Use of ECOSTRESS data in Public Health Applications

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NASA Earth Observations for Health Information Systems (NEOH)
John Beck[1], T. Berendes[1], U. Nair[1], J. Painter[2], J. Luvall[3]
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An Ecological Thermodynamic Paradigm

☀ θΔics 🌎

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.

Potentially, An Increased Risk of Transmission

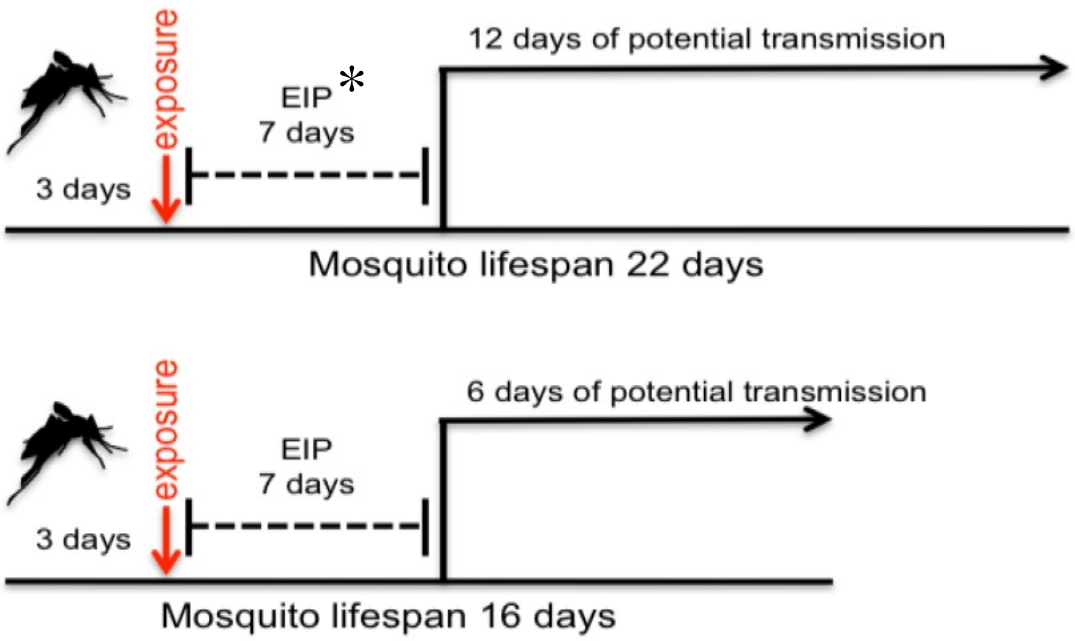


Figure 8 (from Christofferson & Mores 2016): Schematic demonstrating the impact of mosquito mortality on the cumulative transmission potential of an arbovirus.

*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)

Surface Radiation and Energy Budgets

$$Q^* = (K^{\downarrow} + K^{\uparrow}) + (L^{\downarrow} + L^{\uparrow})$$

$K^{\downarrow}$ = Incoming Solar

$K^{\uparrow}$ = Reflected Solar

$L^{\downarrow}$ = Incoming Longwave

$L^{\uparrow}$ = Emitted Outgoing Longwave

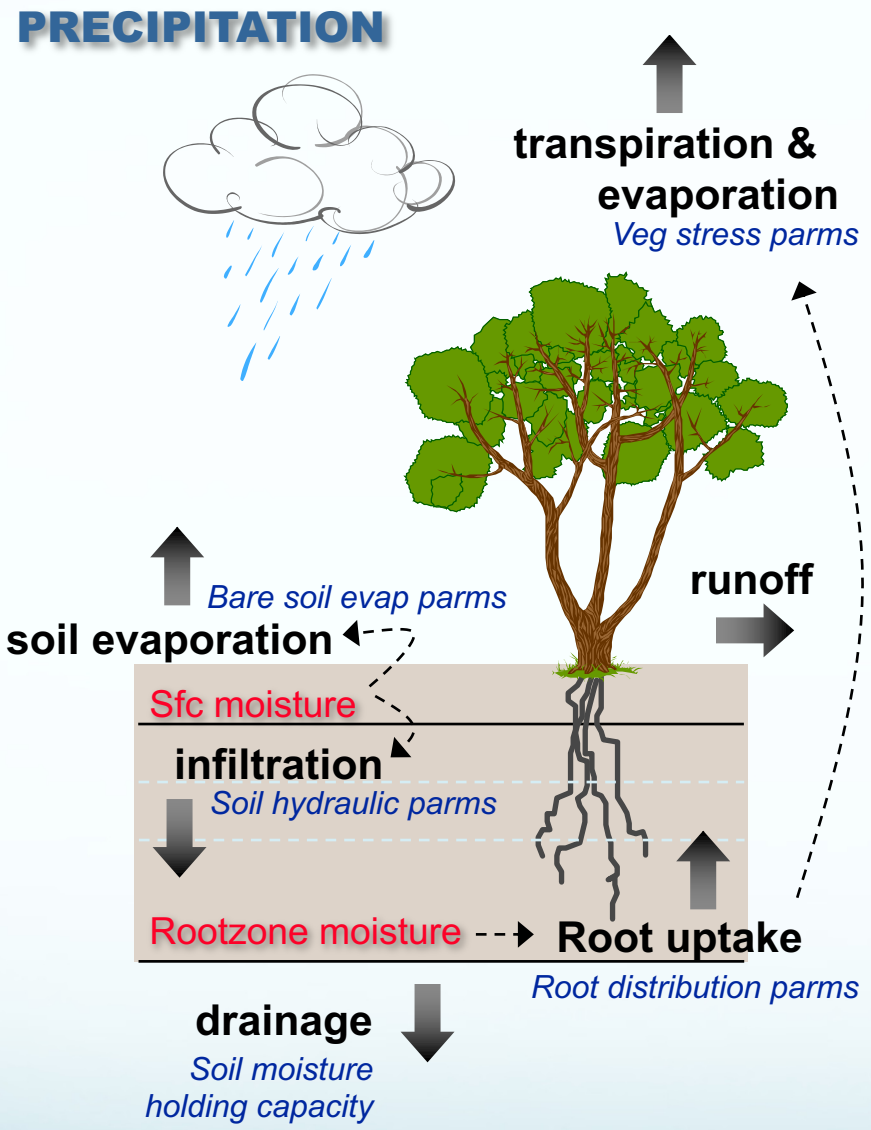
$$Q^* = H + LE \pm G$$

H = Sensible Heat Flux

LE = Latent Heat Flux

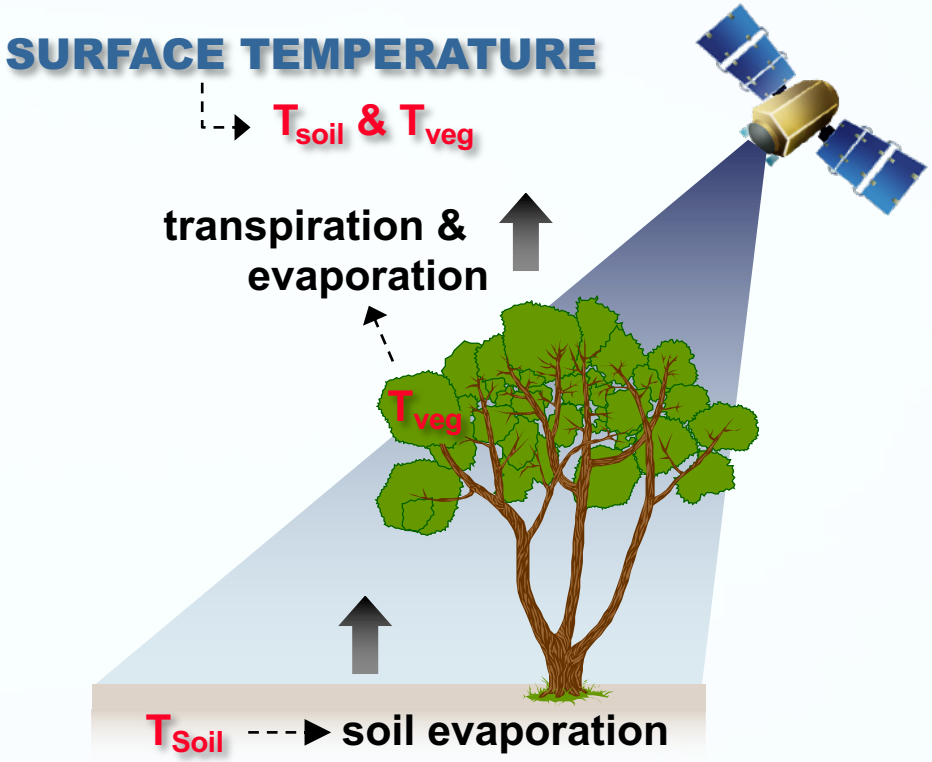
G = Storage Flux

Approaches to mapping ET



WATER BALANCE APPROACH

(prognostic modeling)



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

ENERGY BALANCE APPROACH

(diagnostic modeling)

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

Ag and Forest Meteorology, May 2014

GeoHealth: A Surveillance and Response System Resource for Vector Borne Disease in the Americas*

John B. Malone[1], Rebecca Christofferson[1] Prixia del Mar Nieto[1], Jeffrey Luvall[2], Mara Bavia[3], Elivelton Fonseca[4], Raul Guimaraes[4] Moara de Santana Rogers[1]

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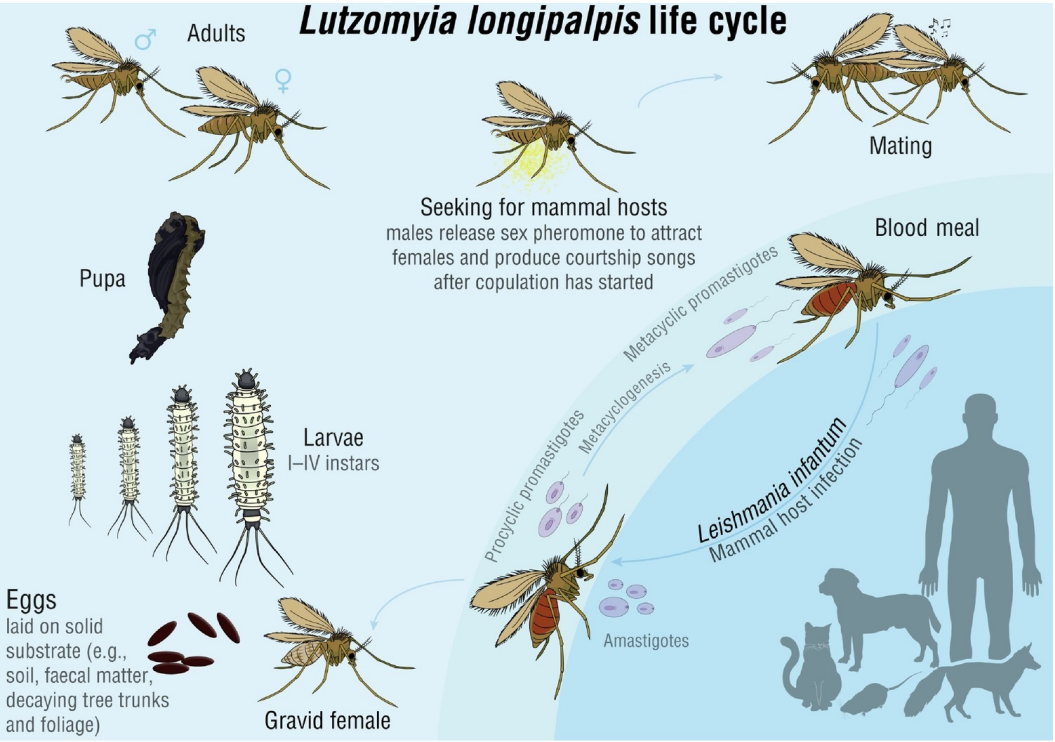
NASA ROSES A.50 Group on Earth Observations (GEO) Work Programme

Visceral leishmaniasis (VL) is a neglected tropical disease transmitted by *Lutzomyia longipalpis*, a sand fly widely distributed in Brazil. Despite efforts to strengthen national control programs for VL, reduction in its incidence and geographical distribution in Brazil has not yet been successful. VL is in fact expanding its range in newly urbanized areas. Ecological niche models (ENM) for use in surveillance and response systems may enable more effective operational VL control by mapping risk areas and elucidation of eco-epidemiologic risk factors

PHLEBOTOMINES (SAND FLIES) - BIOLOGY REVIEW

- Phlebotomines are the sole or principal vectors of *Leishmania*, *Bartonella bacilliformis*, and some arboviruses.
- Despite the importance of the vector, many aspects of the biology of sand flies are poorly understood, especially their breeding sites.
- Unlike mosquitoes, the immature stages of sand flies develop in terrestrial habitats with high humidity that are rich in decaying organic matter or humus.
- Sand fly breeding sites could be an alternative target for control since the immature stages are slow and comprise the longest phase of the life cycle. However, breeding sites are hard to identify as they can occupy a wide range of environments.

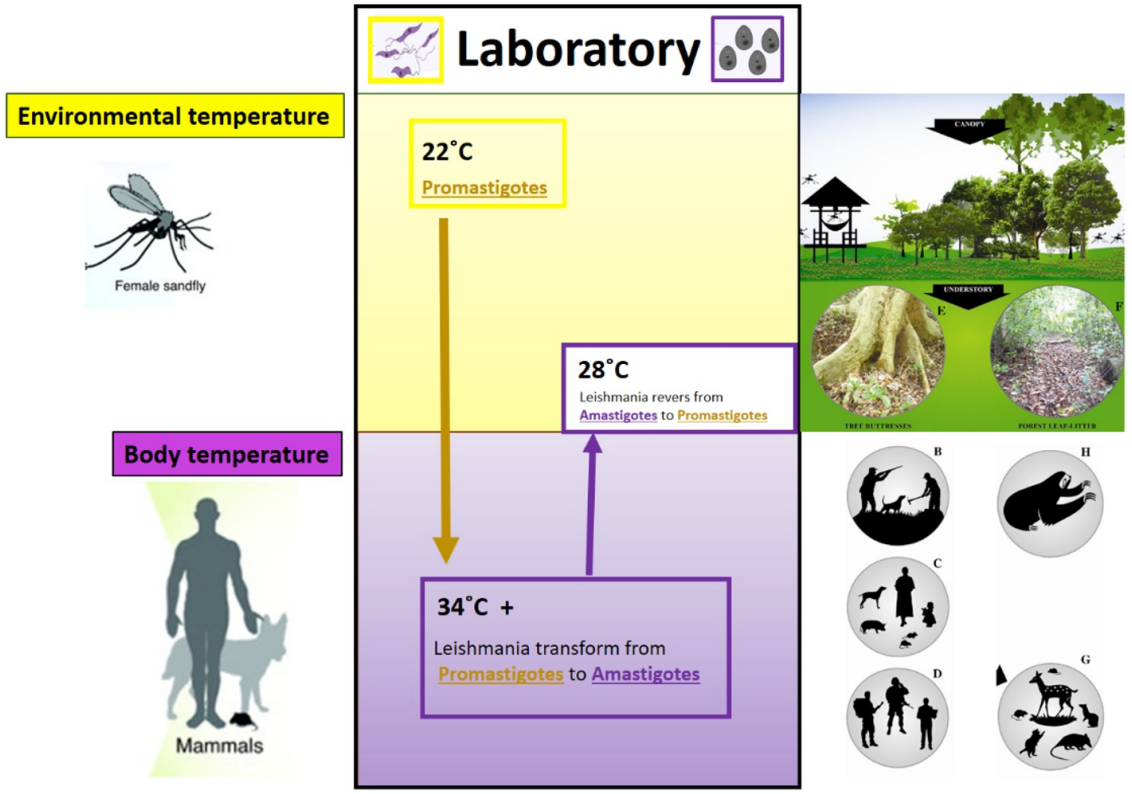


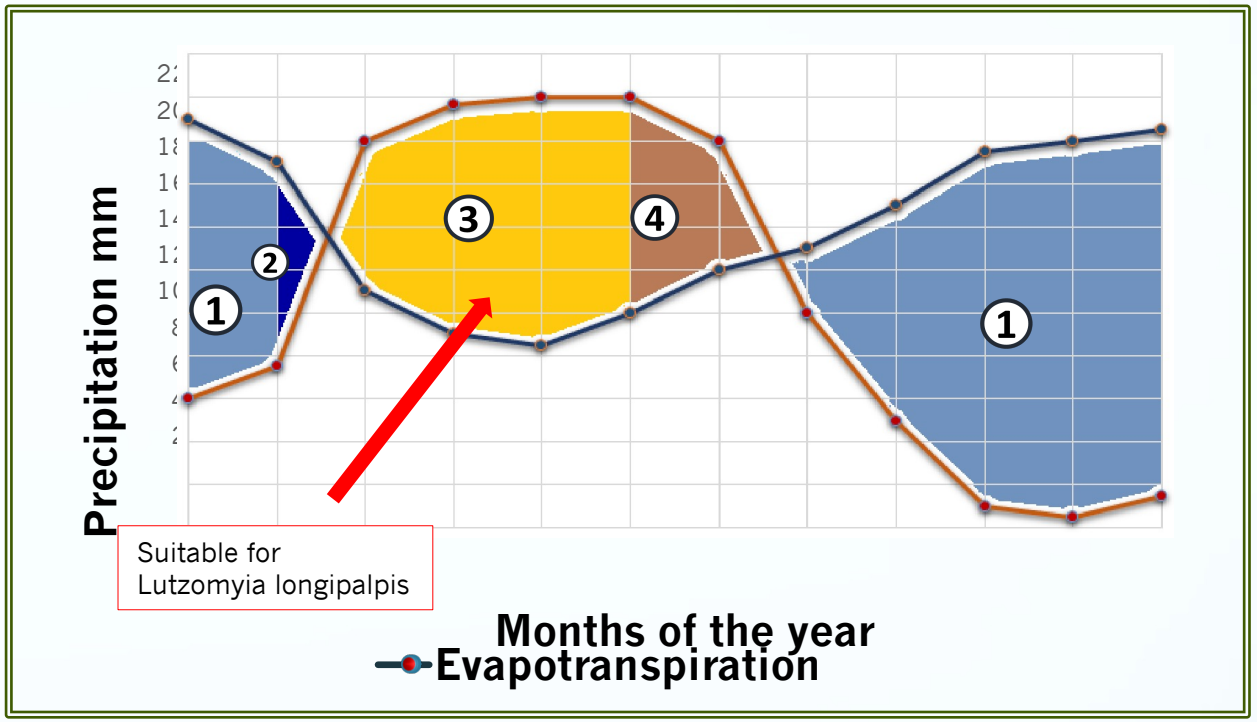
Trends in Parasitology

Developmental times, temperature, adults longevity and productivity of *Lu. longipalpis* colony as observed by different authors.

Developmental times	At room temperature 25°C[1], relative humidity 80%[2]. From engorge to the first emerge of adults is 35[3]-40[1]days Breed in less constant conditions (48-54)[1] (25-42)[2].
Hatching	4-9 days[1] and 6-9 days [2].
Larvae *First instar* *Second instar* *Third instar* *Fourth instar*	Larvae (four instars)14-19) days[2] 3-5 days (first week) [1] 2-4 days (second week) [1] 1-5 days (send week) [1] 3-9 days (third week) [1]
Pupae	Emergence from pupae on day 10[1] (most of the adults) and 8-9 days[2]. **Few males emerges as early as 7 days**[1]
Adults longevity	From 2 weeks-one month (adults are robust in rough conditions). In females that have taken blood is determined by when eggs are laid (few survive 24 hours after ovoposition). Most live for more than one month[1].
Productivity of the colony	23 generations in 36 months [1] 23/3= 7.7
Cultures of promastigotes and amastigotes	Promastigotes at 22 °C, amastigotes at 34 °C, reversion from amastigotes to promastigotes at 28°C[4]

[1]Killick-kendrick et al., 1977; [2]Rangel et al., 1986; [3]Modi and Tesh, 1983; [4]Aquino-Teixeira et al., 2002.

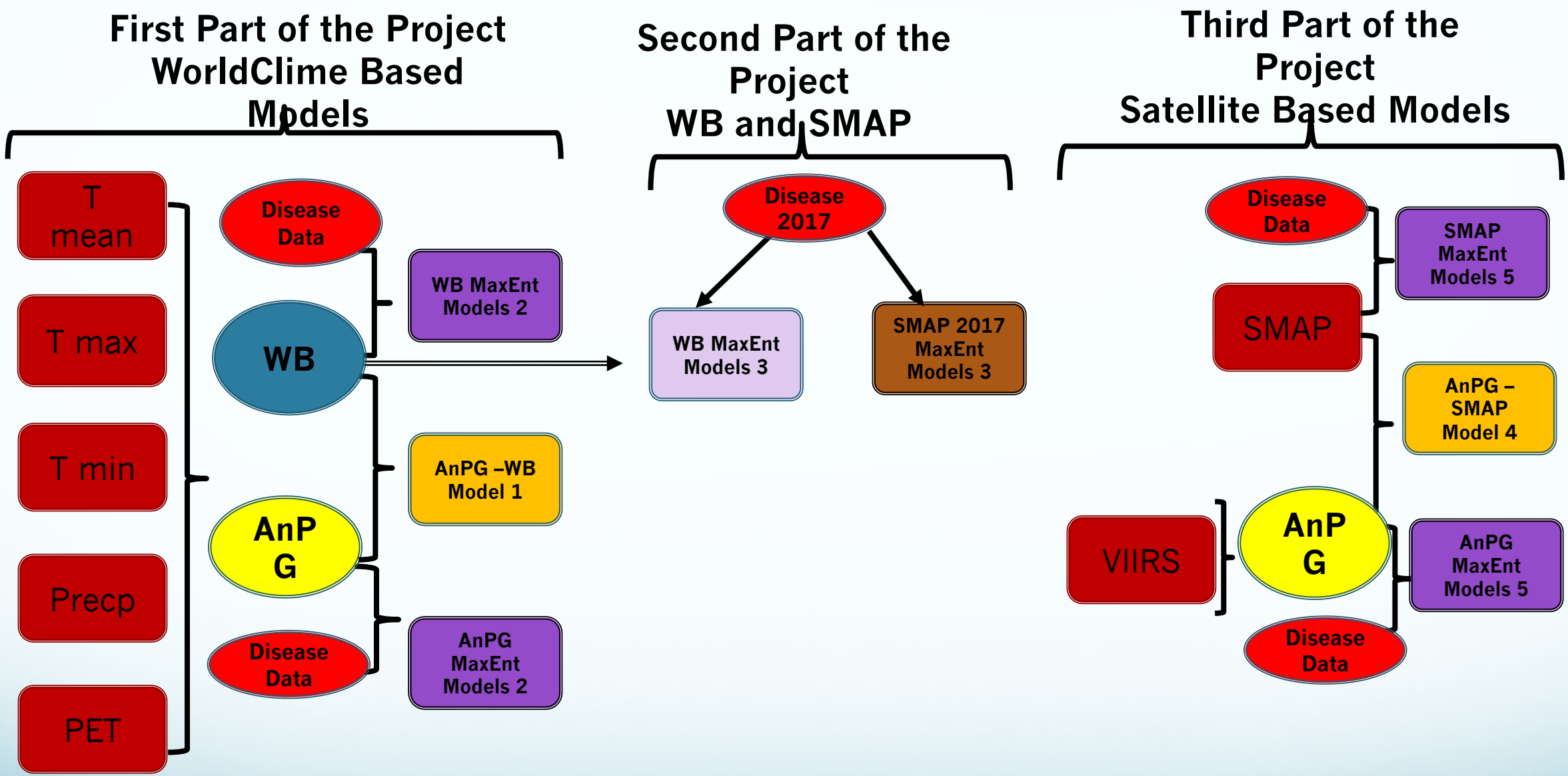




1. Soil Moisture Recharge
2. Soil Moisture Surplus
3. Soil Moisture Utilization
4. Soil Moisture Deficit

GDD (Heat accumulation) Growing degree day (GDD) – water budget (WB) analysis can be used to define the suitability gradient in the environment for propagation and transmission of the vector-parasite system.

GDD-WB (Water Balance) analysis is a method used for crop production models. Limited data is available on the environmental preferences and limits of tolerance of the *Leishmania chagasi- Lutzomyia longipalpis* system. In the present study, this analysis was used to define thermal hydrological suitability gradients in the environment for the VL vector *Lutzomyia longipalpis* in the state of Bahia, Brazil.



30 year average WorlClime and disease data (13 years BA; 20 years SP)	Water balance Vs SMAP 2017and SINAN human VL 2017 cases (BA and SP)	Monthly satellite 2018 data and SINAN human VL 2018 cases (BA)

Study #1
Environmental and Biological Risk Models to Predict Visceral Leishmaniasis in the State of Bahia , Brazil. 1990-2000

- Area of Study: State of Bahia.
- Parasitological data: Annual human cases.
- Data from 1990-2000 (collected by Fundação Nacional de Saude (FUNASA)).
- Vector developmental times, temperature, adults longevity and productivity of *Lu. longipalpis* colonies.
- Satellite data: AVHRR, MODIS.

Study #2
Environmental and biological Risk Models to Predict Visceral Leishmaniasis in the State of Bahia , Brazil.

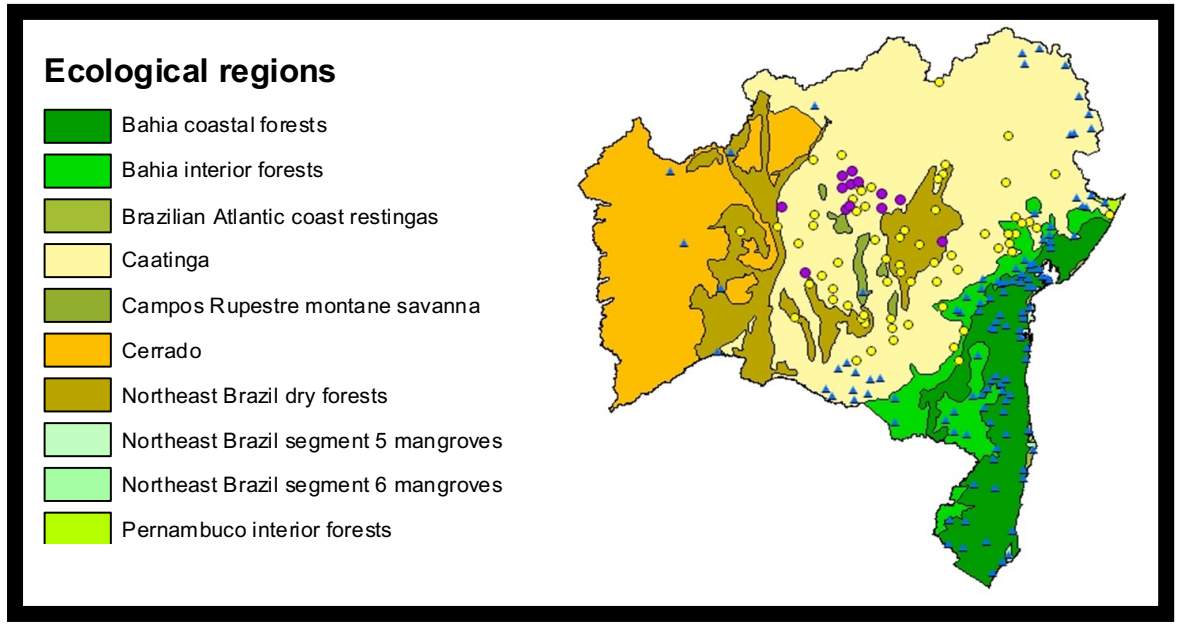
- Area of Study: State of Bahia.
- Parasitological data: Annual human cases.

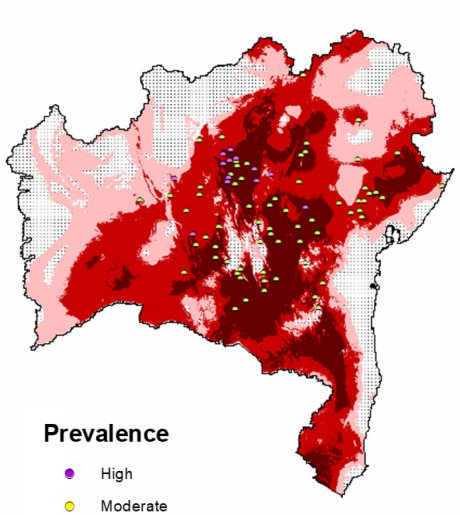
13-year period in **Bahia** State 2004-2018
20-year period in **Sao Paulo** State 1997-2018

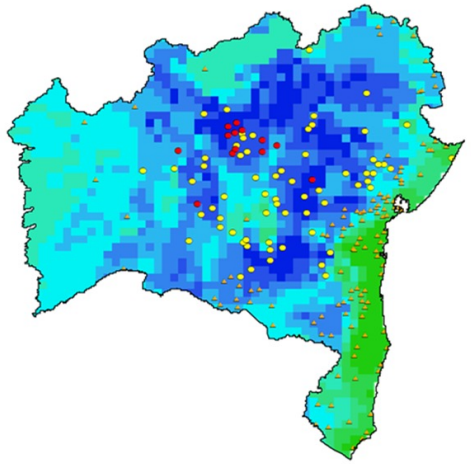
- Satellite data: **WorldClime** 30 year average

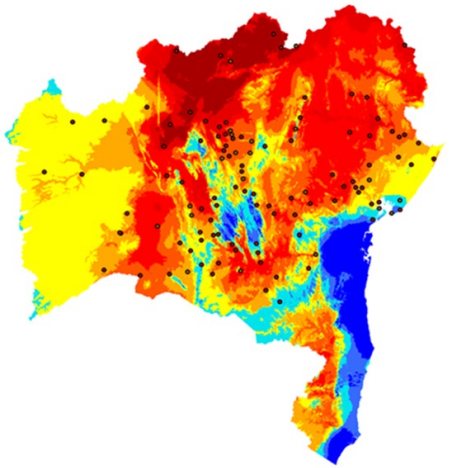
SMAP, GPM, VIIRS (2017)

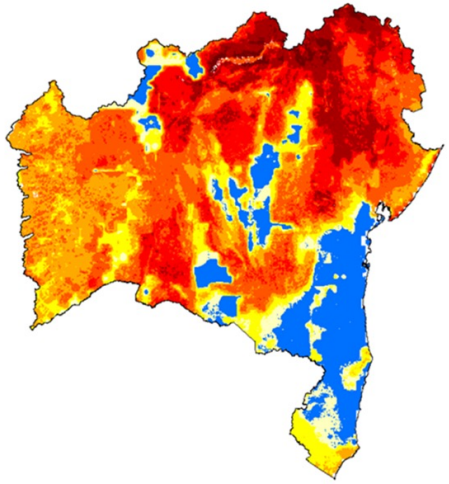
Prixia del Mar Nieto, Meraki Solutions LLC

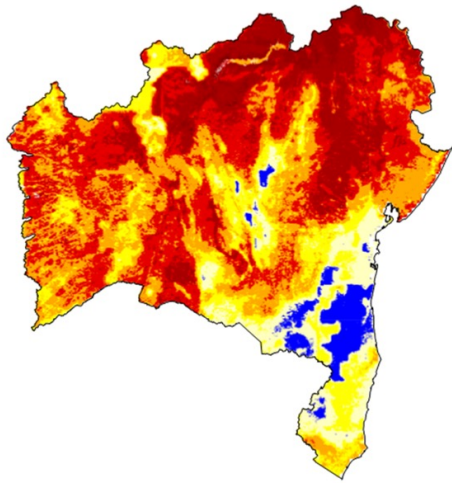












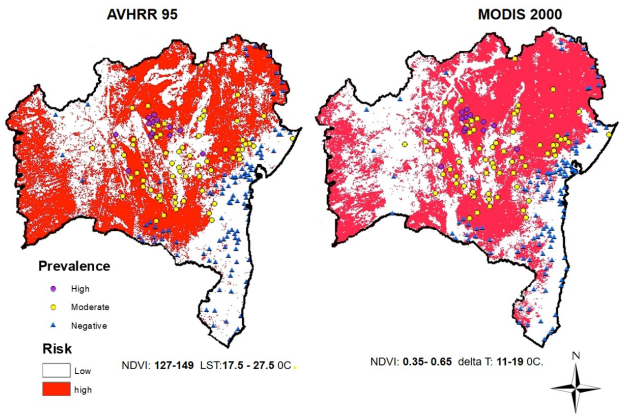
1990-2000

2004-2018

Satellite Based Models

State of Bahia , Brazil. 1990-2000

Buffers were used to extract values for statistical analysis.
Map queries were performed to establish ranges for different prevalences (high, moderate and low).



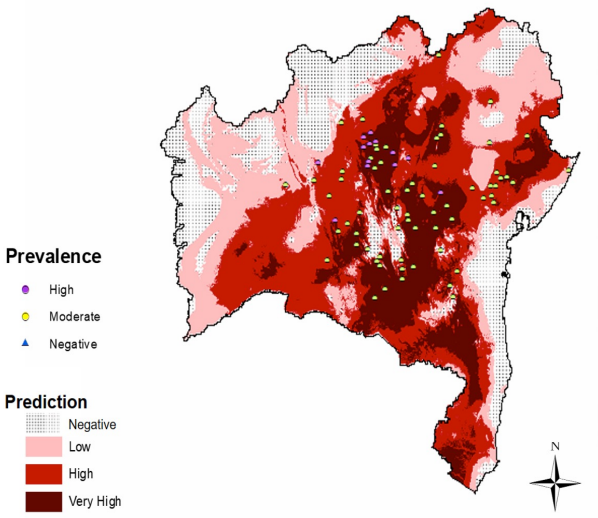
AVHRR
Variable: NDVI, population, mean LST, ecoregions
Variables statistically significant: NDVI, LST and ecoregions
NDVI: 127-149; LST:17.5-27.5 ^{0}C.
Elevation 436- 950 Mts.

MODIS
Variables: night temperature, day temperature, delta T and NDVI.
Variables statistically significant:
NDVI and delta t.
NDVI: 0.35- 0.65; delta T: 11-19 ^{0}C.

GARP Ecological Niche Model

State of Bahia , Brazil. 1990-2000

The GARP was run each of the eleven years (1990-2000). To optimize performance, 100 replicates/year were developed based on random 50-50 splits of available occurrence points (50% to run the GARP and 50% to test the model).

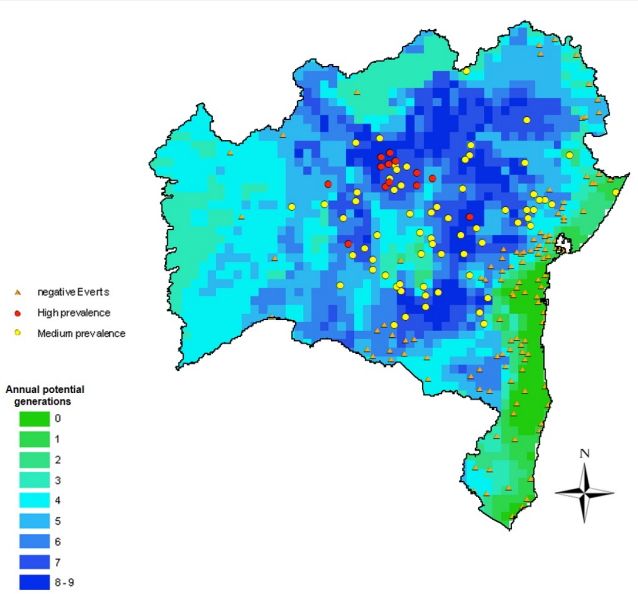


The best annual models were summed and ranked by the criteria of how many times each model predicted the same pixel within the endemic area. The final model predicts the areas where visceral leishmaniasis is most likely to happen during this period of time (11 years).

***Based on statistically significant variables obtained from satellite data queries.**

Vector Biology Model

Growing Degree Day-Water Budget Model. A 30-year average monthly climate surface grid (18 x 18 km cells) of South America included: Maximum temperature, Minimum temperature, Precipitation, Potential evapotranspiration (PET). Human VL prevalence data 1990-2000.



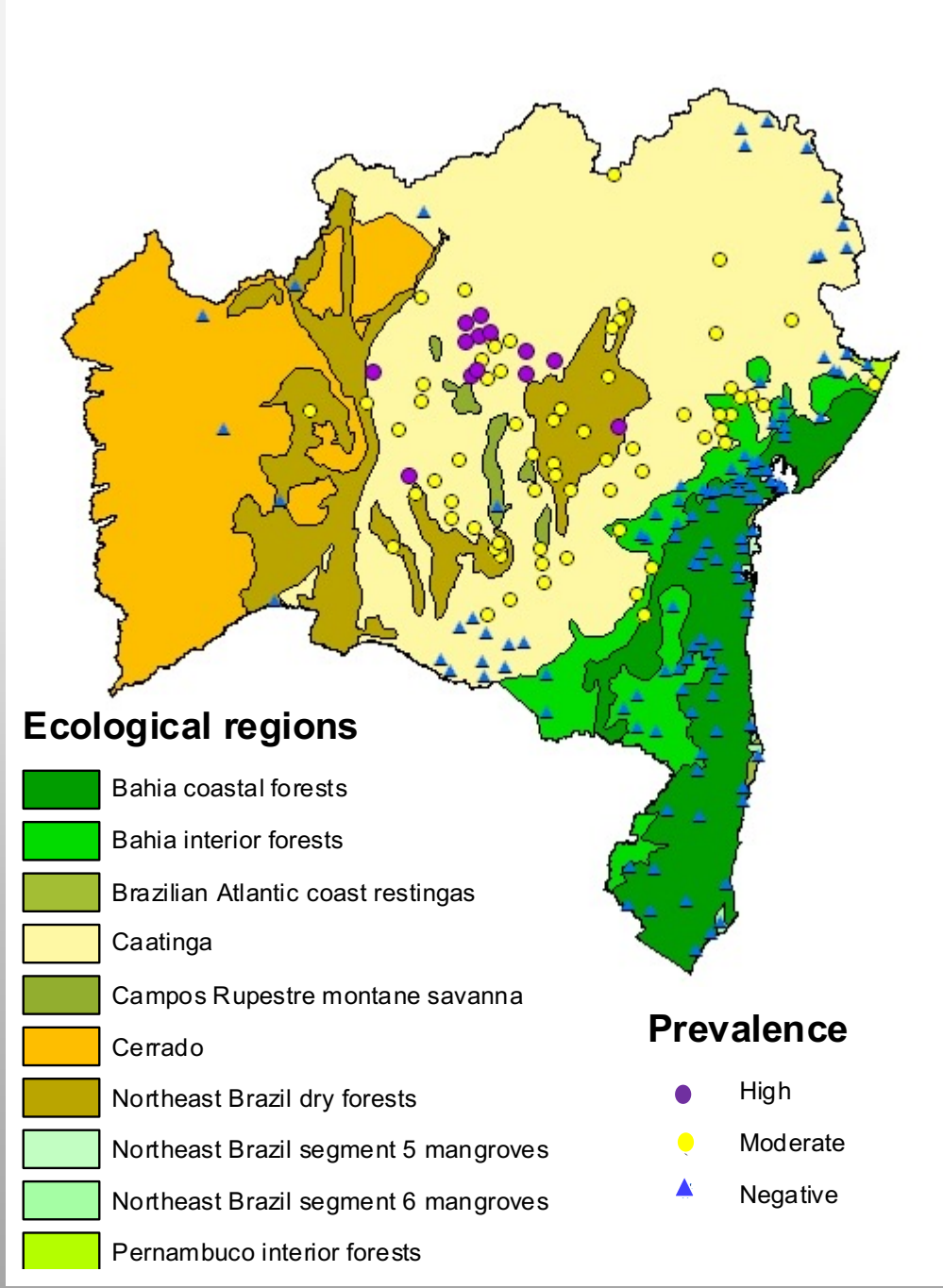
This model defines a suitability gradient in the environment for propagation and transmission of the *Lutzomyia longipalpis-Leishmania chagasi* system and calculate the potential number of generations per year.
Vector biology: Developmental data obtained from different studies where *Lu. longipalpis* colonies established and maintain in laboratory.

PPE or water Budget WB is a moisture accounting system used to indicate the presence of a suitable amount of soil moisture or surface water for development based on the water balance in the top layers of soil or ground surface.

GDD growing degree days
Number of the degrees over a based value (base temperature) below which no development of a species occur. A commonly used index of heat accumulation (crops)

AnPG annual potential generations
Number of potential generations that can be completed in one year

Prixia del Mar Nieto, Meraki Solutions LLC



Conclusions

-The AnPG ranged from 0-9

-High – medium prevalence all found in regions >5 generations

-Caatinga have at least 5 generations characterized as hot semiarid region

-Cerrado predicted to have 2-4 generations

-Most of the Bahia costal forest was predicted with 0-3 generations
Indicating low development of the vector and consequently low risk.

-Potential generations decrease proximity to east and west

-The High prevalence distribution of the disease is limited to
the central Plateau, where the vegetation in predominantly xerophilous.

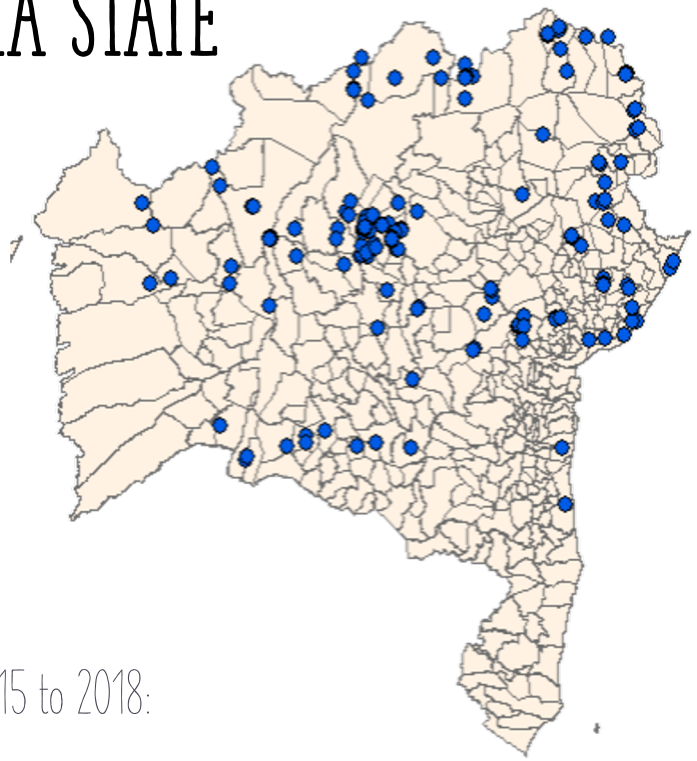
-GIS queries showed:

Max mean temperature for development was 28°C
Mean temp under no development can occur is 16°C

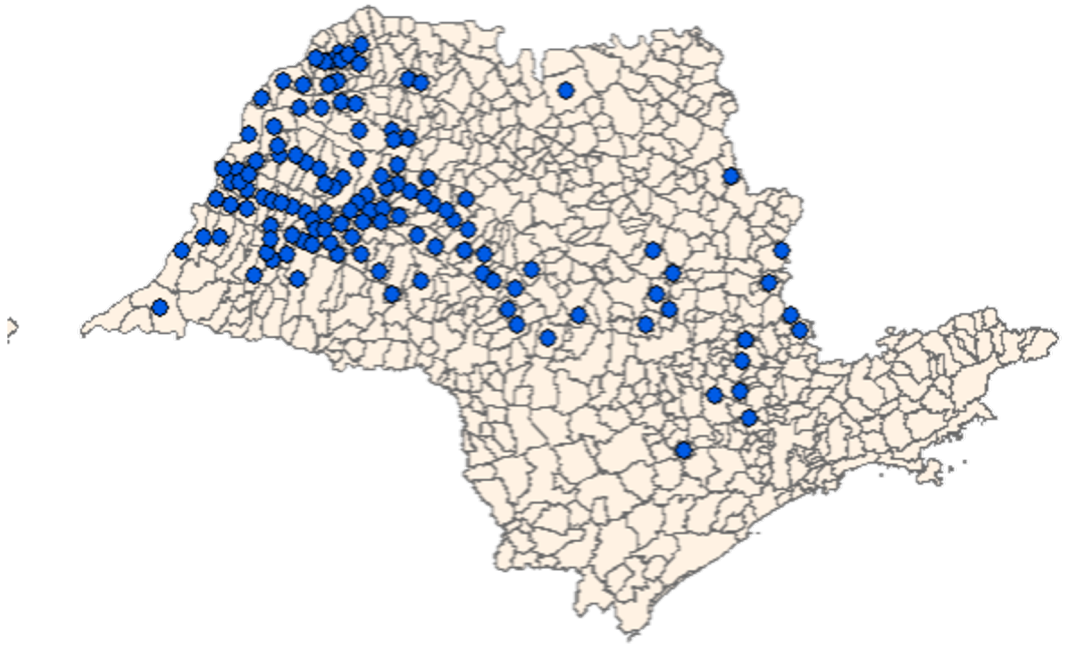
Prixia del Mar Nieto, Meraki Solutions LLC

SPATIAL DISTRIBUTION OF SAND FLIES

BAHIA STATE



SÃO PAULO STATE



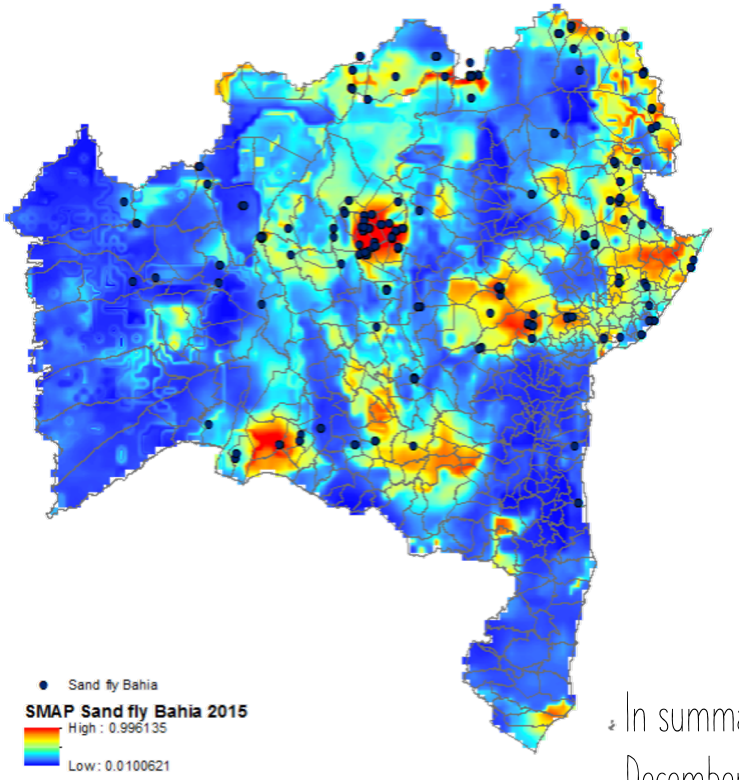
From 2015 to 2018:

VL Cases: 202 municipalities in Bahia; 62 municipalities in Sao Paulo

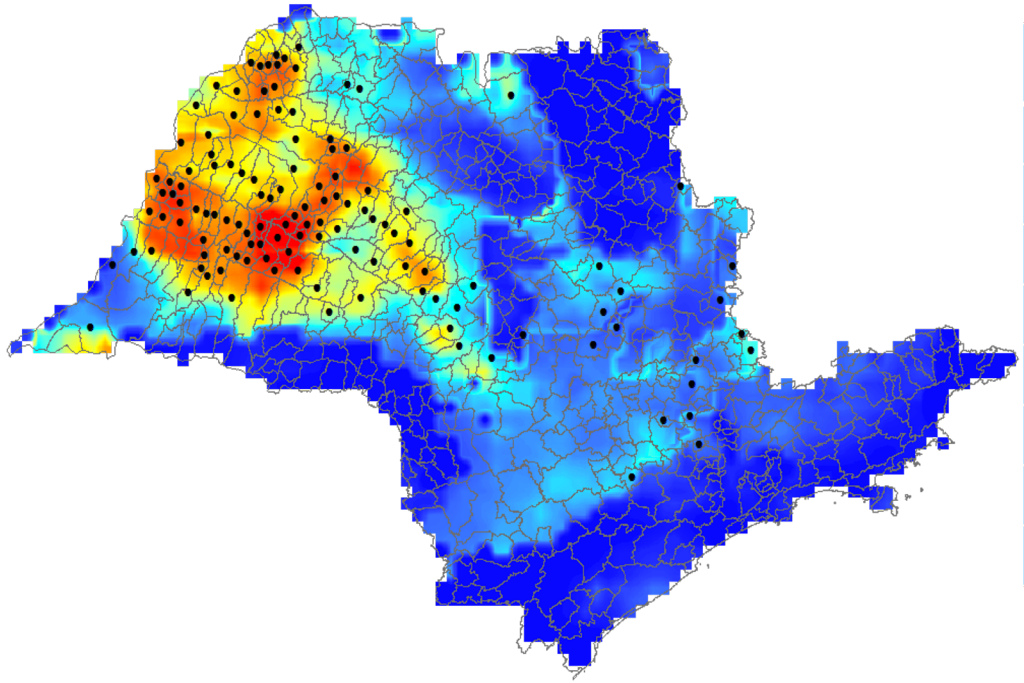
Vector: 76 municipalities in Bahia; 123 municipalities in Sao Paulo

SOIL MOISTURE - SMAP

BAHIA STATE



SÃO PAULO STATE

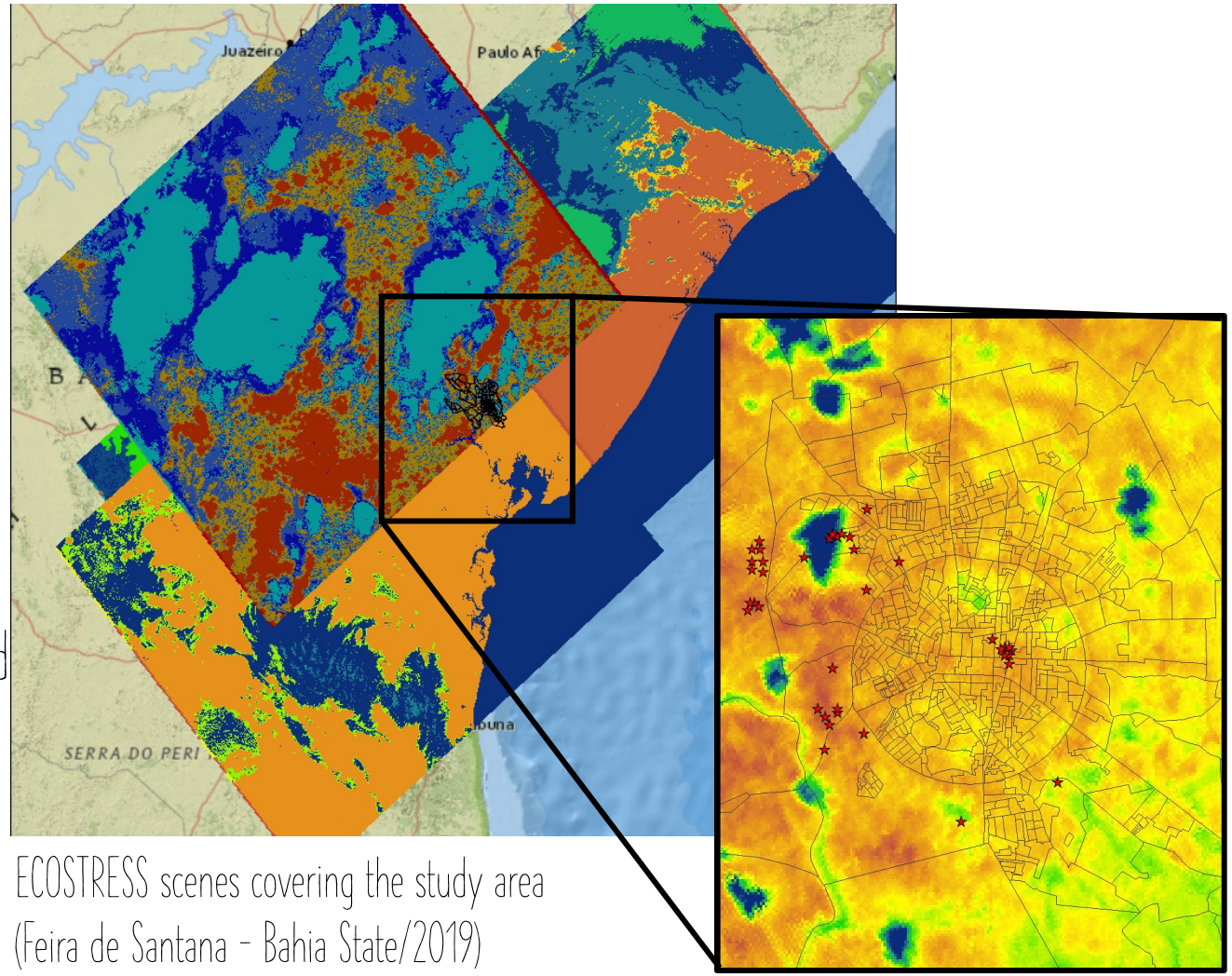


SMAP	Years	AUC	%Contribution	Jackknife test (Highest gain)	(Decrease gain)
SF BA	2015	0.85	SMAP 12 (44.2)	SMAP 12	SMAP 12
	2016	0.859	SMAP 11 (31.9)	SMAP 11	SMAP 01
	2017	0.828	SMAP 02 (20.8)	SMAP 02	SMAP 11
	2018	0.869	SMAP 01 (32)	SMAP 01	SMAP 12
SF SP	2015	0.869	SMAP 06 (29.3)	SMAP 08	SMAP 07
	2016	0.874	SMAP 11 (29.6)	SMAP 11	SMAP 11
	2017	0.878	SMAP 07 (27.2)	SMAP 06	SMAP 07
	2018	0.878	SMAP 06 (45.5)	SMAP 09	SMAP 02

- In summary, for the sand fly model in Bahia, it was possible to observe a seasonality for soil moisture that encompasses the period between December to February (Summer or dry season period)
- The sand fly model for Sao Paulo showed SMAP of June, July (Winter or wet season) and November as the most important variables.

ECOSTRESS USE AT THE MUNICIPALITY LEVEL

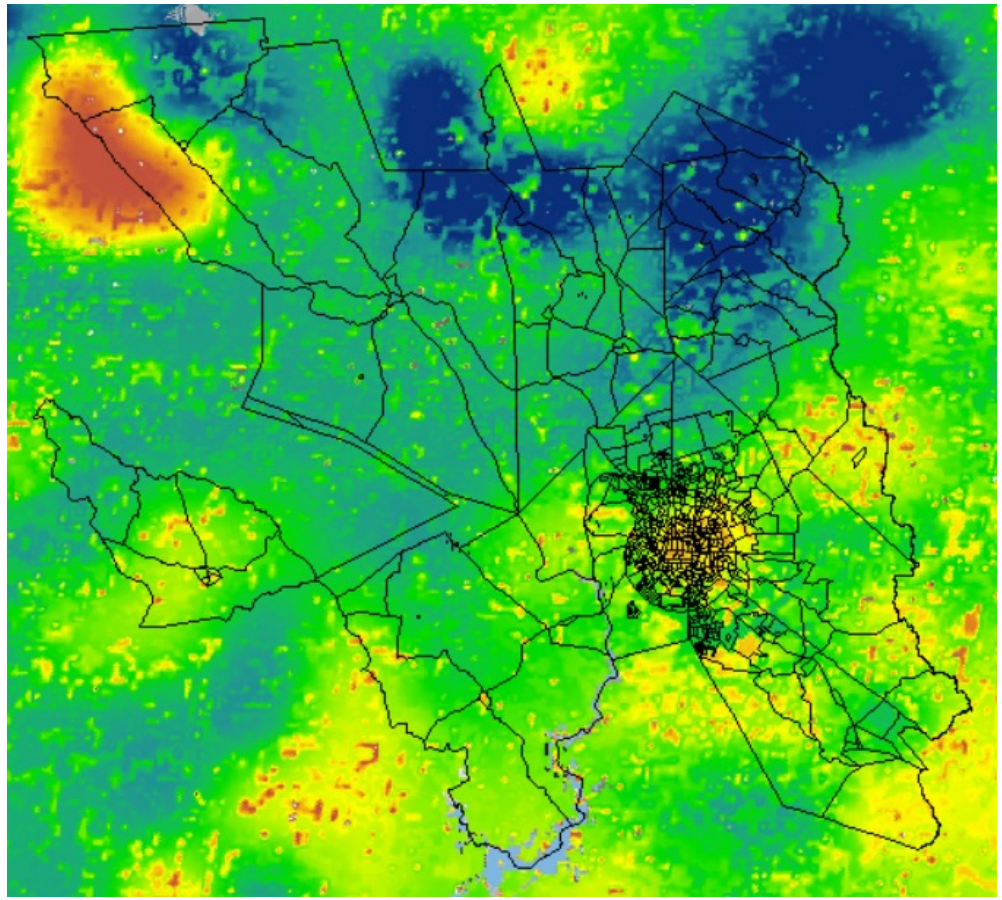
- Sand flies are dependent on climate, environmental, demographic, and human behavioral factors.
- Preliminary study extracted high resolution land surface temperature (LST), evapotranspiration (ET), evaporative stress index (ESI) and potential evapotranspiration (PET) measurements from the Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station data (ECOSTRESS 2018-2020), to produce fine resolution (70 m) maps of sand fly distribution models in Feira de Santana, Bahia, Brazil.



ECOSTRESS scenes covering the study area (Feira de Santana - Bahia State/2019)

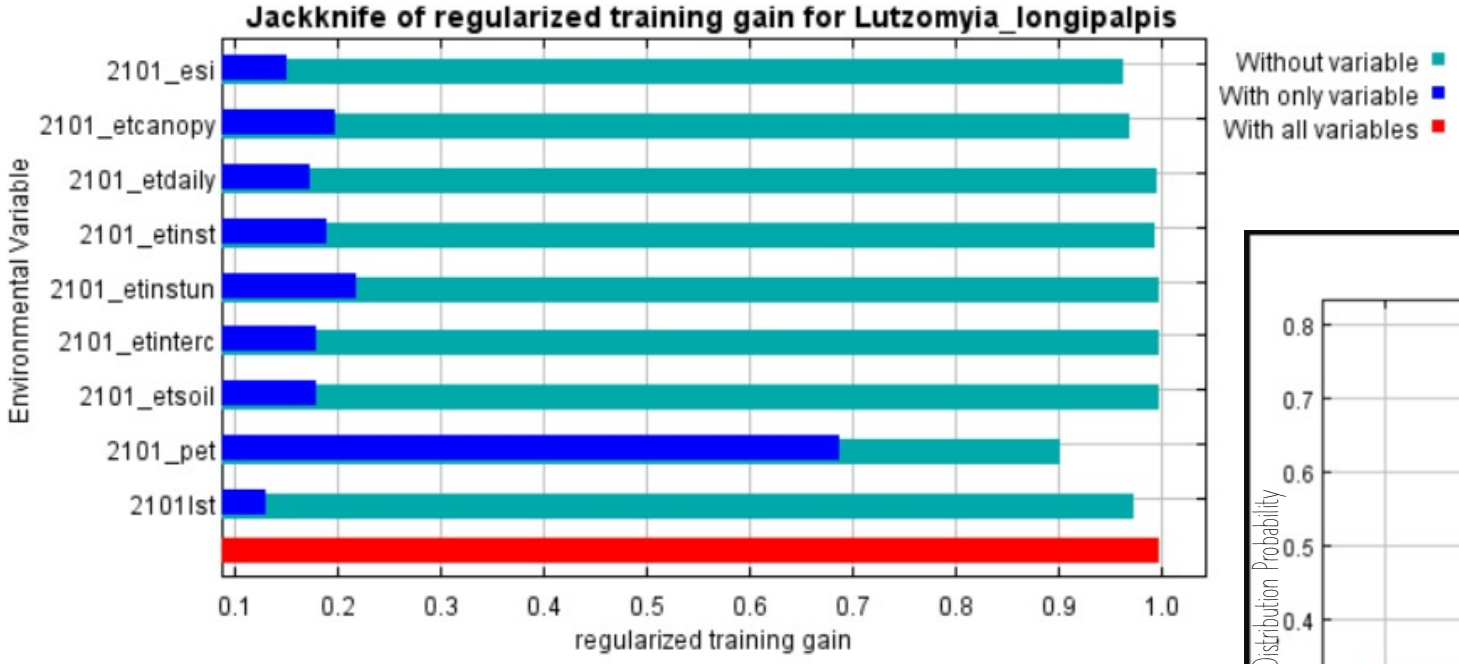
VARIABLE IMPORTANCE IN THE ENM MODELS

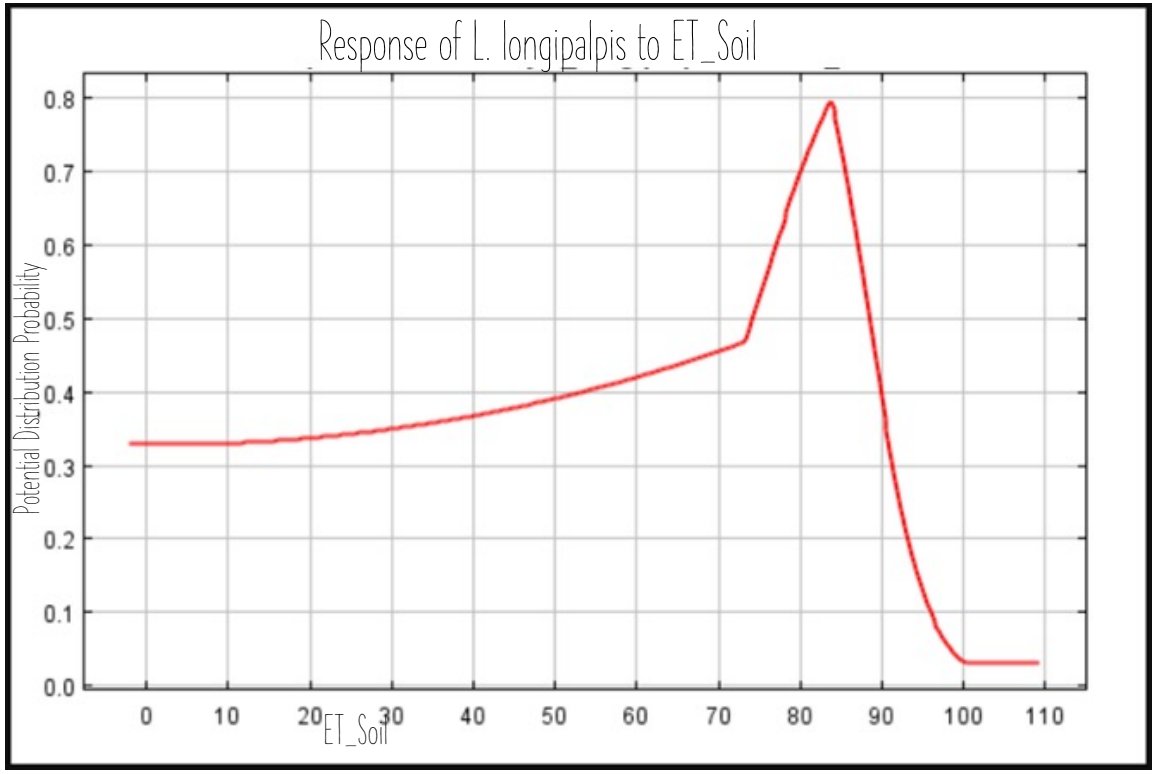
- *Lutzomyia longipalpis* (main vector of VL in the study area) ecological niche models (ENMs) found that potential evapotranspiration (PET) was the most contributing variable in the models (88%). The following variables from the evapotranspiration dataset: ET canopy, ET intercept and ET soil were also the most contributing variables in the ENMs after PET. Sand fly potential distribution decreases as the PET increases. Considering ET, the potential distribution of *L. longipalpis* increases as ET increases (ET soil being the most accentuated increase observed ET=increased peak between 74%, limiting at 85% (sharp decline in probability distribution).
- Many authors highlighted the role of soil conditions in spatial repartition of sand flies and also for characterization of sand fly breeding sites. High soil moisture provides favorable conditions for an increase in the sand fly abundance.



ECOSTRESS Evaporative Stress Index (ESI) – 2019

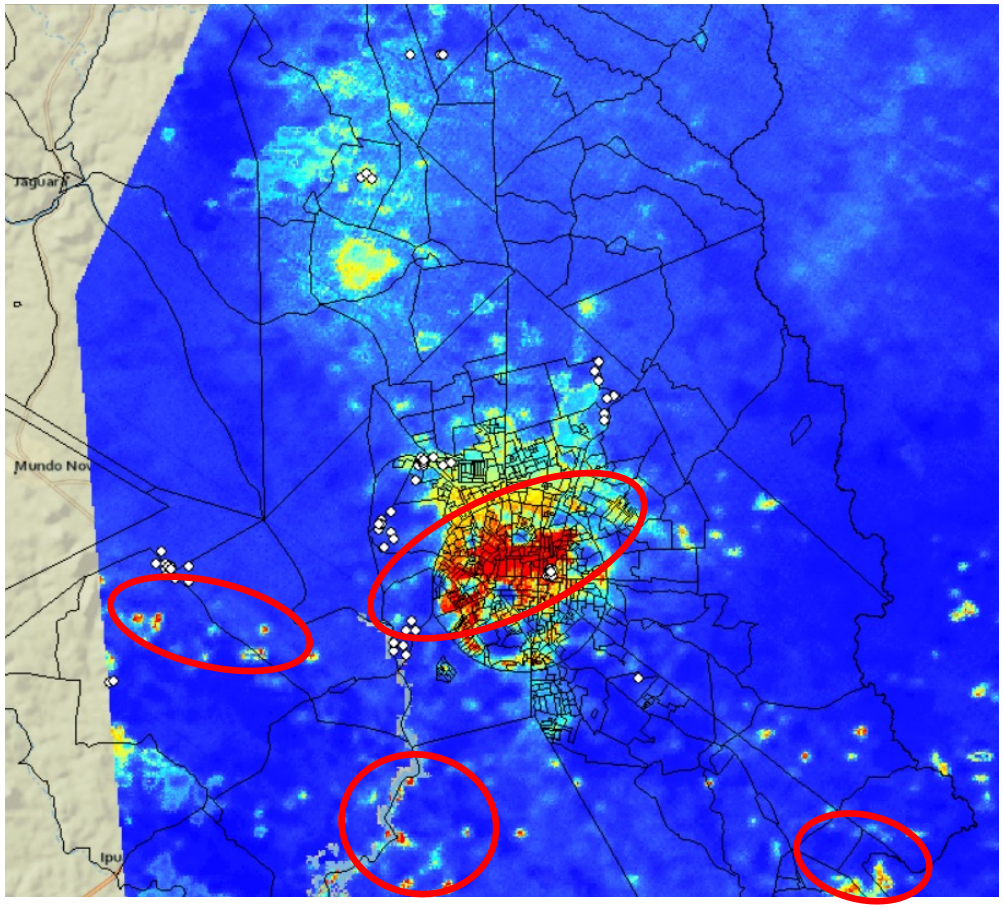
MAXENT ECOLOGICAL NICHE MODELS





PROBABILITY DISTRIBUTION OF SAND FLIES

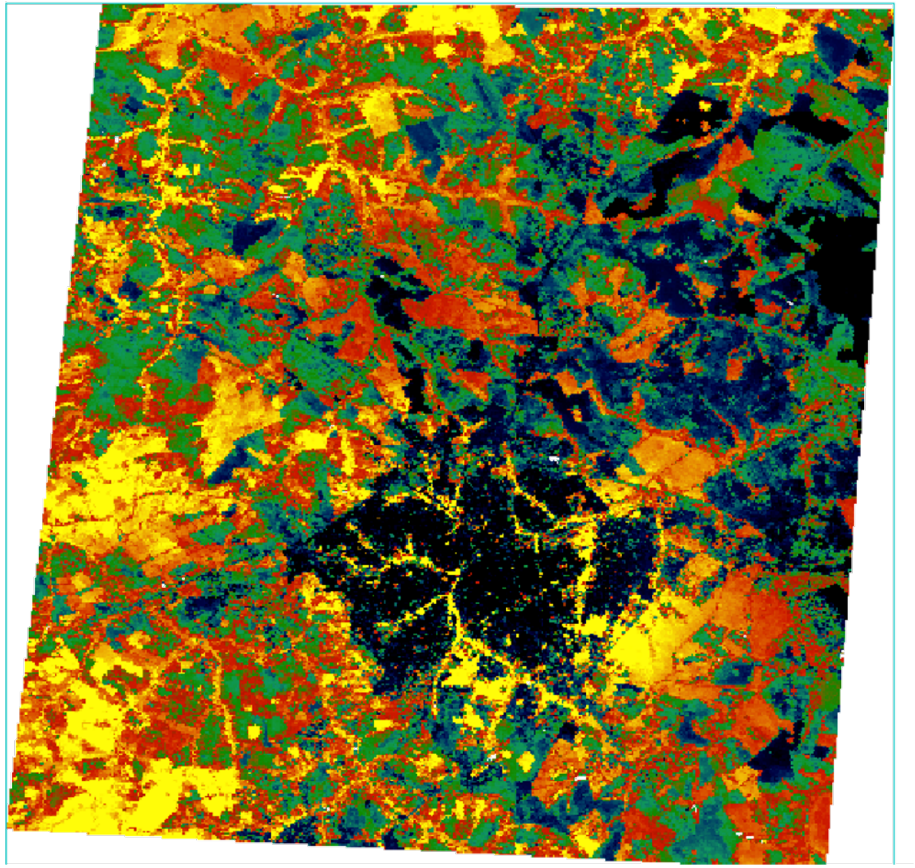
- Sand fly collection took place in rural areas of the district as well as in peripheric areas of the urban region. The ENMs demonstrated that *L. longipalpis* has a higher distribution probability in the center of the urban area despite no collection being done in this region. Some hotspots in the southwest/southeast region were also identified.
- The use of ECOSTRESS data to study vector biology can provide important information that can be used to anticipate areas of disease risk and characterize areas of surveillance priorities for leishmaniasis to guide the efforts for successful vector surveillance and control programs.



Species distribution probability generated using ECOSTRESS data (ESI, LST, ET, PET).

FUTURE DIRECTIONS

- Data point extraction to generate regression models for disease cases and sand fly presence using a wider range of images. Addition of current ECOSTRESS and disease data (Years 2020-2021)
- Comparison of Ecological niche model performance and similarities for ECOSTRESS vs SMAP.
- Evaluation and comparison of models in São Paulo State at the municipality level (Bauru)



Bauru study site

Submitted Publication:

Use of Soil Moisture Active Passive satellite data (SMAP) and Worldclim2 data to predict the potential distribution of visceral leishmaniasis and its vector Lutzomyia longipalpis (Psychodidae: Phlebominae) in Sao Paulo State and Bahia State, Brazil

Rodgers, MSM[1], Fonseca E[2], Nieto P[1], Malone JB[1], Luvall J[3], McCarroll JC[1], Avery RH[1], Bavia ME[4], Guimaraes R[2], Xue Wen[1], Silva MMN[4], Carneiro DDM[4], Cardim LL[4]
[1]Pathobiological Sciences, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA, USA; [2]Sao Paulo State University, Presidente Prudente, Brazil; [3]NASA Marshall Space Flight Center, Huntsville AL, USA; [4]Federal University of Bahia, Salvador, Brazil

Dissertations through the Interdepartmental Program in Veterinary Medical Sciences though the Department of Pathobiological Sciences, LSU:

Remote Sensing and Ecological Niche Models to Predict Visceral Leishmaniasis in the State Of Bahia, Brazil & Diagnosis and Clinical-Pathological Findings of Chagas Disease (Trypanomoma Cruzi) in Dogs in South Central Louisiana
Prixia del Mar Nieto Bedoya, DVM., 20008

The Use of Geographic Information Systems and Ecological Niche Modeling to Map Transmission Risk for Visceral Leishmaniasis in Bahia, Brazil
[1]Moara de Santana Martins, 2015.

[1]Former NASA DEVELOP National Program – Summer 2011 (Team Member)– Summer 2012 (Team Leader)

Incorporating NASA Earth Science Data into the DHIS2 Health Information System

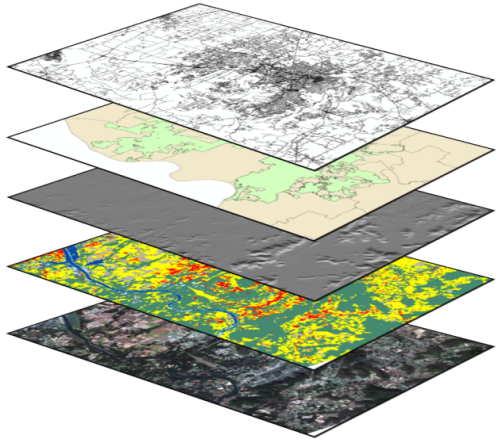
April 12-14, 2022

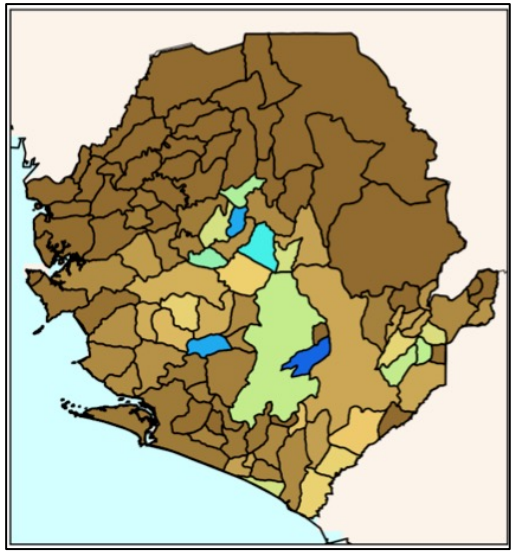
Presenter: Jeffrey Luvall
Marshall Space Flight Center NASA

*Co-Authors: *John Beck, *T. Berendes, *U. Nair, **J. Painter*
UAH,CDC*

NASA Earth Observations for Health Information Systems (NEOH)

- Researchers at the University of Alabama in Huntsville (UAH) in collaboration with the U.S. Centers for Disease Control and Prevention (CDC) and NASA have developed a layer of web services to ease the complications of accessing NASA Earth observations from multiple repositories with myriad datasets.
- The web services are designed to integrate with public health software already in-use by nearly all malaria endemic countries and provide several key earth observation datasets that are pre-aggregated to regional and sub-regional administrative areas within each country.





District Health Information System 2 (DHIS2)

- NEOH services are currently being utilized in support of a web application for the District Health Information Software 2 (DHIS2) system that is used widely across at least 73 countries.
- In most of these countries, for example, monthly counts of malaria cases (malaria incidence) are reported to the DHIS2.
- The frequency and geospatial areas of the earth observation data are designed to match those of malaria case, thus facilitating comparisons and correlations of earth observation data with malaria incidence.

Project Objectives

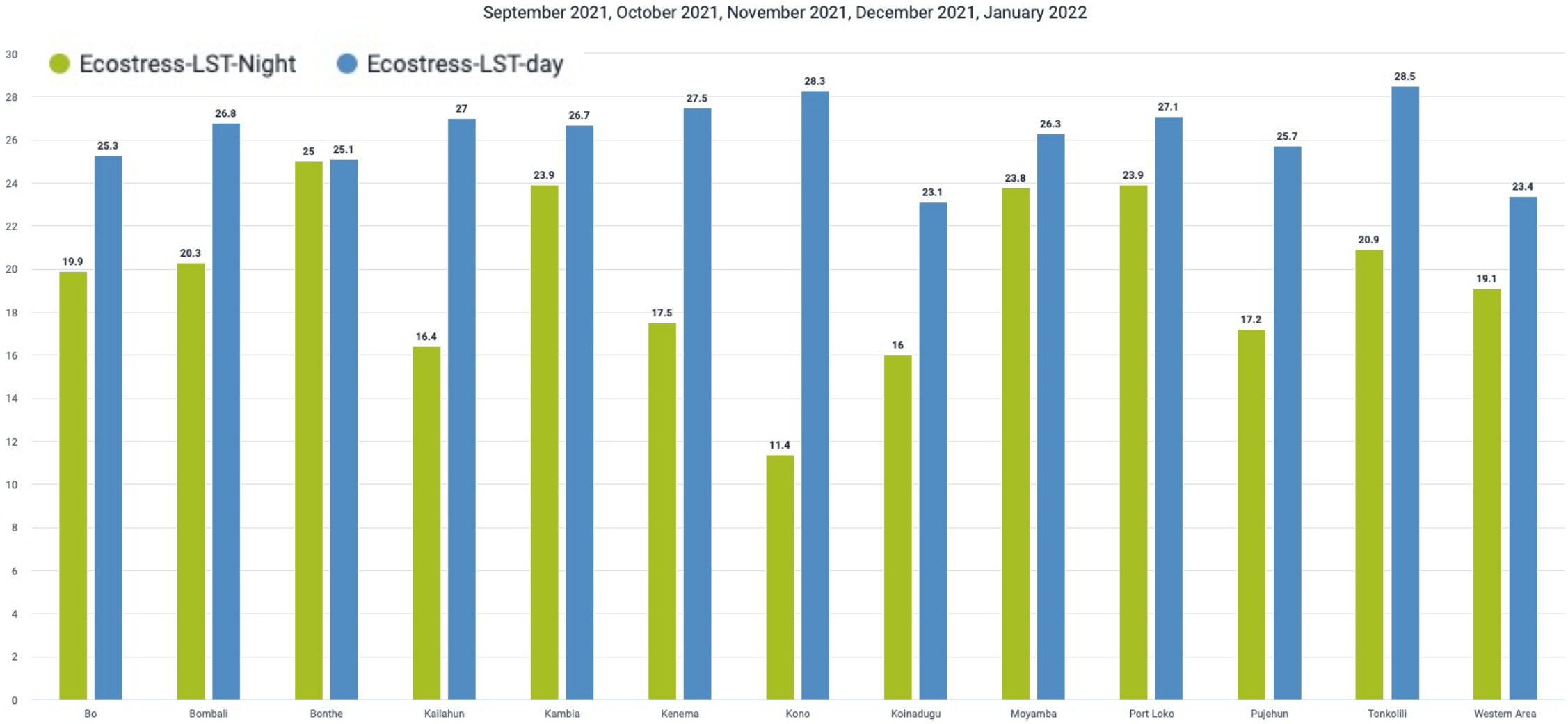
- Enhance health decision making for malaria control by integrating the latest relevant **NASA Earth observations** (Precipitation, Temperature, and Vegetation Health) into an existing decision-making activity through a DHIS2 web application.
- Demonstrate that **integration of environmental data with disease and health information** will provide disease control decision makers with the integrated, accurate, and up-to-date situational view needed to optimize interventions.
- Develop and deploy a technology solution that will provide a path to long-term sustainability for the use of NASA Earth observations to end-user **health decision makers**.

ECOSTRESS Surface Temperatures

- One of the key Earth observations needed for this project is surface temperatures.
- NEOH services were developed to ingest and process ECOSTRESS surface temperatures into DHIS2 through our Web Application.
- Our services allow for the ingestion of both day and night pairs.

ECOSTRESS Surface Temperatures

An example of NASA's ECOSTRESS derived Land Surface Temperature (LST) Averages in Celsius for each district in Sierra Leone.



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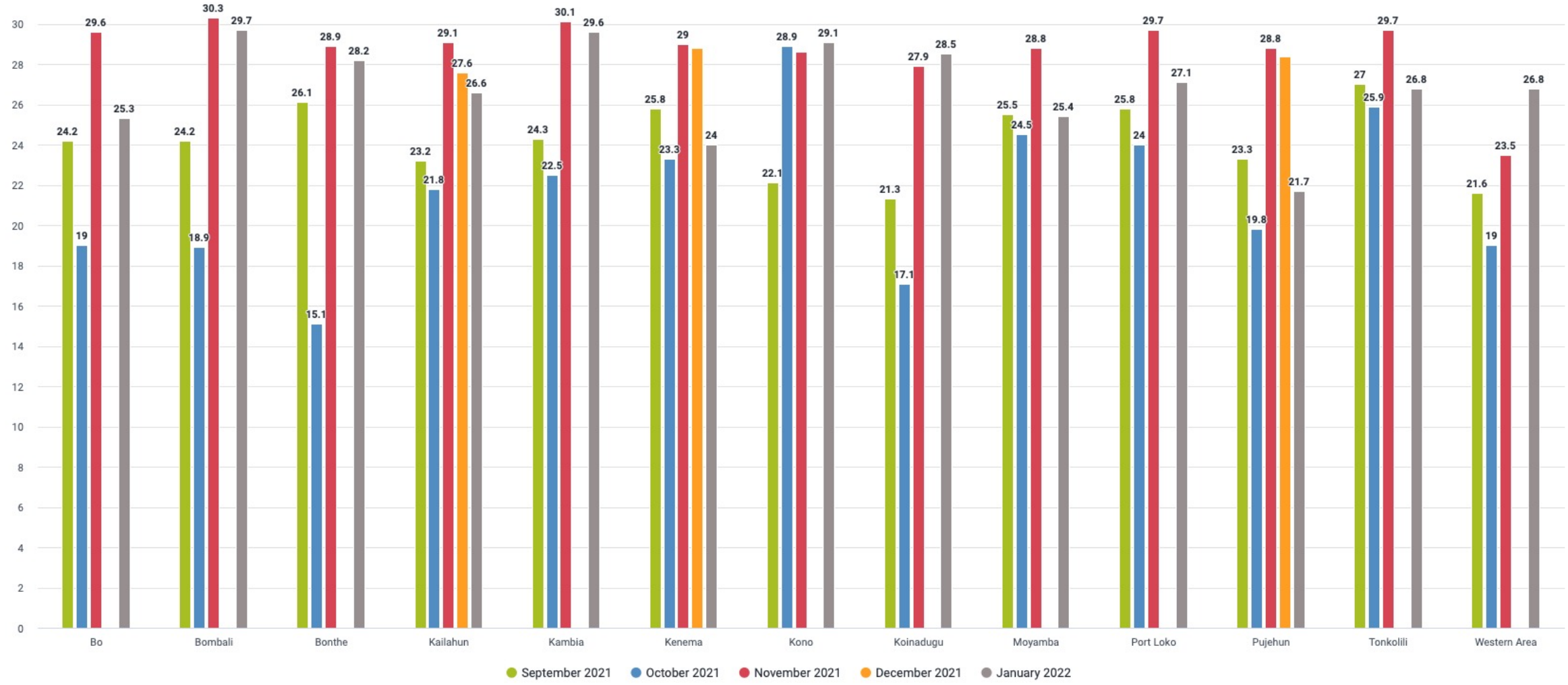
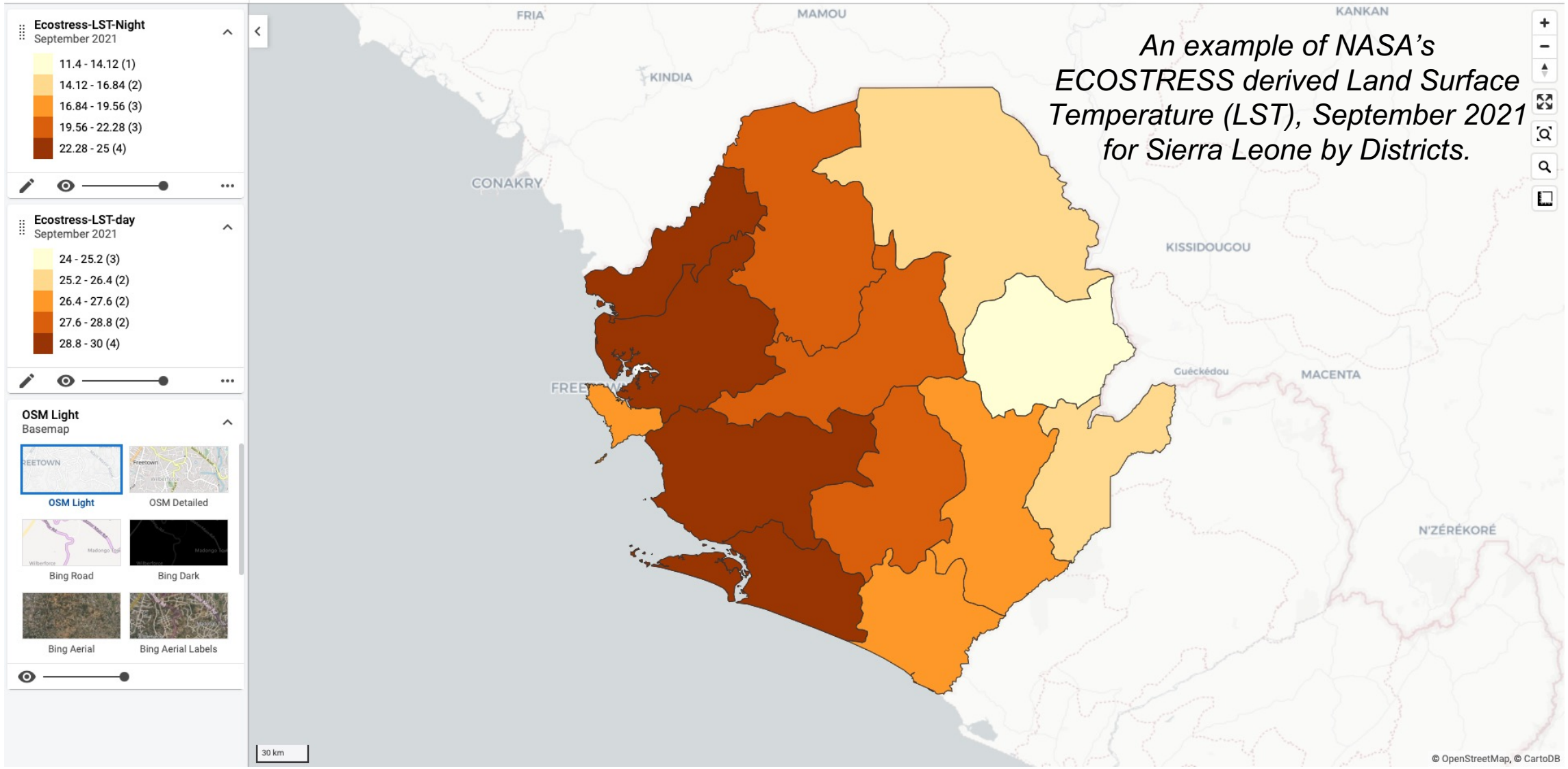
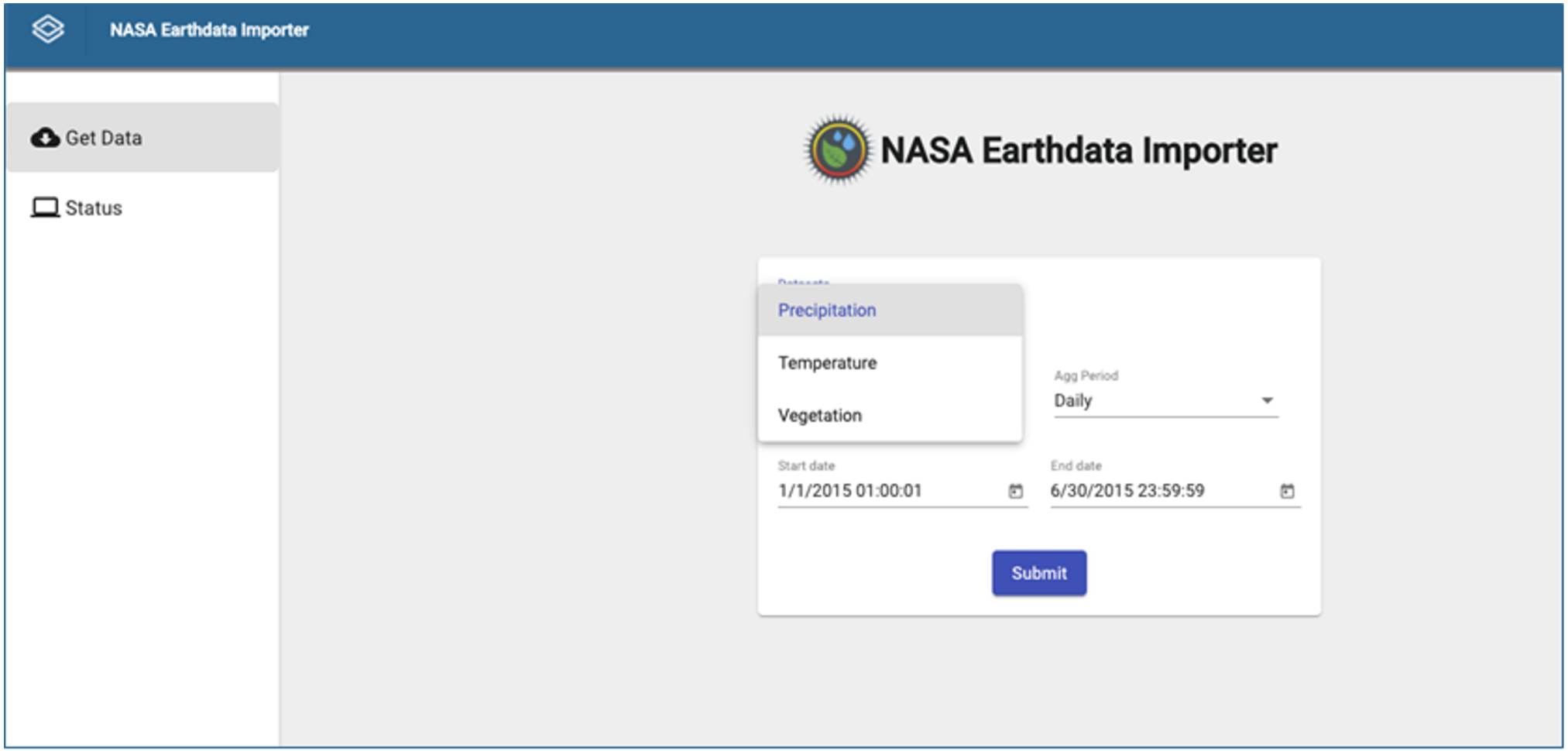


ECOSTRESS Surface Temperatures



An example of NASA's ECOSTRESS derived Land Surface Temperature (LST), September 2021 for Sierra Leone by Districts.

DHIS2 EO Import App



Web Application Interface for the NASA Earthdata Importer for DHIS2.

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