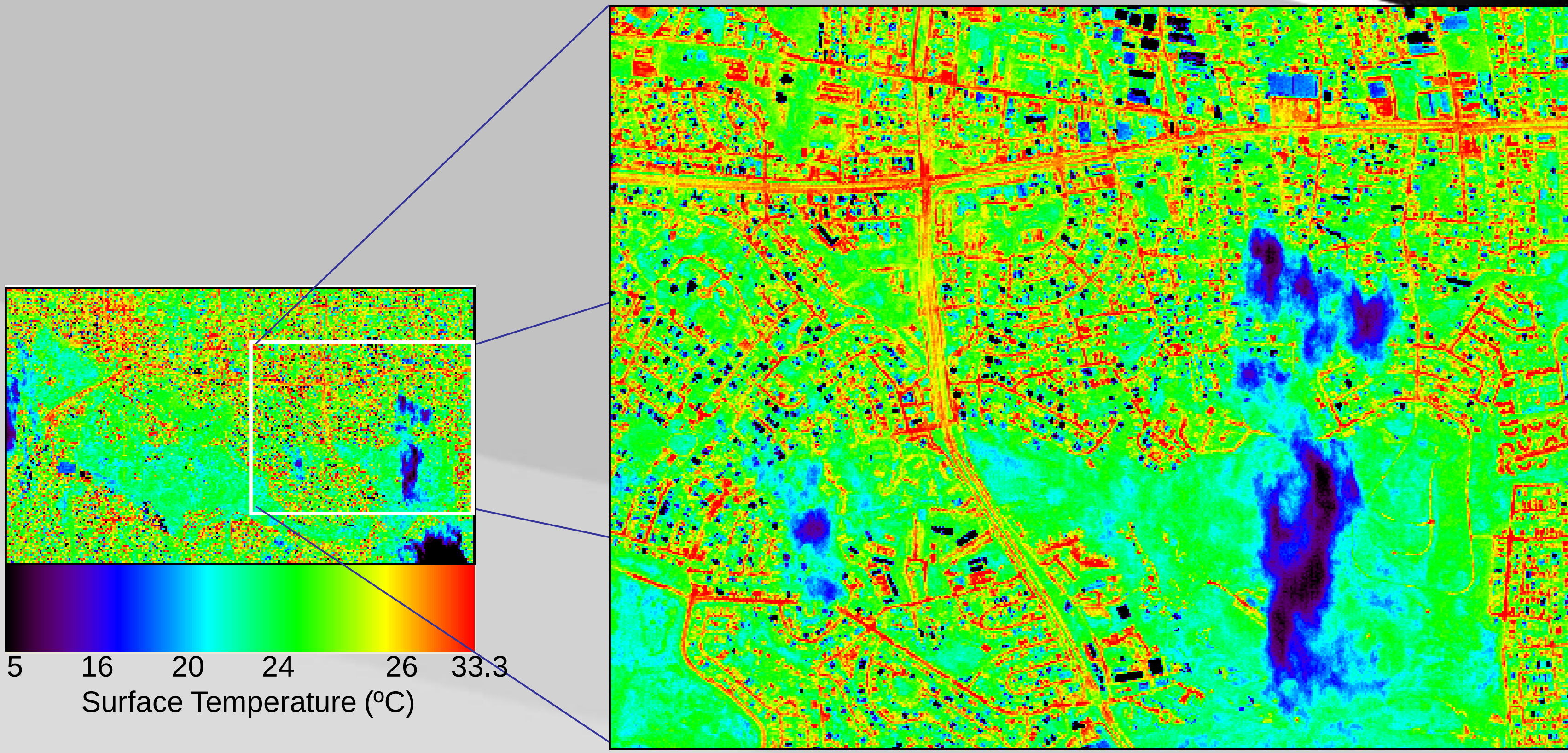


Surface Temperature Day: Flight 1 Line 23 Hato Rey



Luvall et al. 2004

Surface Temperature at Night: Flight 2 Line 23 Hato Rey



Luvall et al. 2004

Thermal Response Number

TRN = Q*/delta T

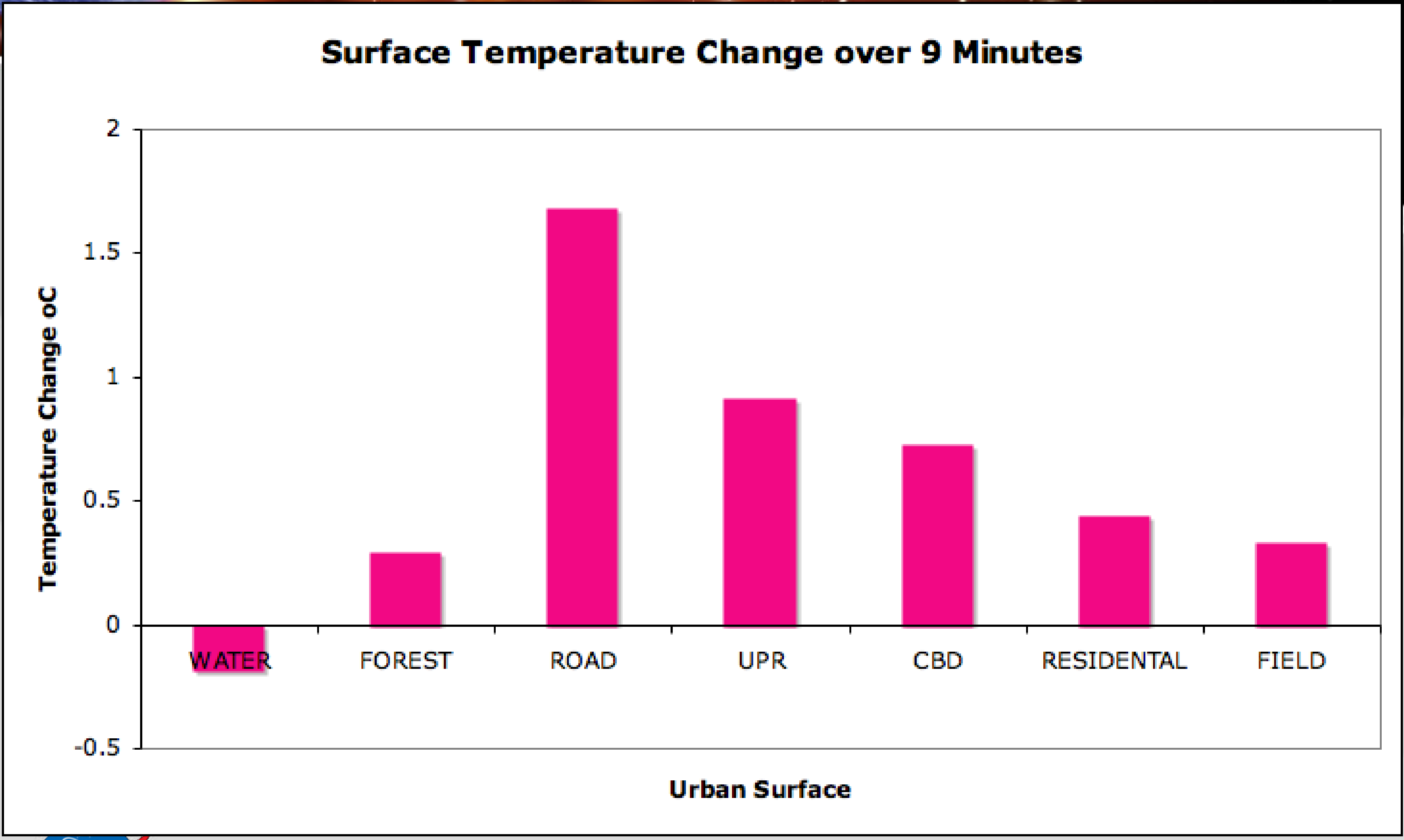
where:

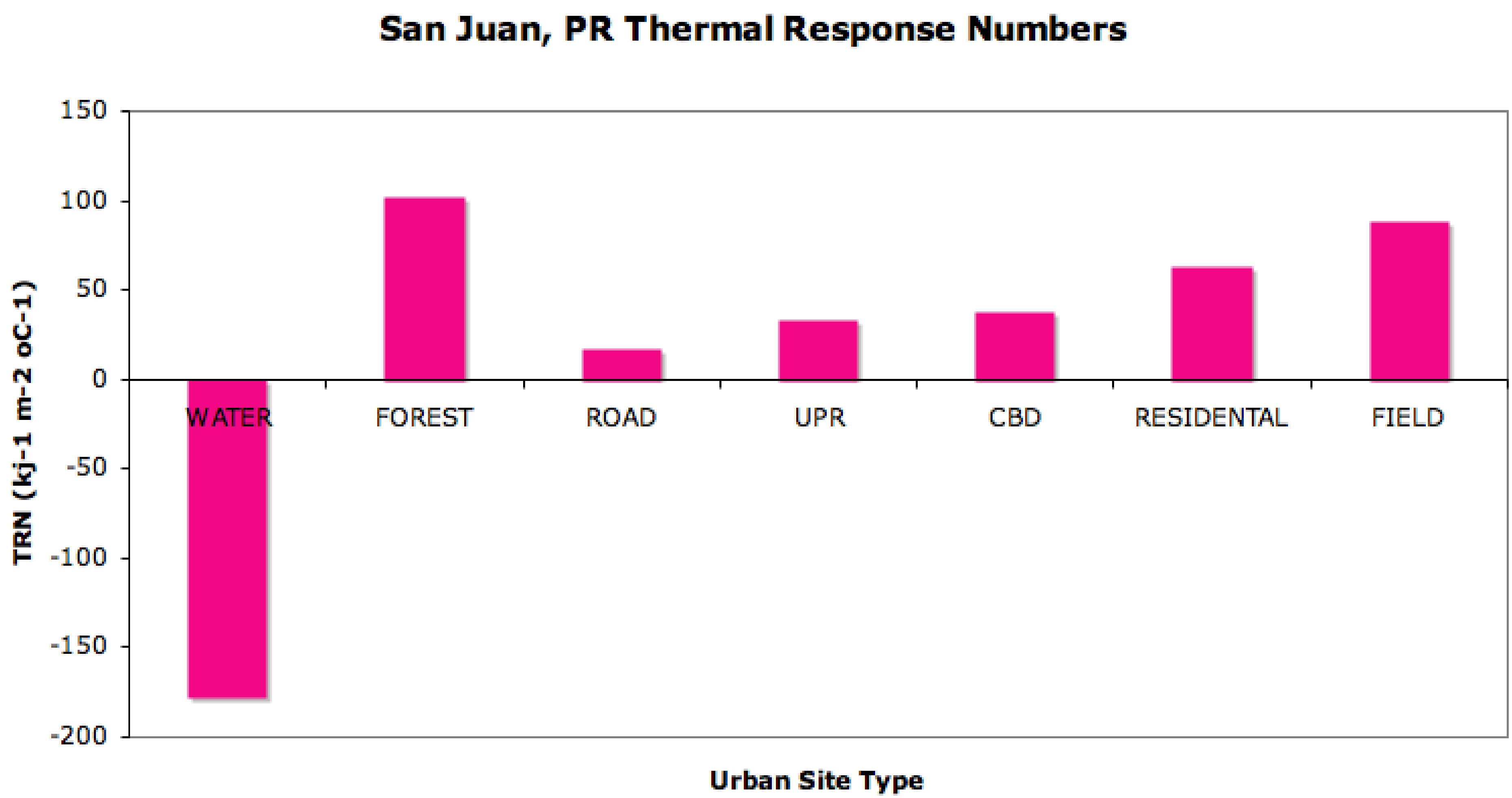
Q* = net radiation

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 Change over 9 Minutes
Temperature Change oC
2
1.5
1
0.5
0
-0.5
WATER
FOREST
ROAD
UPR
CBD
RESIDENTAL
FIELD
Urban Surface


San Juan, PR Thermal Response Numbers
150
100
50
0
-50
-100
-150
-200
TRN (kj-1 m-2 oC-1)
WATER
FOREST
ROAD
UPR
CBD
RESIDENTAL
FIELD
Urban Site Type

A High Spatio-temporal Resolution Land Surface Temperature (LST) Product for Urban Environments

Glynn Hulley[1], and Jeffrey Luvall[2],

Iphigenia Keramitsoglou[3], Panagiotis Sismanidis[3]

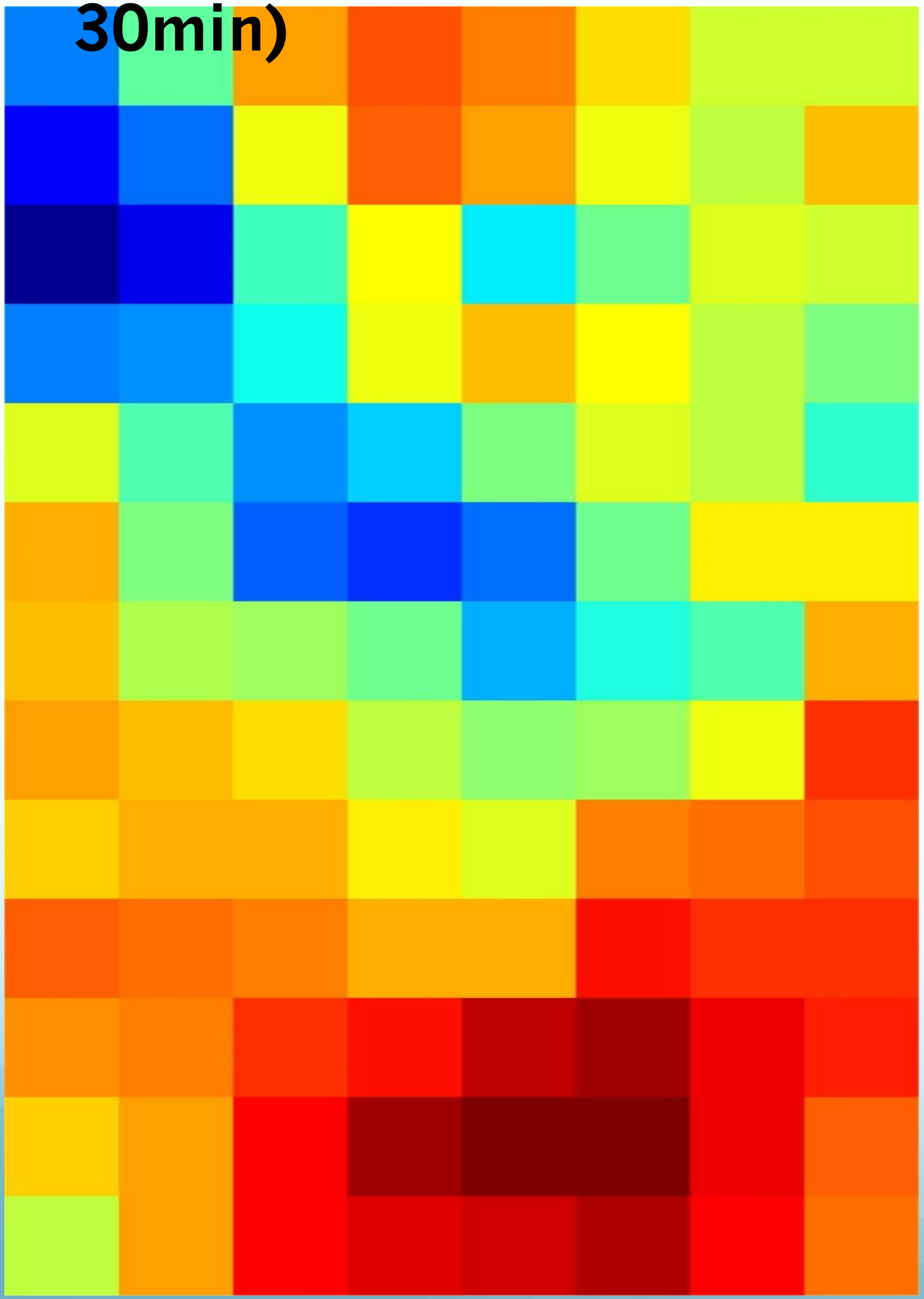
[1]Jet Propulsion Laboratory, California Institute of Technology

[2]NASA Marshall Space Flight Center

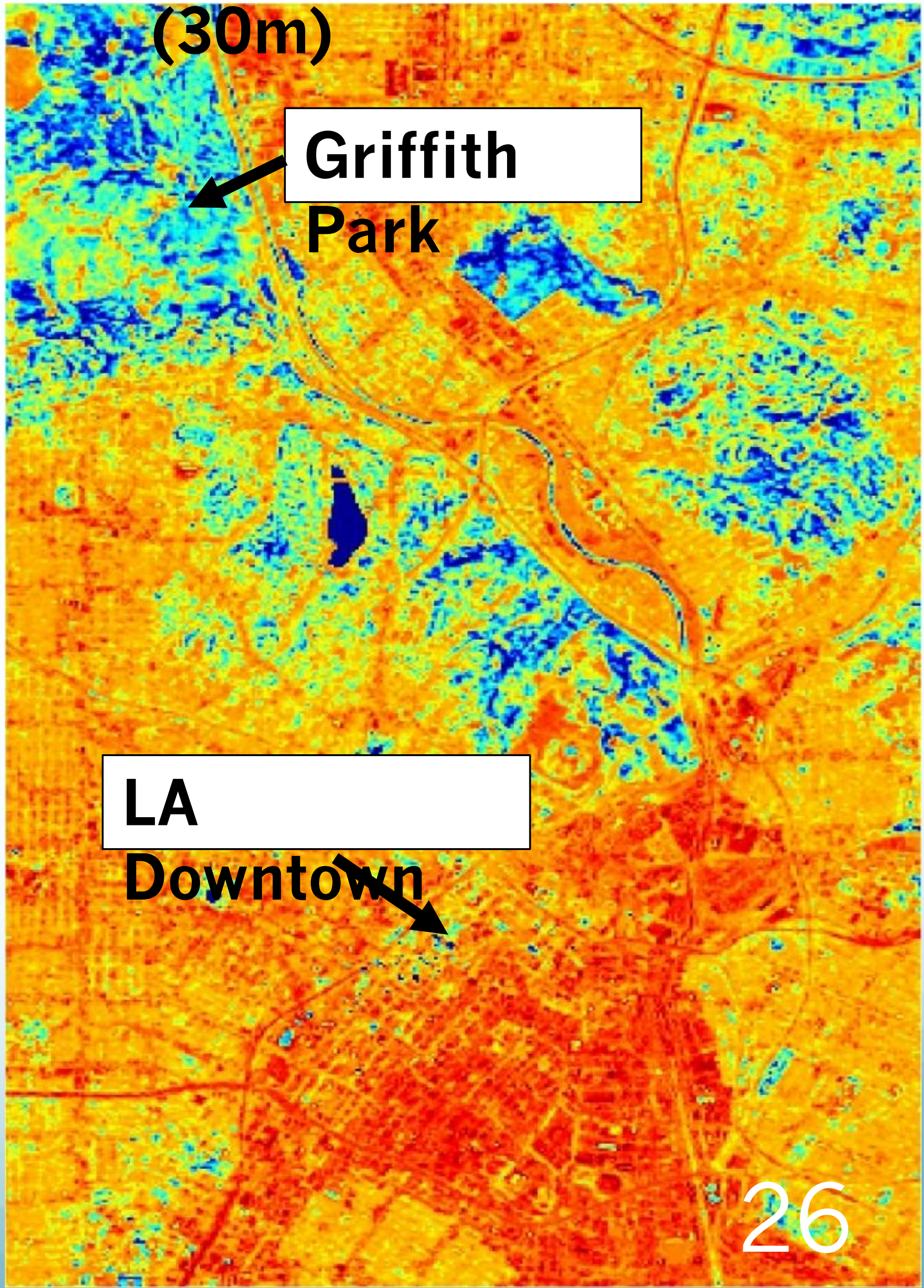
[3]National Observatory of Athens (NOA)

A.2 ROSES-2017 Land-Cover/Land-Use Change

GOES-MODIS LST (1 km, 30min)

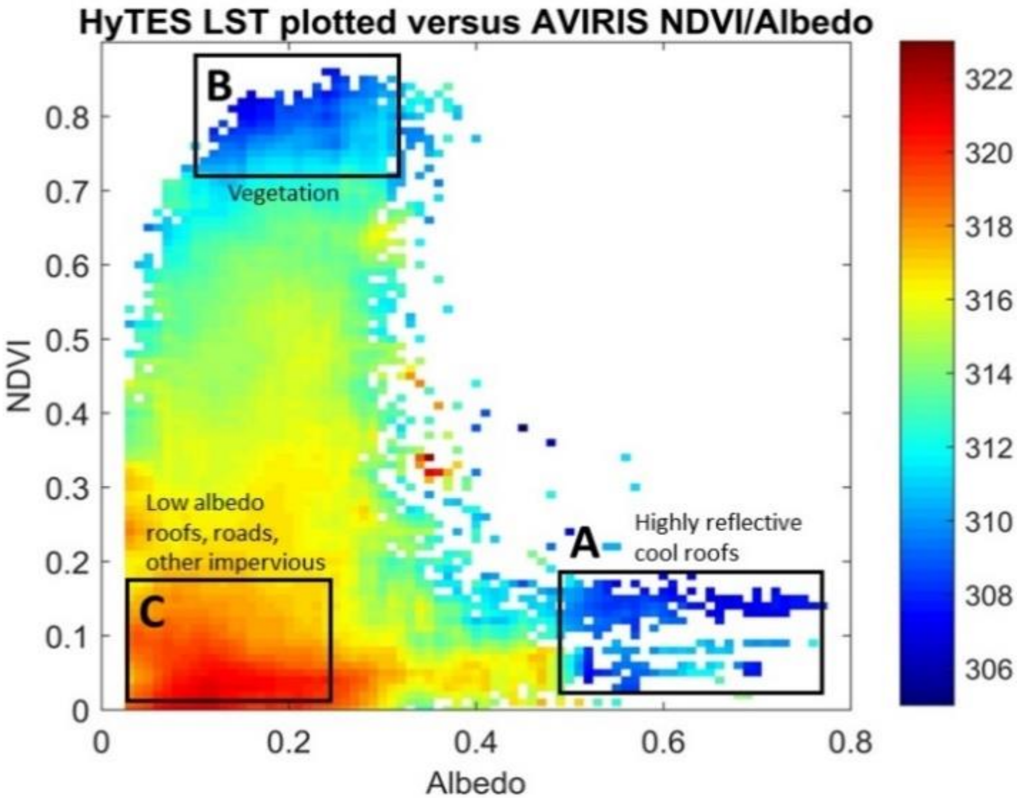


NASA-NOA Urban LST (30m)

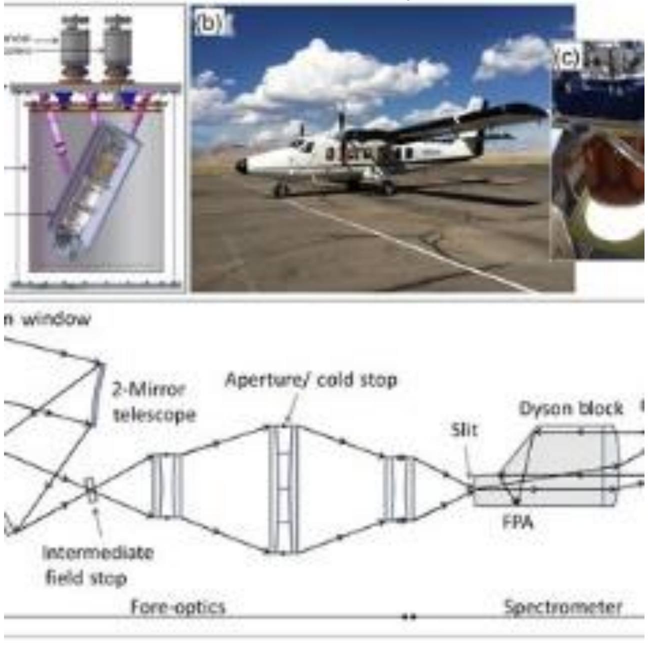


HUTS: High Resolution Urban Thermal Sharpener

Dominguez et al. 2011



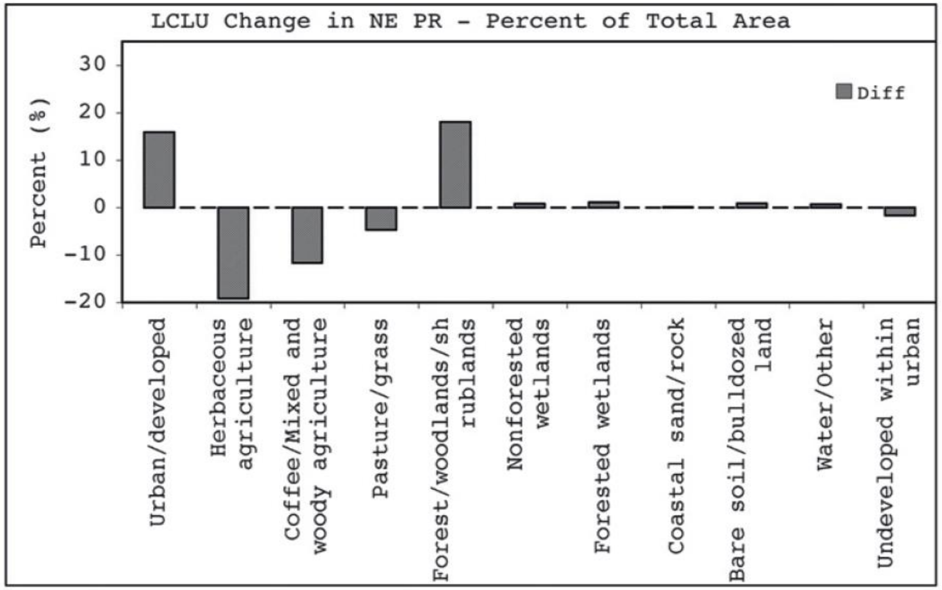
Airborne Thermal/VSWIR

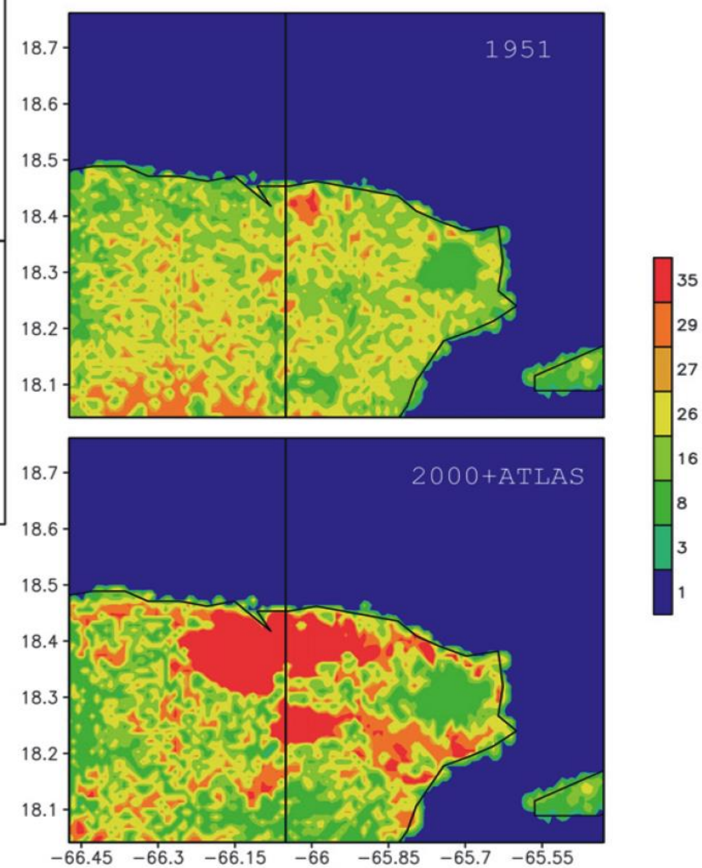


Hulley & Luvall A.2

$$LST_{sharp} = p_1 NDVI^4 + p_2 NDVI^3 \cdot \alpha + p_3 NDVI^2 \cdot \alpha^2 + p_4 NDVI \cdot \alpha^3 + p_5 \alpha^4 + p_6 NDVI^3 + p_7 NDVI^2 \cdot \alpha + p_8 NDVI \cdot \alpha^2 + p_9 \alpha^3 + p_{10} NDVI^2 + p_{11} NDVI \cdot \alpha + p_{12} \alpha^2 + p_{13} NDVI + p_{14} \alpha + p_{15} + \mathrm{dLST}$$

Normalization factor





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.

RESILIENT URBAN ENVIRONMENTS Grand Challenges

Urban Climate Modeling & Observation Grand Challenges

- Storm surges modeling and prediction
- Tropical and extra-tropical storms in cities
- Modeling and observations of urban flooding
- Modeling and observations of extreme heat events in cities
- Boundary layer and canopy layer urban heat islands
- Modeling and observation of surface energy and water balances
- Flows and dispersion in the urban canopy layer
- Modeling and observation of clouds-aerosol interactions in UBL flows
- Air quality/aerosols/radiative transfers in the urban boundary layer.

Knowledge Transfer & Applications Grand Challenges

- Climate change mitigation & adaptation in urban environments
- Bioclimatology and public health
- Urban design and planning with climate
- Design for resiliency
- Energy supply and demand in cities – the role of urban climates
- Eco-system services and urban environments
- Socio-economics aspects of urban climate.

Cyber-Informatics Grand Challenge

- Climate information services for cities
- Big data for urban climate studies
- Advance computational processes for high resolution weather and climate modeling
- Sensing challenges for complex urban environments
- Citizen driven sensing and informatics.

AMERICAN METEOROLOGICAL SOCIETY IAUC World Meteorological Organization NSF

WORKING GROUP GOALS

To leverage ICUC10 to conduct a comprehensive survey study and for exploring solution pathways to the grand challenges in representing resilient urban environments in terms of:

- physical processes
- modeling and observational strategies
- socio-economic impacts
- alternatives for resiliency, and public outreach.

NASA

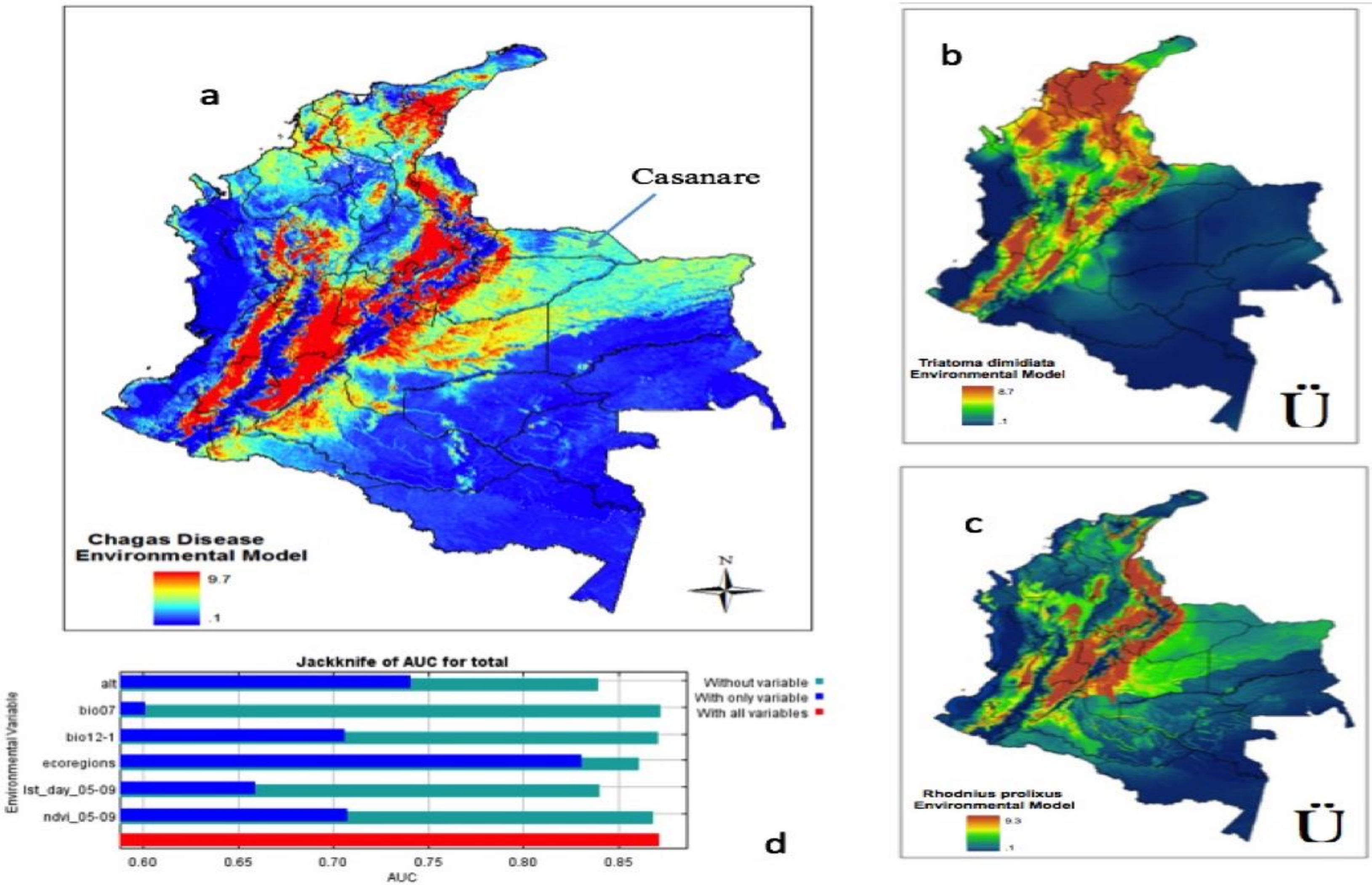
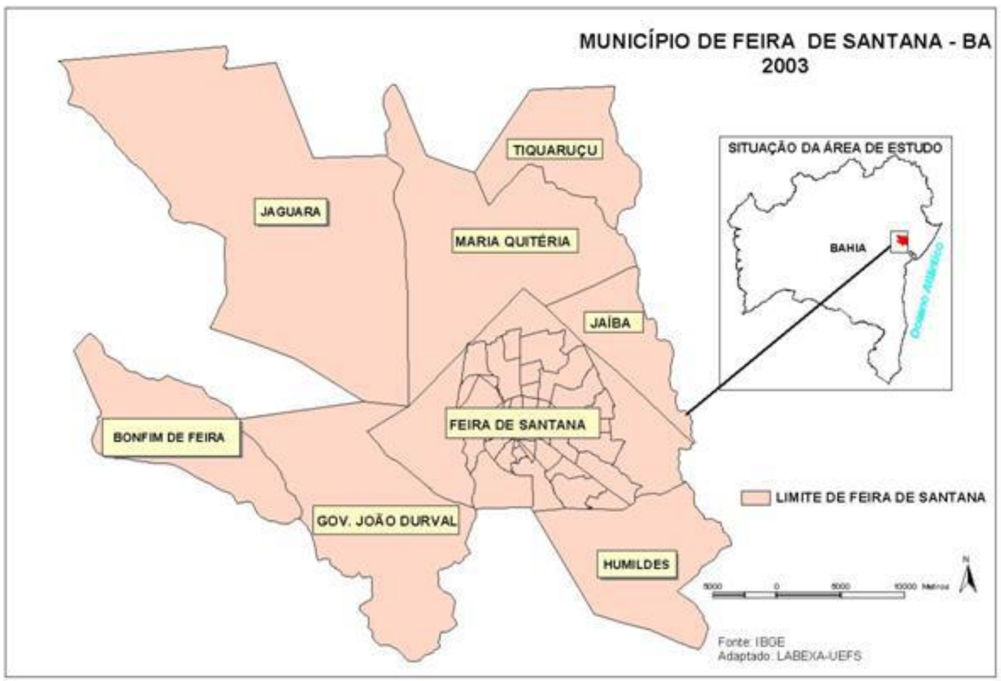


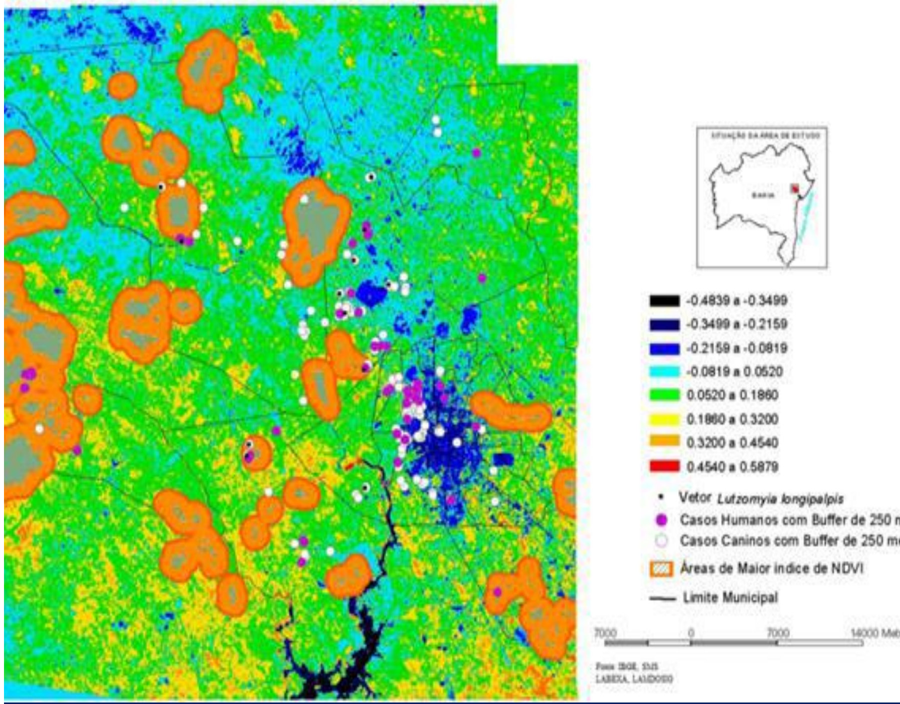
Figure 4. Maxent generated risk surfaces for Colombia generated from national scale data on Chagas disease (a) vector distribution (b, c). Note unique but overlapping geospatial ranges for Triatoma dimidiata and Rhodnius prolixus. Maxent generated Jackknife results (d) show the relative influence of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

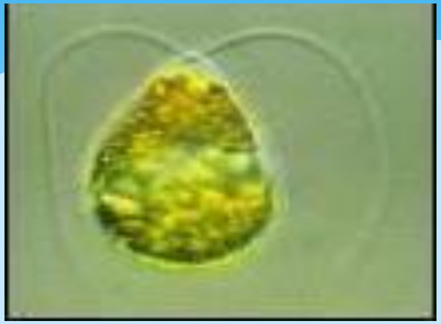
Feira de Santana **VL**

NDVI and visceral leishmaniasis cases, seropositives dogs, sand fly (*Lutzomyia longipalpis*) in Feira de Santana, Bahia, Brazil .





Spectral identification of phytoplankton from space

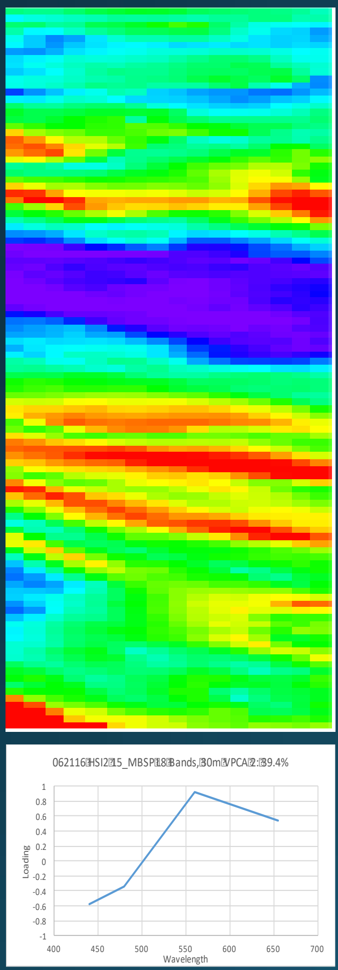


- Different types of phytoplankton and cyanobacteria have different pigments.
- Pigments have specific absorption and reflectance patterns
- Spectral shapes can be used to identify different algal and cyanophyte phyla
- Capitalizes on all information available in hyperspectral-resolution spectra
- But, must unmix reflectance spectra

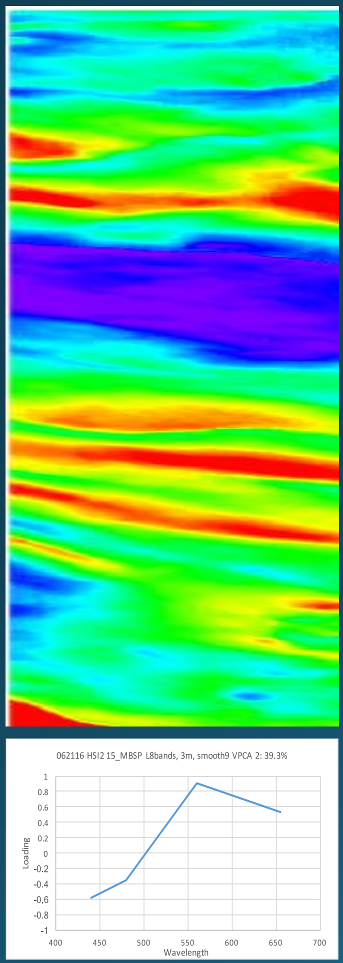
Graphics: Courtesy of NASA/GSFC.

Ortiz et al., (HyspIRI 2015)

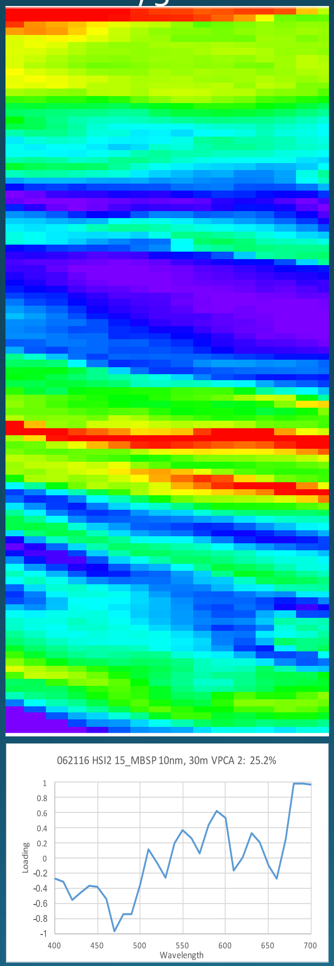
VPCA 2 Simulated L8 bands, 30m



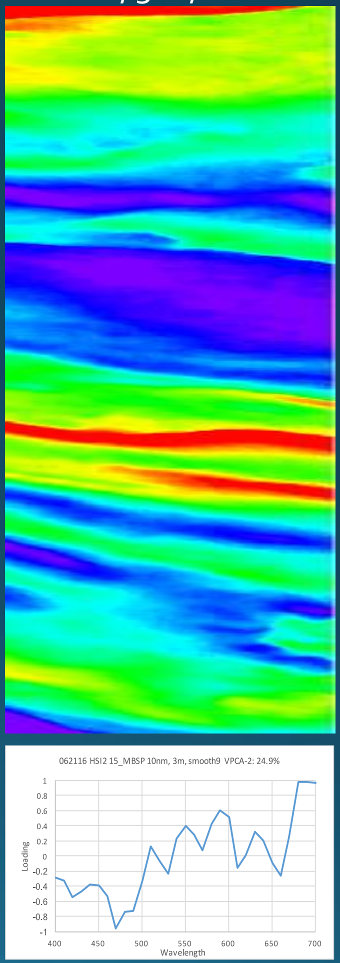
VPCA 2 Simulated L8 bands, 3m, Smooth 9x9



VPCA 2 HSI2 10nm, 30 m



VPCA 2 HSI2 10nm, 3 m,

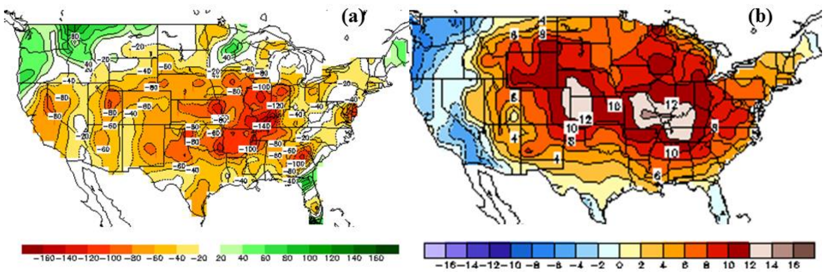


Composition: Haematite, Green algae, -α carotene and phycocyanin (R=0.90)

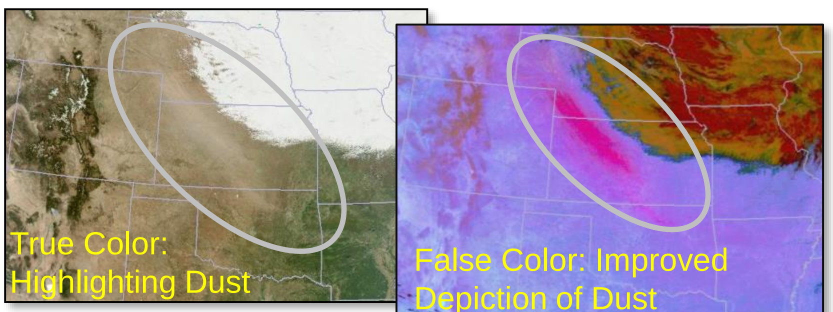
↑N

Ortiz et al., (HyspIRI 2017; jortiz@kent.edu)

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.

pagepress

Geospatial Health

Health Applications in Geospatial Science

Università degli Studi di Napoli Federico II

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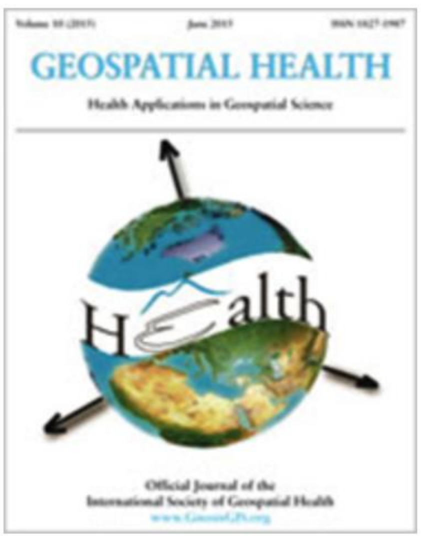


Geospatial Health is the official journal of the International Society of Geospatial Health (www.GnosisGIS.org).

The journal was founded in 2006 at the University of Naples Federico II by Giuseppe Cringoli, John B. Malone, Robert Bergquist and Laura Rinaldi. The focus of the journal is on all aspects of the application of geographical information systems, remote sensing, global positioning systems, spatial statistics and other geospatial tools in human and veterinary health. The journal publishes two issues per year.

Announcements

https://geospatialhealth.net/index.php/gh/index

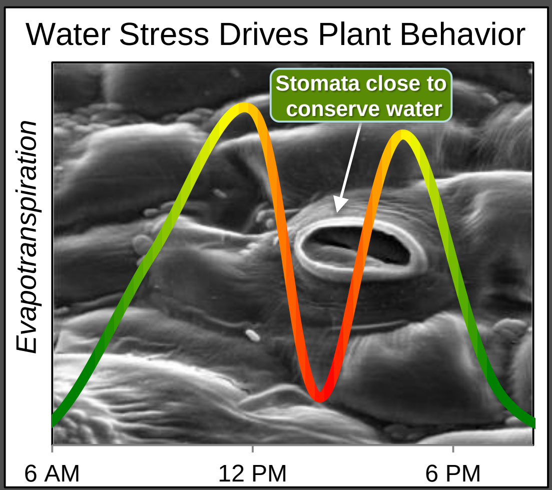
ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

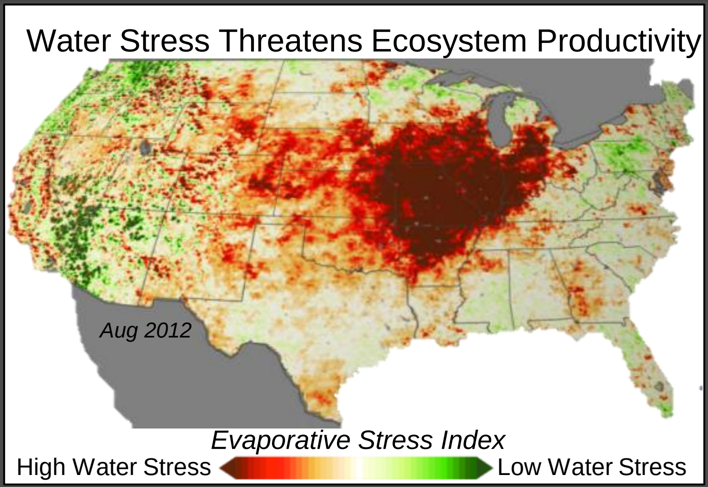
Dr. Simon J. Hook, JPL, Principal Investigator

Science Objectives

- Identify **critical thresholds of water use and water stress** in key climate-sensitive biomes
- Detect the timing, location, and predictive factors leading to plant **water uptake decline** and/or cessation over the **diurnal cycle**
- Measure **agricultural water consumptive use** over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy



When stomata close, CO_2 uptake and evapotranspiration are halted and plants risk starvation, overheating and death.



Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

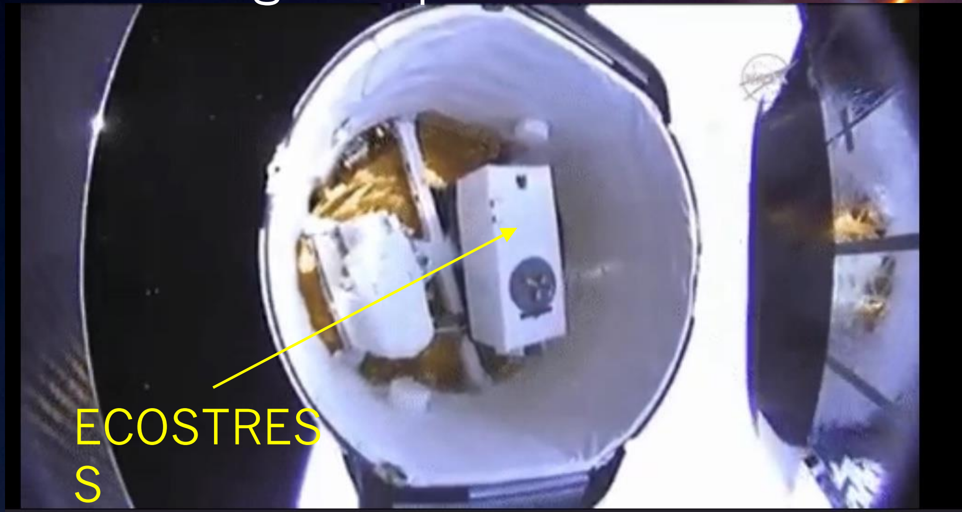
*ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration from the International Space Station (ISS).*

ECOSTRESS launch
06/29/2018
Space-X Falcon 9
Cape Canaveral, Florida, USA

Quick Facts:

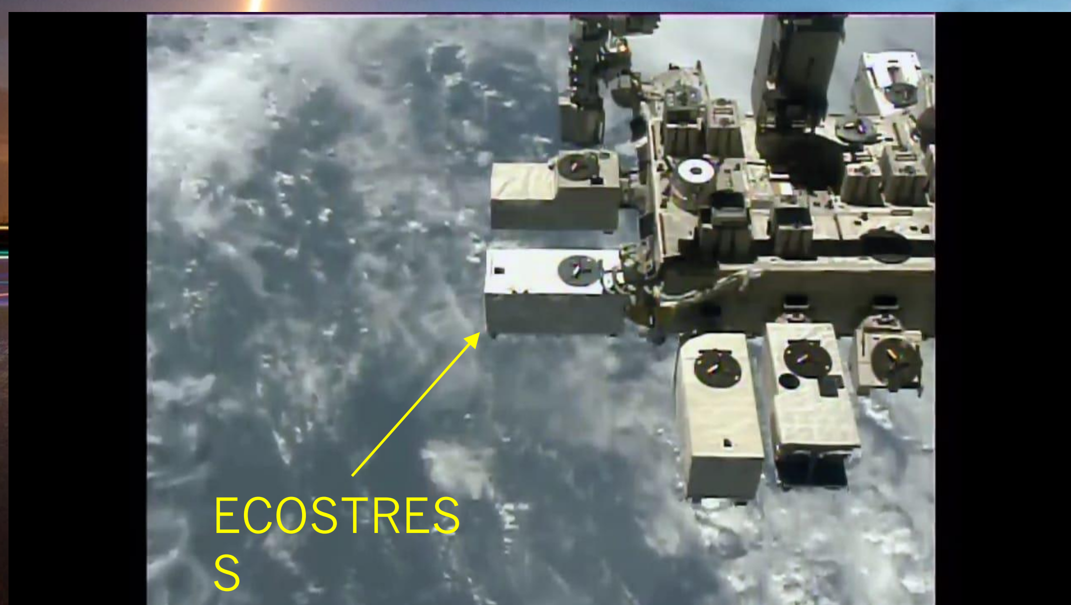
- Selected in NASA EVI-2 (2014), Class-D $30M
- Nominal mission lifetime 1 year + 30 day checkout
- Targeted acquisitions: CONUS Cal/Val targets, global cities

Dragon separation 06/29/2018



Dragon capture 07/02/2018

Installation on JEM-EF:

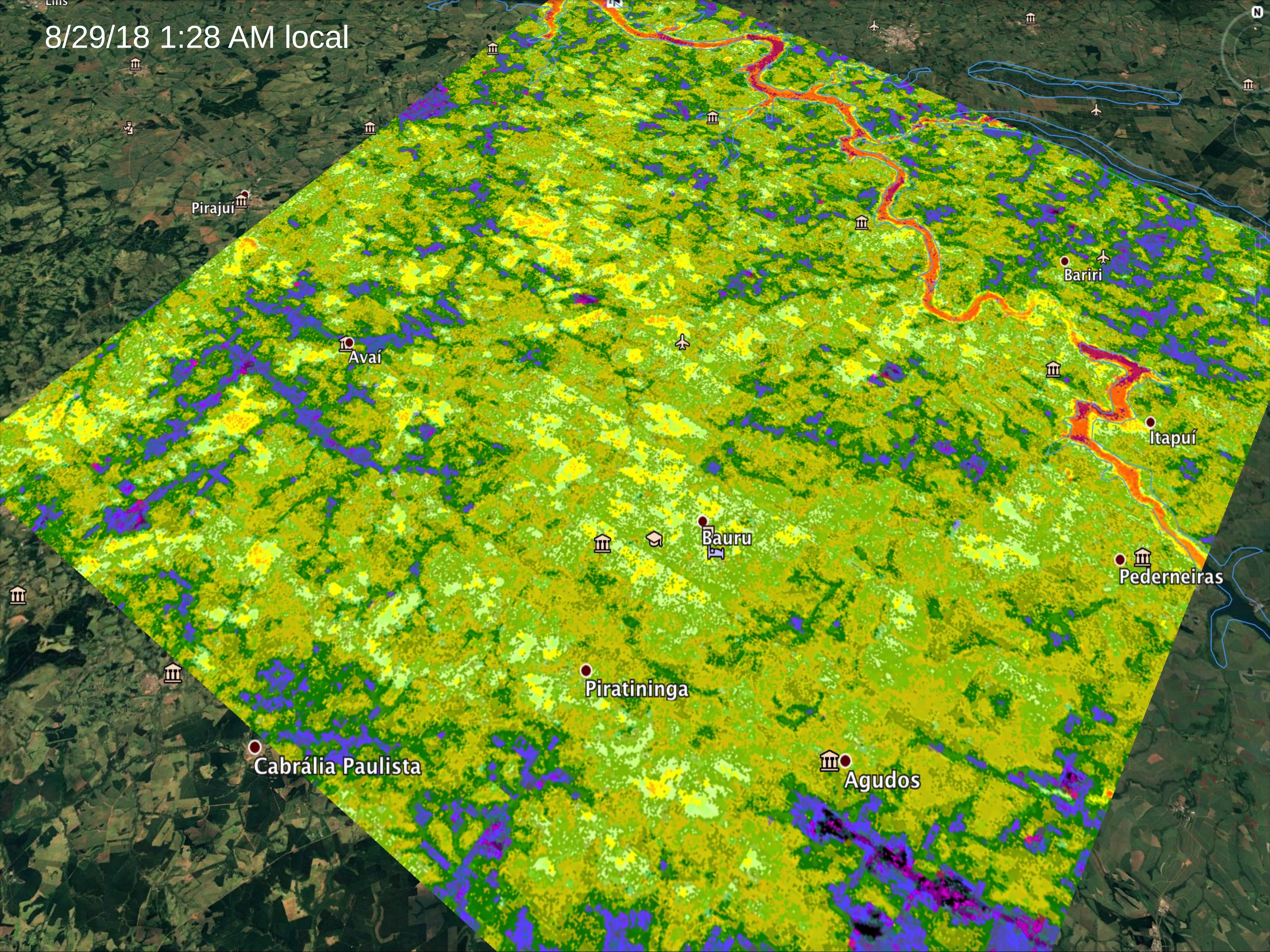


ECOSTRESS Science Data Products

Data Product	Description	Initial Availability to NASA DAAC	Median Latency in Product Availability to NASA DAAC after Initial Delivery	NASA DAAC Location
Level 0	Raw collected telemetry	6 months after IOC	12 weeks	LP DAAC
Level 1	Calibrated Geolocated Radiances	6 months after IOC	12 weeks	LP DAAC
Level 2	Surface temperature and emissivity	6 months after Level 1 data products are available	12 weeks	LP DAAC
Level 3	Evapotranspiration	2 months after Level 2 data products are available	12 weeks	LP DAAC
Level 4	Water use efficiency and evaporative stress index	2 months after Level 3 data products are available	12 weeks	LP DAAC

The Land Processes Distributed Active Archive Center (*LP DAAC*) was assigned for ECOSTRESS since KDP-B.

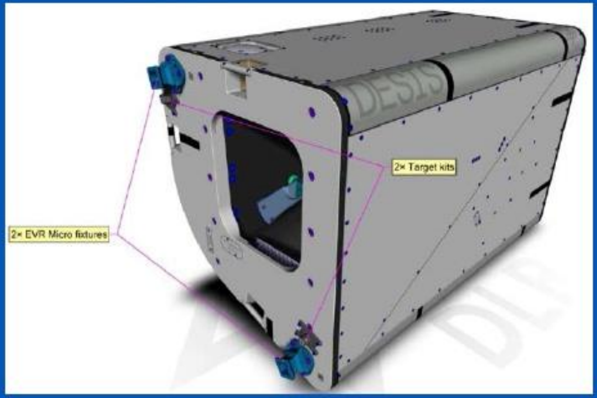

Promissão
Lins
Matão
Pirajuí
Avaí
Garça
Itapuí
Jaú
Bauru
Pederneiras
Piratininga
Lucianópolis
Cabrália Paulista
Agudos
Macatuba



8/29/18 1:28 AM local
Pirajuí
Avaí
Bariri
Itapuí
Bauru
Pederneiras
Piratininga
Cabrália Paulista
Agudos

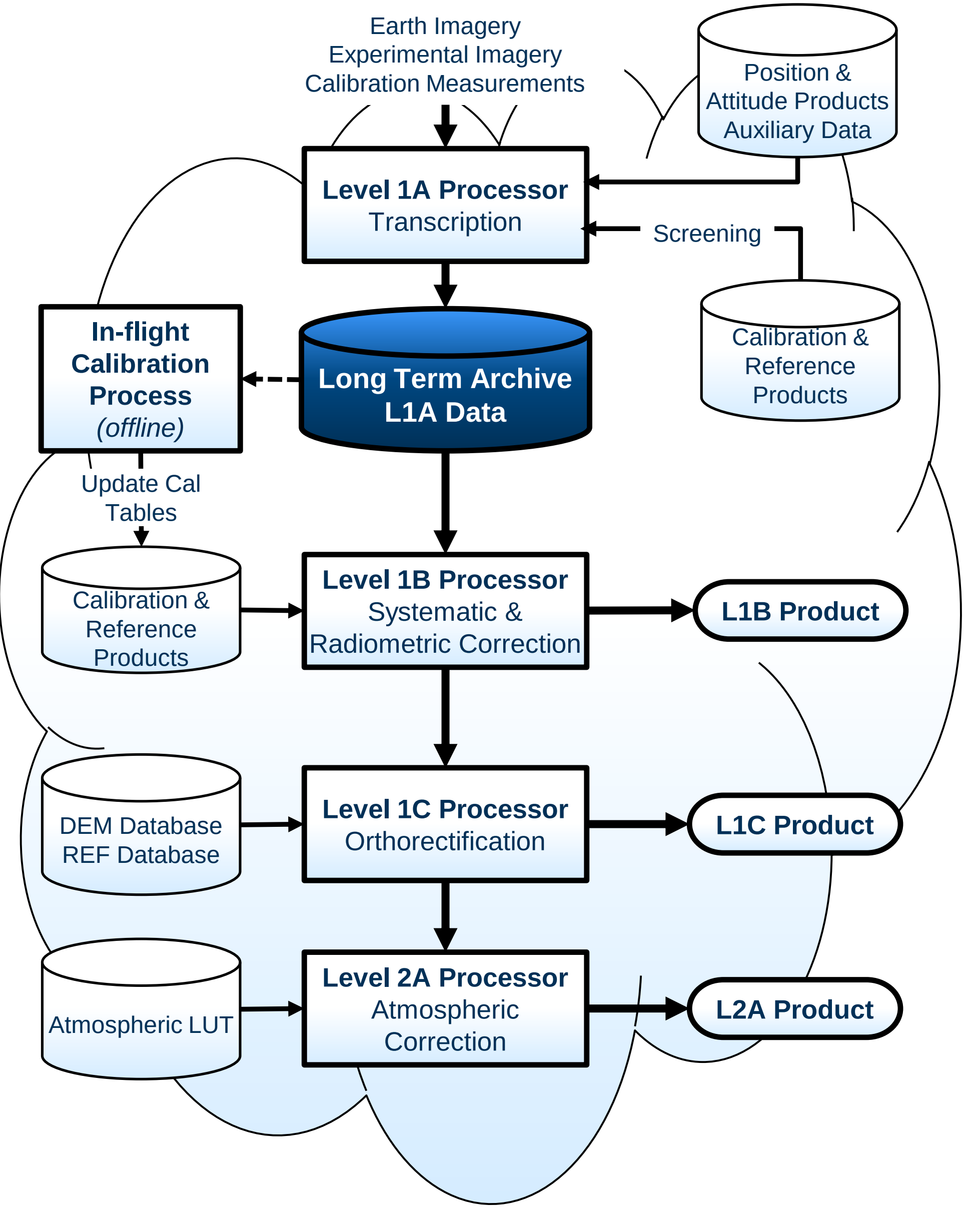
Hyperspectral Data from LEO

- Teledyne and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (DESIS) from the Teledyne-owned MUSES Platform on the ISS
- DESIS Provides:
  - 30 m GSD, 30 km swath
  - 235 contiguous bands of 2.55 nm
  - Senses from 400 nm to 1000 nm
- Commercially available in Q2, 2018 through Teledyne's Earth Sensor Portal



Ray Perkins, Teledyne Geospatial Solutions
17 October, 2017 NSSTC presentation

Products and Processing Chain



L0 Internal Product
Raw data w/supplemental information

L1A Internal Product / Archive
Level 0 data w/ radiometric, spectral and geometric data appended but not applied

L1B* Delivered Product
Radiometrically calibrated, spectrally and geometrically characterized.
Top of Atmosphere Radiance

L1C* Delivered Product
L1B data orthorectified and resampled
Direct georeferencing using DEM
Map projection.

L2A* Delivered Product
Earth located pixel values converted to ground surface reflectance

* Products available for customer delivery

DLR Earth Sensing Imaging Spectrometer(DESIS)

"First Look" by DLR - Huntsville, AL Sept. 4, 2018

- Processed level 1C (georeferenced and resampled to UTM grid using bilinear interpolation).
- Accuracy <one pixel size w.r.t.
- B 463nm G 553nm R 639nm
- Full Width Half Maximum (FWHM) of ~ 3.5 nm for all bands.

Image supplied by:
Jack Ickes, Senior Vice President, Teledyne Brown Engineering
Jack.Ickes@teledyne.com

Global Ecosystem Dynamics Investigation Lidar (GEDI) (~2018)

The GEDI instrument is a geodetic-class, light detection and ranging (lidar) laser system comprised of 3 lasers that produce 10 parallel tracks of observations.

Forest height and vertical structure; habitat quality & biodiversity; Forest carbon sinks & source areas; loss of carbon from extreme events such as fires and hurricanes; parameterization of ecosystem models	Forest Management & Carbon Cycling
Canopy 3D structure that influences snowmelt, evapotranspiration, canopy interception of precipitation. Glacier surface elevation change; lake & river stage; snowpack elevation; coastal tides.	Water Resources
Improved canopy aerodynamic profiles to parameterize weather prediction models. Canopy and biomass products that initialize and constrain climate models; impacts of land use change on climate	Weather Prediction
Accurate bare earth and under canopy topographic elevations for improved digital elevation models from radar. Calibration of satellite based observations of surface deformation and earthquakes	Topography & Surface Deformation

~~HyspIRI Science and Applications~~

Surface Biology and Geology (SBG)

Key Science and Science Applications

Climate: Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/Ice; biomass burning; evapotranspiration.

Ecosystems: Global plant functional-type, physiological condition, and biochemistry including agricultural lands.

Fires: Fuel status, fire occurrence, severity, emissions, and patterns of recovery globally.

Coral reef and coastal habitats: Global composition and status.

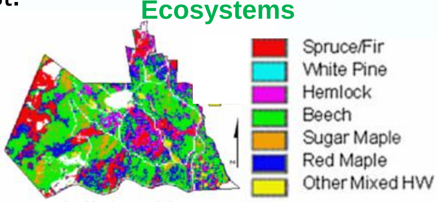
Volcanoes: Eruptions, emissions, regional and global impact.

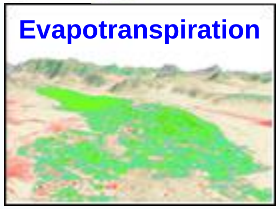
Natural and resources: Global distributions of surface mineral resources and improved understanding of geology and related hazards.

Societal Factors: Urban environment, habitability and resources.

Mission Urgency

The HyspIRI science and application objectives are important today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.



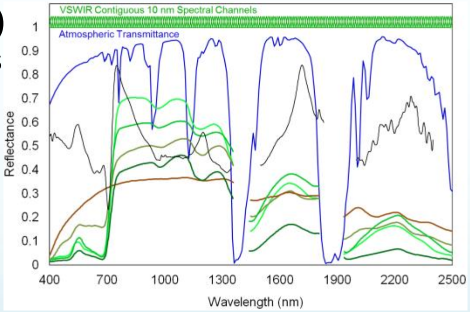


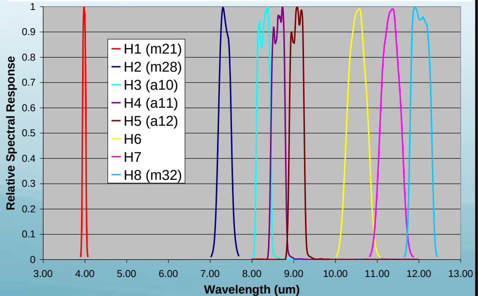
Measurement

Imaging Spectrometer (VSWIR)
- 380 to 2510 nm in 10nm bands
- 30 m spatial sampling
- 16 days revisit
- Global land and shallow water

Thermal Infrared (TIR):
- 8 bands between 4-12 μm
- 60 m spatial sampling
- 5 days revisit
- Global land and shallow water

IPM-Direct Broadcast





Workshop Objectives

Interact with broad science and applications research community

Review science inputs to the Decadal Survey

Review HyspIRI Mission Concept efforts in 2017

Discuss ECOSTRESS TIR mission headed to the ISS

Present new relevant Science and Applications Research

Review results from the U.S. HyspIRI preparatory airborne campaigns

Review AVIRIS-NG VSWIR Asian Environments campaign in India

Support current Decadal Survey process

Information and Registration at: http://hyspiri.jpl.nasa.gov

ISS

- ✓ ECOSTRESS
- ✓ DESIS
- ➢ GEDI
- ➢ (EMIT & HISUI)

Airborne data

(aircraft & UAV)

Hyperion

11/21/2000 to 2/22/2017

Satellite

Big Data and Deep Learning + Intelligent Payload Module (IPM)= ???

Applications Policy

NASA HEADQUARTERS
SCIENCE MISSION DIRECTORATE (SMD)

EARTH SCIENCE DIVISION

DIRECTIVE ON PROJECT
APPLICATIONS PROGRAM

Approved by:

Michael Freilich
Director, Earth Science Division
Science Mission Directorate, NASA Headquarters

29 June 2016
Date

4.1 Pre-Phase A

Purpose: To enhance overall science objectives and societal benefits from the project's data, and establish characterization of the Communities of Practice and Potential. Initiate a team for the integration and inclusion of applications in the project concept review, and for articulation at the Key Decision Point for Phase A (KDP-A).

Focus: To determine and clarify the applications dimension of the overall project concept and initiation to amass the applications communities (Community of Potential and Community of Practice).

Implementation Activities: Perform assessments to determine what results techniques and products are useful to the applications community, as a result of associated research. A strong characterization of the Communities of Practice and Potential will enhance overall science objectives and societal benefits from the project's data. Produce a Community Assessment and Report.

Guidance: There are a number of people and organizations that may supply information or capabilities such as the Project Manager, the Project Scientists, the Science Team lead, the Project Science Data Systems Representative, the NASA Distributed Active Archive Centers (DAAC), and the Project Applications Coordinator (PAC). Additionally, it is expected that the Program Executive (PE), the Program Scientist (PS) and the Program Applications (PA) lead will be engaged in supporting the project's applications activities.

Space Policy 29 (2013) 76–82

Contents lists available at SciVerse ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Policy for robust space-based earth science, technology and applications

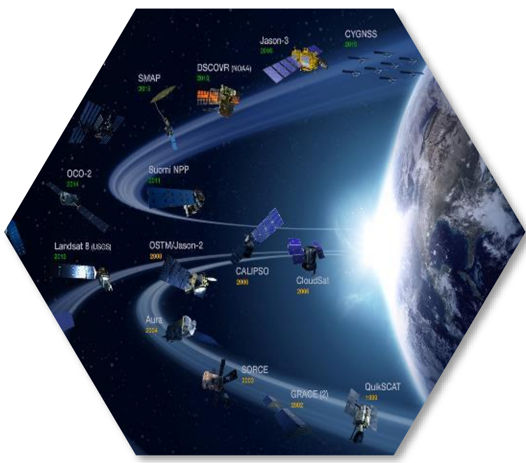
Molly E. Brown[a,*], Vanessa M. Escobar[b], Josef Aschbacher[c], Maria Pilar Milagro-Pérez[d], Bradley Doorn[e], Molly K. Macauley[f], Lawrence Friedl[g]

APPENDIX A: PROJECT PRODUCTS BY DEVELOPMENT PHASE

NASA Earth Science Division Guidelines for a Project Applications Program					
	Pre-Phase A	**Phase A**	**Phase B**	**Phases C & D**	**Phase E**
Project Life Cycle Phases	Concept Studies	Concept and Technology Development	Preliminary Design and Technology Completion	Final Design, Fabrication, System Assembly, Test and Launch	Operations and Sustainment
Purpose	Scope the applications portion of the mission concept	Articulate the applications plan for the mission	Implement the plan and build the applications user base	Engage Communities, articulate key applications benefits, support applications readiness and receive feedback	Realize and communicate the applications and societal benefits
Activities	Conduct Mission Studies	Generate a Project Applications Plan	Launch an EA Program	Conduct periodic EA meetings, Hold EA workshops and benchmark meeting	Conduct periodic EA meetings
	Characterize the applications value of the mission	Articulate audiences and implementation activities	Conduct workshops to inform communities about the mission	Receive feedback from EAs	Communicate societal benefits of the mission
	Identify and characterize applications communities	Develop the Applications Traceability Matrix (ATM) to inform the Science Traceability Matrix (STM)	Build awareness and receive input and feedback	Build awareness and encourage applications ideas and readiness	Conduct socioeconomic analysis of select EAs and conduct impact workshops
	Support MCR and design trade-offs	Conduct workshops to inform and build user community	Inform remaining design elements	Identify and maintain key applications for mission communications and outreach	Inform the Community of Practice of the status of the mission, data products, reprocessing, Science Team meetings and other items
	Consult with other projects to scope approaches to applications	Gather input and examine alternative to develop Project Applications Plan	Make open call(s) for EAs	Make open call(s) for EAs	Enable use of beta data by EAs and receive feedback
	Develop information to inform the FAD and PLRA	Compile contact information to support communications with users	Articulate DAAC support for applications users	Conduct events and data workshops to engage communities and build familiarity with access	Conduct events and data workshops to engage communities and build familiarity with access
	Inform concept discussions	Initiate use cases to examine uses in design	Identify simulated data products for testing in decision systems	Conduct case studies with EAs	Revisit Community Assessment Report and reassess user communities and opportunities
			Continue use cases to examine uses in-depth	Support efforts to test and practice with simulated data	Assess and report on the Project Applications Program (PAP) and Plan
				Prepare baseline information to support Senior Review	
Deliverables	Project Studies	Project Applications Plan	Updated applications plan and Applications Traceability Matrix	Updated applications plan and Applications Traceability Matrix	Updated Community Assessment Report
	Community Assessment and Report	Applications Traceability Matrix	Applications Posters	EA telecons and case studies	EA telecons and case studies
		Applications Workshop and report	Applications Workshop(s) and report(s)	Applications Workshop(s) and report(s)	Applications Workshop(s), short courses and report(s)
		Community Contact List	DAAC Engagement summary	Data workshops and short courses	Socioeconomic analyses and reports
		Use Cases/Case Studies	Use Cases/Case Studies	Baseline report for Senior Review	Information for Senior Review Submissions
Events	MAR: Conduct a Mission Applications Review prior to MCR	SRR: Systems Requirements Review	PDR: Preliminary Design Review	CDR: Critical Design Review	Commissioning
	MCR: Articulate applications as part of the overall mission concept			SIR: Systems Integration Review	Data Availability
				ORR: Operations Readiness Review	
				MRR: Mission Readiness Review	
	KDP-A	KDP-B	KDP-C	KDP-D/KDP-E	KDP-F

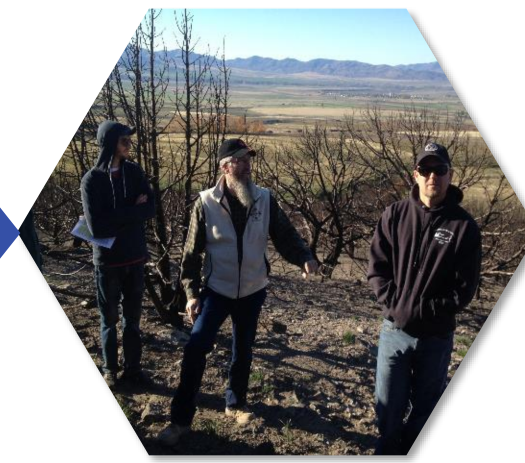
What is DEVELOP?

DEVELOP addresses environmental and public policy issues through interdisciplinary feasibility studies that apply the lens of NASA Earth observations to community concerns around the globe. Bridging the gap between NASA Earth Science and society, DEVELOP projects build capacity in both participants and partner organizations to better prepare them to address the challenges that face our society and future generations.



NASA Earth Science

DEVELOP



Decision Makers

Developing an Applied Science traceability matrix that is defensible and measurable in conjunction with the Science Traceability Matrix

Characterize the problem space or the baseline

- What are the characteristics of your application's current information product(s):
    - Variable
    - Temporal
    - Spatial
    - Units
    - Geographic domain
- How is the information currently used?

Your hypothesis and objective.

- How would you evaluate the complementarity or the utility of your proposed work versus the baseline?
- How does your proposed work improve upon that baseline?

Science and Applications Traceability Matrix

- Define your (Applied) Science Question and Objective
- Document your observables and their requirements and make the case that they can be used to address the hypotheses/objectives

Developing an SATM

Characterize the problem space or the baseline

- What are the characteristics of your application's current information product(s):
  - Variable
  - Temporal
  - Spatial
  - Units
  - Geographic dom
- How is th

the

y of the utility of your

ed work versus the baseline?

How does your proposed work improve upon that baseline?

Add sample text describe each category – start with baseline and hypothesis/objective

Your hypothesis and objective

Science and Applications Traceability Matrix

- Define your (Applied) Science Question and Objective
- Document your observables and their requirements and make the case that they can be used to address the hypotheses/objectives

Developing an SATM

Characterize the problem space or the baseline

- What are the characteristics of your application's current information product(s):
  - Variable
  - Temporal
  - Spatial
  - Units
  - Geographic domain
- How is the information currently used?

Example

Heat Index (0-1) based on daily weather forecasts over County region. Spatial resolution TBC.

Information is used to for county level emergency response to heat waves and planning of resources (cooling stations, hospital surveillance for heat stress-related conditions)

Your hypothesis and objective.

- How would you evaluate the complementarity or the utility of your proposed work versus the baseline?
- How does your proposed work improve upon that baseline?

Determine utility of HVI (proposed RS-based product) versus the standard Heat Index for assessing heat wave impacts in X County.

HVI is better correlated with heat-related stress conditions reported at hospitals.

Science and Applications Traceability Matrix

- Define your (Applied) Science Question and Objective
- Document your observables and their requirements and make the case that they can be used to address the hypotheses/objectives

See table on next page.

DS Designated Observables (DOs) ***Surface Biology and Geology (SBG)***

Science – Applications Traceability Matrix Example

Science / Applied Science Question	**Science / Applied Science Objective(s)**	**Partners**	**Partner Data Baseline**	**Physical Parameters**	**Observables**	**Requirements**	**Anticipated / Desired Capability**	**Mission Functional Requirements**	**DS Reference**
What area within an urban region are most impacted or vulnerable to heat stress?	AS-I. Determine areas with highest rates of intensity of heat stress / urban heat island for XXXX dates.	Public Health County Water and Power Utilities	X weather stations in ABC County. Historical daily weather station data, minimal geospatial datasets. ?	Optimally, LST with uncertainty XYZ, with spatial ABC resolution and DEF temporal resolution for GHI years.	Optimally, LST with uncertainty XYZ, with spatial ABC resolution and DEF temporal resolution for GHI years.	pixel size, swath width, wavelength range, dynamic range, NEDT at sensor		Need to have coverage of LA County Region. -- LAC Region is in the XYZ orbit.	W-2, W-3
	AS-II Determine differences in heat stress as determined by HI vs HVI	Public Health County Water and Power Utilities		Spatial Resolution, Temporal Resolution, Spatial Coverage, Uncertainty	Spatial Resolution, Temporal Resolution, Spatial Coverage, Uncertainty			Heat wave info is determined daily by X weather stations. XYZ instrument will fill spatial gaps on days data are available.	
	AS-III. Determine urban heat island and vulnerability climatology data over 15 years to inform long term planning metrics to mitigate impacts of heat stress	City or County Planning			Urban vegetation (?)				

Submit Request for ECOSTRESS Data Acquisition

https://ecostress.jpl.nasa.gov/applications/app_request

ECOSTRESS standard products will include evapotranspiration (PT-JPL and ALEXI) as well as evaporative stress index and water use efficiency. These products can be used to assess vegetation water stress over managed (such as agricultural) and natural landscapes and have the potential to support management decisions. The ECOSTRESS Applications Area is seeking core partners and activities to pursue to demonstrate applications of ECOSTRESS or ECOSTRESS-like products in applied contexts. Christine Lee - christine.m.lee@jpl.nasa.gov

HyspIRI https://hyspiri.jpl.nasa.gov

The Decadal Survey's Designated Observables (DOs)

Surface Biology and Geology (SBG)

Decadal Survey Questions

https://science.nasa.gov/earth-science/decadal-surveys/decadal-survey-questions

Decadal Survey Community Forums

https://science.nasa.gov/earth-science/decadal-survey-community-forum