The Power of the Pixel- A Thermodynamic Paradigm for Studying Disease Vector's Habitats & Life Cycles Using NASA's Remote Sensing Data

Jeffrey C. Luvall
NASA Marshall Space Flight Center
Huntsville, AL
jluvall@nasa.gov

Figure 3-4 Photograph of Gaspard Felix Tournachon (1820-1910), the famous Parisian photographer. He called himself Nadar. Here he is seen kneeling in a fragile balloon gondola. He obtained the first aerial photograph from a balloon in 1858 near Paris, France, and patented the aerial survey as we know it today. Unfortunately, the first aerial photograph did not survive (© Roger-Viollet, Paris, France; used with permission).

Figure 3-5 A portion of an aerial photograph of downtown Boston, MA, obtained by aeronauts James W. Black and Samuel A. King from a tethered balloon at an altitude of 1,200 ft on October 13, 1860. It is believed to be the first aerial photograph taken from a captive balloon in the United States and the earliest aerial photograph still in existence. It was obtained using a wet collodion plate (used with permission of the Smithsonian Institution, Washington, DC; #3B-15472).

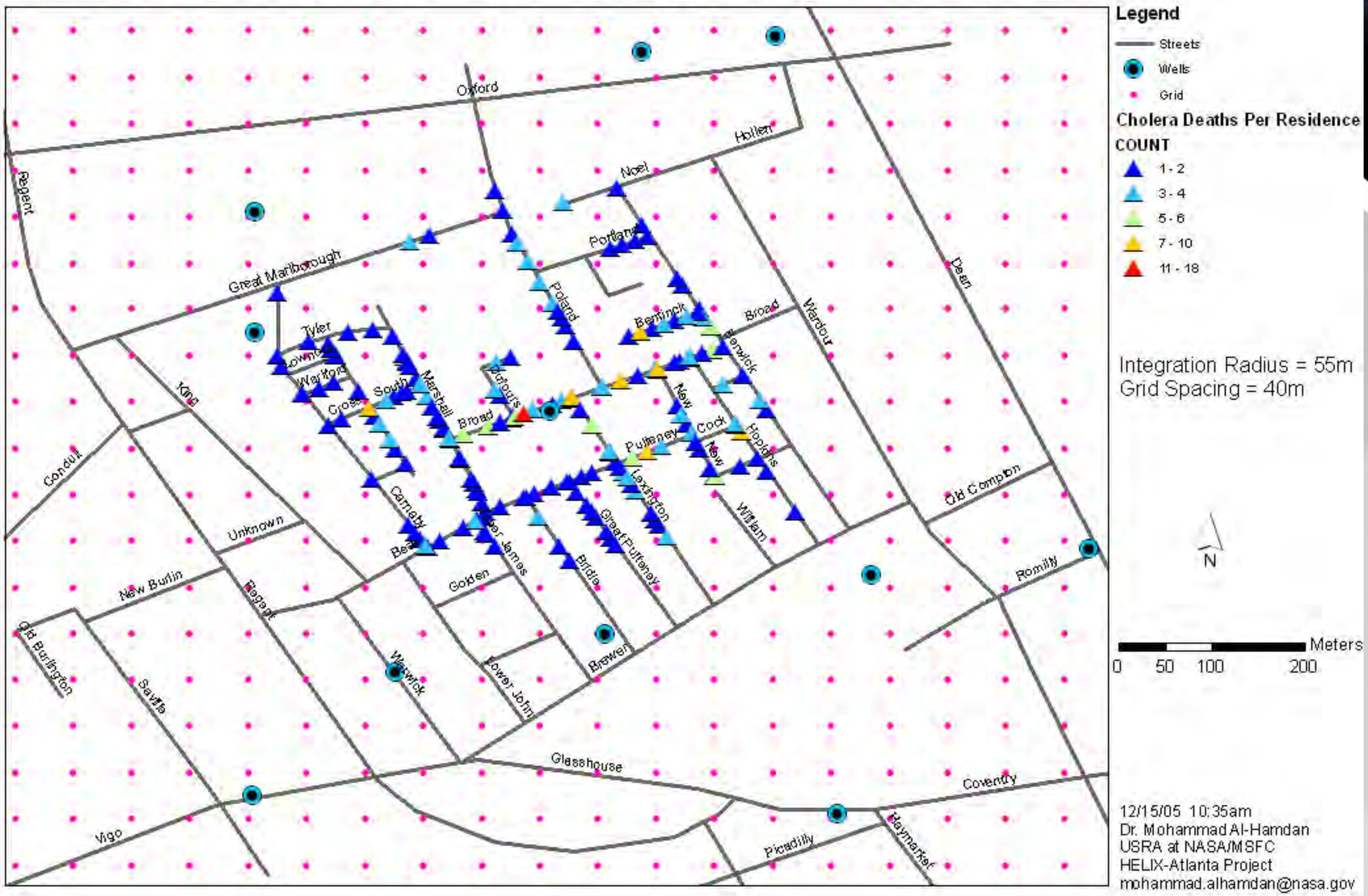
Gaspard Tournachon, AKA Nadar 1858

Boston, MA 1860, Black & King

Formulation
Implementation
Primary Ops
Extended Ops
NI-SAR
PACE
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS
RapidScat, CATS,
LIS, SAGE III (on ISS)
SMAP
SORCE
TRMM
QuikSCAT
EO-1
Landsat-7
(USGS)
Aquarius
Terra
Suomi NPP
(NOAA)
Aqua
Landsat-8
(USGS)
ECOSTRESS
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

Public Health Surveillance

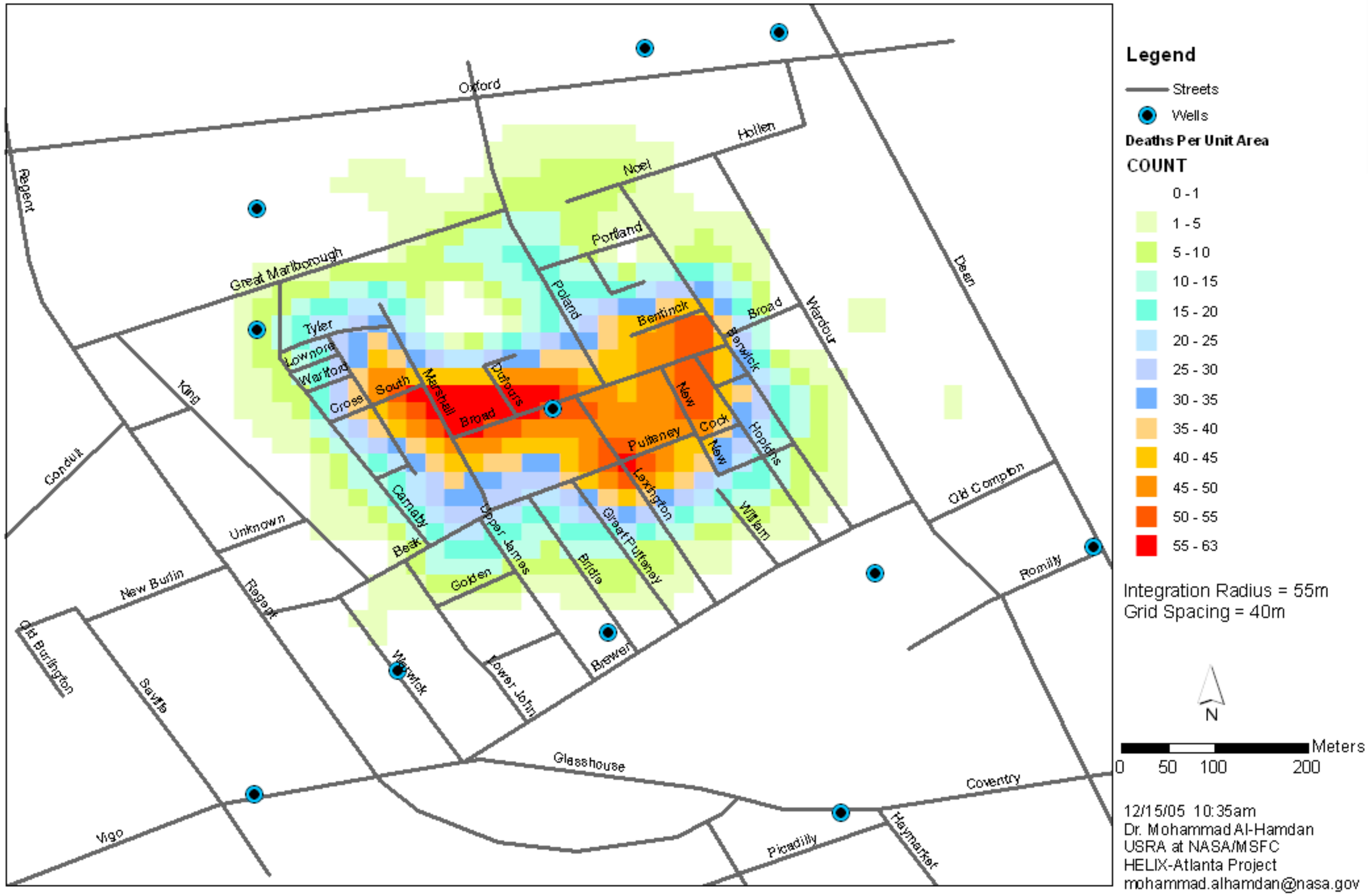
Cholera Deaths Soho, London August-September, 1854



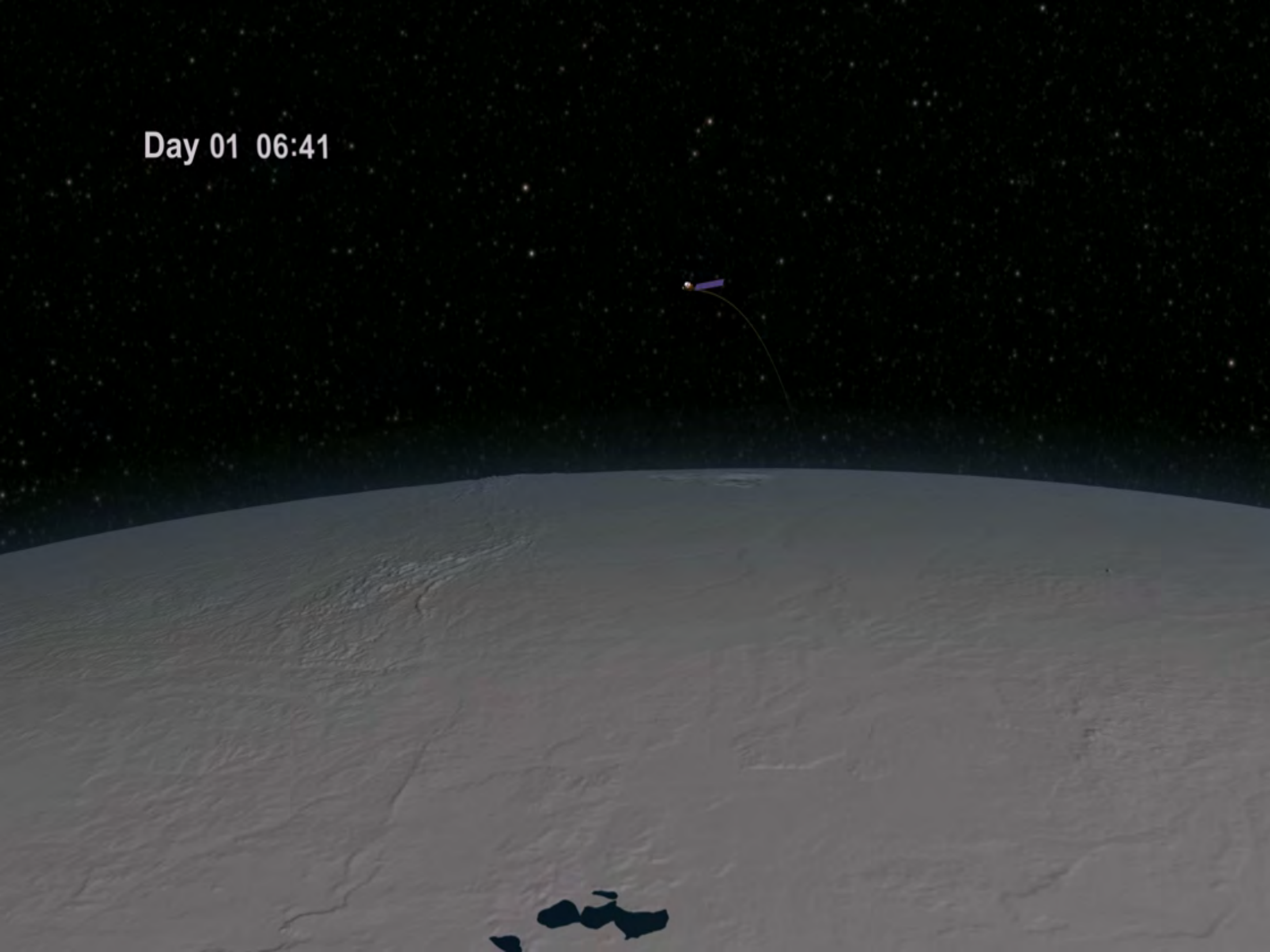
*Original data were published by C.F. Cheffins, Lith, Southhampton Buildings, London, England, 1854 in Snow, John. On the Mode of Communication of Cholera, 2nd Ed, John Churchill, New Burlington Street, London, England, 1855.
**Digital Data of Streets, Wells, and Deaths Residences which were used to creat this surface were downloaded from the UCLA Department of Epidemiology Website at http://www.ph.ucla.edu/epi/snow.html.

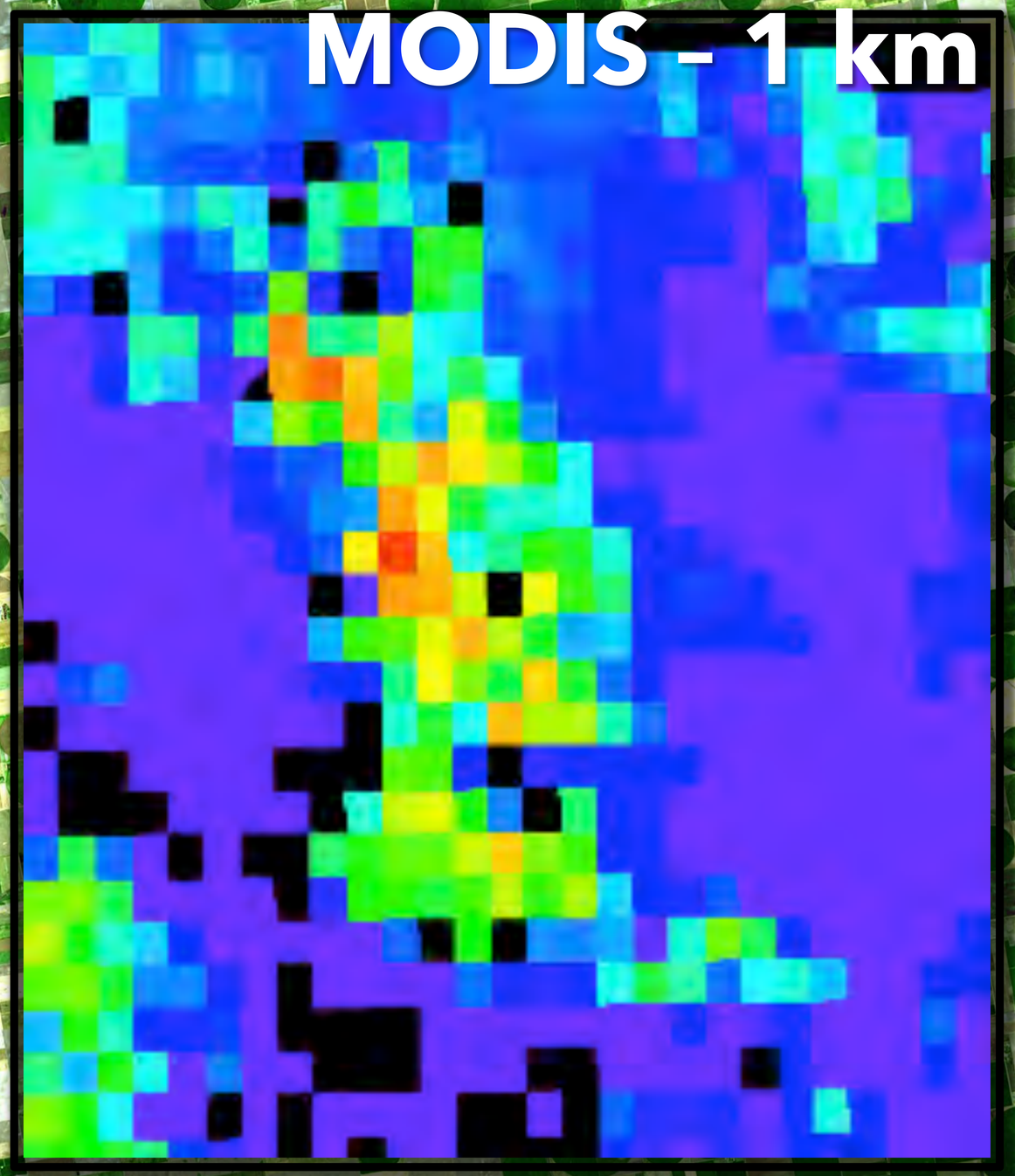
Public Health Surveillance

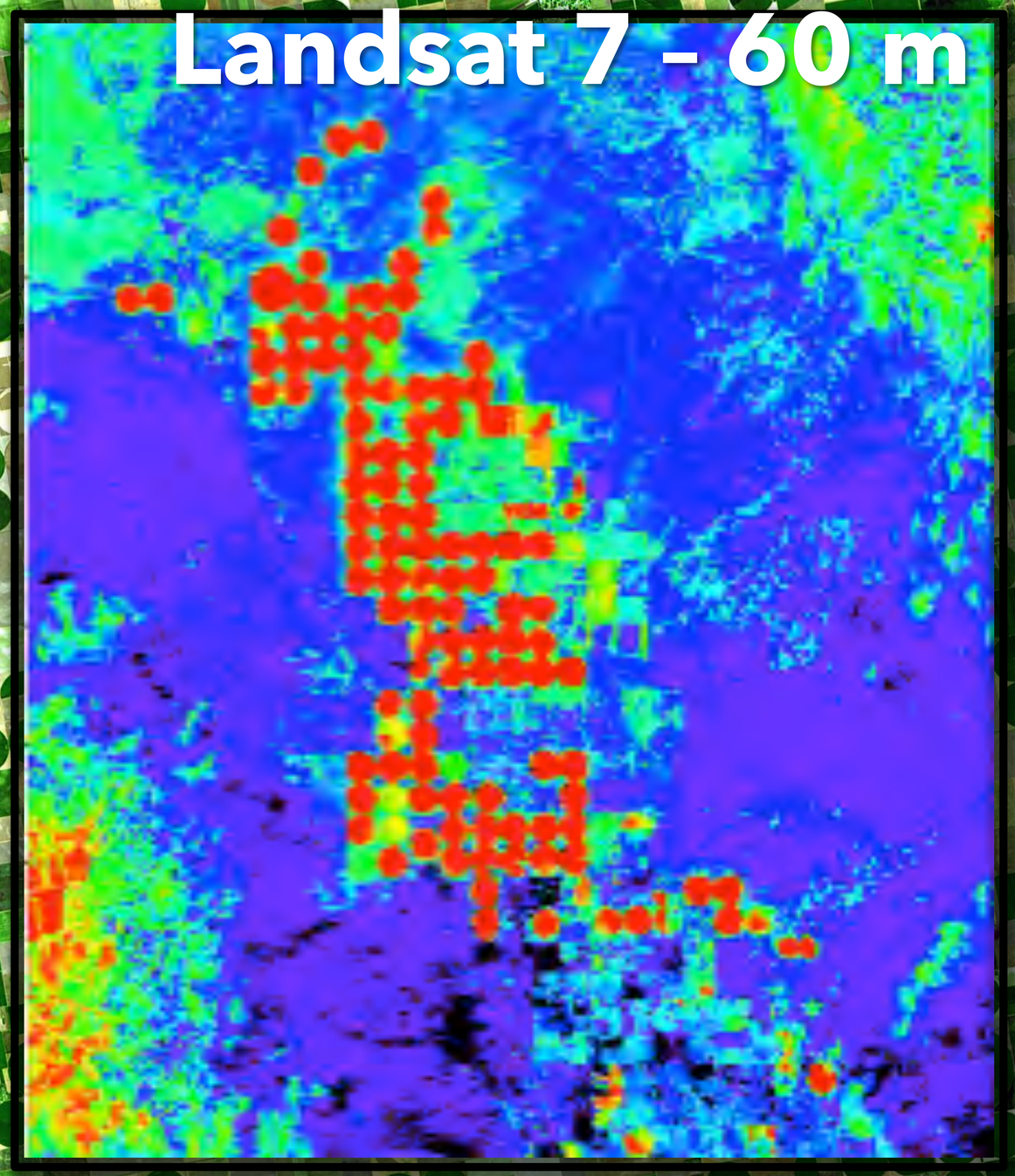
Cholera Deaths Soho, London August-September, 1854



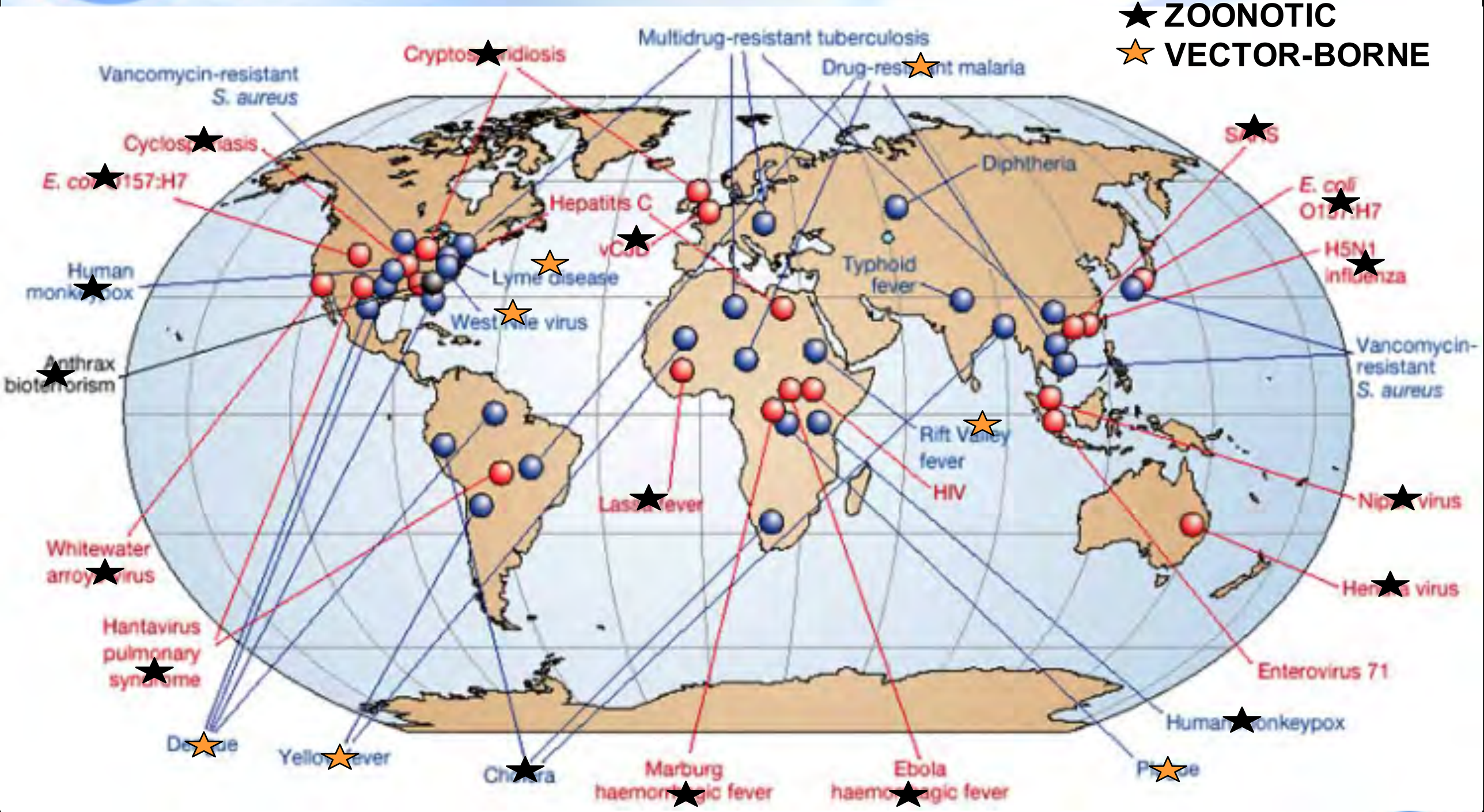
*Original data were published by C.F. Cheffins, Lith, Southhampton Buildings, London, England, 1854 in Snow, John. On the Mode of Communication of Cholera, 2nd Ed, John Churchill, New Burlington Street, London, England, 1855.
**Digital Data of Streets, Wells, and Deaths Residences which were used to creat this surface were downloaded from the UCLA Department of Epidemiology Website at http://www.ph.ucla.edu/epi/snow.html.


Day 01 06:41


MODIS - 1 km


Landsat 7 - 60 m

Global Emerging Diseases*



EMERGING

RE-EMERGING

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

WHO is currently focusing on 14 neglected tropical diseases:

- Buruli ulcer
- Chagas disease
- Cholera/Epidemic diarrhoeal diseases
- Dengue/dengue haemorrhagic fever
- Dracunculiasis (guinea-worm disease)
- Endemic Treponematoses (yaws, pinta, endemic syphilis…)
- Human African trypanosomiasis
- Leishmaniasis
- Leprosy
- Lymphatic filariasis
- Onchocerciasis
- Schistosomiasis
- Soil-transmitted helminthiasis
- Trachoma
- Yaws
- Rabies

World Health Organization 2006, 2014

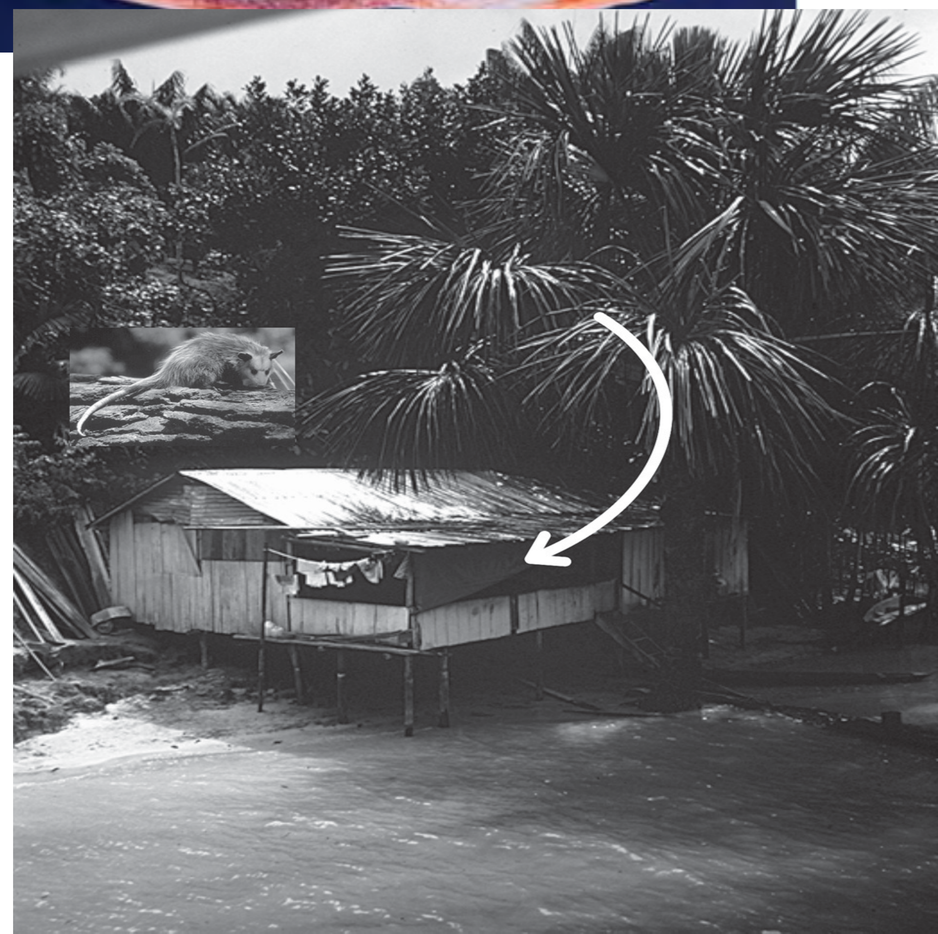
a

1

e

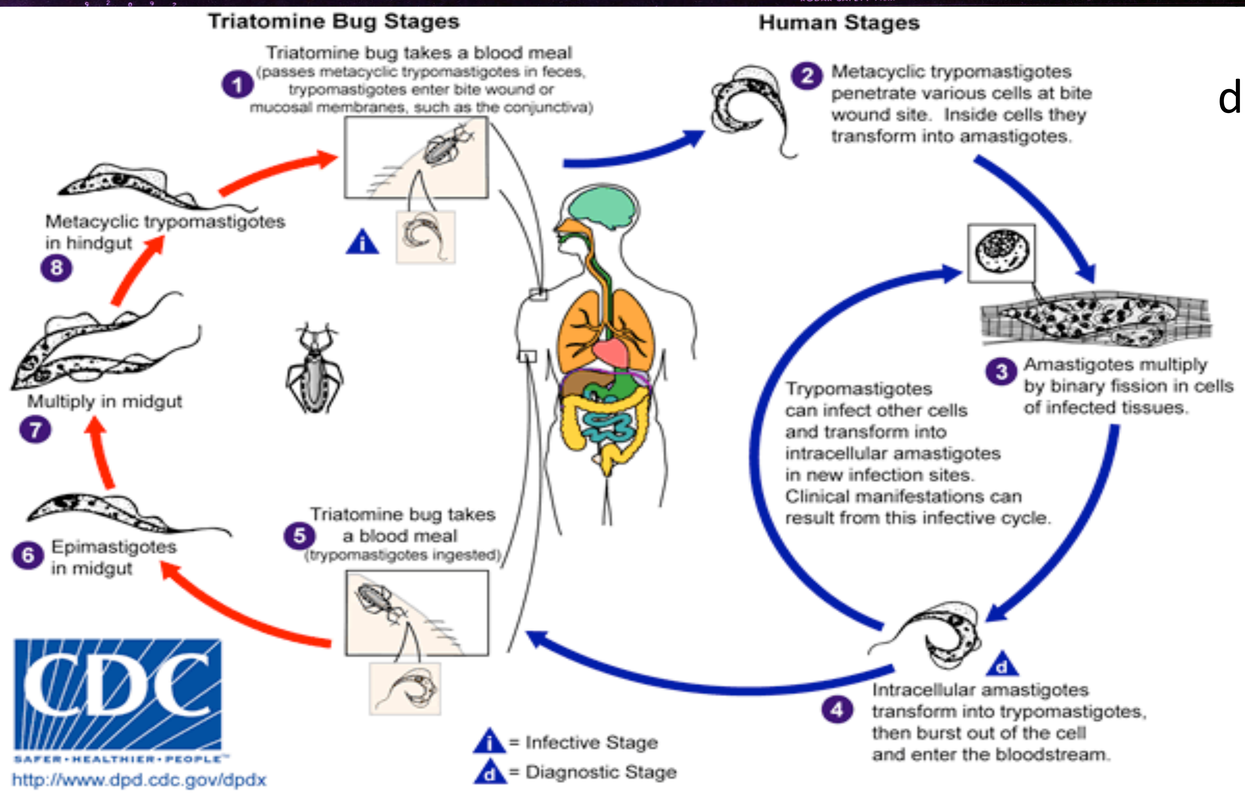
3

b



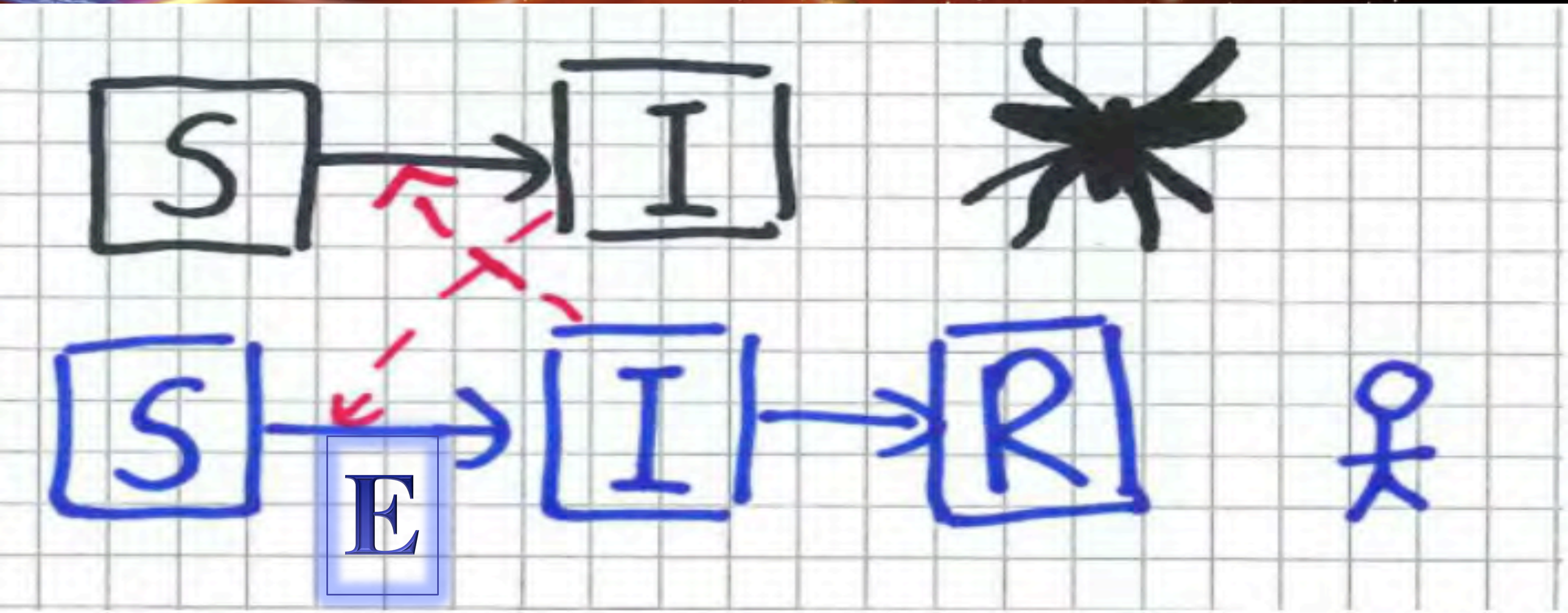
2

d


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
i = Infective Stage
d = Diagnostic Stage
CDC
SAFER • HEALTHIER • PEOPLE
http://www.dpd.cdc.gov/dpdx

c

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 journal1.2830 (1915): 546

Strengths Of Satellite Observations

Measures environmental state functions important to vector & disease life cycles (within vector)
Precipitation, soil moisture, temperature, 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 the greatest strength:
Provides a time series of measurements

A Ecological Thermodynamic Paradigm

θ Δics

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.

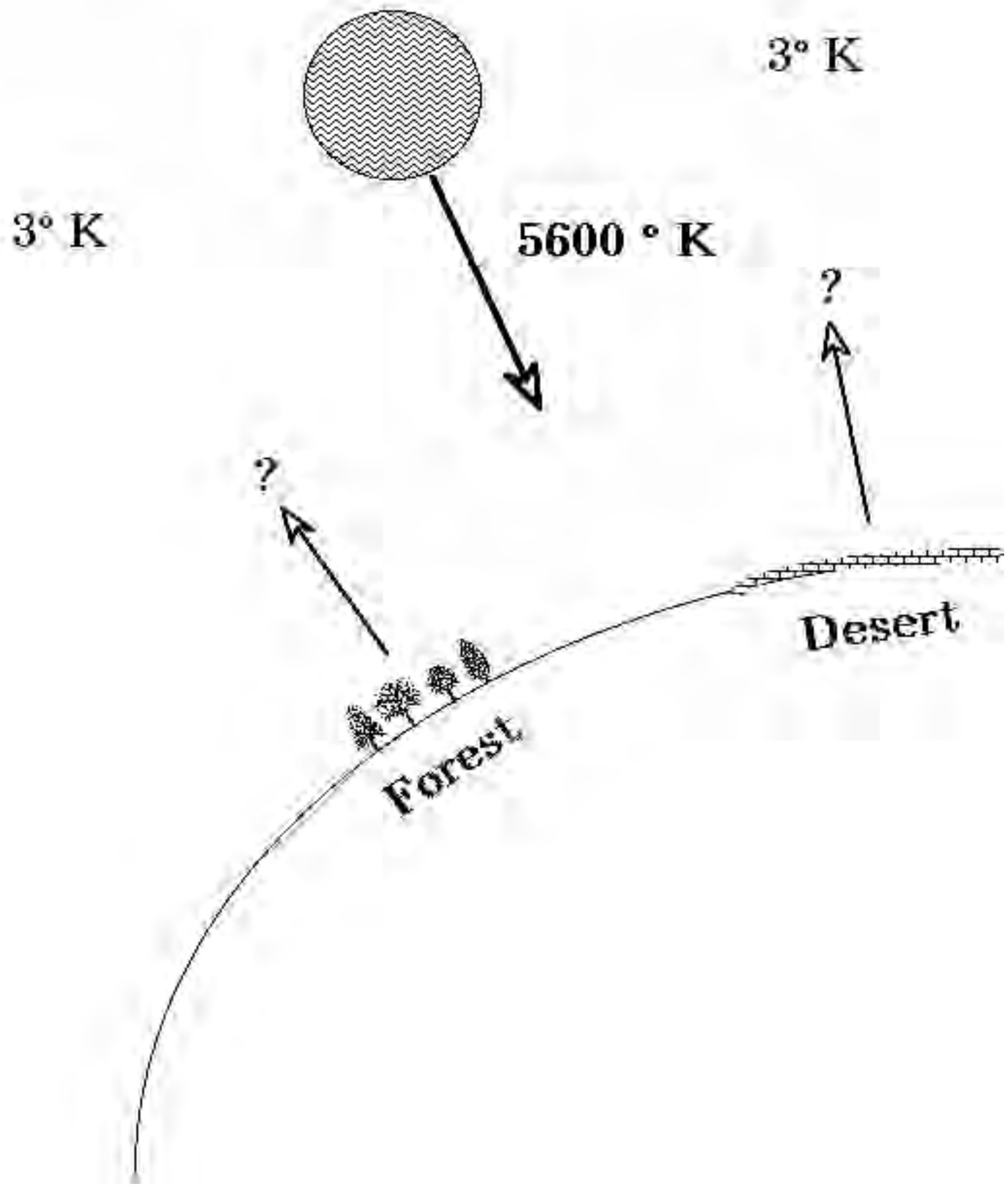
Thermal Remote Sensing and the Thermodynamics of Ecosystem Development

Jeffrey C. Luvall[1], Doug Rickman[1], and Roydon F. Fraser[2]

[1]NASA, Marshall Space Flight Center, Huntsville, AL 35812 jluvall@nasa.gov
[2]University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

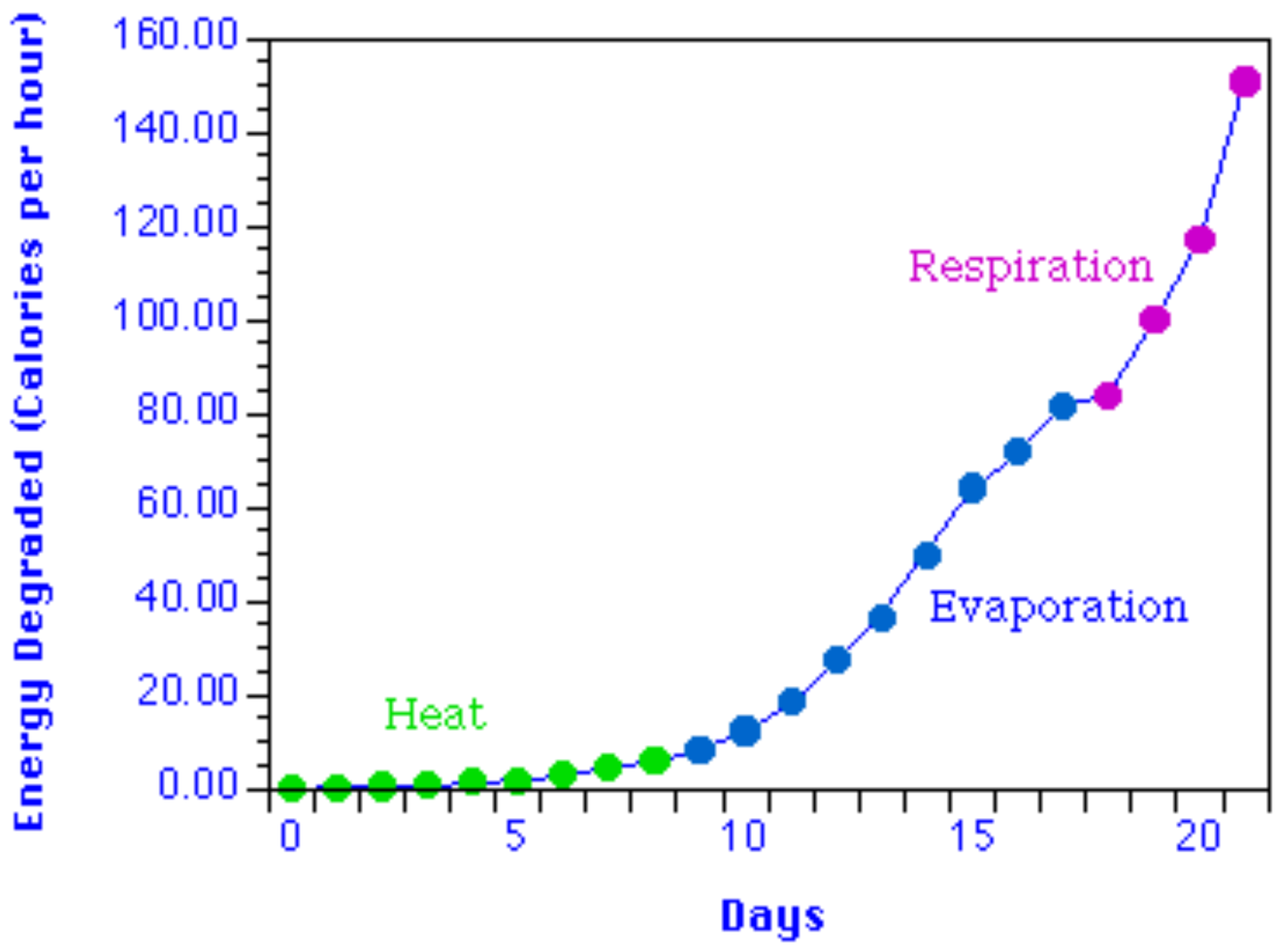
In Memory of James J. Kay 1954-2004

Which degrades more energy?



Dissipation rate for a chicken embryo

(Data from Briedis and Seagrave, 1984)



Second law and ecosystems

What is the thermodynamic game?

Store energy

Increase Biomass

Make use of as much of the exergy as possible to perform tasks. Make the most effective use of the energy. Win!

(H.T. Odum was right! If maximum work principle means extract the most available work from the energy source.)

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

Nonequilibrium thermodynamic hypotheses concerning ecosystem development

- Exergy utilization will increase
  - Rn/K* will increase
  - Surface temperature will decrease
- Internal equilibrium will increase
  - Spatial variation in surface temperature will decrease (Beta index increases)
  - Temporal variation in surface temperature will decrease (TRN increases)

Surface Temperature

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

θΔics

Environment/interface

1. Temperature- ECOSTRESS (2017), HyspIRI (2020+)
2. Precipitation-GPM 2014
3. Soil Moisture-SMAP(2015)
4. Hyperspectral-proposed Space Station (~2017)
5. Structure- IceSat-2 (2016)
6. Flooding/water levels lakes streams – SWOT (late 2020)

ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

Simon J. Hook and the ECOSTRESS Team
Jet Propulsion Laboratory,
California Institute of Technology, Pasadena, CA

With support, encouragement and participation from many!

© 2014 California Institute of Technology. Government sponsorship acknowledged.

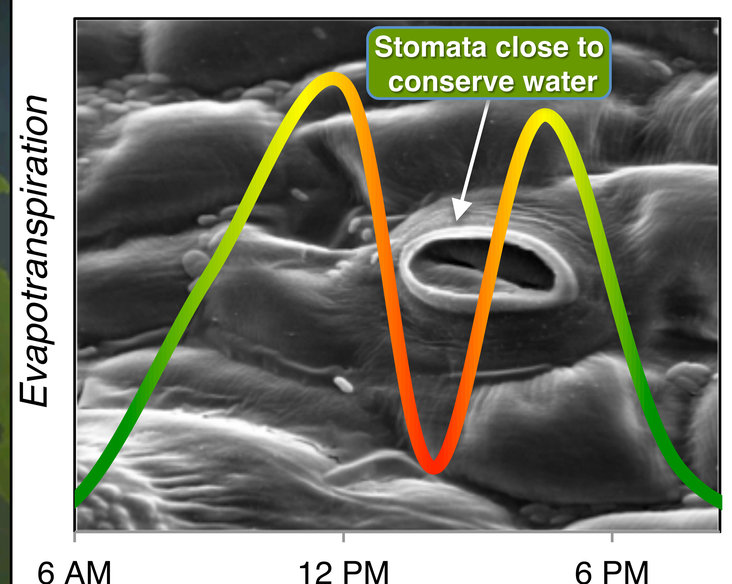
ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

Dr. Simon J. Hook, JPL, Principal Investigator

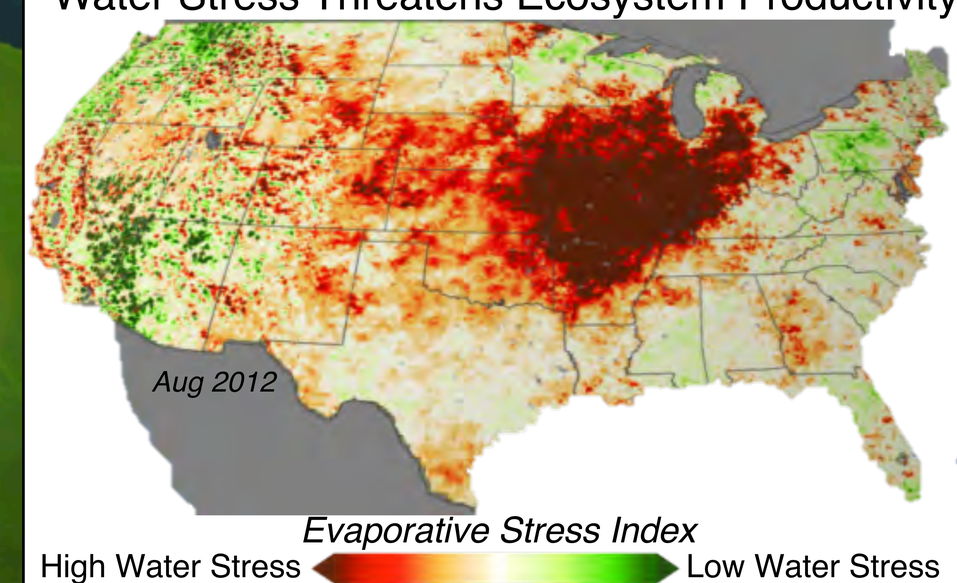
*ECOSTRESS will provide critical insight into **plant-water dynamics** and how **ecosystems change with climate** via **high spatiotemporal** resolution thermal infrared radiometer measurements of evapotranspiration from the International Space Station (ISS).*

Water Stress Drives Plant Behavior



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

Water Stress Threatens Ecosystem Productivity



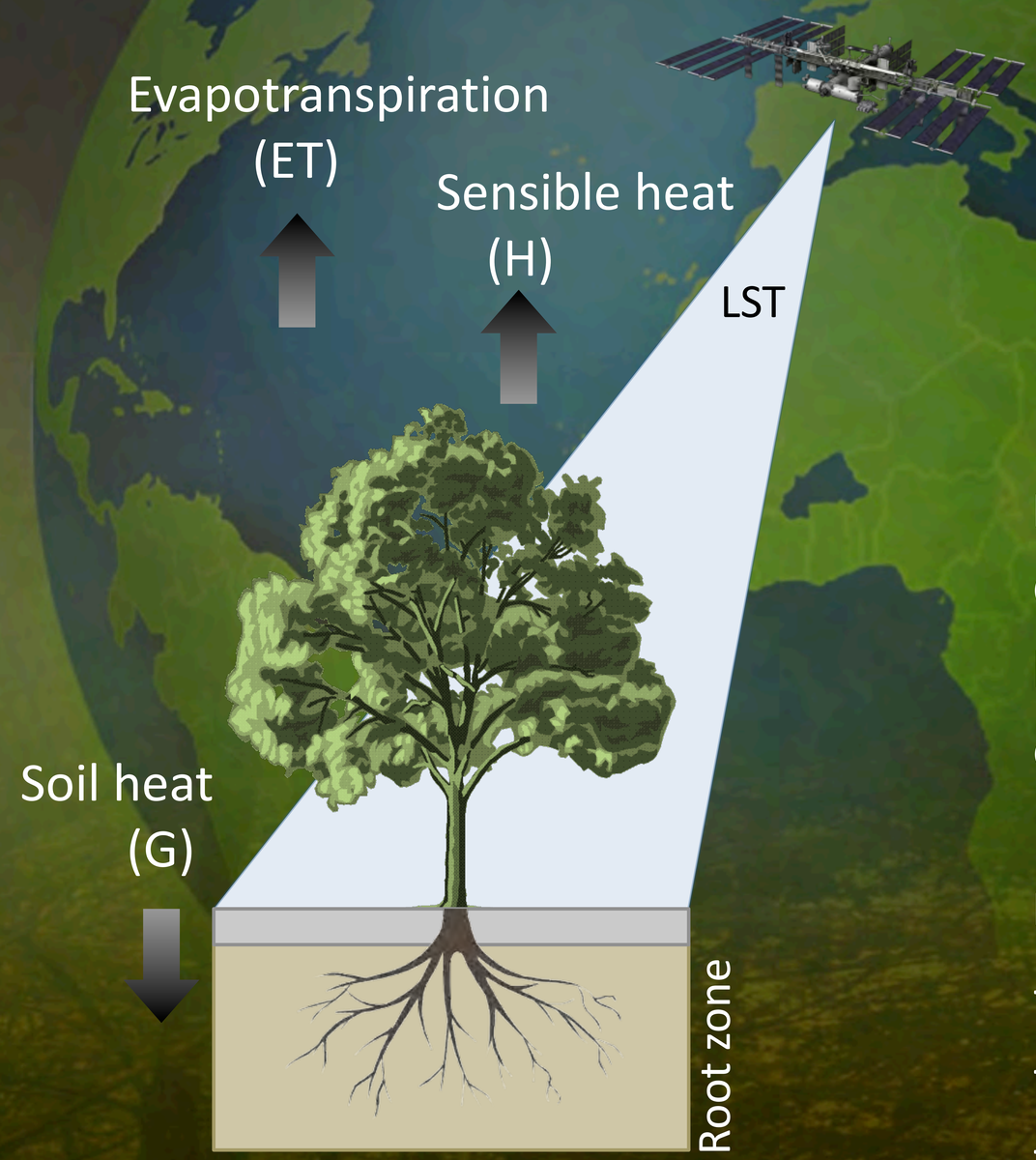
Water stress is quantified by the Evaporative Stress Index, which relies on evapotranspiration measurements.

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*

ECOSTRESS approaches to mapping ET

Relationship between LST and ET



$$ET = R_n - H - G$$

with R_n the net radiation
H the sensible heat flux
G the soil heat flux

} LST dependent

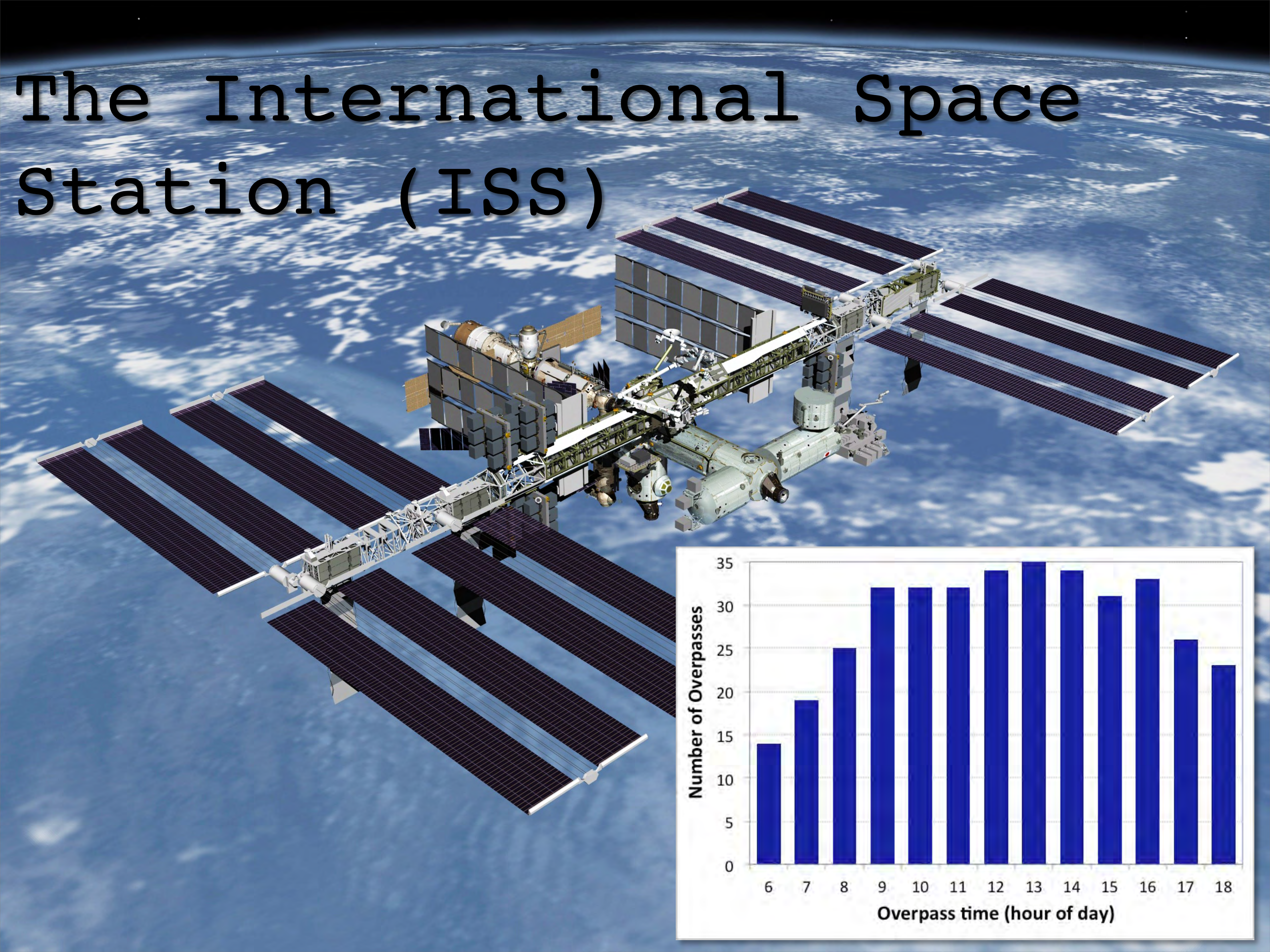
Energy balance approach:

Given known radiative energy inputs (R_n), how much water loss is required to keep the soil and vegetation at the observed temperatures?

Ensemble of ET models for ECOSTRESS:

- ALEXI from USDA (Two-source Energy balance)
- METRIC from U. of Idaho (In-scene approach)
- PT-JPL from JPL (Radiation based model)

The International Space Station (ISS)

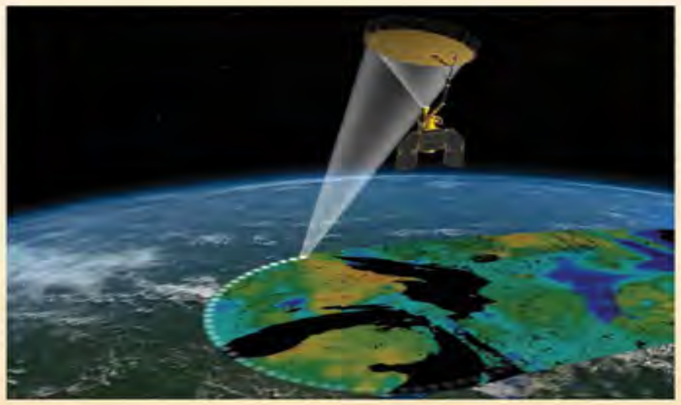


National Aeronautics and Space Administration

Soil Moisture Active Passive (SMAP)

APPLIED SCIENCE

Mapping soil moisture and freeze/thaw state from space



The SMAP Mission

Objectives: SMAP measurements will be used to enhance understanding of processes that link the water, energy, and carbon cycles, and to enhance the predictive skill of weather and climate models. SMAP data will also be used to quantify net carbon flux in boreal landscapes and to develop improved flood prediction and drought monitoring capabilities.

Observatory: The SMAP observatory employs a dedicated spacecraft with an instrument suite that will be launched on an expendable launch vehicle into a 680-km near polar, sun-synchronous orbit, with equator crossings at 6 AM and 6 PM local time.

Instrument: The SMAP instrument includes a radiometer and a synthetic aperture radar operating at L-band (1.20-1.41 GHz). The instrument is designed to make coincident measurements of surface emission and backscatter, with the ability to sense the soil conditions through moderate vegetation cover. The conically-scanning antenna covers a 1000 km swath providing global coverage within 3 days at the equator and 2 days at boreal latitudes (>45° N).

Operations: SMAP science measurements will be acquired for a period of three years. A comprehensive validation program will be carried out after launch to assess the science data products. The products from these activities will be made available through a NASA data archive center.

Area	Likely Mission Applications	Potential Mission Applications
Weather	More accurate weather forecasts; prediction of severe rainfall	Regional weather prediction improvements
Natural Disasters	Drought early warning decision support; key variable in floods and landslides; operational flood forecasts; lake and river ice breakup; desertification	Fire susceptibility; heat-wave forecasting
Climate Variability and Change	Extended climate prediction capability; linkages between terrestrial water, energy, and carbon cycles; land/atmosphere fluxes and carbon (CO_2) source/sink activity for atmospheric greenhouse gases	Long term risk assessments
Agriculture and Forestry	Predictions of agricultural productivity; famine early warning; monitoring agricultural drought	Crop management at the farm scale; input to fuel loading models
Human Health	Landscape epidemiology; heat stress and drought monitoring; insect infestation; emergency response plans	Disease forecasting and risk mitigation
Ecology	Carbon source/sink monitoring; ecosystems forecasts; improvements in monitoring of vegetation and water relationships over land	Wetlands resources and bird migration monitoring; cap-and-trade carbon inventory assessment and monitoring
Water Resources	Regional and local water balance; more effective management	Variability of water stored in lakes, reservoirs, wetlands and river channels monitoring
Ocean Resources	Sea ice mapping for navigation, especially in coastal zones; temporal changes in ocean salinity	Provision of ocean wind speed and direction, related to hurricane monitoring
Insurance Sector	More accurate forecasts of weather; prediction of severe rainfall; operational severe weather forecasts; mobility and visibility	Crop insurance programs; flood insurance programs; tourism and recreation
Coastal Inundation	Input to sea level rise products	Maps of coastal inundation; ocean winds monitoring for hurricanes
Drought	Early warning decision support; drought monitor products	Desertification identification
Flood	Improved forecasts, especially in medium to large watersheds; flood mapping; protection of downstream resources; soil infiltration conditions; prediction of ice breakup	Prediction of the impact of tropical storms on hydrology
Ecosystem Health	Improvements in monitoring of vegetation health and change; ecosystem dynamics	Wetlands and bird migration monitoring; Rangeland forage productivity forecasts
Wildfires	Input into fire potential models	Improvements in fuel loading models, especially for non-heavily forested areas

www.nasa.gov

Public Health

- Landscape epidemiology
- Heat stress & drought monitoring
- Insect infestation
- Emergency response plans
- Disease forecasting
- Risk mitigation

- Global Coverage once every 3 days
- Products for soil moisture & temperature
- 1-36 km resolution
- Jan 2015

HyspIRI Decadal Survey Mission

Key Science and Science Applications

Climate: Ecosystem biochemistry, condition & feedback; evapotranspiration

Ecosystems: Global biodiversity, plant functional types, physiological condition, and biochemistry

Fires: Fuel status; fire frequency, severity, emissions, and patterns of recovery globally

Coral reef and coastal habitats: Global composition and status

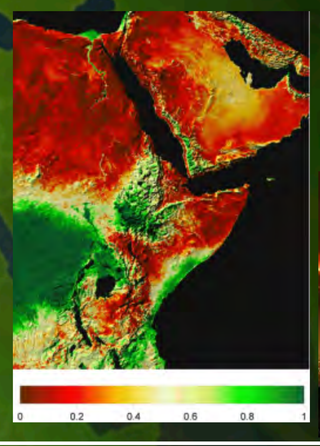
Volcanoes: Eruptions, emissions, regional and global impact

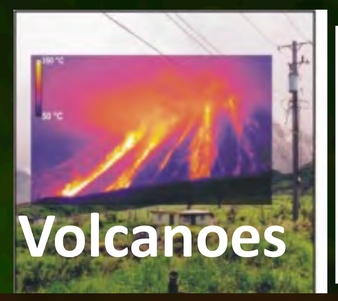
Geology and resources: Global distributions of surface mineral resources

Mission Urgency

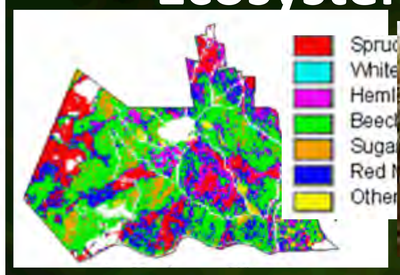
The HyspIRI science and applications objectives are critical today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.

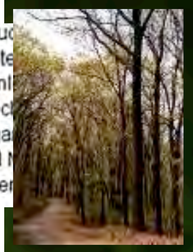
Evapo-transpiration

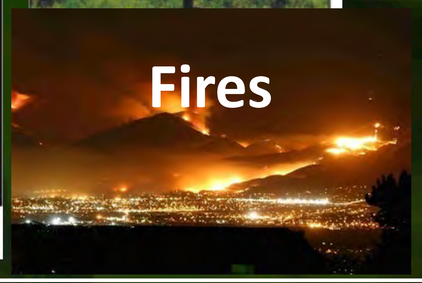


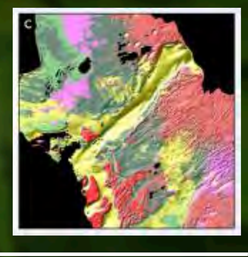


Ecosystems









Measurement

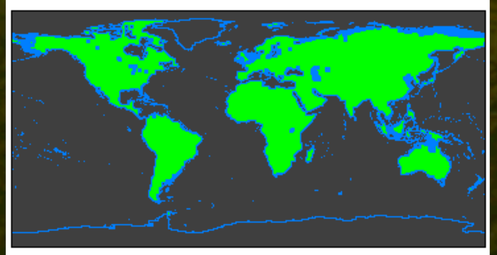
Imaging Spectrometer (VSWIR)

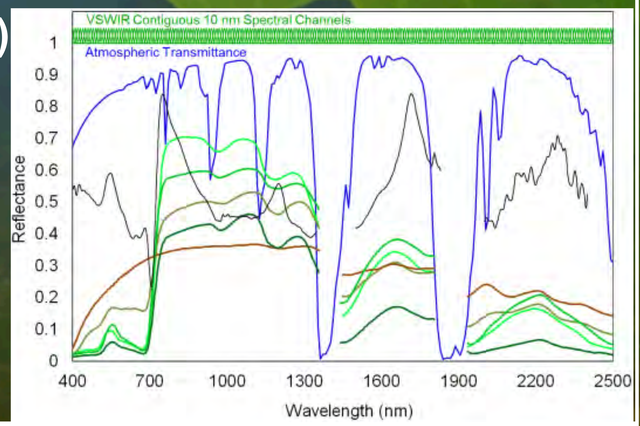
- 380 to 2500nm in 10nm bands
- 60 m spatial sampling
- 19 days revisit
- Global land and shallow water

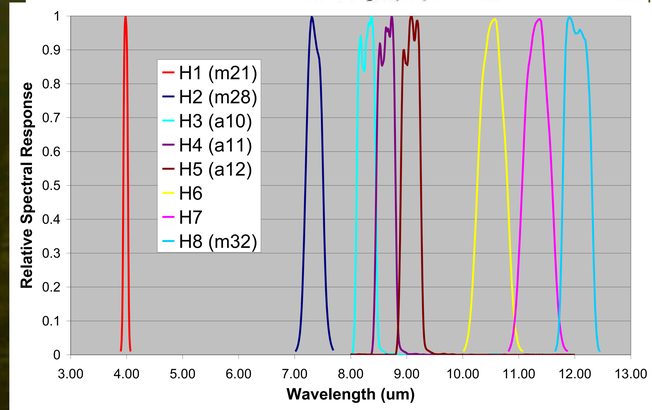
Thermal Infrared (TIR):

- 8 bands between 4-12 μm
- 60 m spatial sampling
- 5 days revisit; day/night
- Global land and shallow water

IPM-Low Latency data subsets







Mission Concept Status

Preliminary Draft Program Level 1 Requirements: Stable

Payload: Imaging Spectrometer, Thermal Infrared Imager, and IPM-Low Latency subsets

Spacecraft: RFI responses in

Payload: TBD - JPL/GSFC concept

Launch Vehicle: Small class

Launch date: ≥2024

Mission: Class C, 3-year baseline

Trajectory or Orbit: LEO, Sun sync.

S/C & Instrument Mass: 686kg (30% margin)

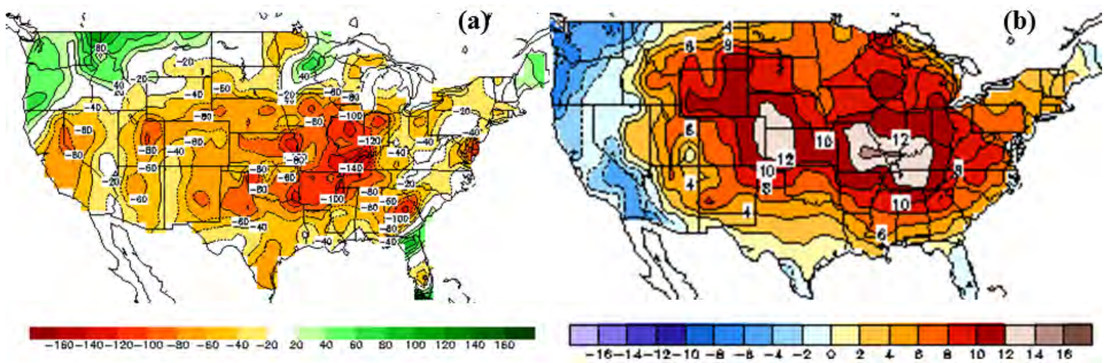
S/C & Instrument Power: 708W (45% margin against peak)

Mission Cost (FY12 est.): $506M incl. 30% reserve except for LV

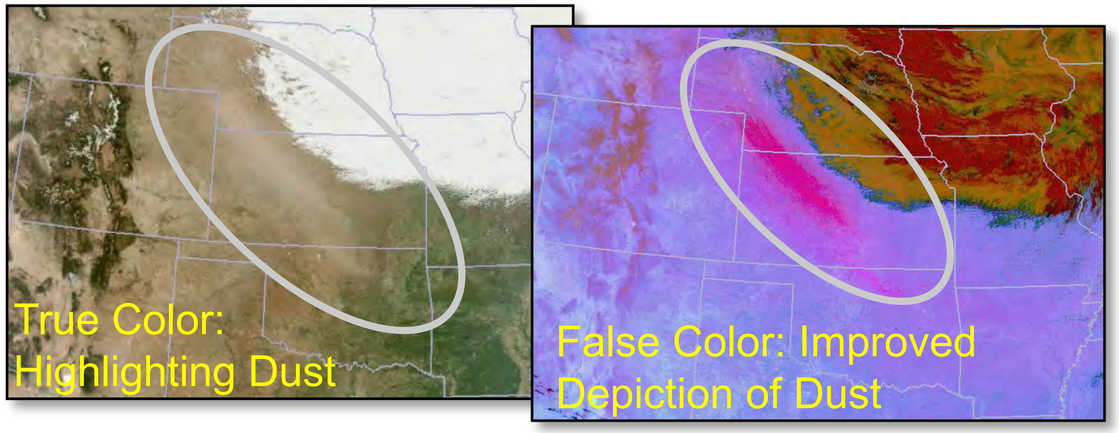
The HyspIRI mission concept is mature and stable with excellent heritage, low risk and modest cost.

(Examples above demonstrate existing capabilities.)

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.

GROUP ON EARTH OBSERVATIONS

GEOSS Portal

Discover, Access, Contribute
Earth Observations, Information and Services

HOME | VIDEO TUTORIAL | SEND FEEDBACK

SEARCH

- Agriculture
- Biodiversity
- Climate
- Disasters
- Ecosystems
- Energy
- Health
- Water
- Weather

+ Country/Geography [?]

+ Data Access Conditions [?]

+ Earth Observation Catalogs [?]

CLEAR | SEARCH

WHAT IS GEOSS PORTAL

The GEOSS Portal is your main entry point to Earth Observation data from all over the world. Search our data or Contribute to our resources and data discovery tools. We also link world-wide community of practice in nine SOCIETAL BENEFIT AREA

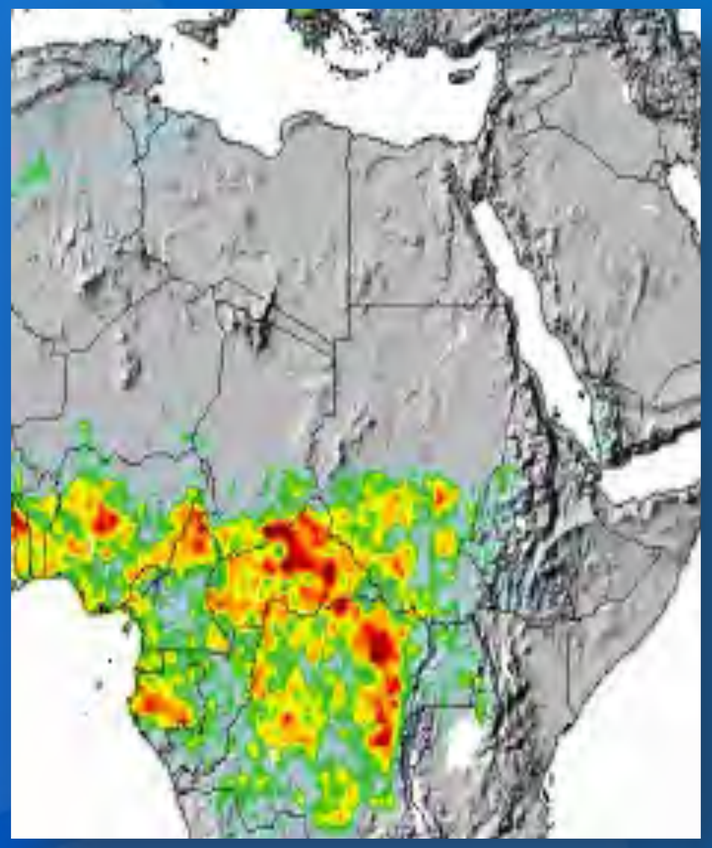
Register Your Resources

Make your Geospatial Data discoverable here.

SERVIR

Regional Platform for Science and Policy in the Americas, Africa, and Asia

Using earth observations and predictive models for environmental management, disaster response, and climate change adaptation.



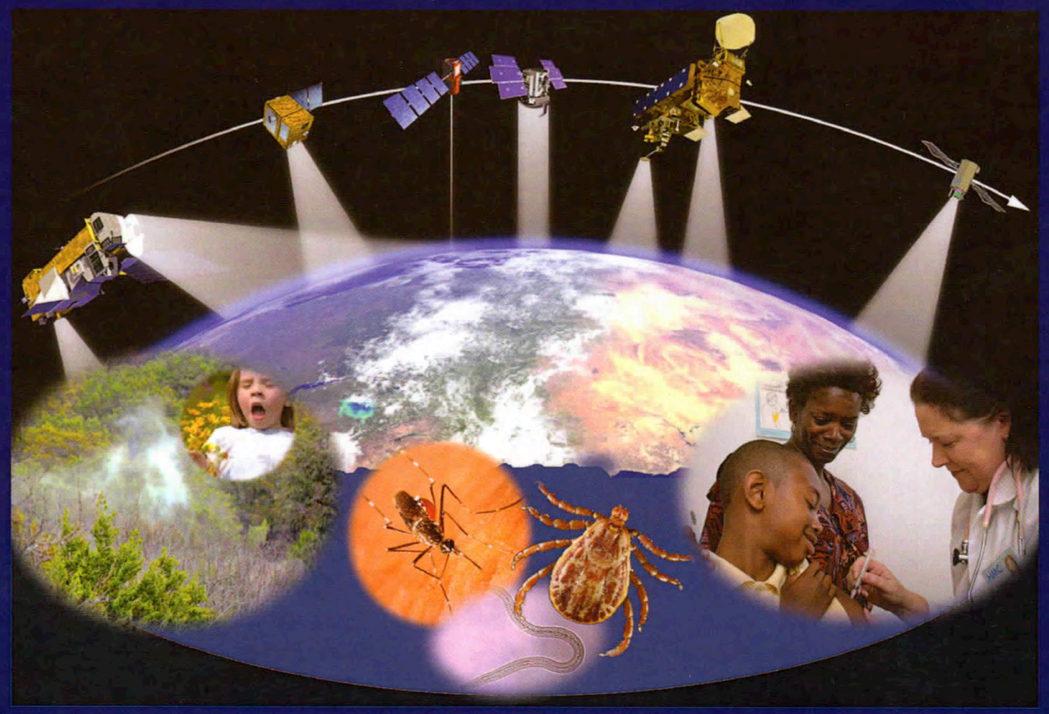
Flood Forecasting in Africa

Training and Capacity Building

Tracking Fires in Guatemala Mexico

- Data and Models
- Online Maps
- Visualizations
- Decision Support
- Training
- Partnerships

ISPRS Book Series



Environmental Tracking for Public Health Surveillance

Editors: Stanley A. Morain & Amelia M. Budge

CRC Press
Taylor & Francis Group
A BALKEMA BOOK

Luvall, J. C. and H. R. Holbo, 1989 *Measurement of short-term thermal responses of coniferous forest canopies using thermal scanner data. Remote Sensing of Environment* 27:1-10.

Holbo, H. R. and J. C. Luvall, 1989. *Modeling surface temperature distributions in forest landscapes*. Remote Sensing of Environment 27:11-24.

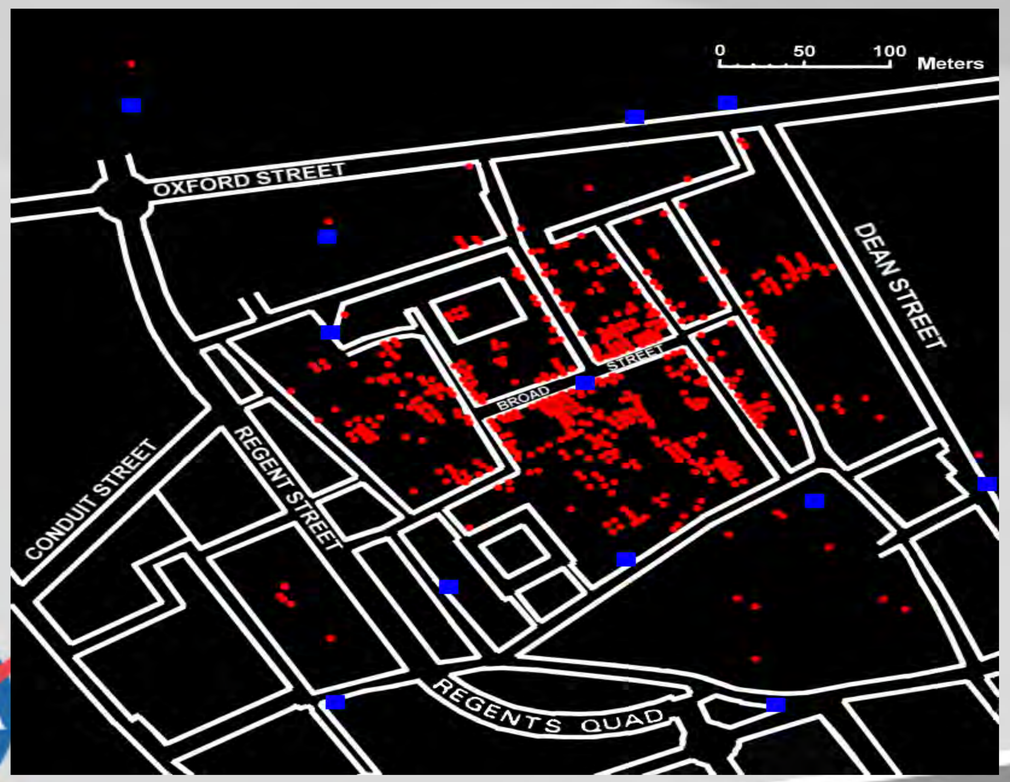
Schneider, E.D, Kay, J.J., 1994*, "Life as a Manifestation of the Second Law of Thermodynamics", Mathematical and Computer Modelling, Vol 19, No. 6-8, pp.25-48.*

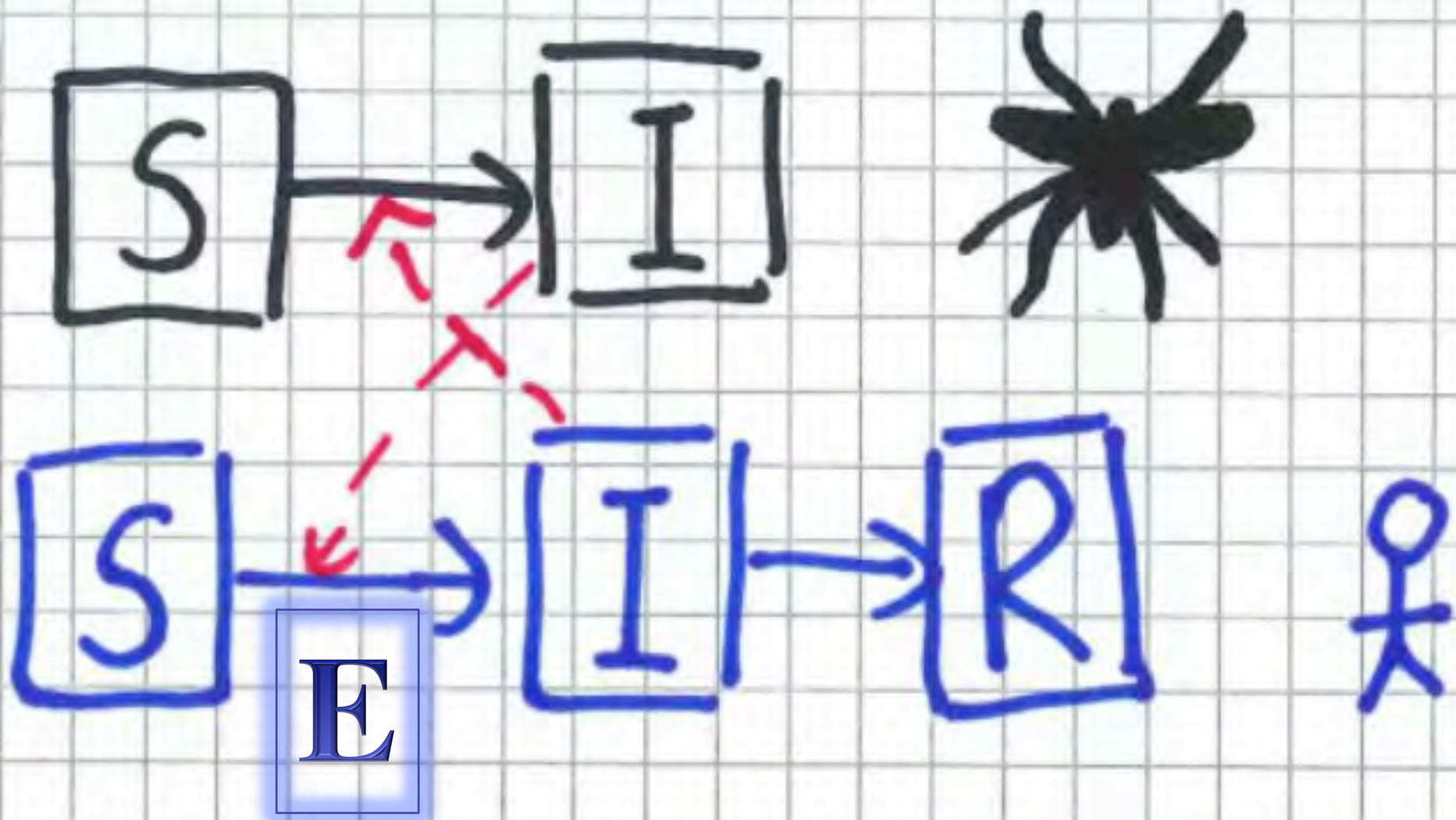
Fraser, R. A.; Kay, J. J., Quattrochi, D. A.; Luvall, J. C., eds., 2004. "Exergy Analysis of Eco-Systems: Establishing a Role for the Thermal Remote Sensing", *Thermal Remote Sensing in Land Surface Processes (Taylor & Francis).*

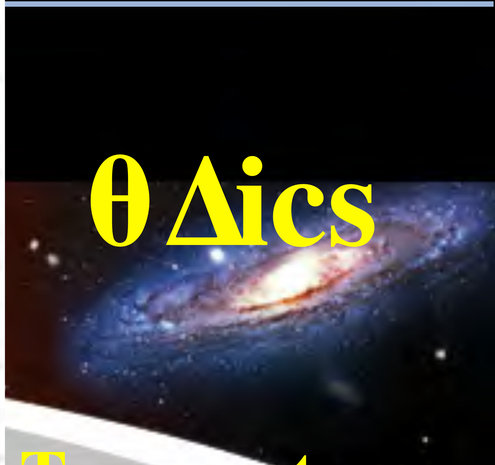
Schneider, E. D. and D. Sagan. 2005. *Into the Cool - Energy Flow, Thermodynamics, and Life, University of Chicago Press. 362 pp.*

Epidemiology in the 21st Century

Ok, so where do we go from here?







Temperature
Soil moisture
Preciptation
TRN
Evapo-transpiration

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

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