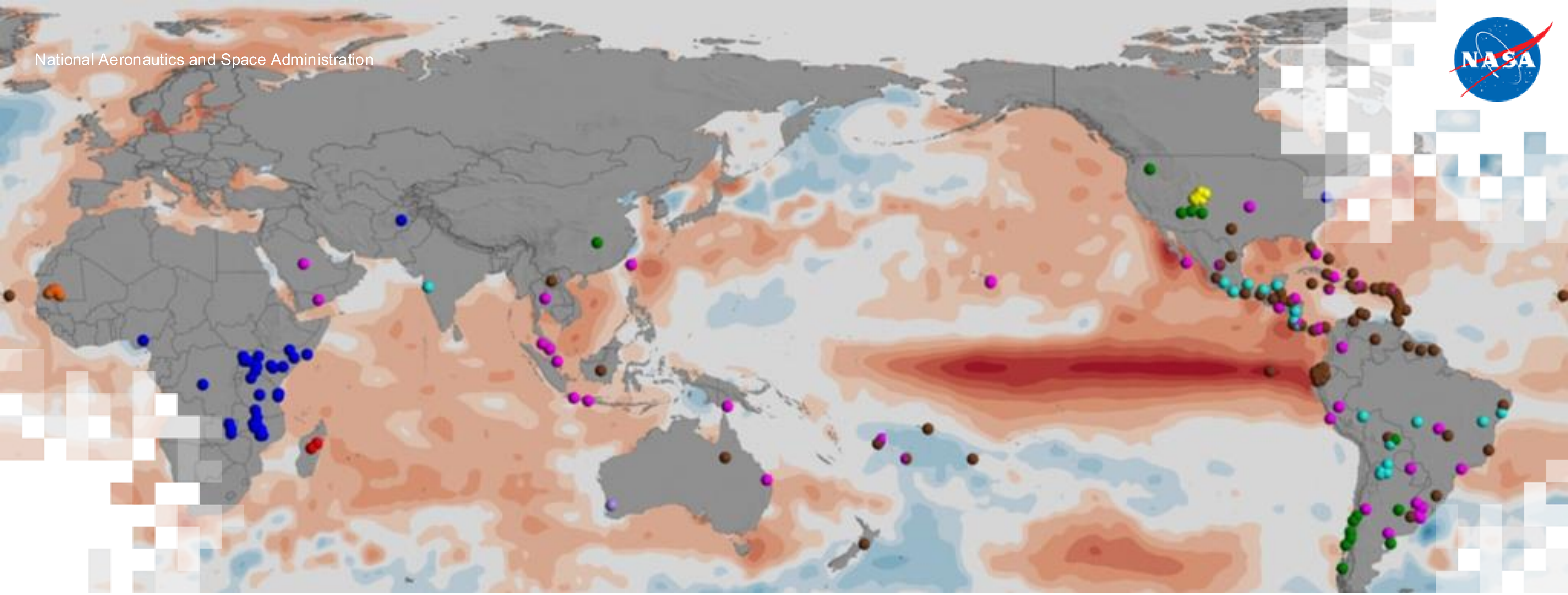
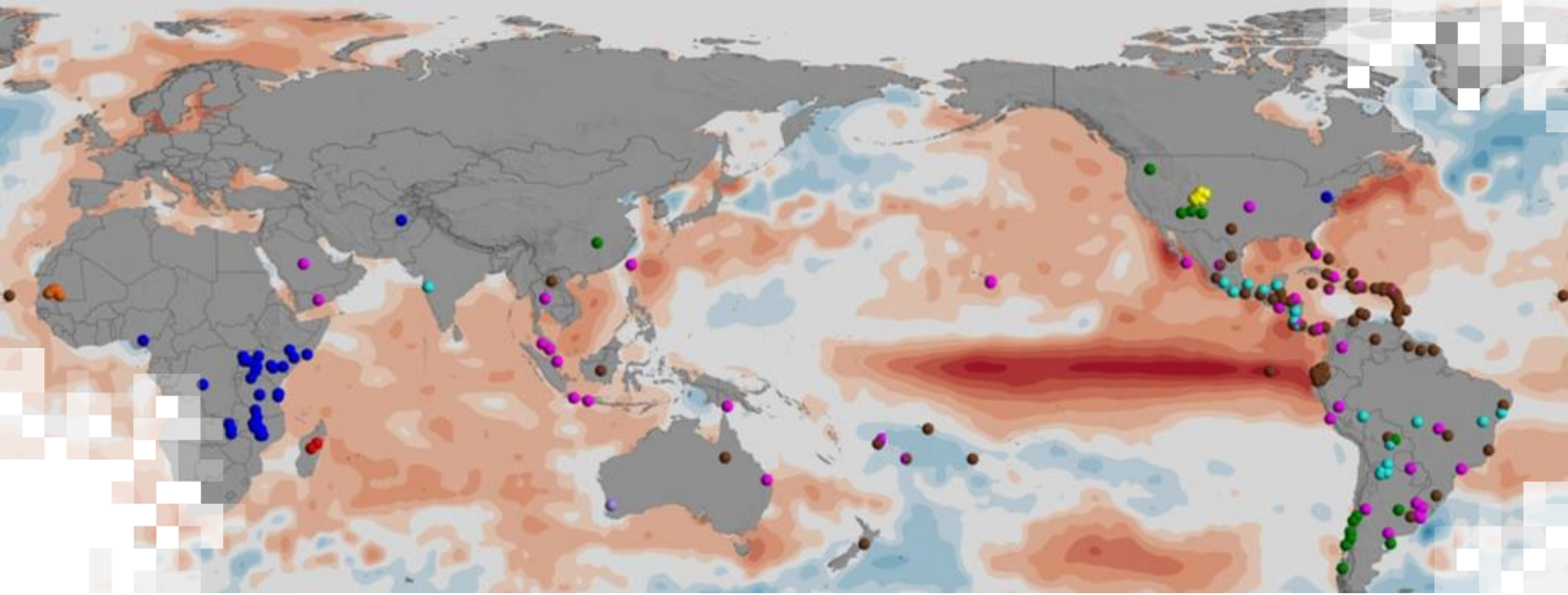


Remote Sensing for Climate-Sensitive Infectious Diseases

Part 1: How Remote Sensing Can be Used to Study Climate-Sensitive Infectious Diseases

Assaf Anyamba (UMBC/NASA GSFC), Tatiana Loboda (UMCP), Michael Wimberly (OU)

October 7, 2025



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

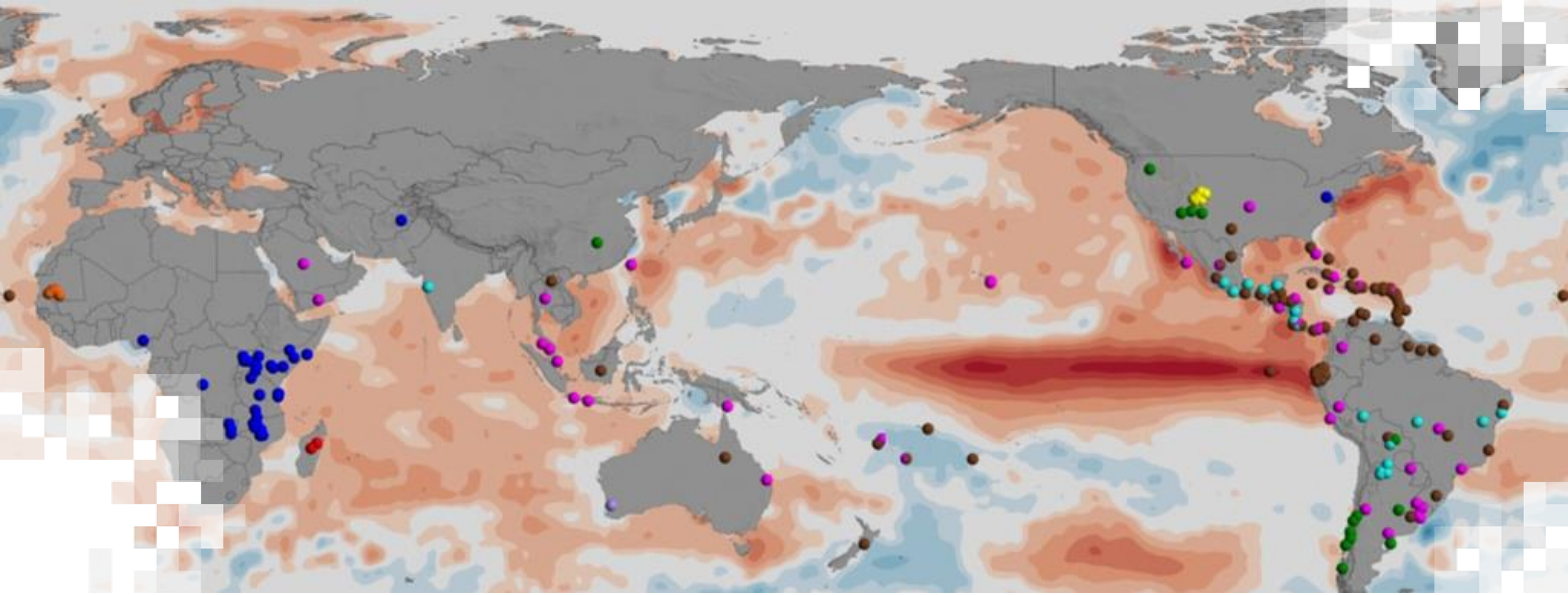
WATER RESOURCES

WILDLAND FIRES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

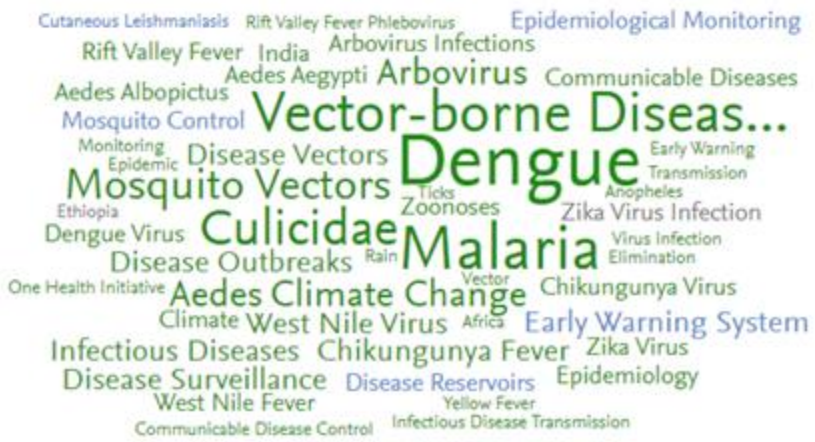
- Visit the ARSET website to learn more.

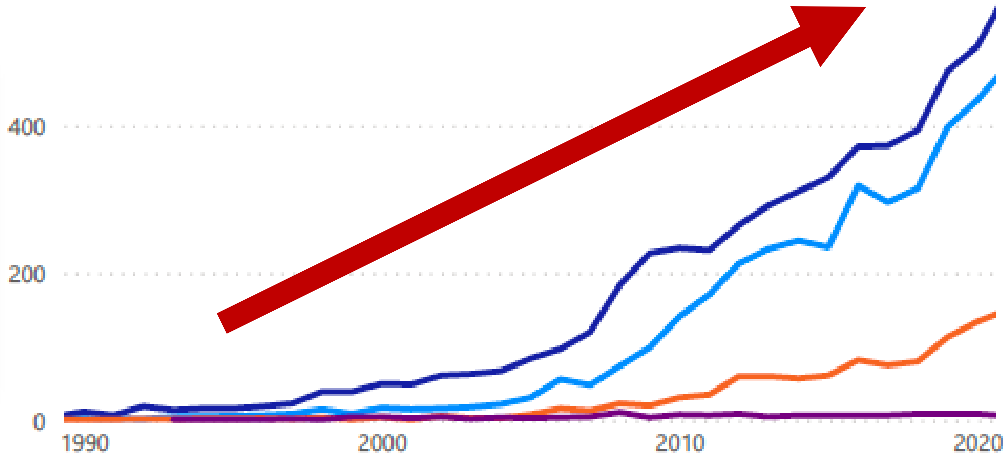


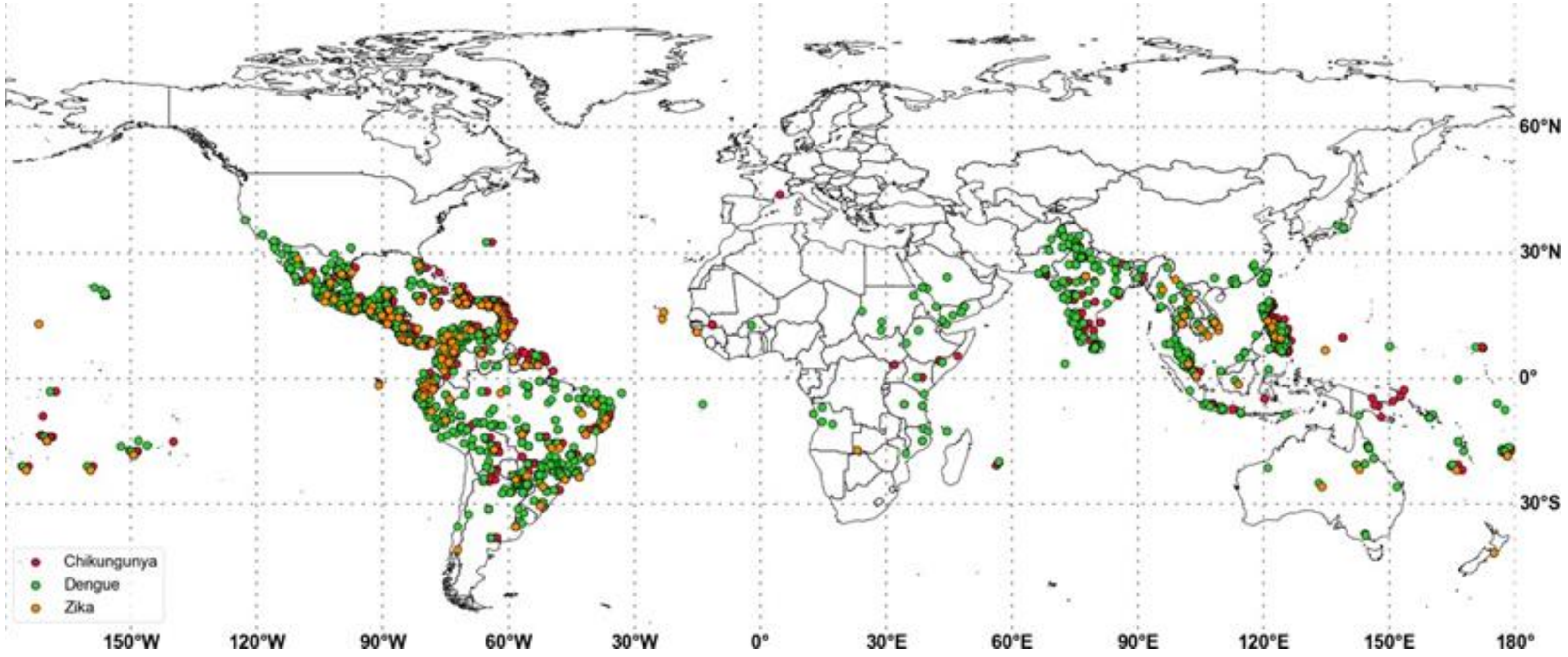
Remote Sensing for Climate-Sensitive Infectious Diseases

Overview

Why Climate-Sensitive Infectious Diseases

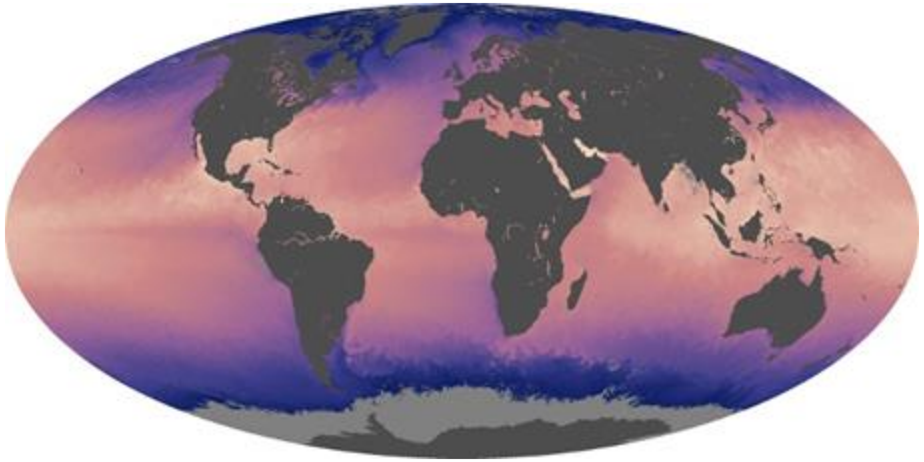




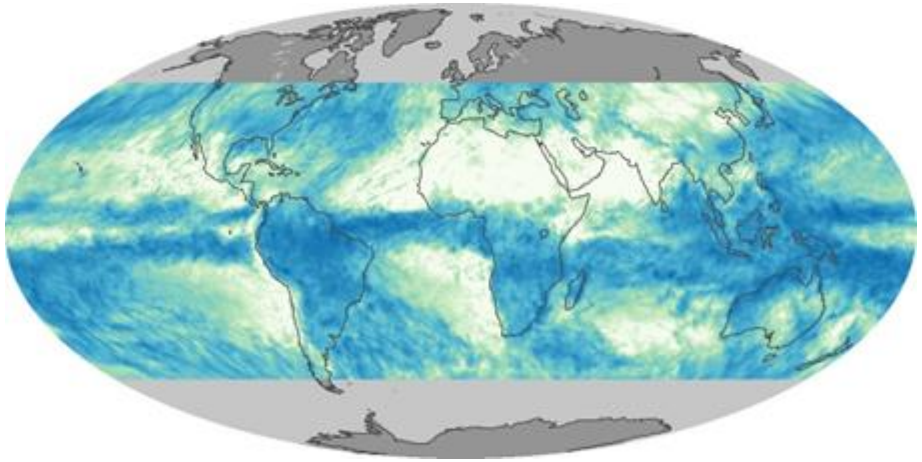


Observing Climate Variables from Space

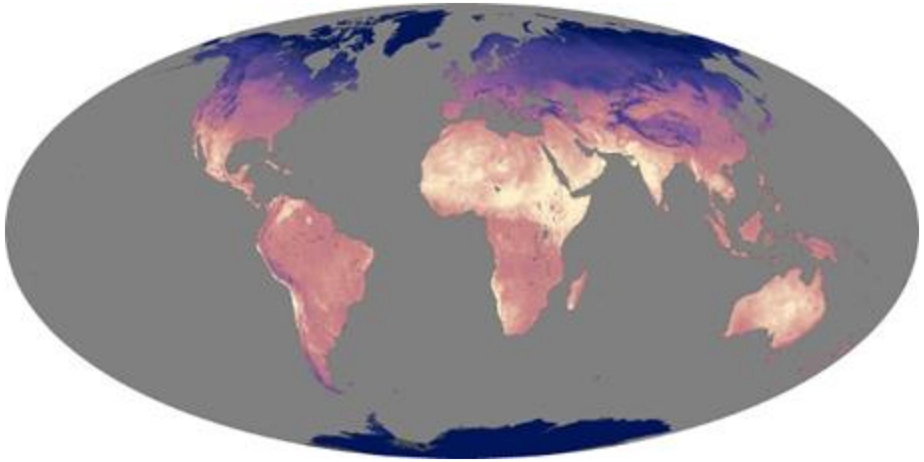
Sea Surface Temperature: 40 yrs



Precipitation: 42 yrs

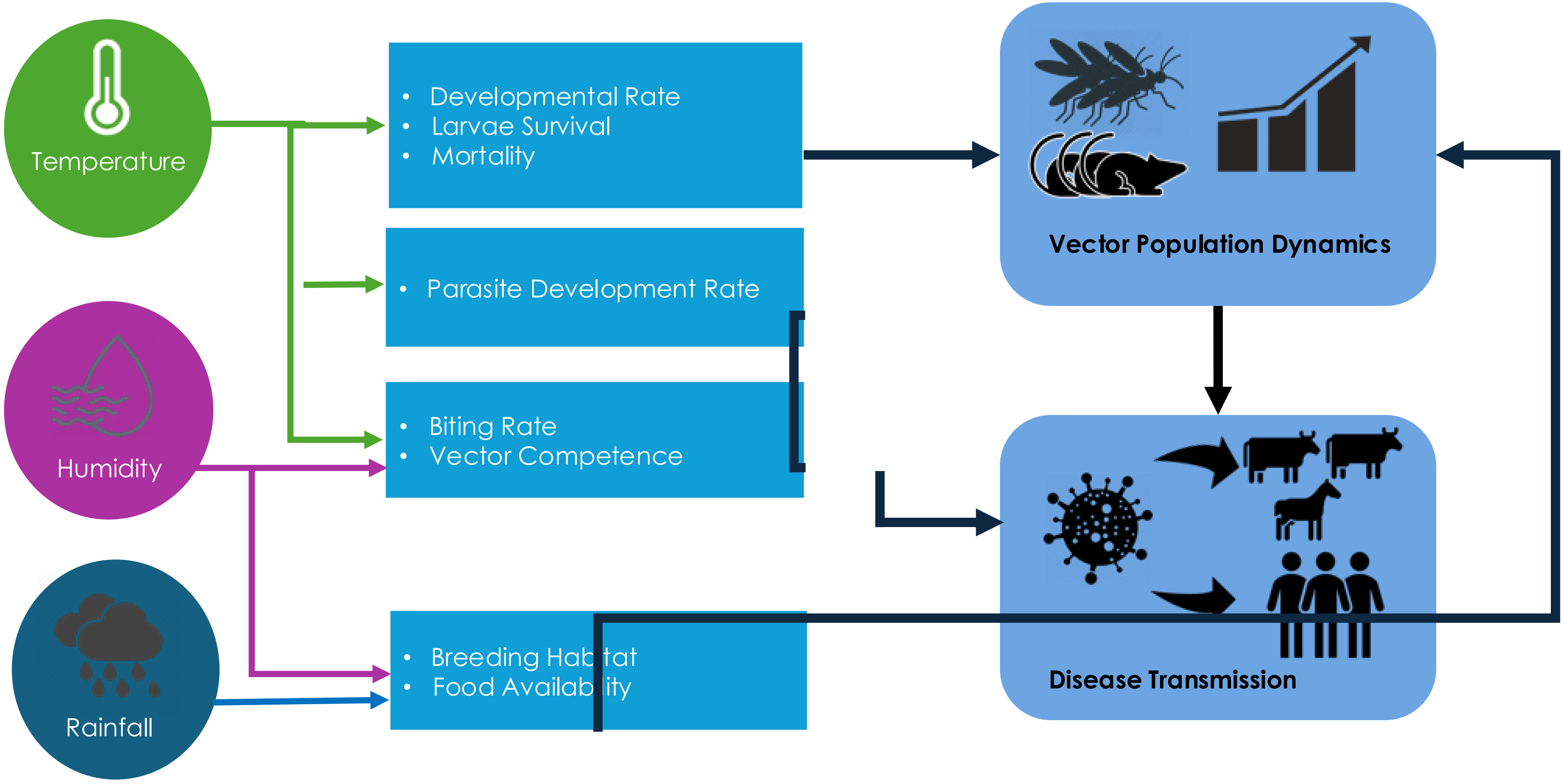


Land Surface Temperature: 21 yrs



Vegetation: 40 yrs

Climate, Environment, and Disease Outbreaks



Training Learning Objectives

By the end of this training attendees will be able to:

- Identify environmental variables and conditions that can be observed from space which are relevant to climate-sensitive infectious disease outbreaks.
- Identify the steps and tools needed to study climate-sensitive infectious disease outbreaks using remote sensing data.
- Recognize several remote sensing datasets commonly used to study and forecast climate sensitive infectious diseases, along with their key attributes such as resolution, coverage, latency, and uncertainty.
- Select appropriate remote sensing datasets for studying climate-sensitive infectious diseases based on the disease characteristics, region of interest, and relevant environmental parameters.
- Examine the benefits and challenges of using remote sensing data for studying climate-sensitive infectious diseases through the case study of the EPIDEMIA system tracking and forecasting Malaria in Ethiopia and alternative approaches.

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

How Remote Sensing Can be Used to Study Climate-Sensitive Infectious Diseases

October 7, 2025

11:00 - 13:00 EDT

Part 2

Case Study in the Use of Remote Sensing to Study Climate-Sensitive Infectious Diseases

October 9, 2025

11:00 - 13:00 EDT

Homework

Opens October 9 – Due October 23 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Training Outline

Part 1

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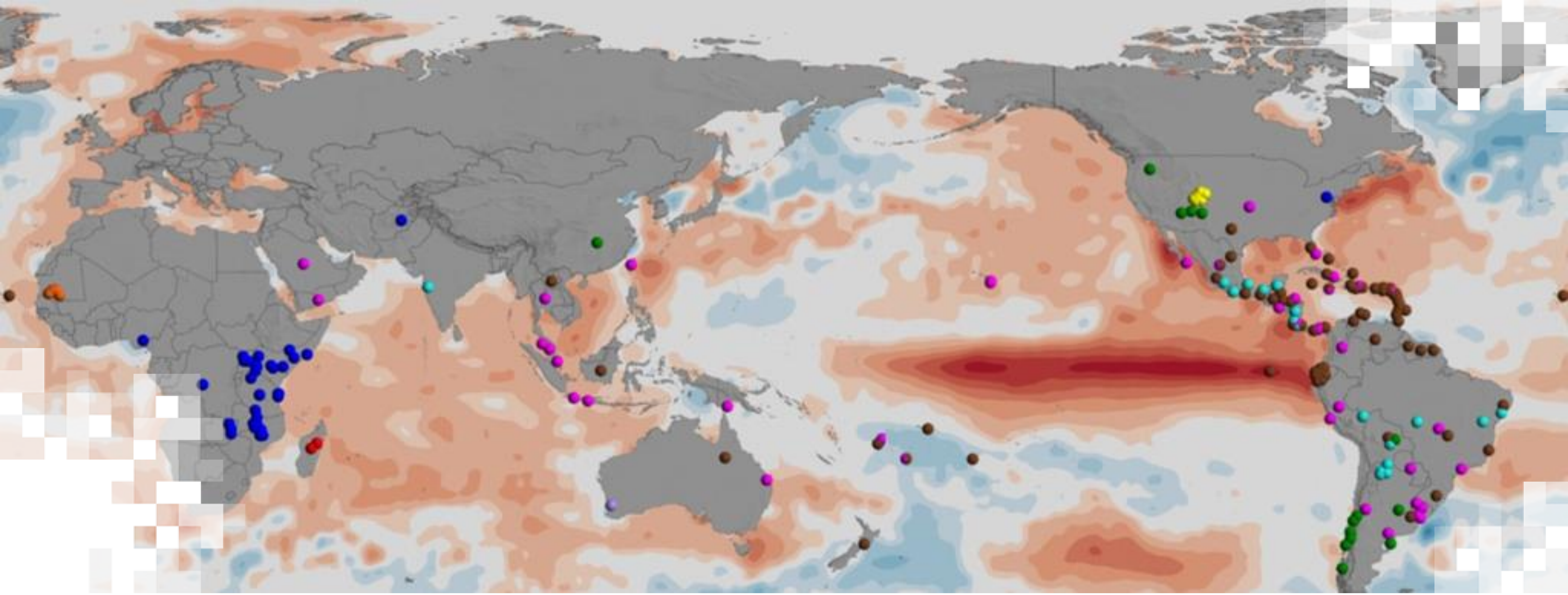


Remote Sensing for Climate-Sensitive Infectious Diseases

Part 1: How Remote Sensing Can be Used to Study Climate-Sensitive Infectious Diseases

Part 1 Objectives

By the end of Part 1, participants will be able to:

- Understand NASA Earth Observation assets and their characteristics which can be used to study climate-sensitive infectious diseases
- Describe how remotely sensed parameters can be used to monitor disease vector habitats
- List the elements of a conceptual framework for disease risk assessment using remotely sensed data
- Determine direct and indirect Earth Observation metrics that can be used to assess disease hazard, exposure, and vulnerability within this conceptual framework
- Identify several common remote sensing missions and derived variables used to map disease risk and assess disease burden
- Articulate some of the common challenges of working with remotely sensed data in infectious disease studies, as well as strategies for overcoming these challenges

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 1 – Trainers

Assaf Anyamba

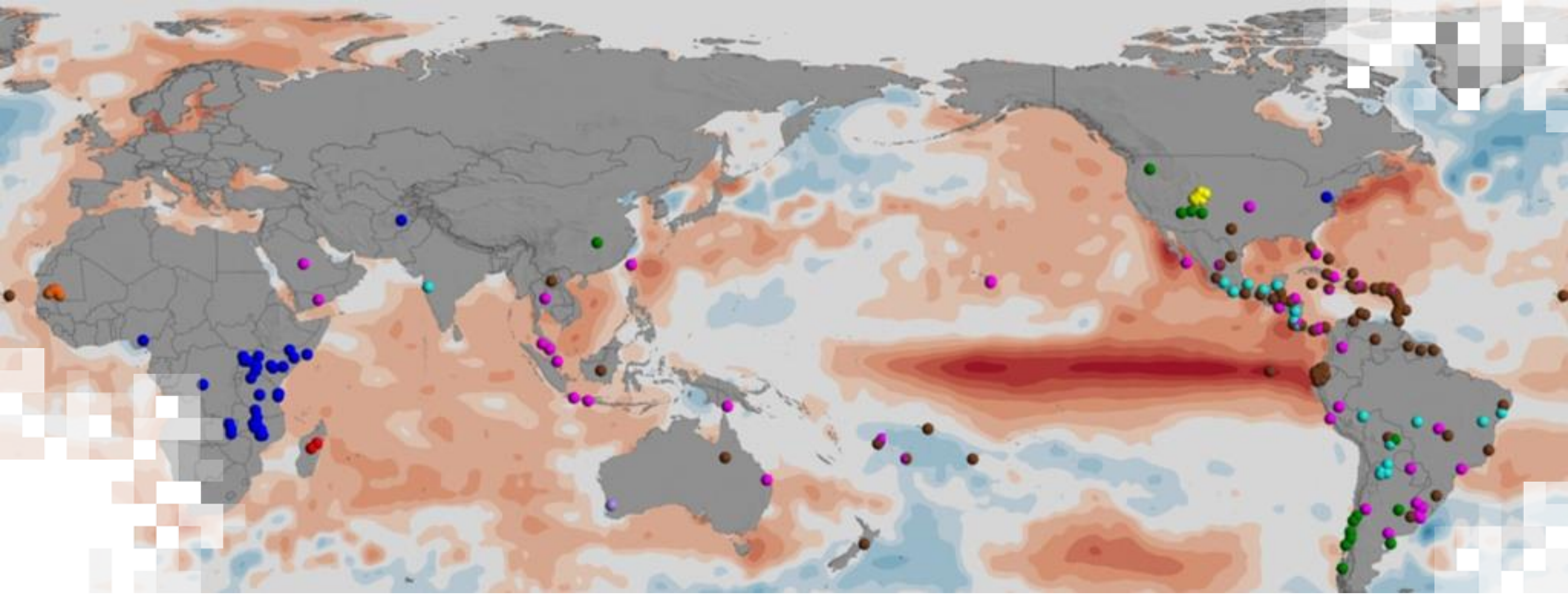
Senior Research Scientist

UMBC & NASA GSFC

Tatiana Loboda

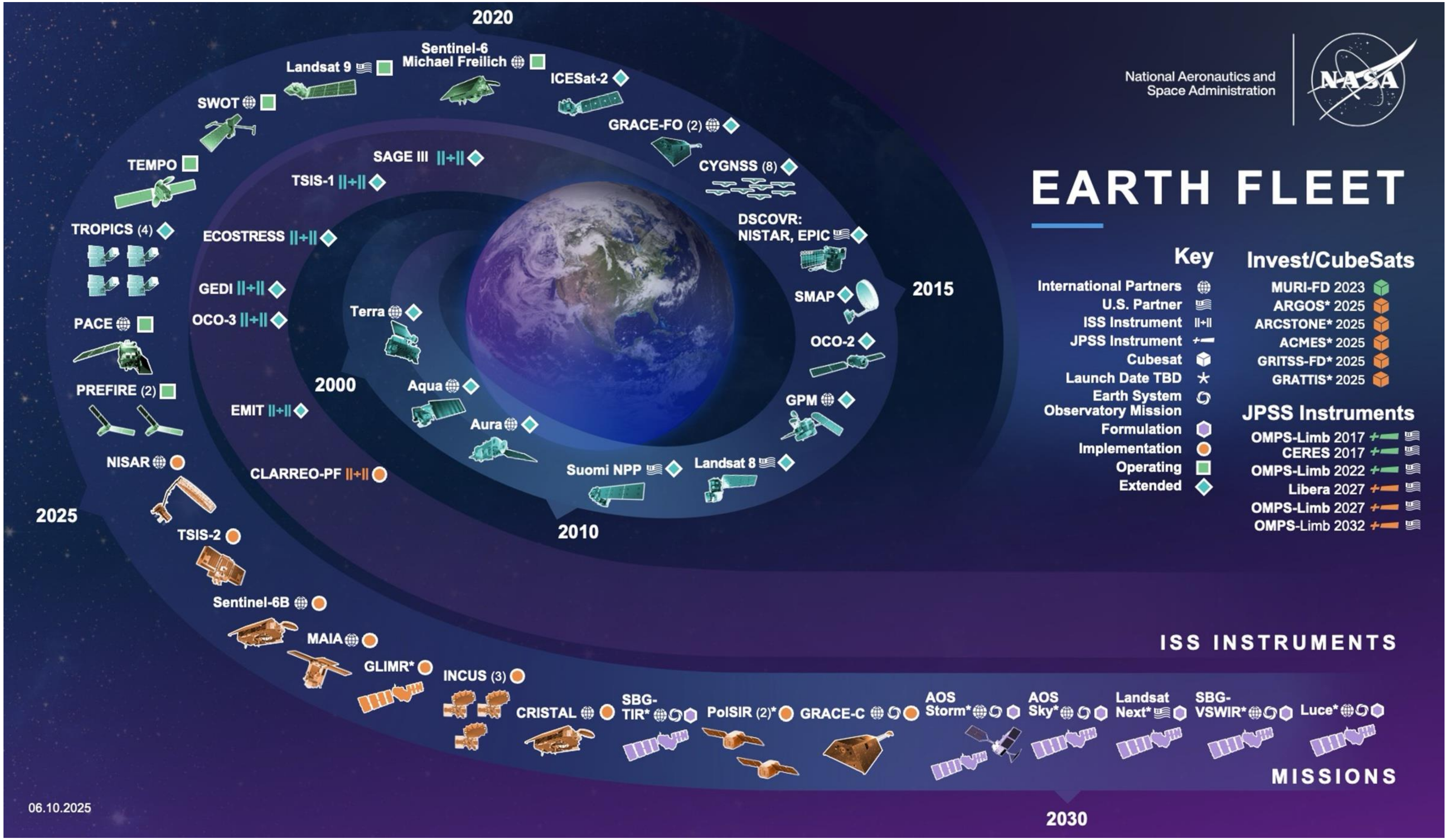
Professor and Chair

Department of Geographical Sciences, UMCP



Why We Use Earth Observations (EO) to Study Climate-Sensitive Infectious Diseases

NASA's Fleet of Earth-Observing Satellites



Infectious Diseases

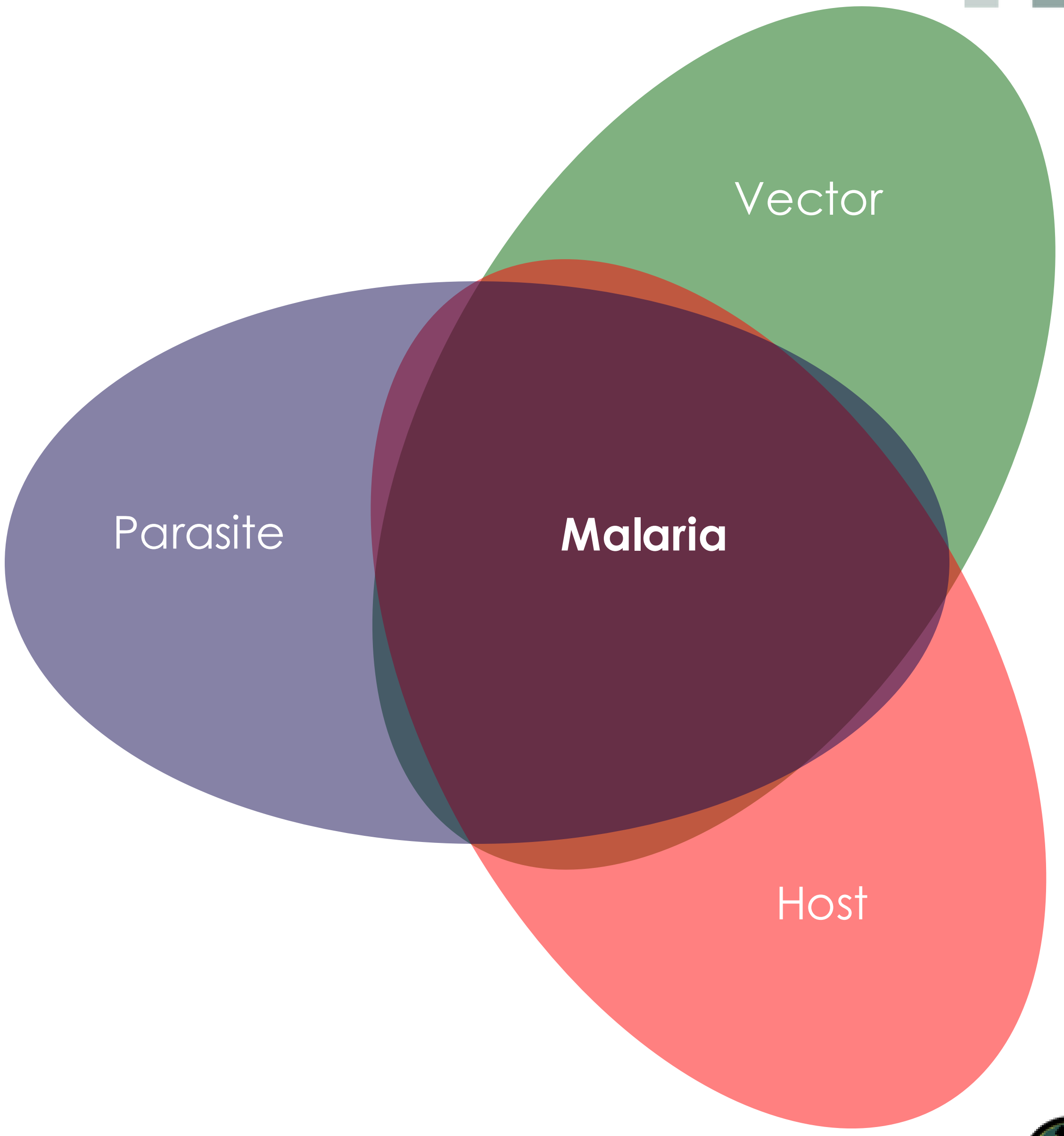
- **Infectious Disease Definition**: (Human) Disease caused by pathogenic organisms

Disease Econiche Concept

- The ecological niche (**econiche**) of an infectious disease represents environmental settings and conditions that allow a pathogen to survive, reproduce, and spread.

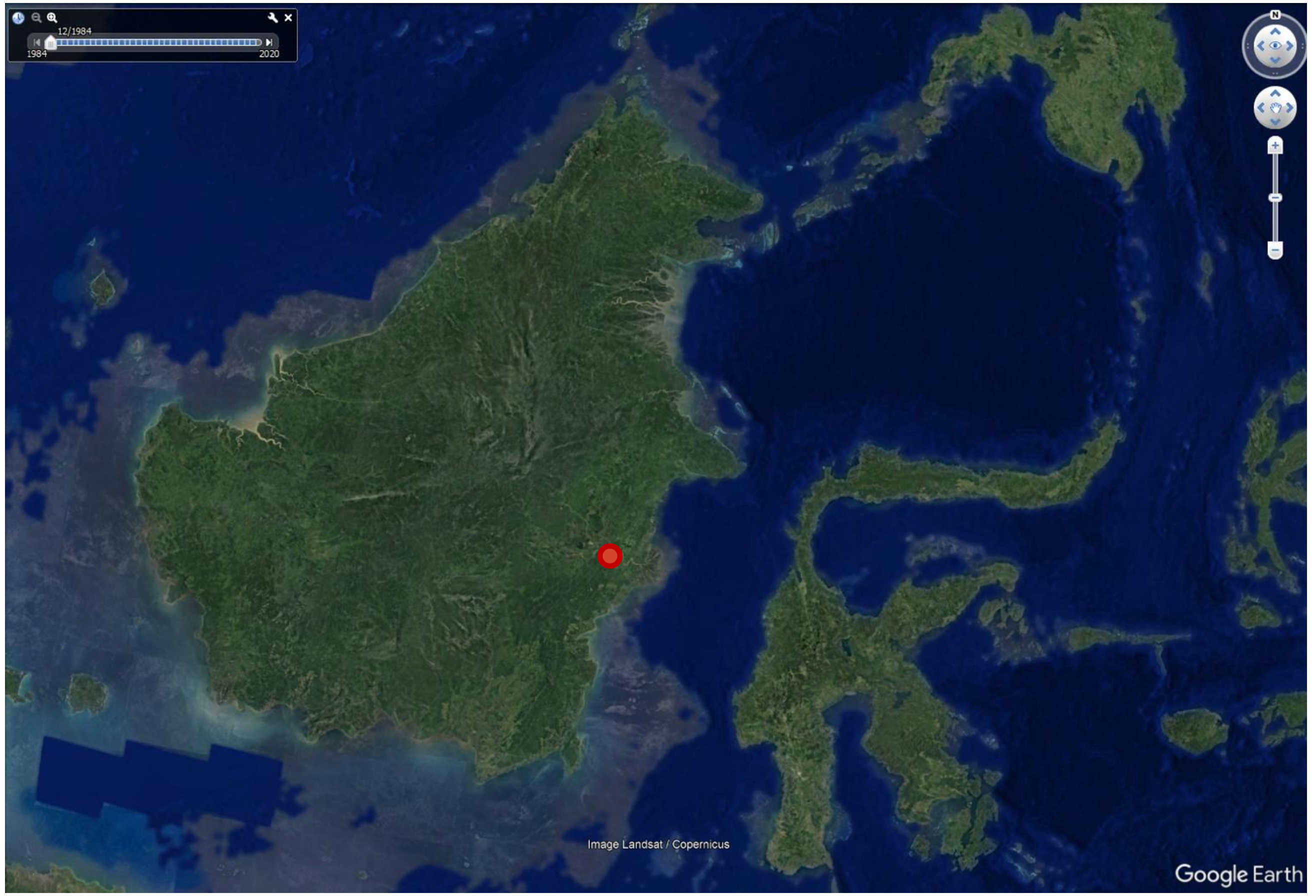
- Disease Econiche Encompasses:
  - Environmental conditions (e.g., weather, land cover, etc.)
  - Interactions with other species (e.g., vectors)
  - Target host availability and distribution

- Primary Characteristics:
  - Variability of each of the econiche components in space and over time
  - Highly complex interactions

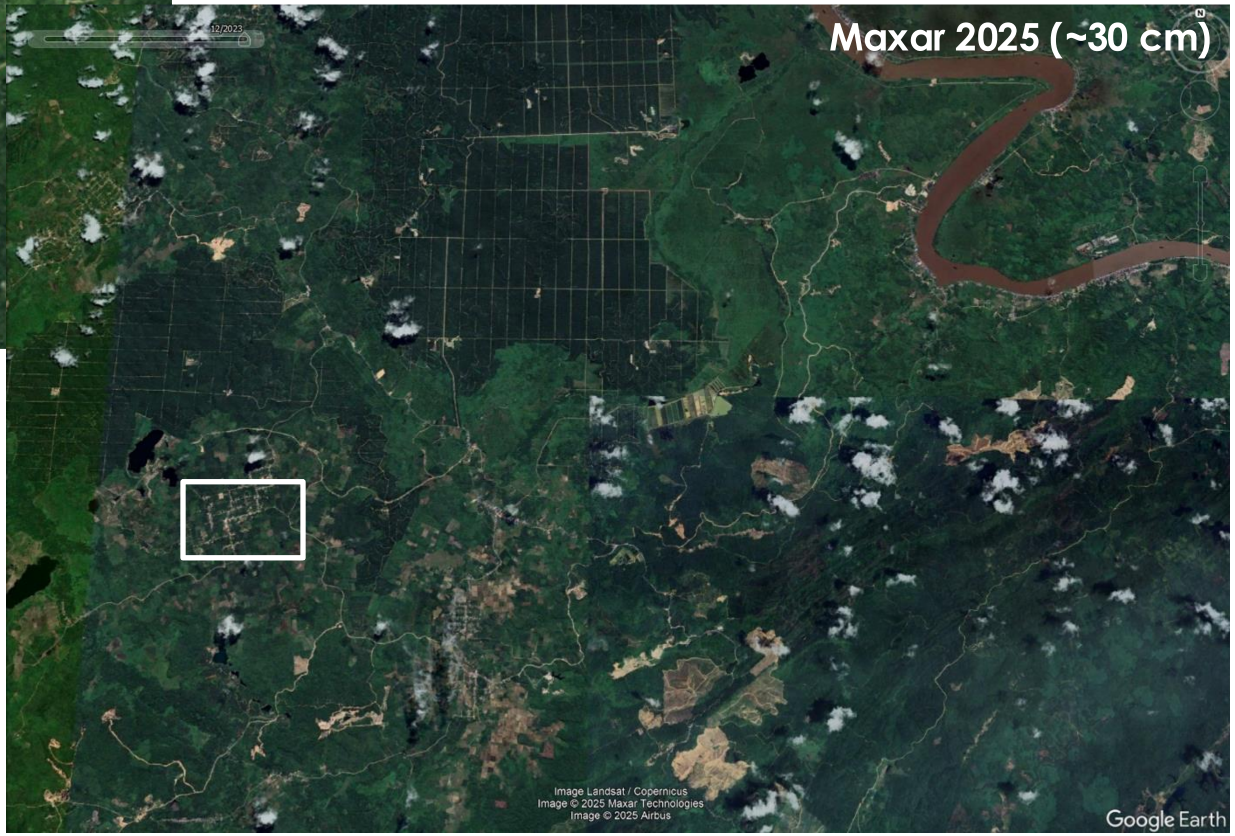


Earth Observations: Scale, Coverage, and Pixel Size/Resolution

- Extensive (local to global) information about various components of disease econiche:
  - EO data from a variety of satellites (including private satellite constellations) deliver imagery at different granularities (i.e., spatial resolution or pixel size).




Landsat 1985 (30 m)
Image Landsat / Copernicus


Maxar 2025 (~30 cm)
Image Landsat / Copernicus
Image © 2025 Maxar Technologies
Image © 2025 Airbus
Google Earth

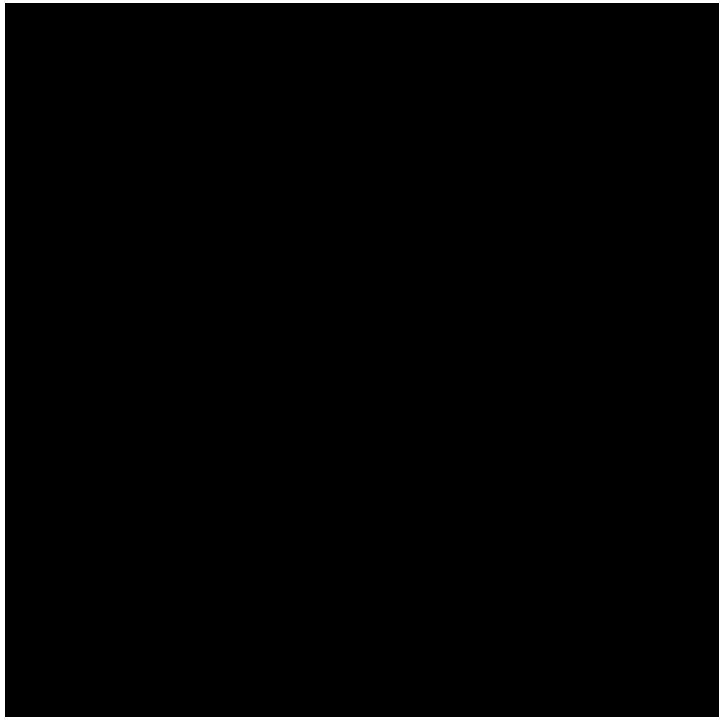

Landsat 1985 (30 m)
Image Landsat / Copernicus


Maxar 2025 (~30 cm)
Image © 2025 Maxar Technologies
Google Earth

Earth Observations: Polar Orbiting Satellites

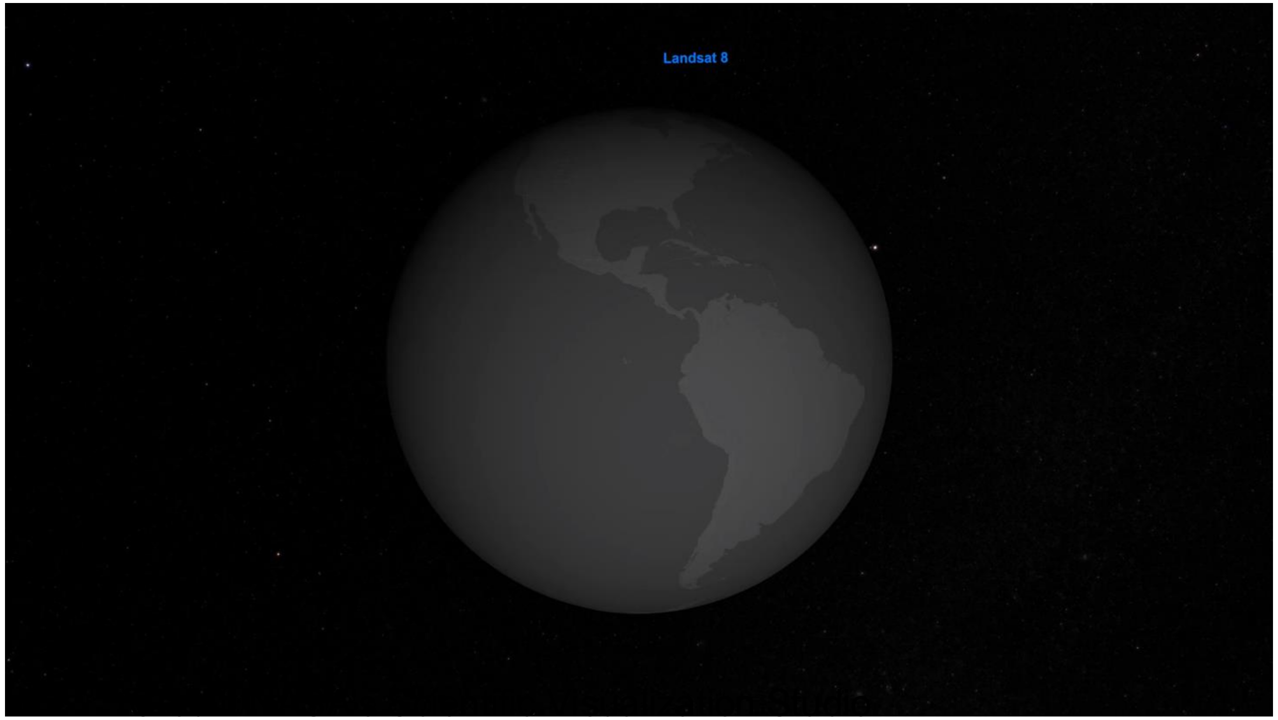
- Consistent, repeatable monitoring, varying return frequency

MODIS (Aqua) 1km Resolution



Credit: NASA Science on a Sphere

Landsat (30 m), Sentinel 2 (10 m) Resolution

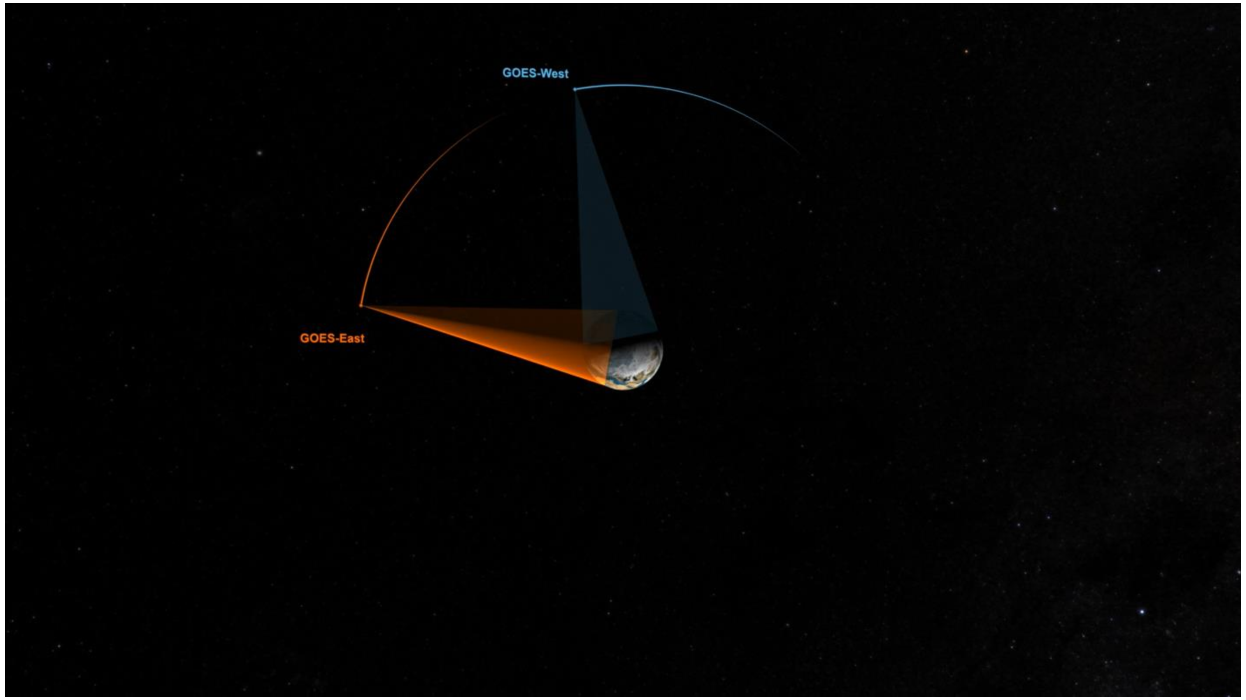


Credit: NASA's Scientific Visualization Studio

Earth Observations: Geostationary Satellites

- Consistent, continuous monitoring, coarser footprint

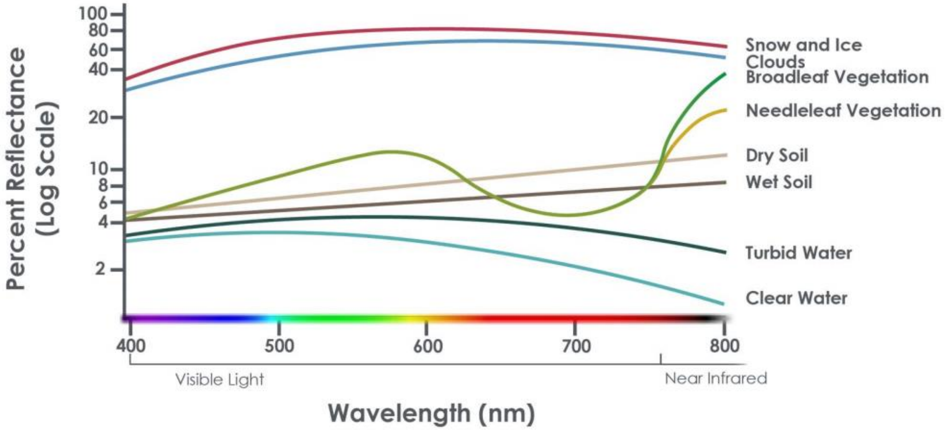
GOES East and West

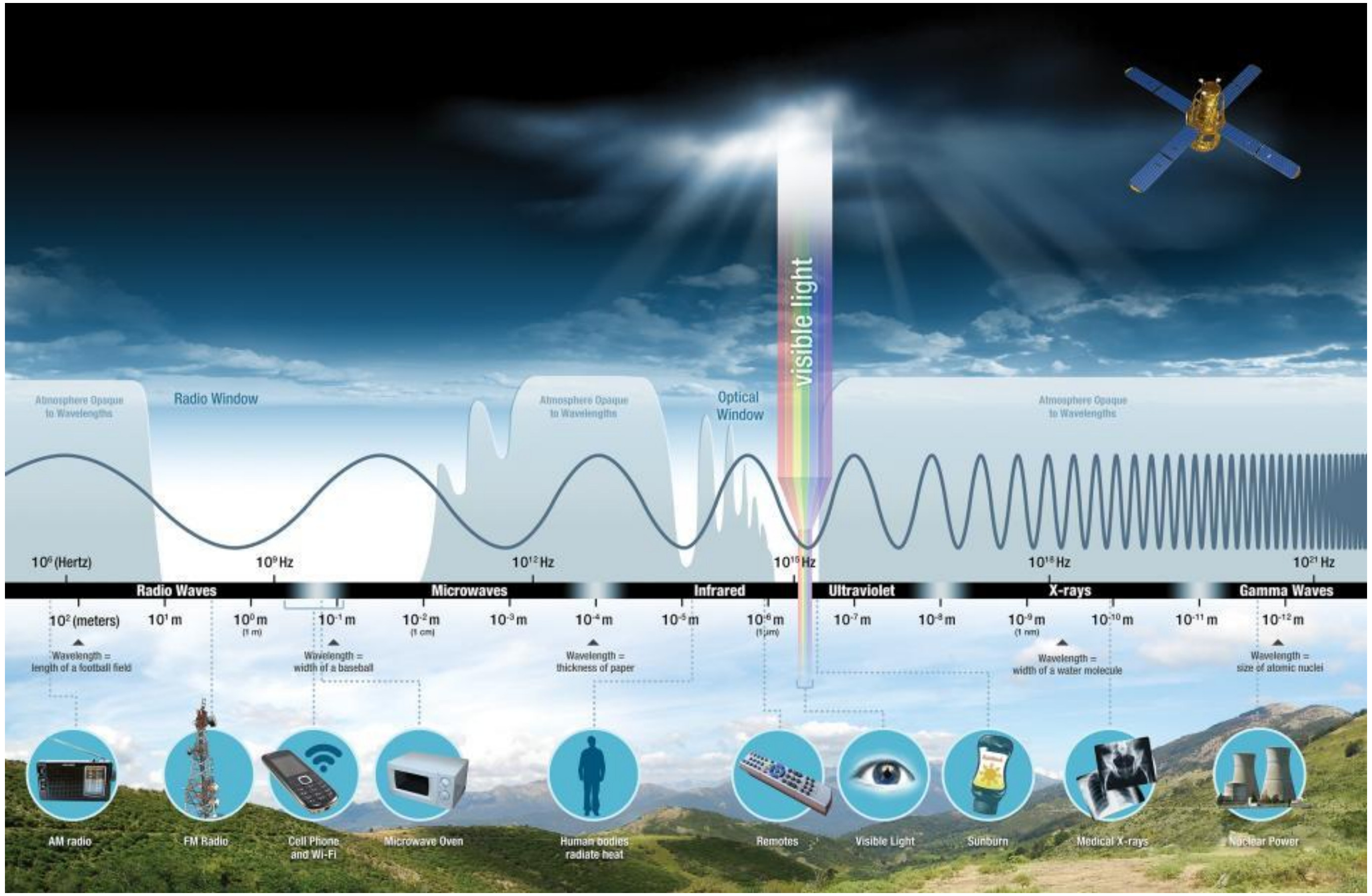


Credit: NASA's Scientific Visualization Studio

Earth Observations: Enhanced Viewing Capabilities

- Ability to observe the environment in ways that are not available to our direct senses
  - Multispectral (beyond just visible)
  - Hyperspectral



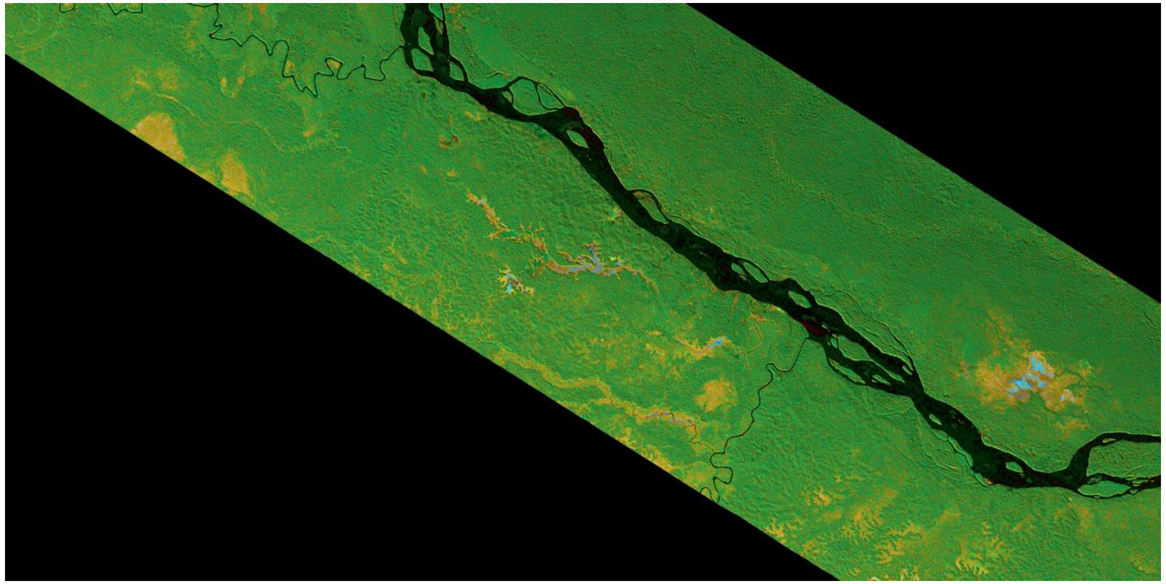


Credit: NASA Science

Earth Observations: Active Sensing Technology

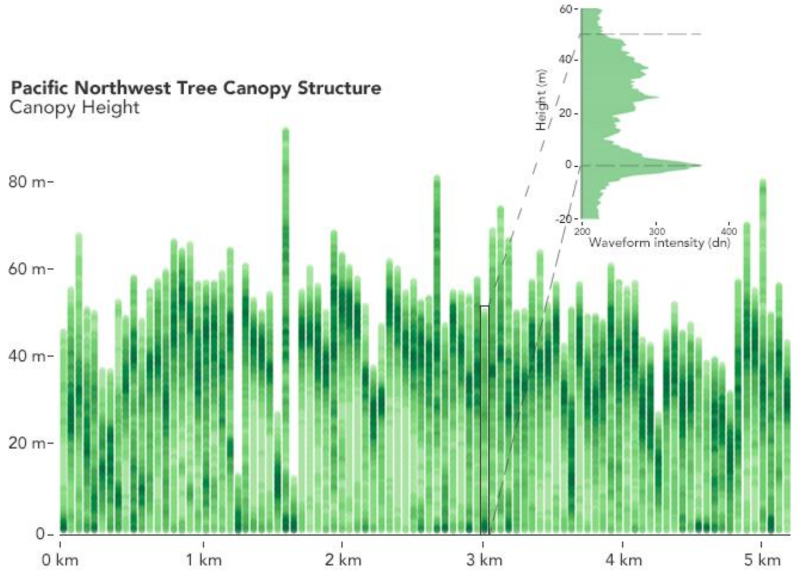
- Ability to observe the environment in ways that are not available to our direct senses
  - Multispectral (beyond just visible)
  - Hyperspectral
  - Radar
  - Lidar

JPL Airborne Radar: Wetlands Under Tree Canopy



Credit: [NASA Earth Observatory]()

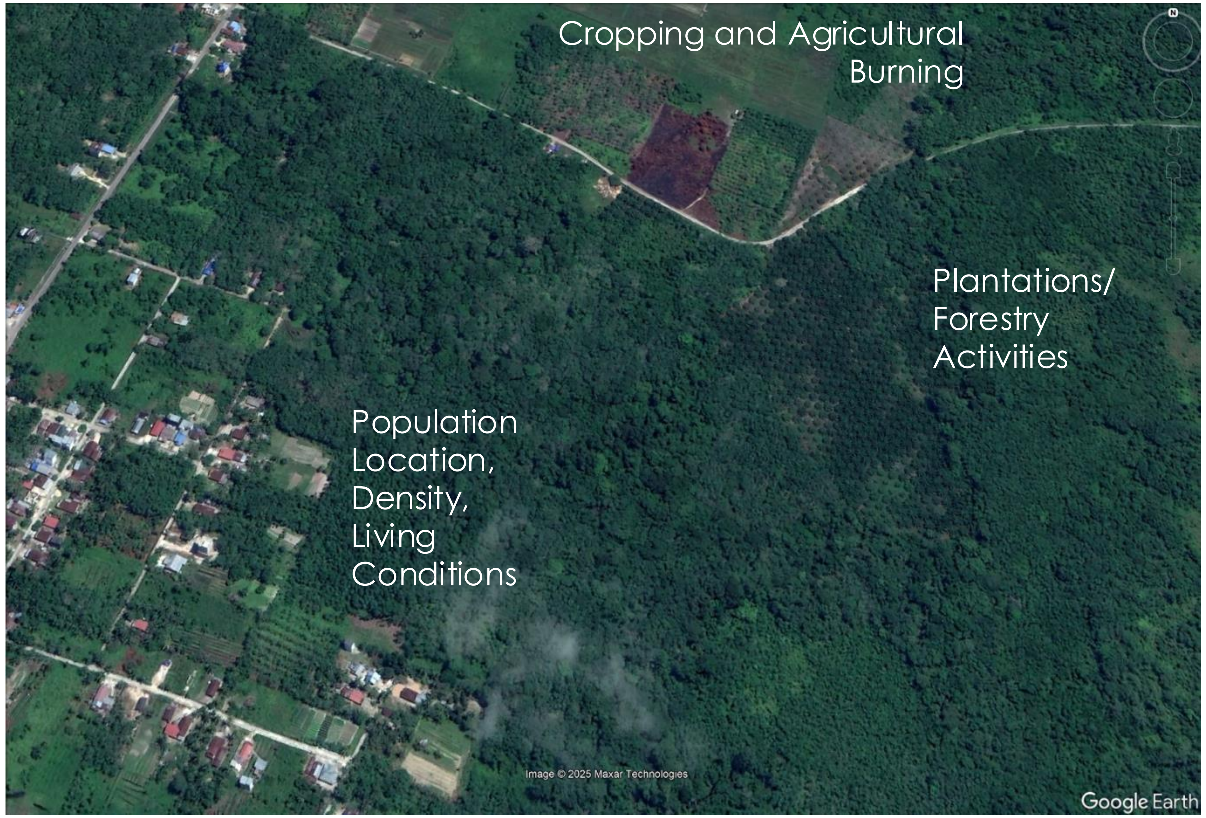
GEDI Lidar: 3-D Structure



Credit: [NASA Earth Observatory]()

Earth Observations: Direct and Proxy Metrics

- Direct and indirect metrics describing disease econiche parameters
  – Direct: e.g., Vegetation Greenness = How much vegetation is there and how healthy and robust it is
  – Indirect: e.g., Land Use = Occupational Exposure

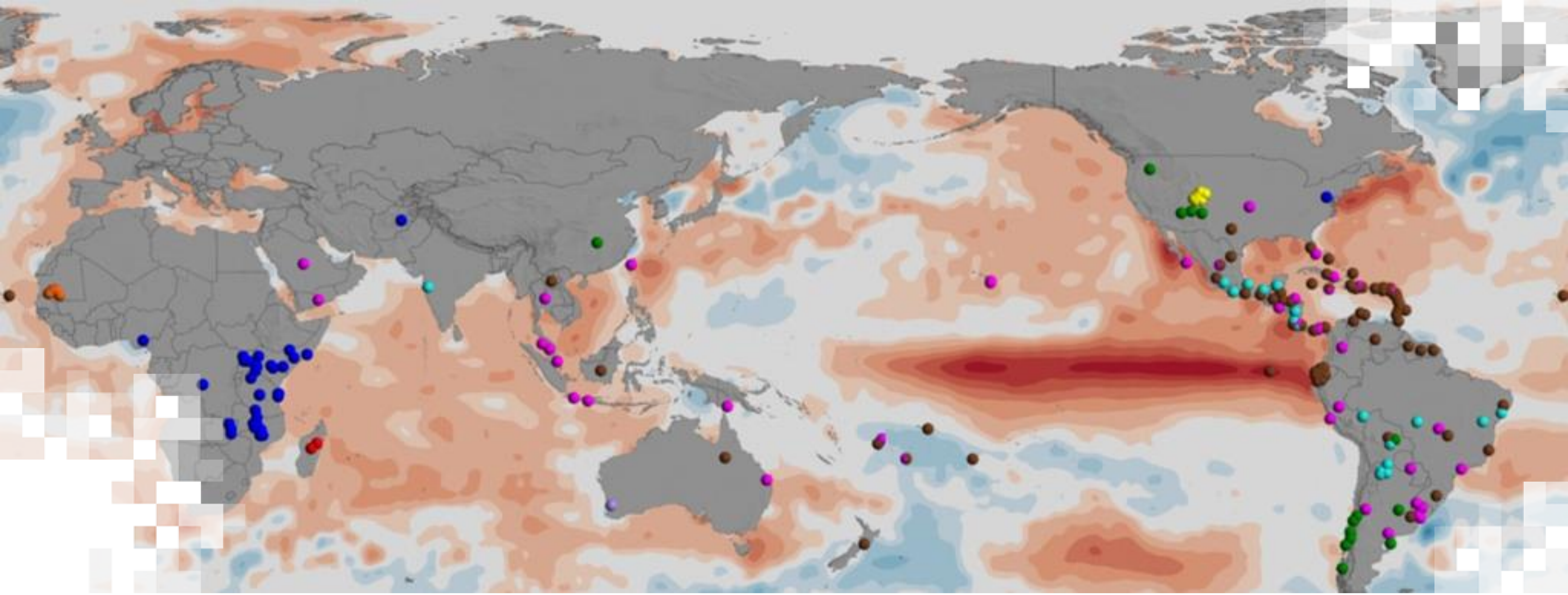


Earth Observations: Summary

- A large fleet of EO satellites is collecting…
  - Comprehensive
  - Repeated
  - Diverse

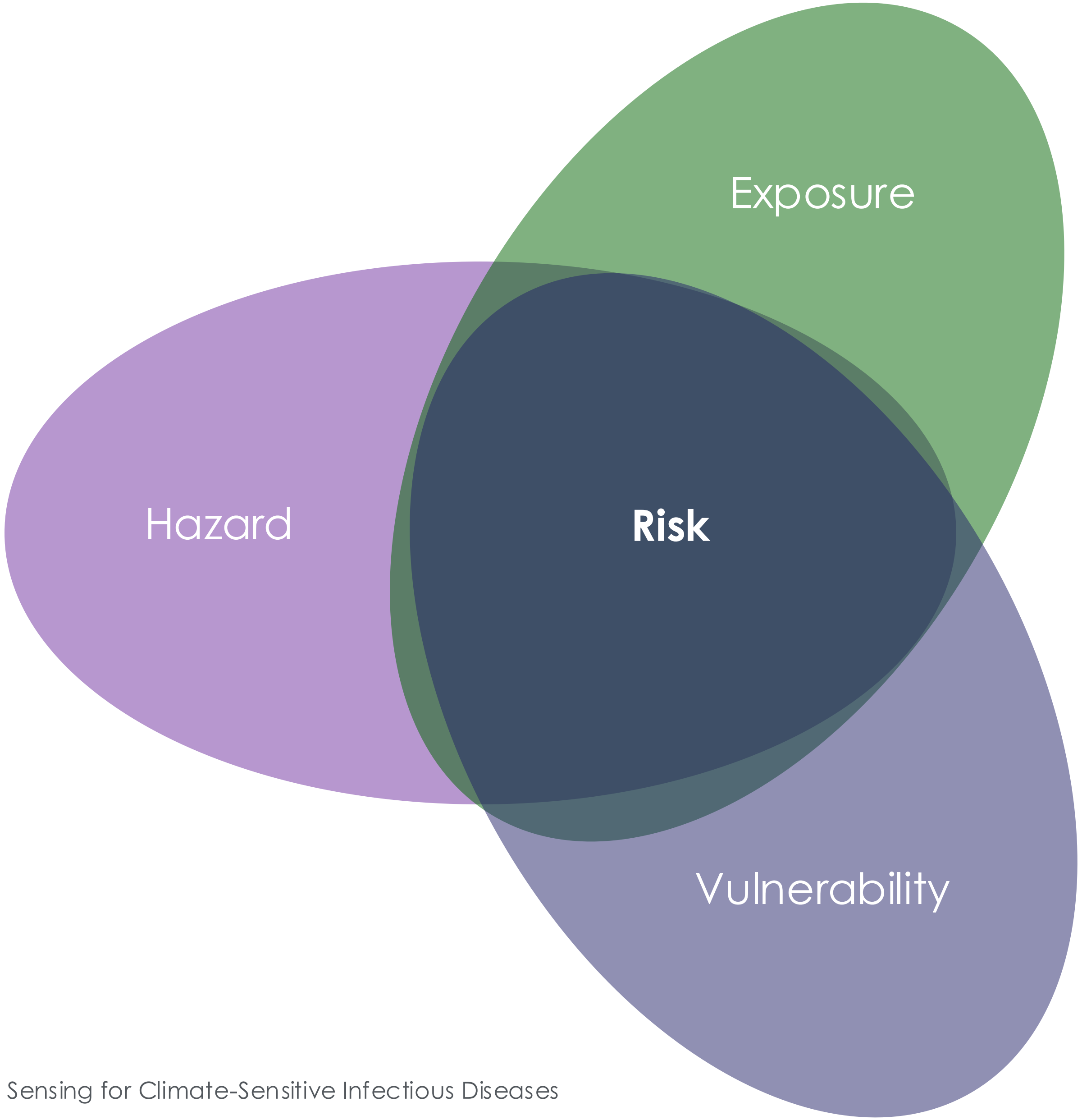
  sets of imagery that are used to derive…
  - Direct
  - Indirect

  metrics which can be used to monitor **disease econiche**.

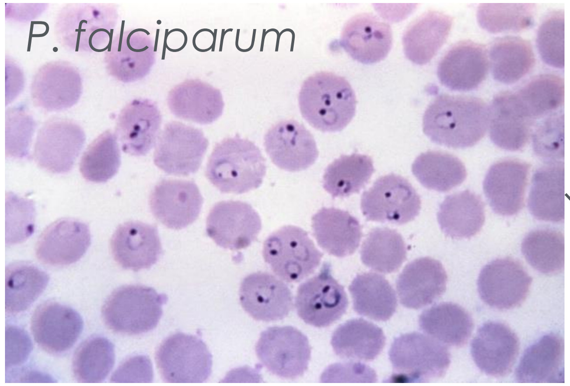


Building a Conceptual Framework for Studying Climate-Sensitive Infectious Diseases (Myanmar Malaria Case Study)

IPCC Conceptual Framework for Risk Assessment

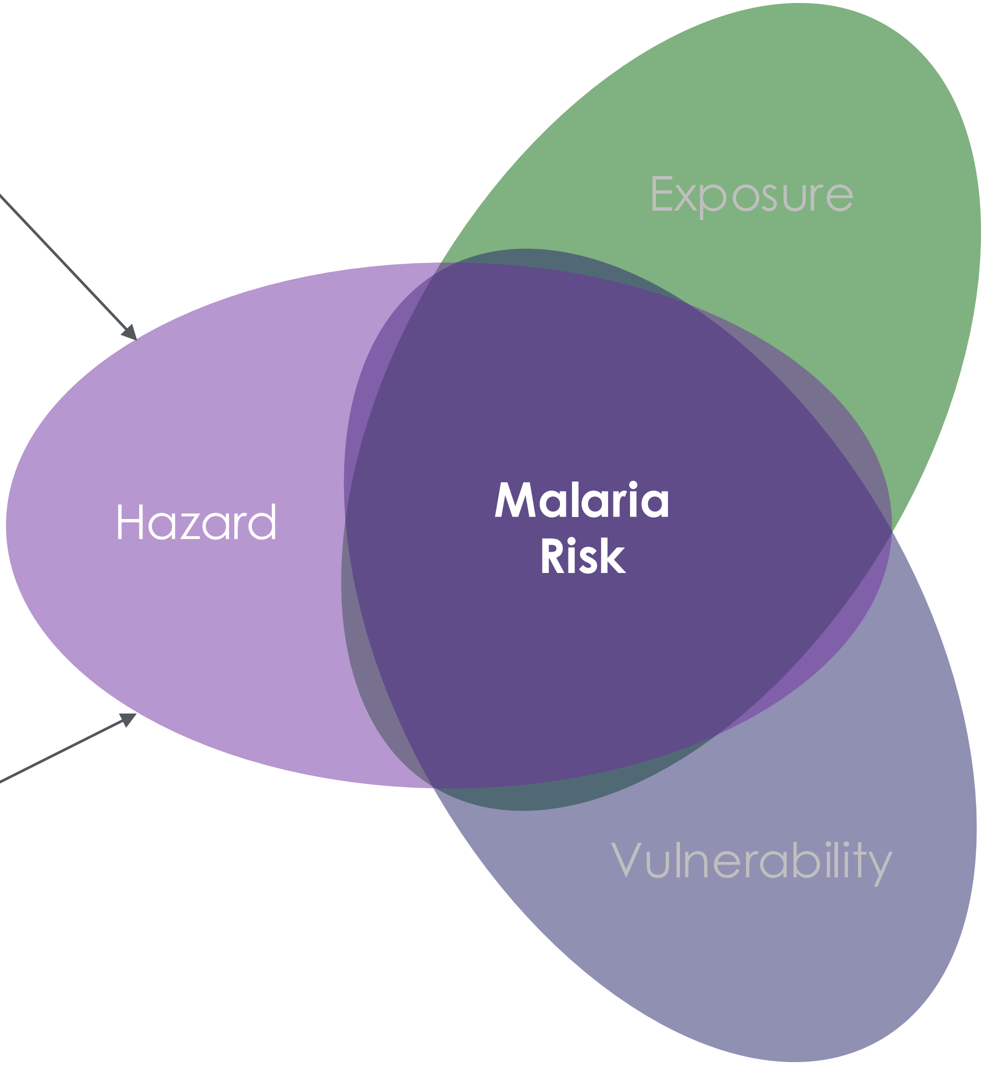


Malaria Risk: Hazard



Source: pixnio.com

Source: CDC



Consideration 1: Malaria Vector Diversity

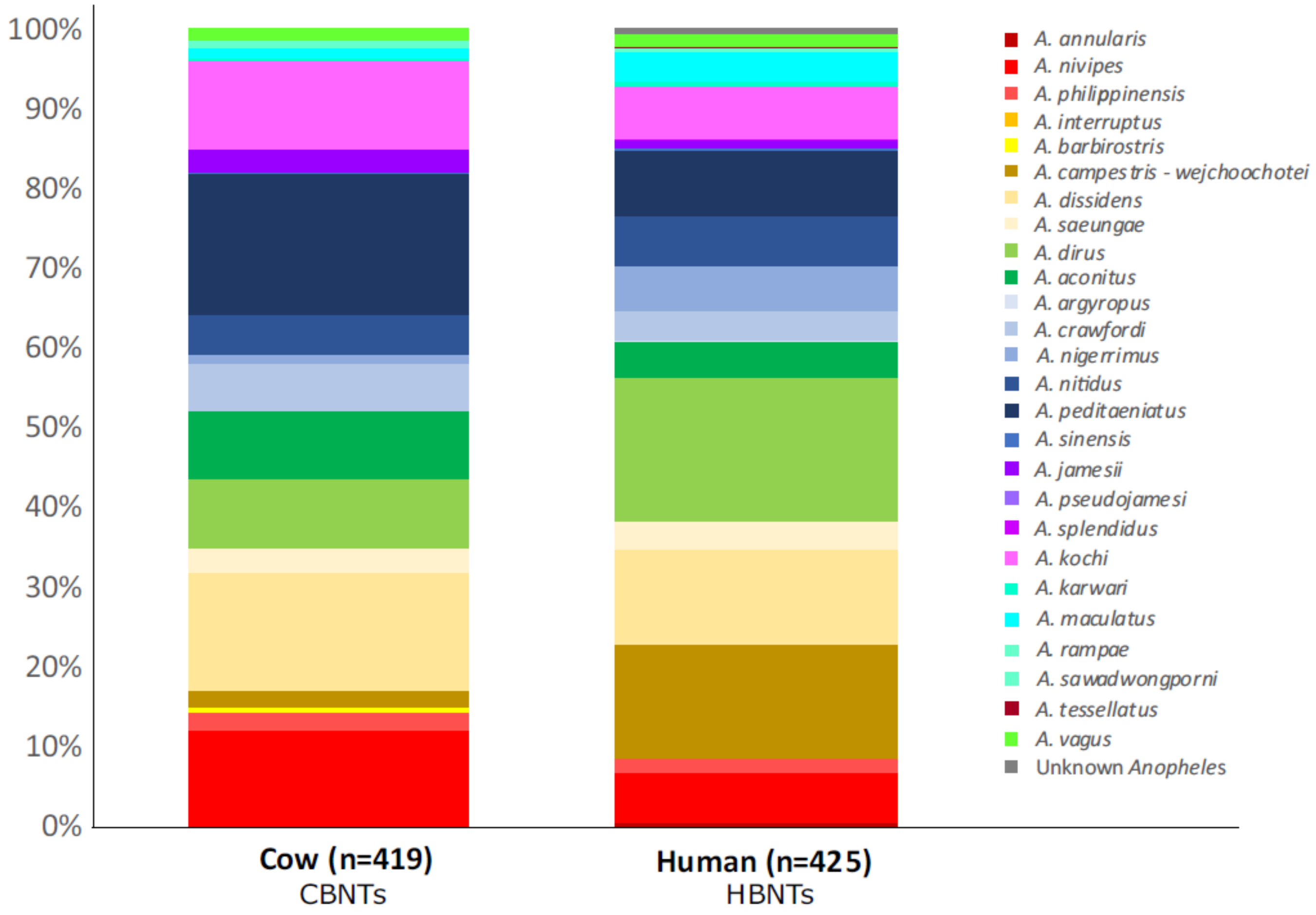


Figure 5 in Vantaux et al. (2021).

- High diversity of Anopheles spp.
- 22 An spp. were found to carry Plasmodium spp. parasites.
- Biting behavior and ecology are reported to differ substantially from previous assumptions.

Vantaux et al 2021. Anopheles Ecology, Genetics, and Malaria Transmission in Northern Cambodia. *Nature Scientific Reports*, 11: 6458

Consideration 2: Malaria Vectors Biting Behavior

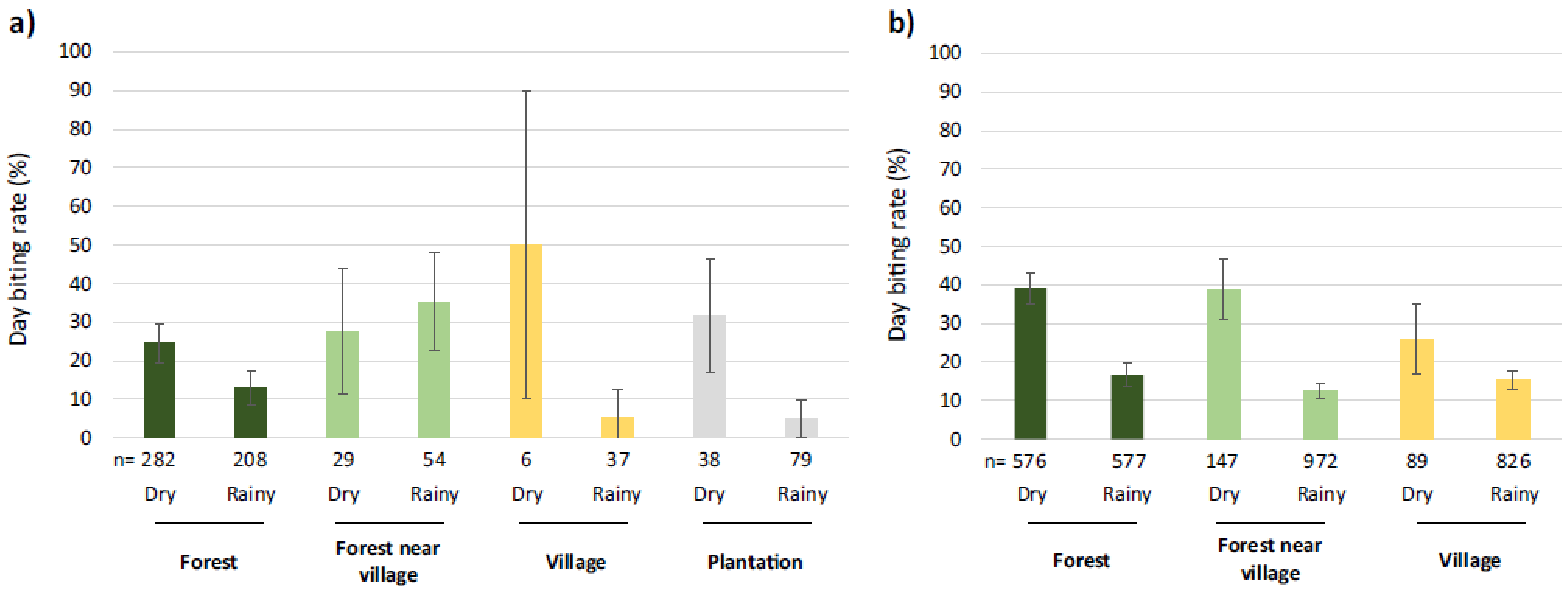


Figure 3 in Vantaux et al. (2021): 6am–6pm Biting Behavior

Vantaux et al 2021. Anopheles Ecology, Genetics, and Malaria Transmission in Northern Cambodia. *Nature Scientific Reports*, 11: 6458

Consideration 3: Probability of Vector Occurrence

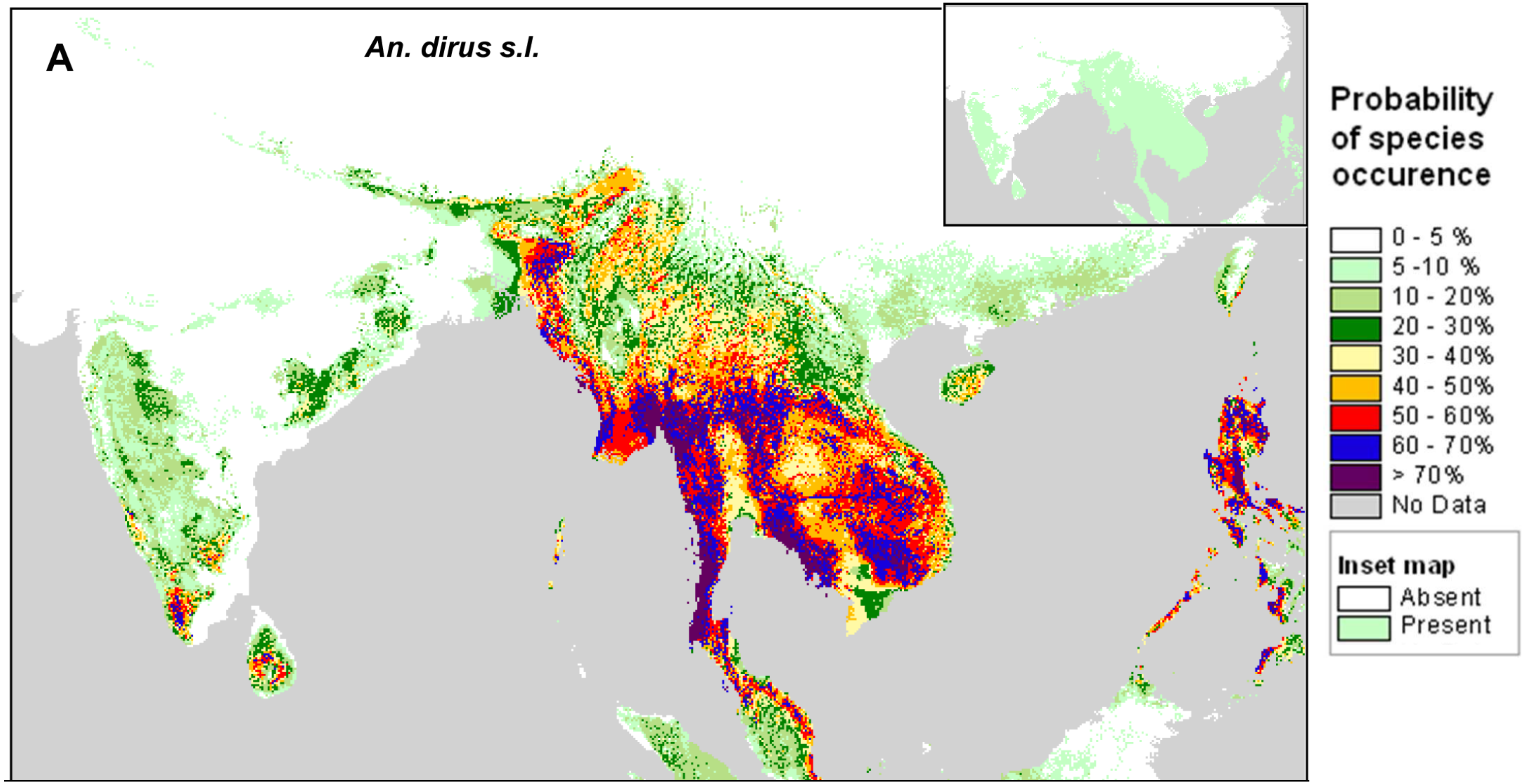


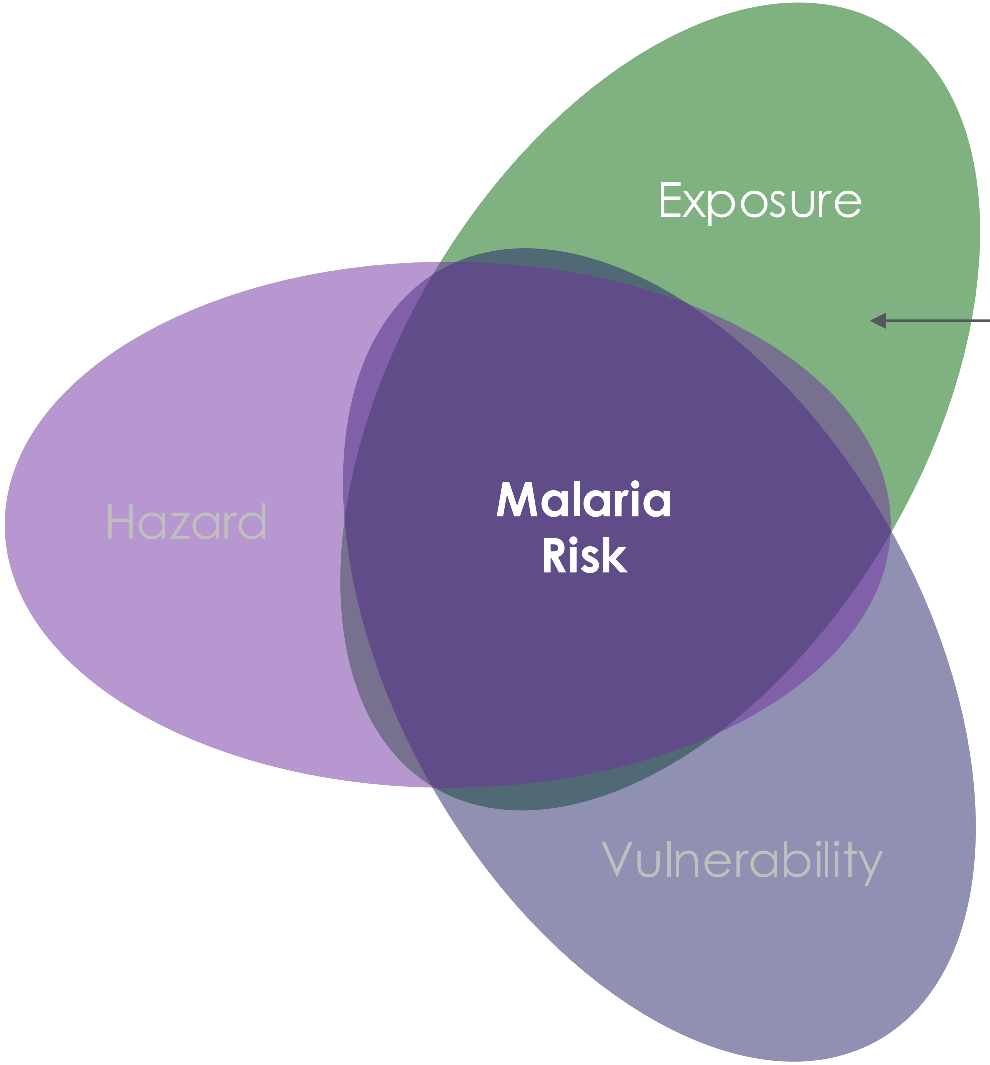
Figure 1, Panel A in Obsomer et al. (2012)

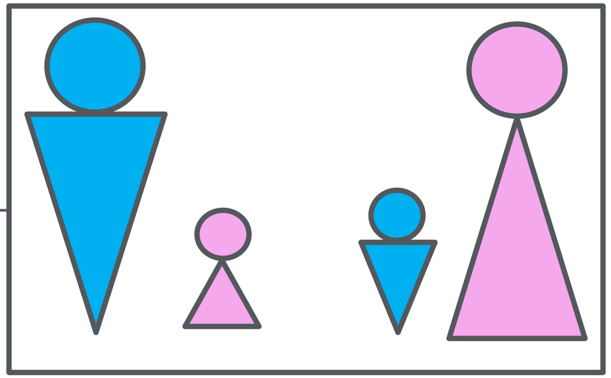
Obsomer et al. 2012. Predicted Distribution of Major Malaria Vectors Belonging to the Anopheles dirus Complex in Asia: Ecological Niche and Environmental Influences. PLoS ONE 7(11): e50475.

Summary of Considerations for Hazard

- Mosquitoes are abundant year-round = requires continuous monitoring of habitat
- Numerous species adapted for various habitats (tree-dominated, grass/shrub-dominated) = requires monitoring of habitat conditions across all vegetated land cover types
- Biting occurs during daytime and nighttime although at different rates for different landscapes = consider occupational exposure during daytime and dwelling exposure during nighttime

Malaria Risk: Exposure





Malaria Risk: Occupational Exposure

Teak Plantations

Mining

Rain-Fed Crops

Flooded Crops & Fishing

Credit: T. Loboda

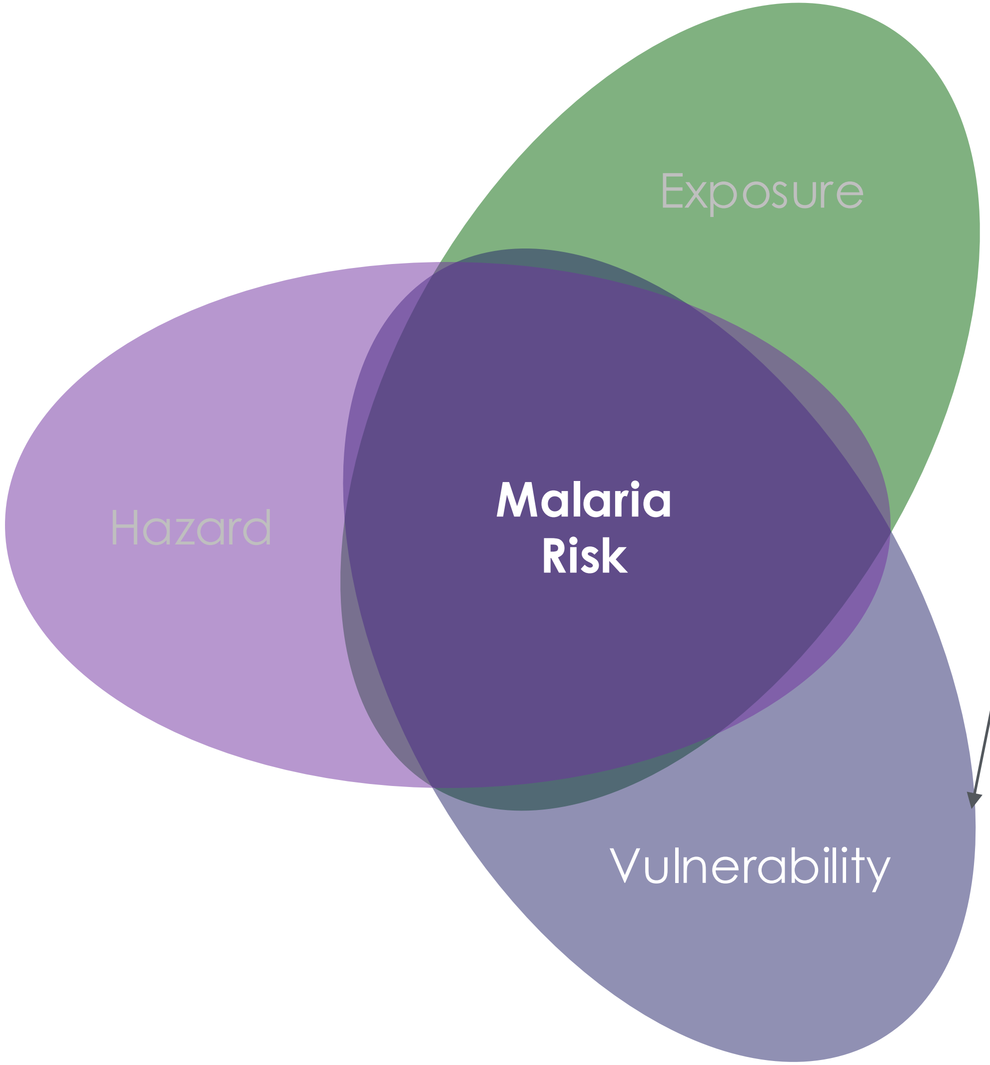
Malaria Risk: Dwelling Exposure

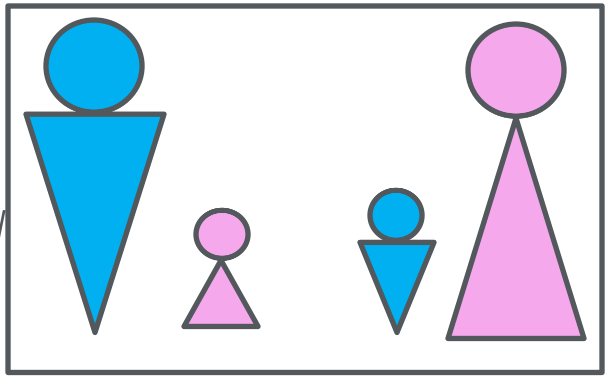
Credit: T. Loboda

Summary of Considerations for Exposure

- Land use maps can serve as a proxy for occupational exposure.
- Daily chores and activities provide insight into people’s exposure within different land covers.
- A combination of “natural” and “man-made” materials in populated areas can serve as a proxy for dwelling exposure.

Malaria Risk: Vulnerability





Malaria Risk: Access to Care

Credit: T. Loboda

Summary of Considerations for Vulnerability

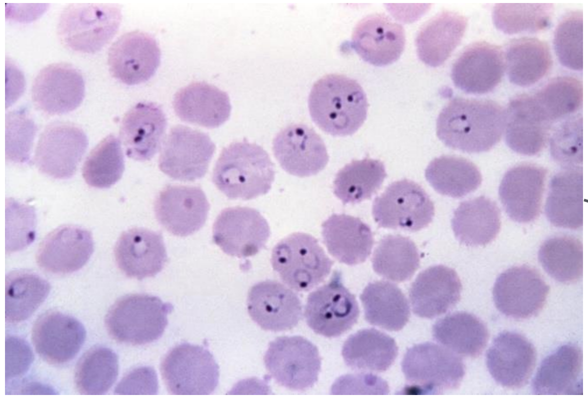
- Various proxies can be extracted from satellite imagery to assess local Socio-Economic Standing.
  - Nighttime lights
  - Prevalence of natural building materials
  - Proximity to logging/mining/etc. activities (subject to local context)

- Identifying groupings of displaced populations (refugee camps) indicates potentially hyper-vulnerable populations.

- Access to care requires knowledge of points of care (usually cannot be retrieved from satellite data) and length/mode/conditions for travel (road networks and pavement can be mapped from satellite imagery and their conditions can be estimated based on weather observations).

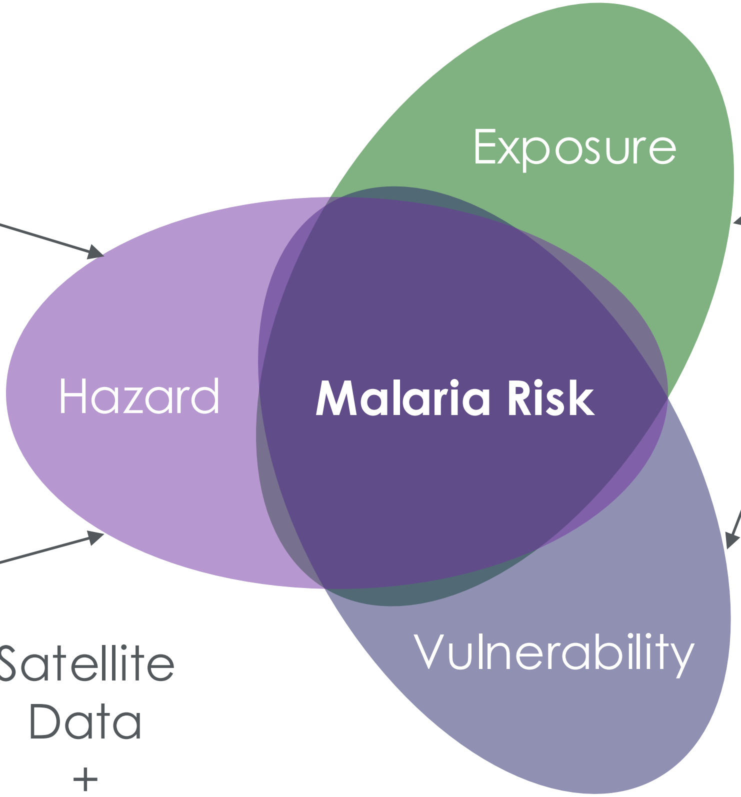
Malaria Risk

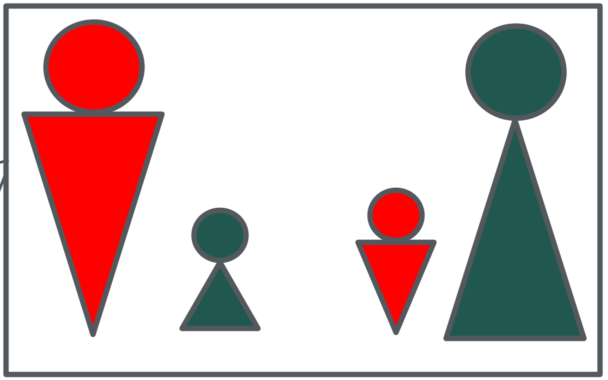
Source: pixnio.com



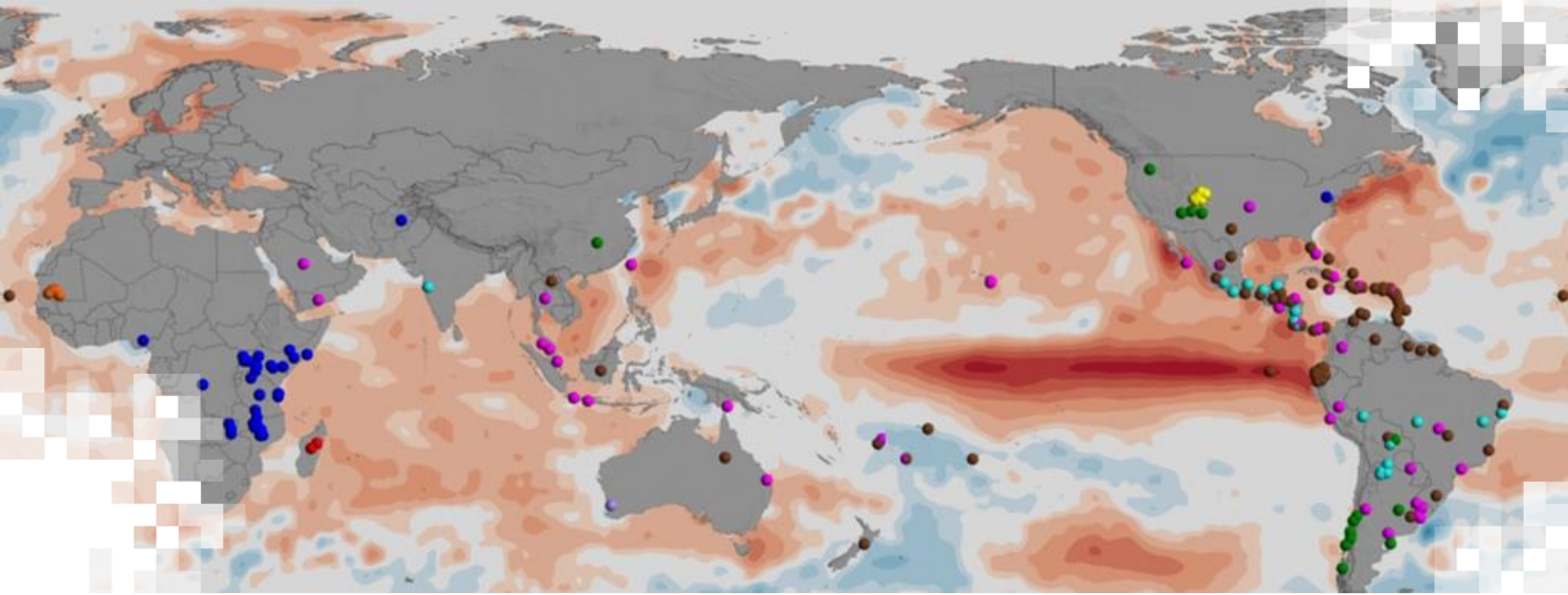
http://sitn.hms.harvard.edu

Satellite
Data
+
Entomological
Surveys





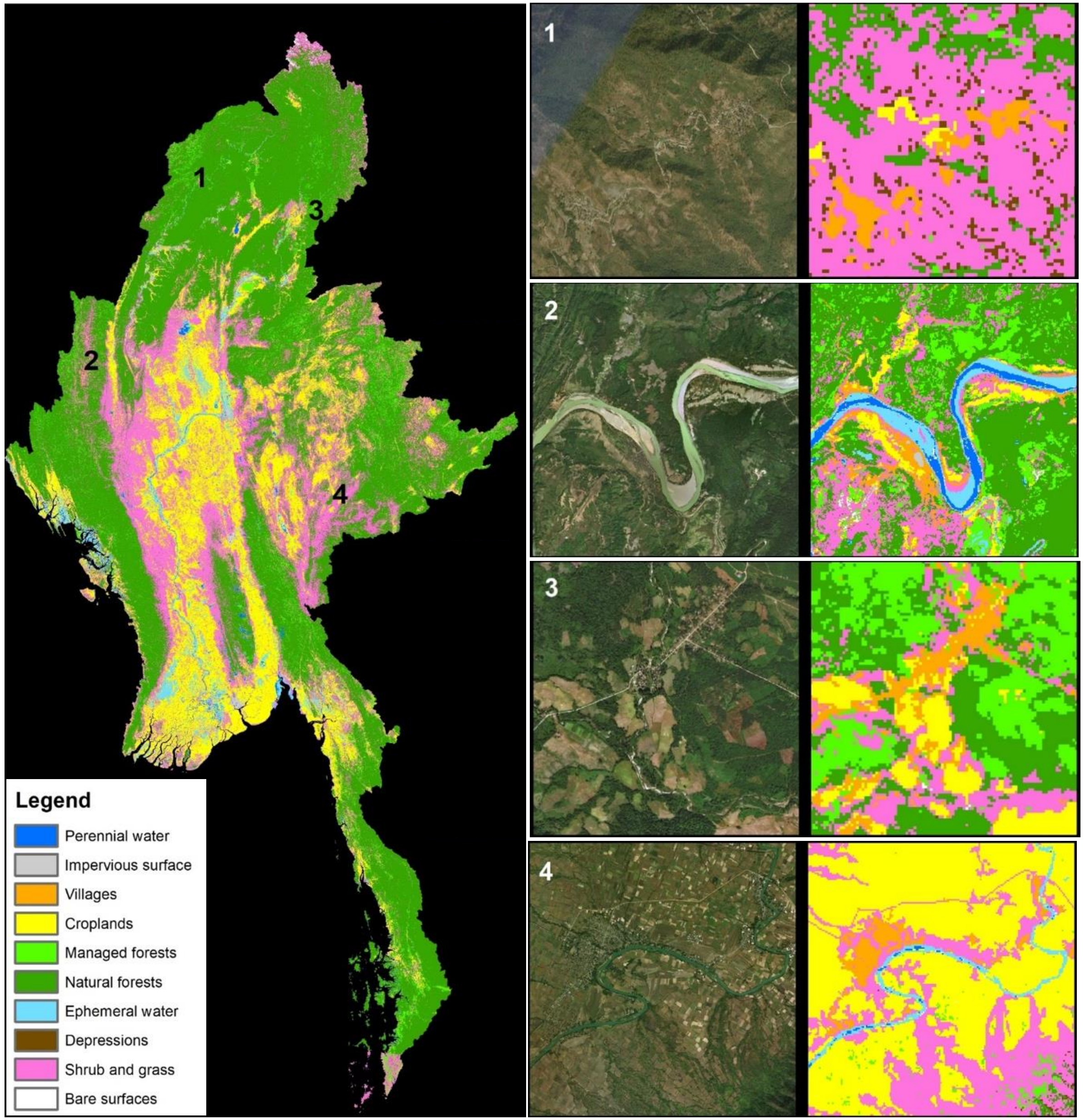
Satellite Data
+
Auxiliary Spatial Data
+
Surveys



Acquiring and Developing EO Datasets to Assess Malaria Risk in Myanmar

Base Map Development

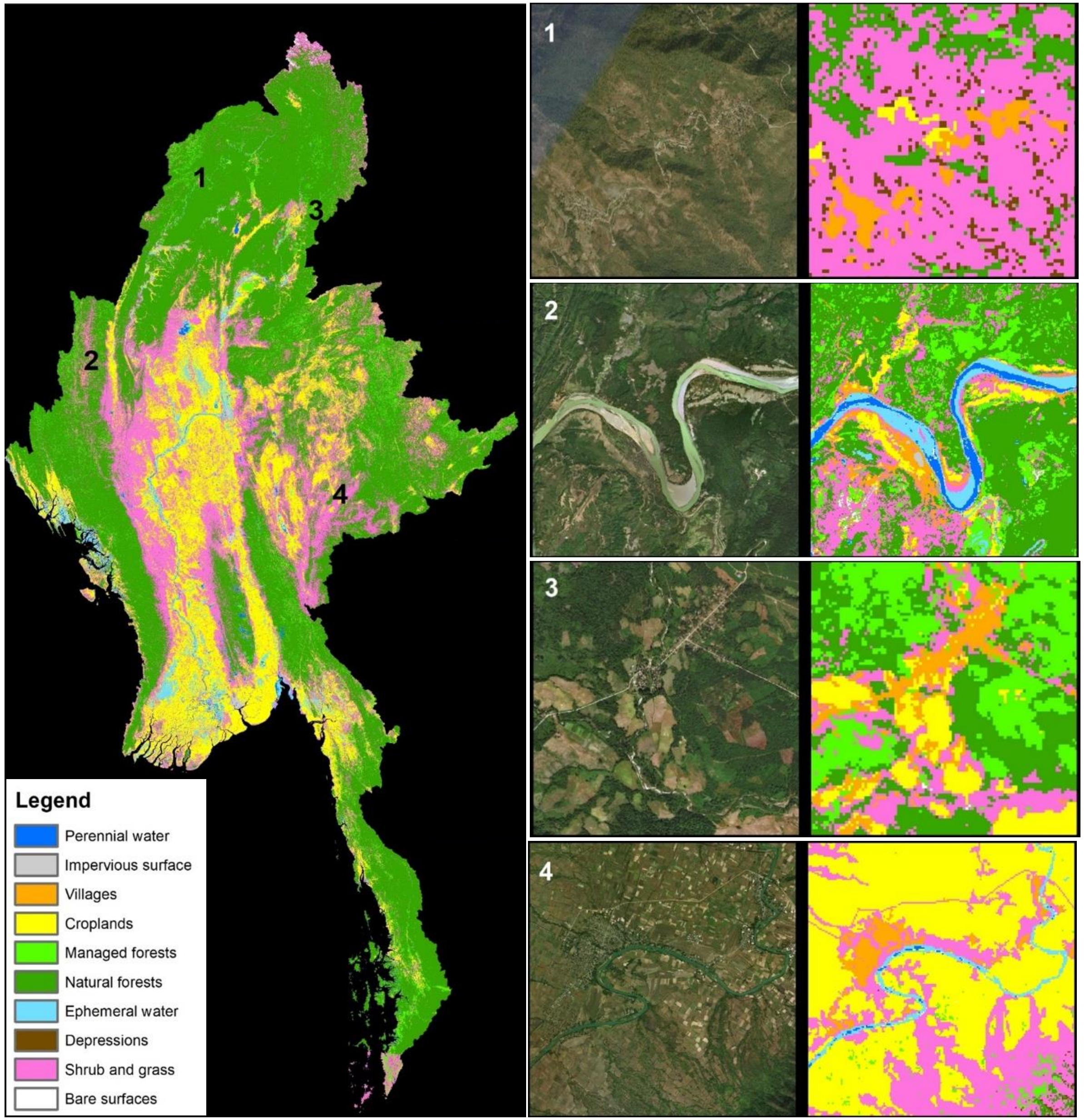
- **Goal:** Map land cover and land use components within Myanmar which are relevant for malaria risk
- **Parameters**:
  - Identify classes/components which are important for malaria risk assessment and determine the necessary spatial resolution = *Legend development + resolution*



Chen et al. 2020. Land cover land use map for Myanmar at 30-m resolution for 2016. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.921126

Base Map Development

- **Goal:** Map land cover and land use components within Myanmar which are relevant for malaria risk
- **Parameters**:
  – Identify classes/components which are important for malaria risk assessment
  – Reuse existing datasets as much as possible (**evaluate!**)
    - Is the metric appropriate?
    - Is the spatial resolution right?
    - What time period does it cover? Or when was it produced?
    - Does it perform well within my area of interest?



Chen et al. 2020. Land cover land use map for Myanmar at 30-m resolution for 2016. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.921126

Comparing the Performance of Various Datasets Mapping Villages

- Visual assessment is valuable and frequently sufficient.
- Many datasets (global and regional) were available:
  - SERVIR Mekong (urban and built-up class)
  - HBASE (built-up and settlement)
  - GHSL (built-up)
- Conclusion: **None** capture Myanmar villages well.

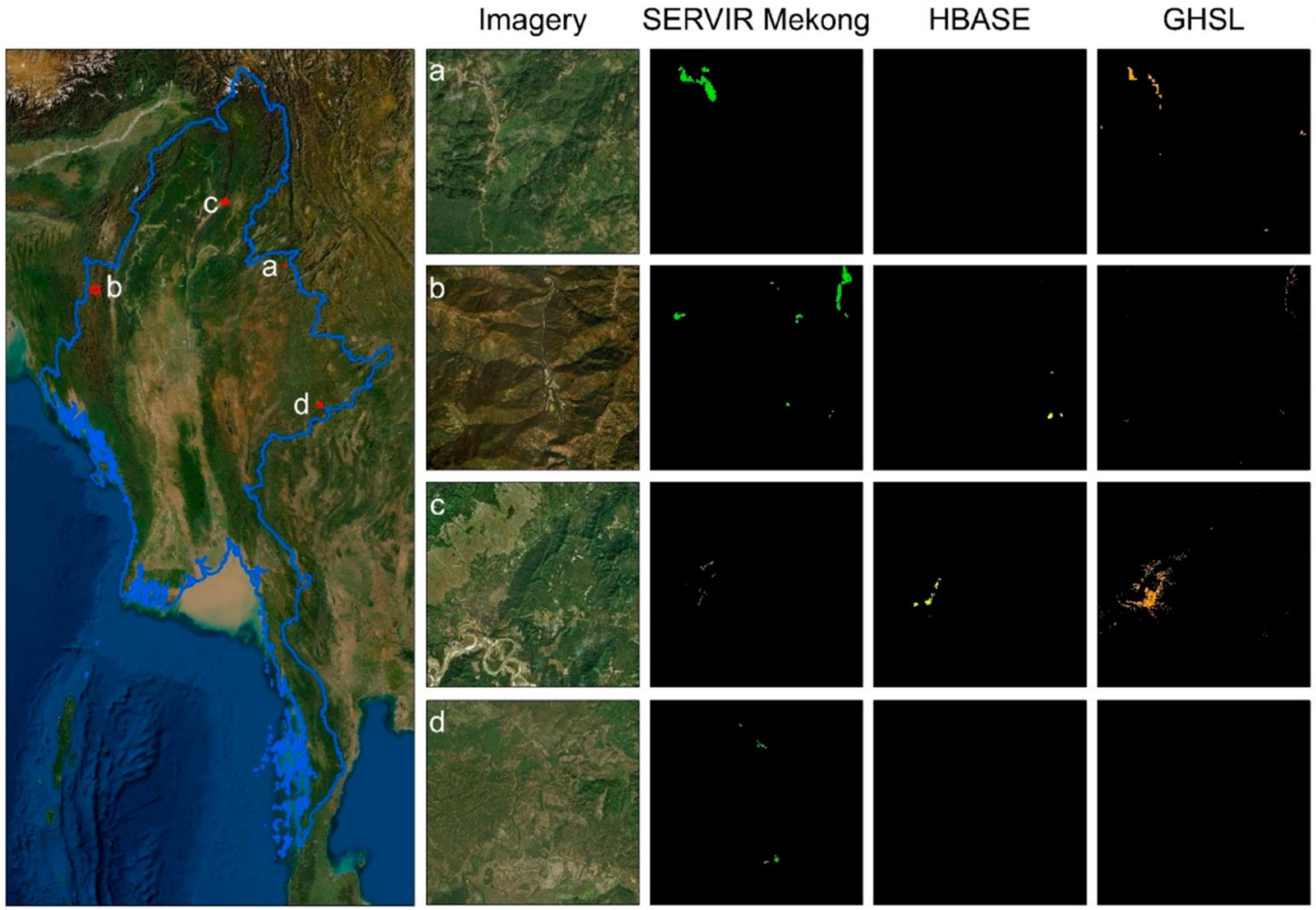
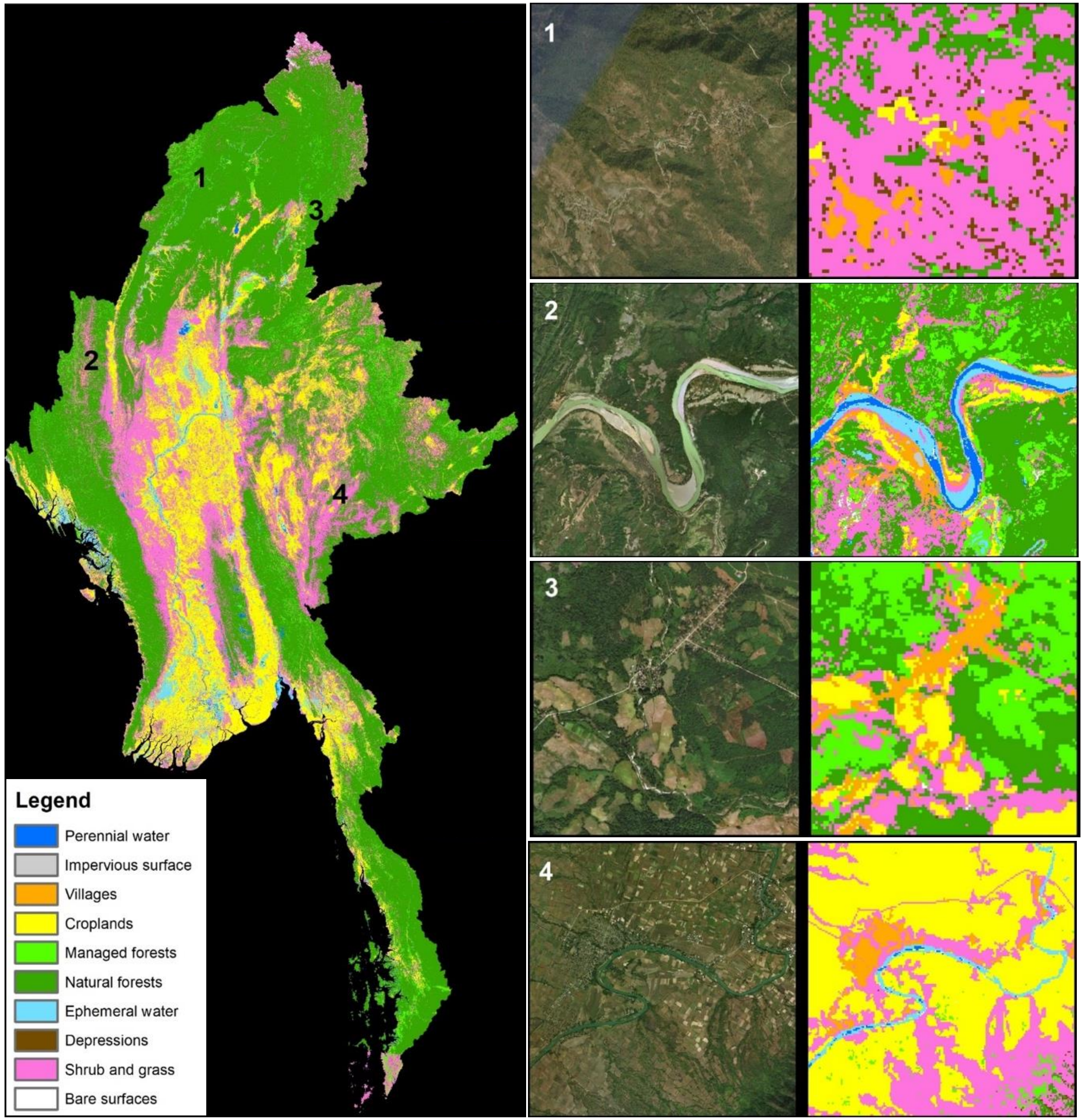


Figure 3 (Modified) in Chen et al. (2021). A disease control-oriented land cover land use map for Myanmar. Data (Basel), 6 (6):63.

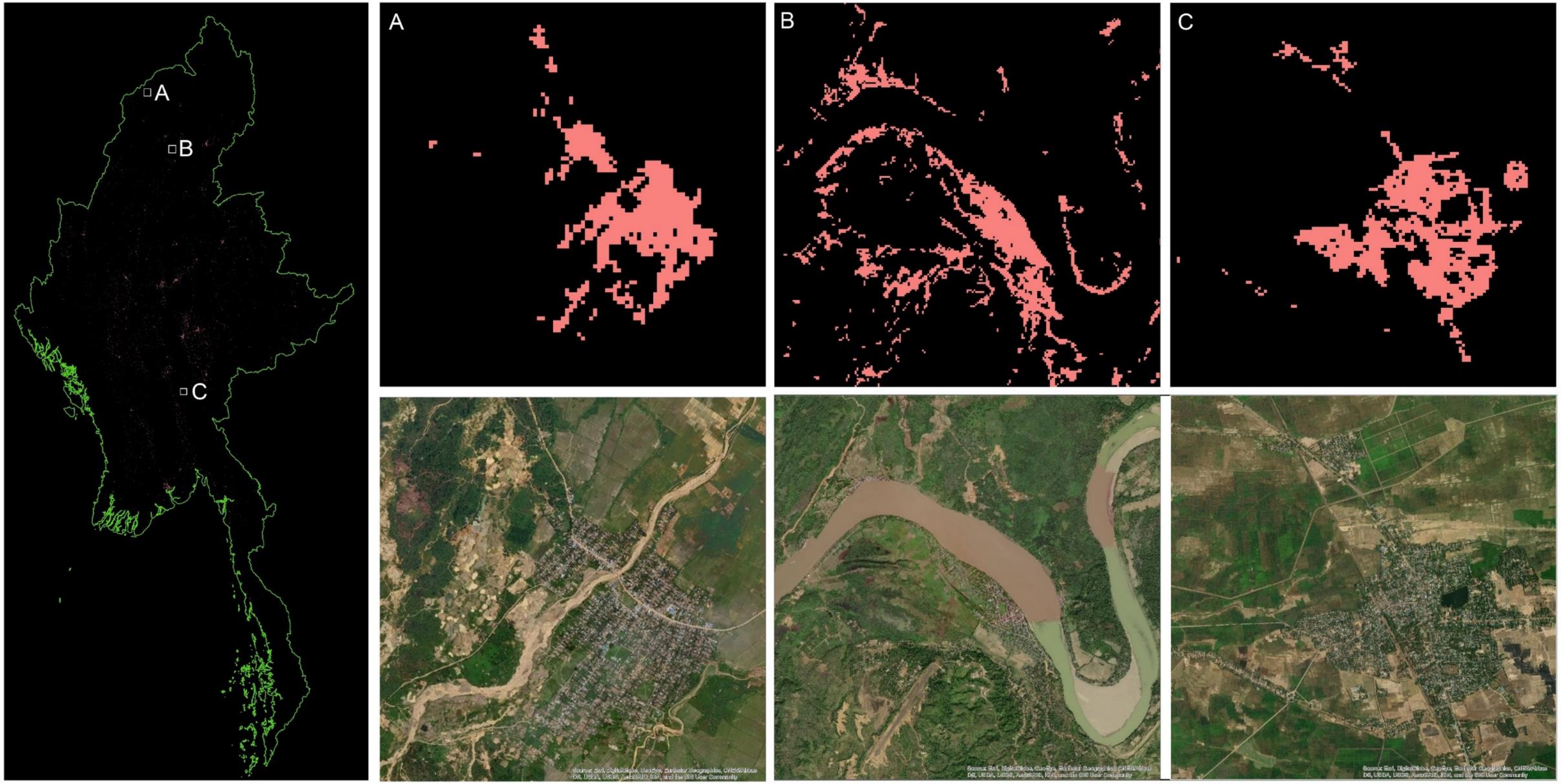
Base Map Development

- **Goal:** Map land cover and land use components within Myanmar which are relevant for malaria risk
- **Parameters**:
  - Identify classes/components which are important for malaria risk assessment
  - Reuse existing datasets as much as possible
  - Develop new components as needed (if accuracy of existing ones is insufficient or in no products exist) – find an expert to do that



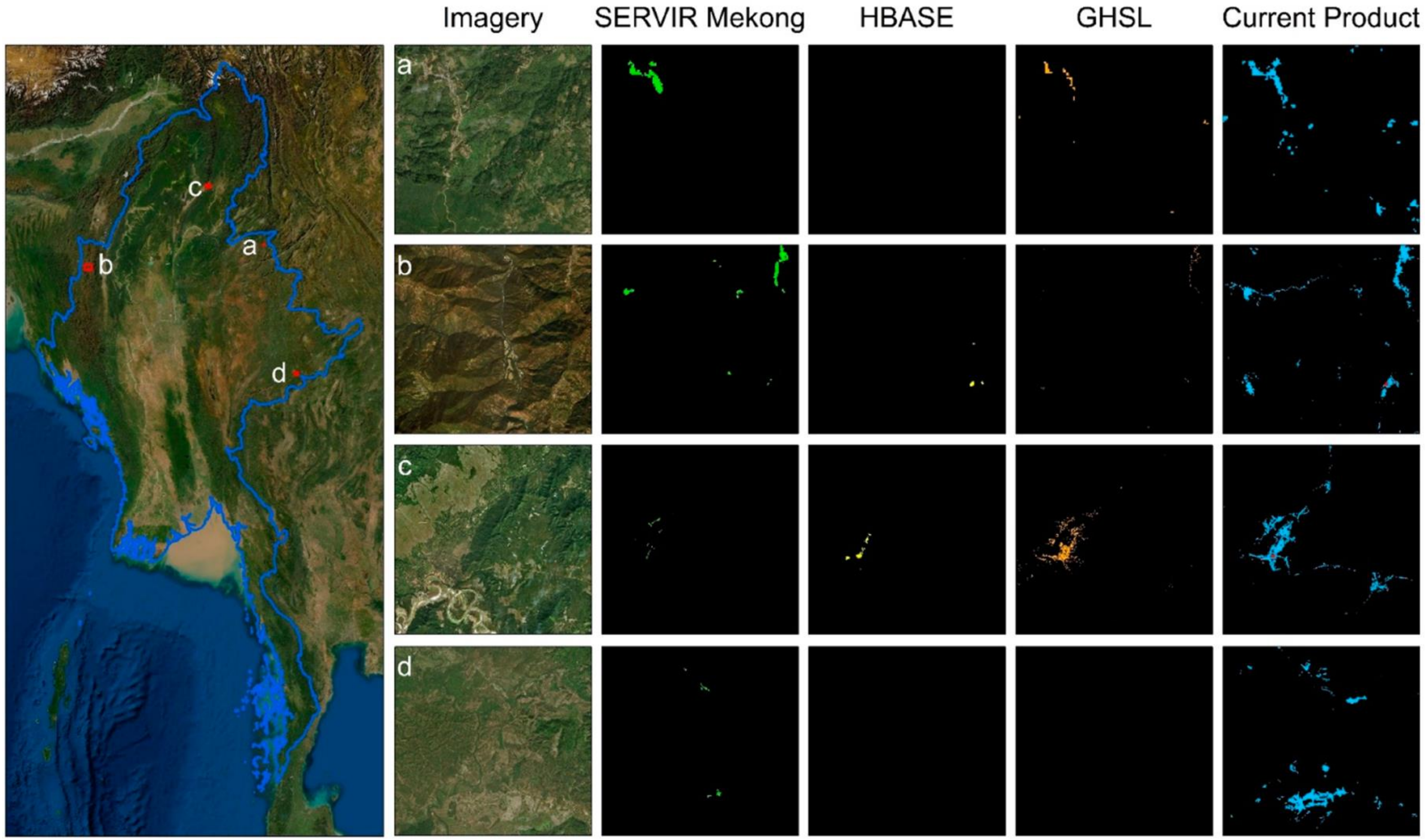
Chen et al. 2020. Land cover land use map for Myanmar at 30-m resolution for 2016. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.921126

Developed New “Human Presence” (i.e., “Villages”) Dataset



Comparing the Performance of Various Datasets Mapping Villages

- Visual assessment is valuable and frequently sufficient.
- Many datasets (global and regional) were available:
  - SERVIR Mekong (urban and built-up class)
  - HBASE (built-up and settlement)
  - GHSL (built-up)
  - Our Dataset = Current Product



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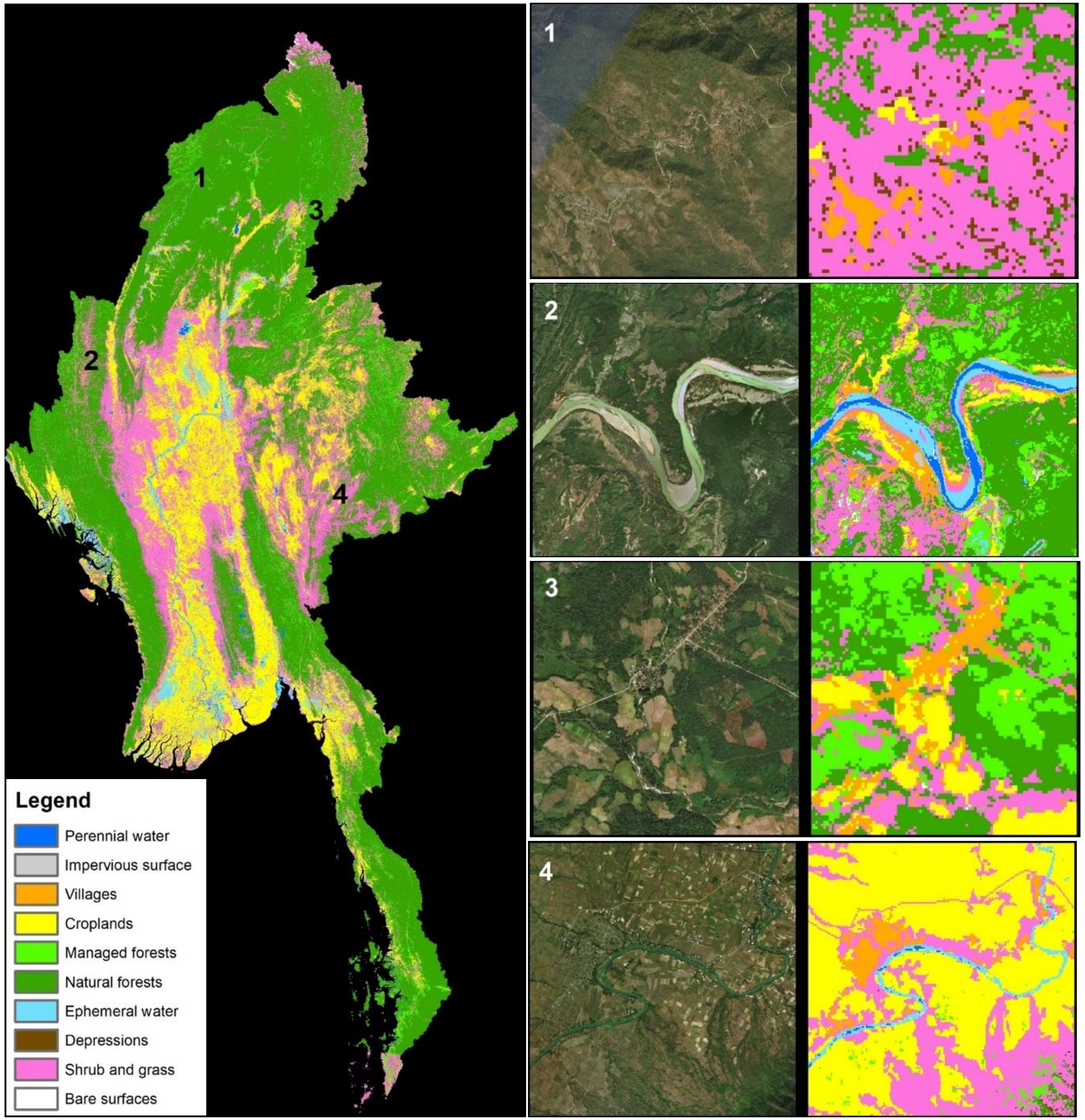
- **Parameters**:
  - Identify classes/components which are important for malaria risk assessment
  - Reuse existing datasets as much as possible
  - Develop new components as needed
  - Prioritize map classes based on their importance in terms of malaria risk modeling



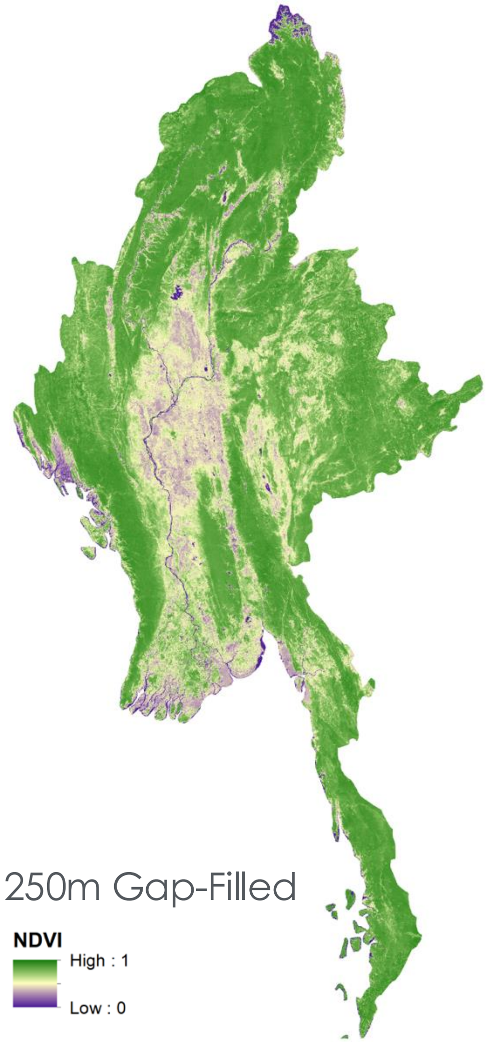
Chen et al. 2020. Land cover land use map for Myanmar at 30-m resolution for 2016. PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.921126

Vector Habitat Monitoring

- **Metrics to Consider:**
  - Temperature (Max and Min)
  - Precipitation Intensity (very difficult in Myanmar from observations)
  - Moisture Availability (retained on the landscape)
  - Habitat Availability
- **Metrics Selected:**
  - Vegetation Stress (NDVI)
  - Land Surface Temperature (Daytime and Nighttime)
- **Parameters to Consider:**
  - No need for high spatial resolution
  - Need frequent updates (daily/weekly)
  - Need full coverage for the country every observation period
- **Data Source Selected:**
  - Moderate Resolution Imaging Spectroradiometer (MODIS) 250m & 1km (downscaled to 250 m) Data, 8-day Composites

Vector Habitat Monitoring

Vegetation Stress

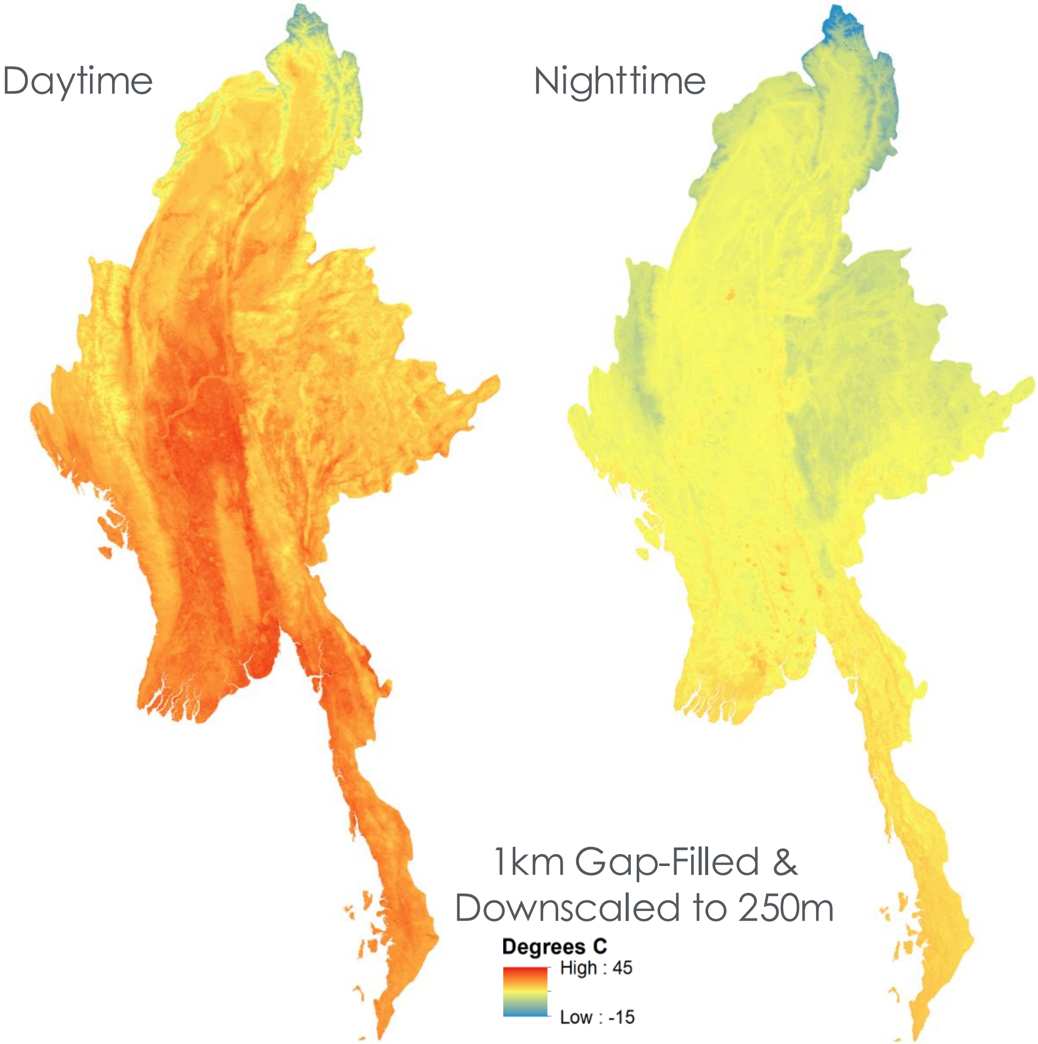


250m Gap-Filled

January 1, 2017 Land Surface Temperature

Daytime

Nighttime



1km Gap-Filled & Downscaled to 250m

Missing Data = Gaps in Observations → Gap-Filling Approaches

- Reasons for missing data:
  - Clouds & Cloud Shadow (most frequent)
  - Atmospheric Transparency (e.g., high concentrations of aerosols or water vapor)
  - Instrument Malfunctioning
    - Landsat 7 (ETM+) scan corrector error
    - MODIS Terra did not function properly and did not collect observations in June-July 2001

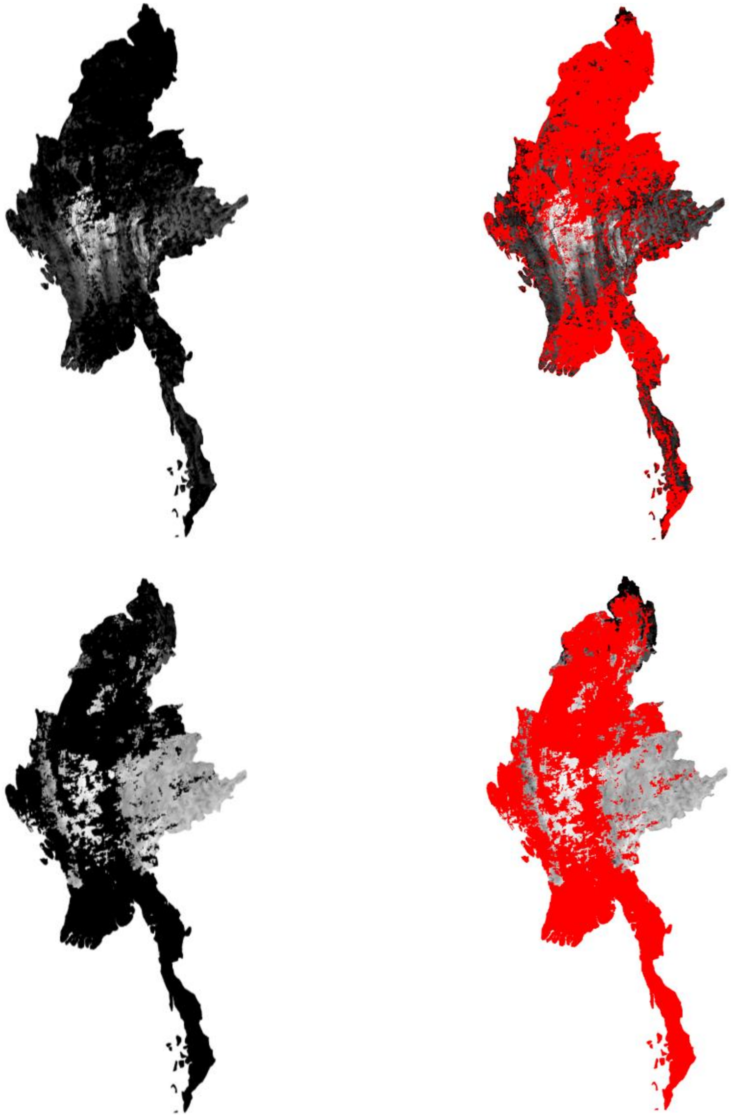
Source: [usgs.gov]

Downscaling and Gap-Filling Land Surface Temperature Data

QA Screened Values　　Missing Values: Red

Daytime LST

Nighttime LST



Downscaling and Gap-Filling Land Surface Temperature Data

- Dual Purpose:
  - Improve the resolution from 1km to 250m
  - Fill the gaps in the observations

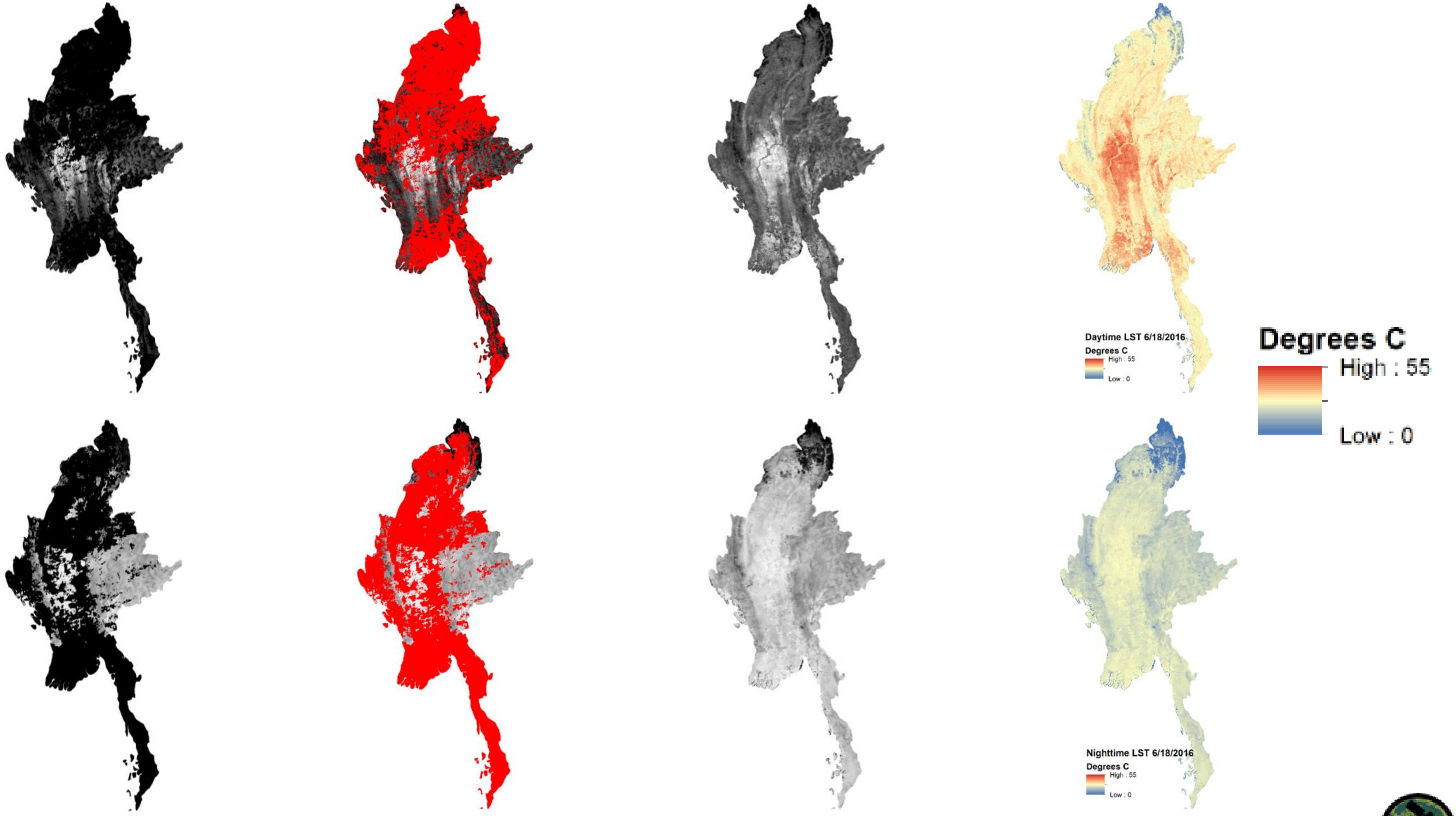
- Adopted operational fire weather interpolation approach:
  - Assign grid value to the center point of the grid cell
  - Using Digital Elevation Model (DEM), convert the value of the grid cell at elevation to that at the sea level
  - Interpolate temperature at surface level using 250m grid to create contiguous temperature surface at the sea level
  - Using DEM, adjust the temperature of the grid cells at sea level to the appropriate elevation for the 250m grid

Downscaling and Gap-Filling Land Surface Temperature Data

QA Screened Values | Missing Values: Red | Gap-Filled Values | LST Estimates

Daytime LST

Nighttime LST



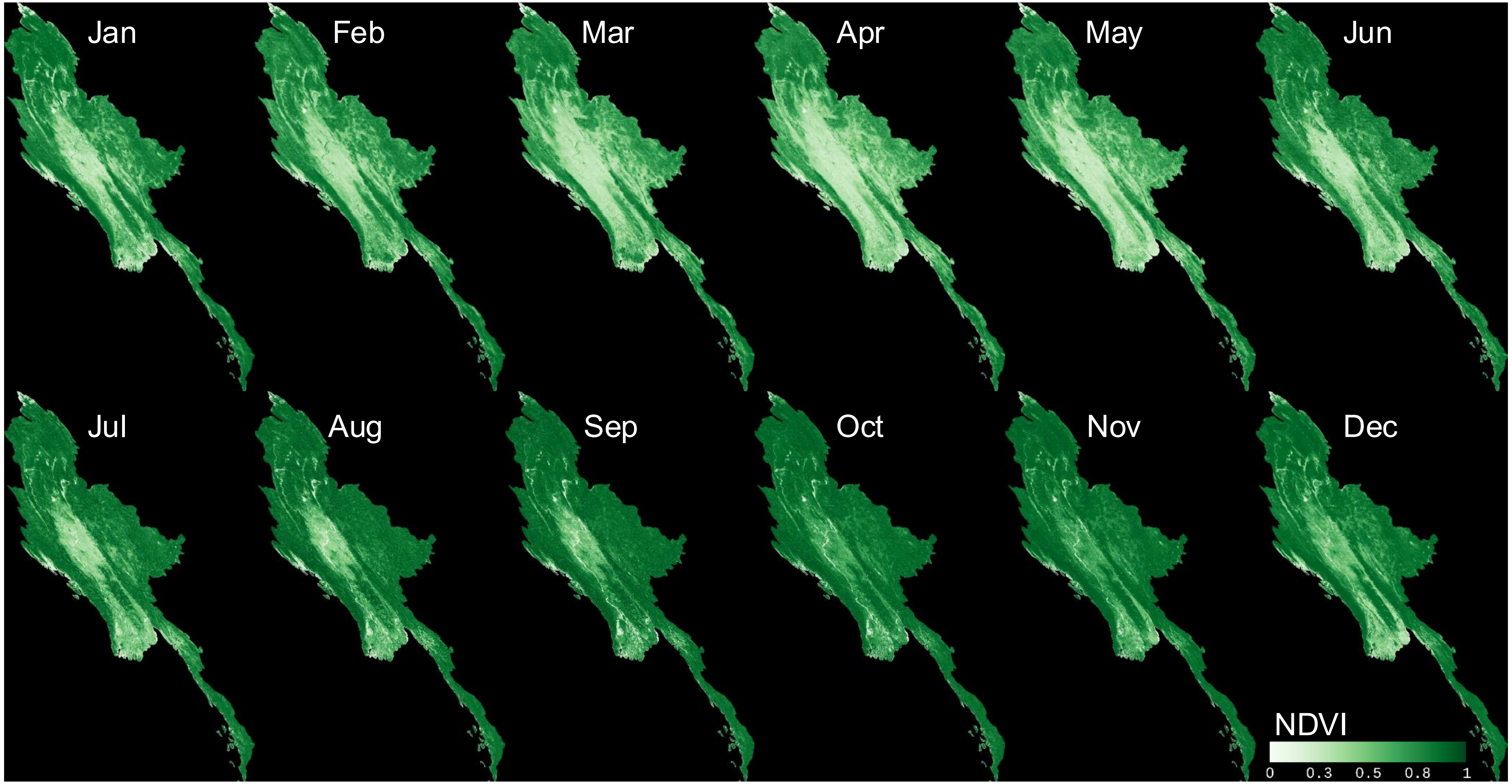
Gap-Filling and Predicting Vegetation Greenness (NDVI) Values

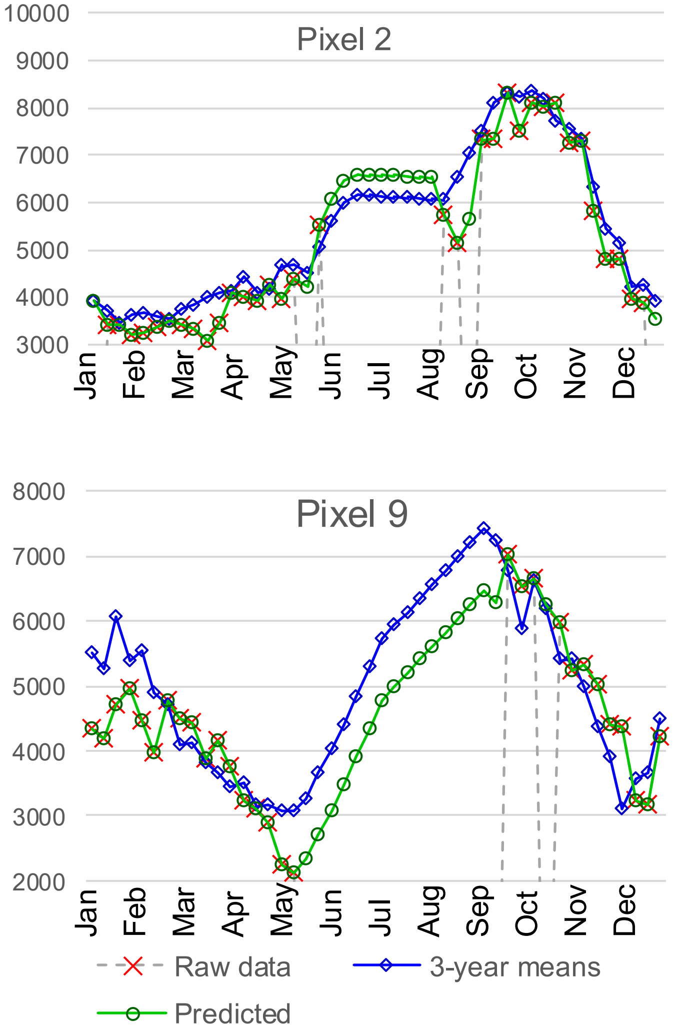
- Big Challenge:
  - With the onset of monsoons in Myanmar, land surface is not observable for months.

- Major Assumption:
  - Vegetation generally remains **undisturbed** (no logging, no harvesting, no burning) during the monsoon period **and** there is no moisture deficit.

- Approach:
  - Extrapolate values of each pixel in time linearly between valid observations (for the past data record)
  - Predict the current value of pixel based on the difference between the last valid observation and the 3-year mean value (for unchanged land cover, e.g., natural forest, only)

Gap-Filling and Predicting Vegetation Greenness (NDVI) Values

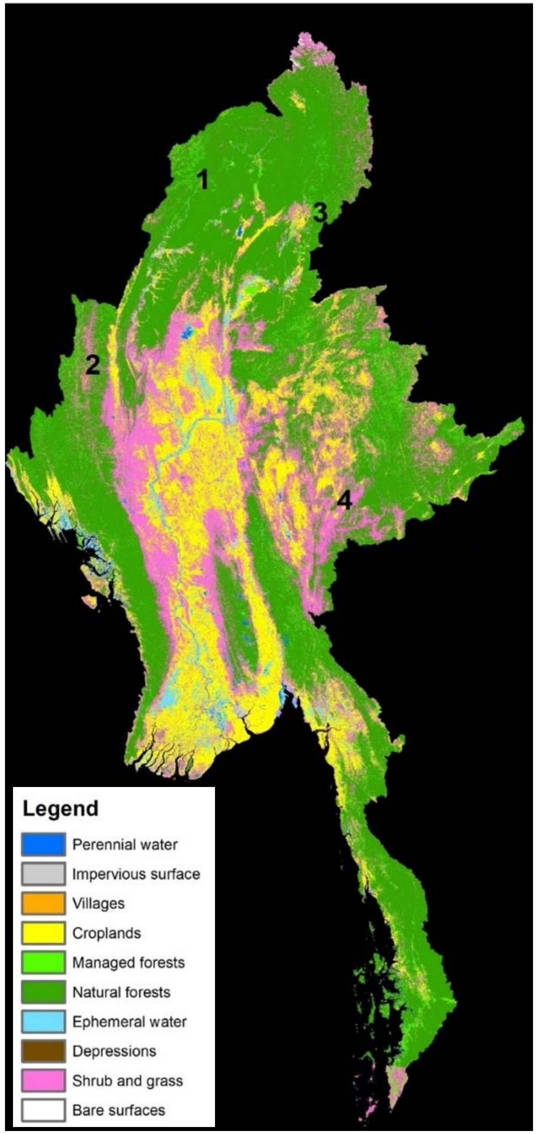


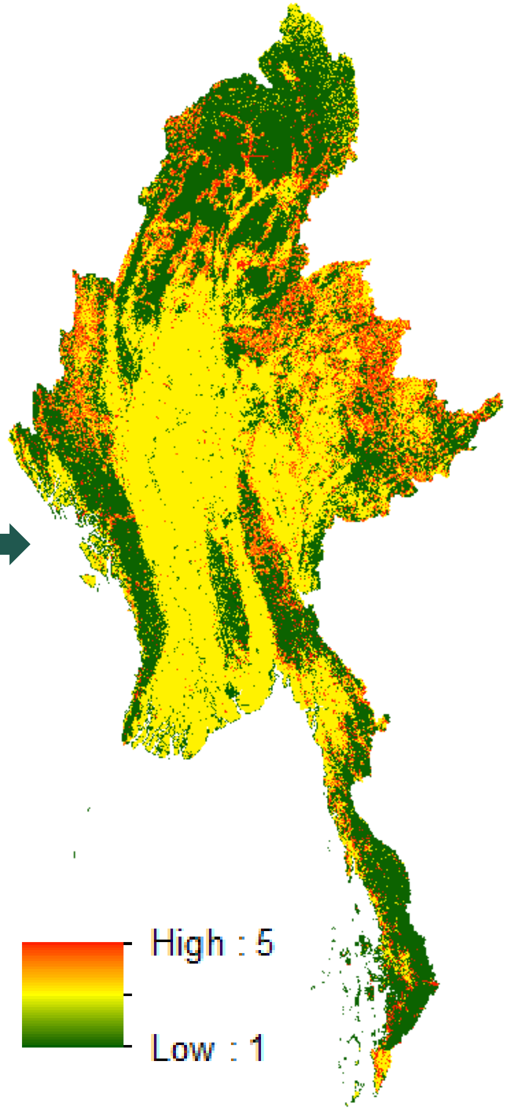


Estimating Occupational Exposure (OE)

- A huge amount of basic science is needed to develop robust quantitative assessments for OE.
- If data is unavailable, create a numeric qualitative reference using land use categories and expert assessments.
  - We assigned values from 1 to 5 (very low – very high) occupational exposure in consultation with public health professionals.

Parameter	Exposure Category Definitions				
	Very Low (1)	Low (2)	Mod (3)	High (4)	Very High (5)
Occ Expos (OE)	Urban Areas	Coastal Fisheries	Crops	Forest Chores	Plantation, Logging, & Mining

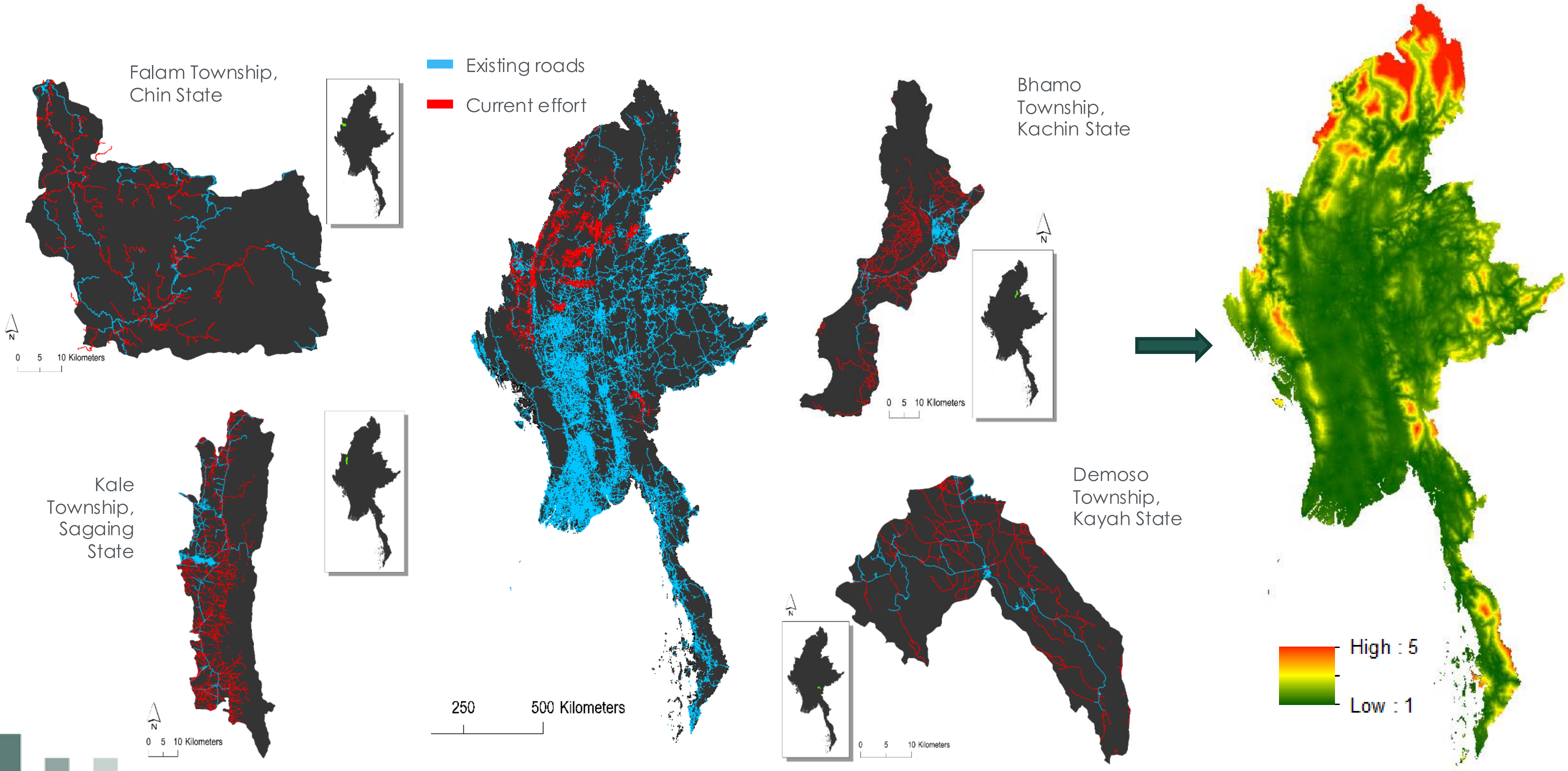




Estimating Access to Care

- Myanmar lacks information about rural (unpaved) transportation routes.
- We hand-digitized roads in rural and most malarious areas of Myanmar using Google Earth imagery (it is possible, but it is a tremendous amount of work and not to be undertaken unless **absolutely** necessary).
- We obtained a GIS layer of medical facilities.
- We computed “travel cost (time)” surfaces using existing algorithms.

Estimating Access to Care

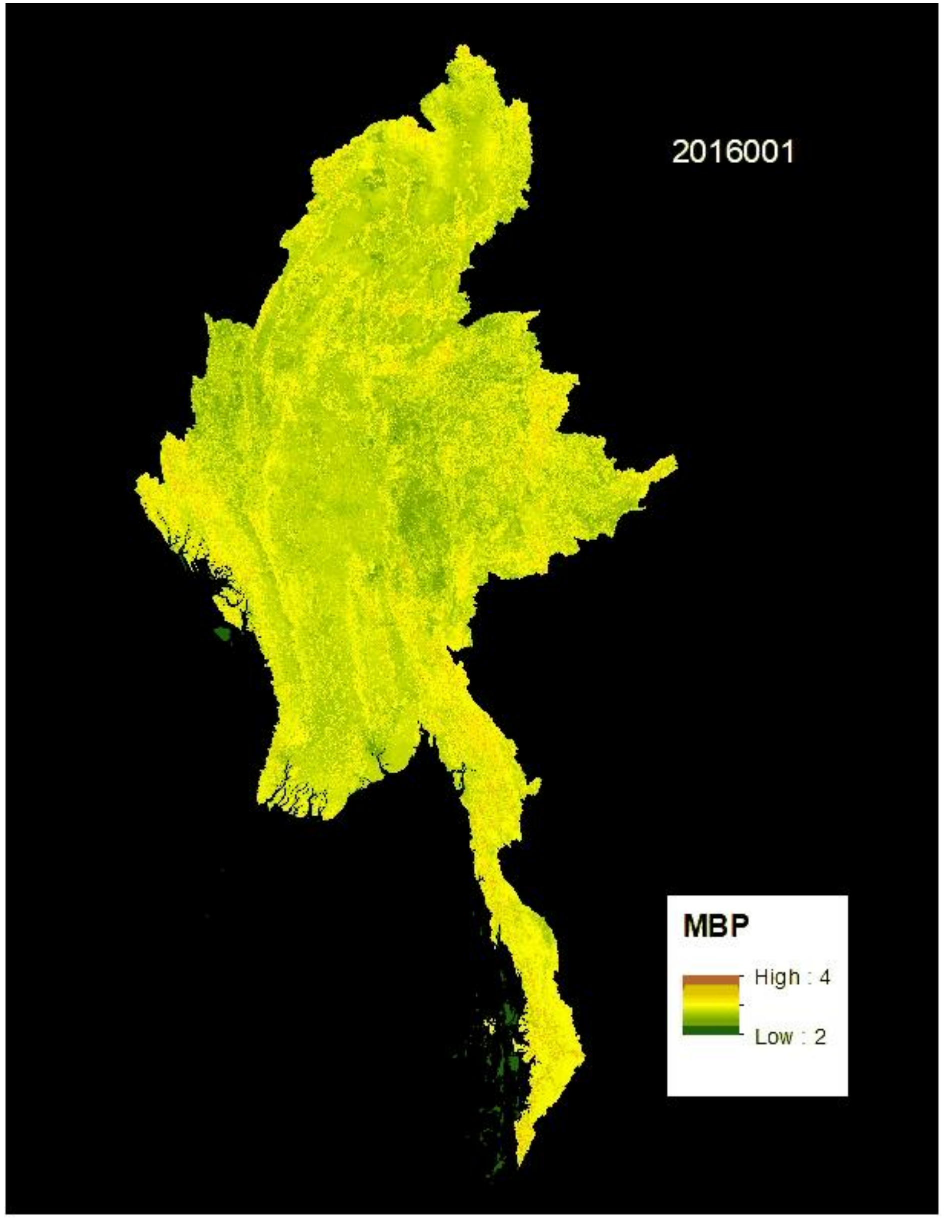


Putting Everything Together to Monitor Malaria Burden Potential

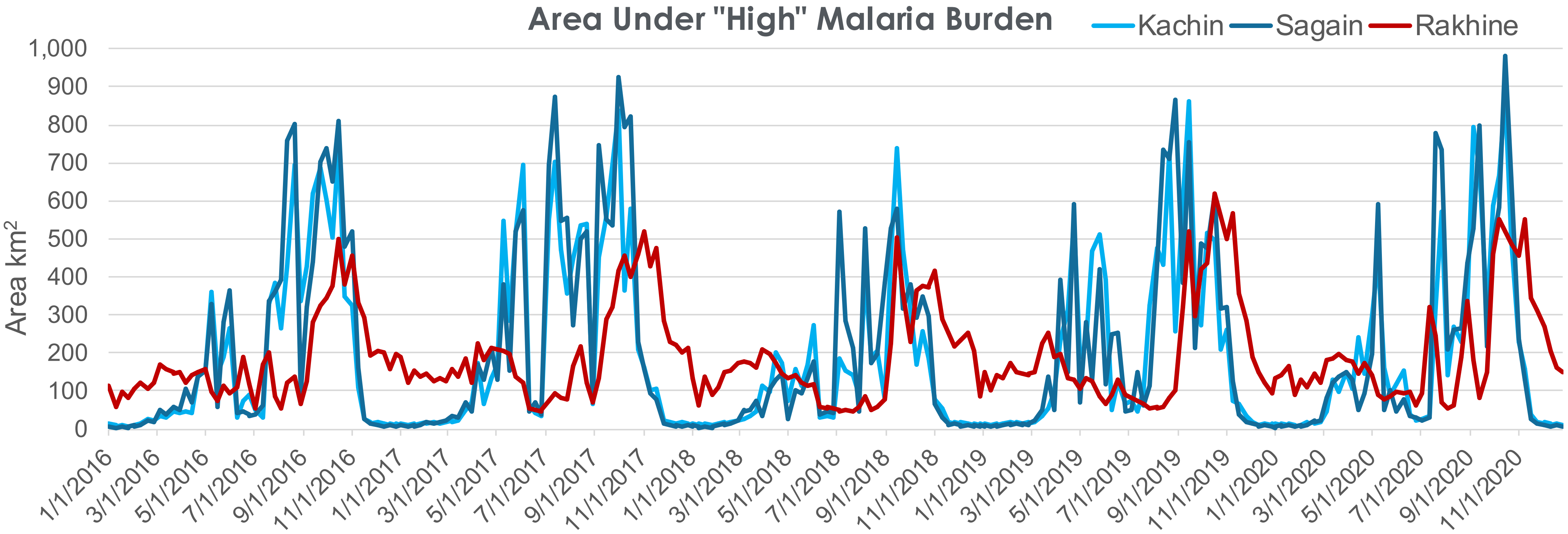
- A lot more work was involved…

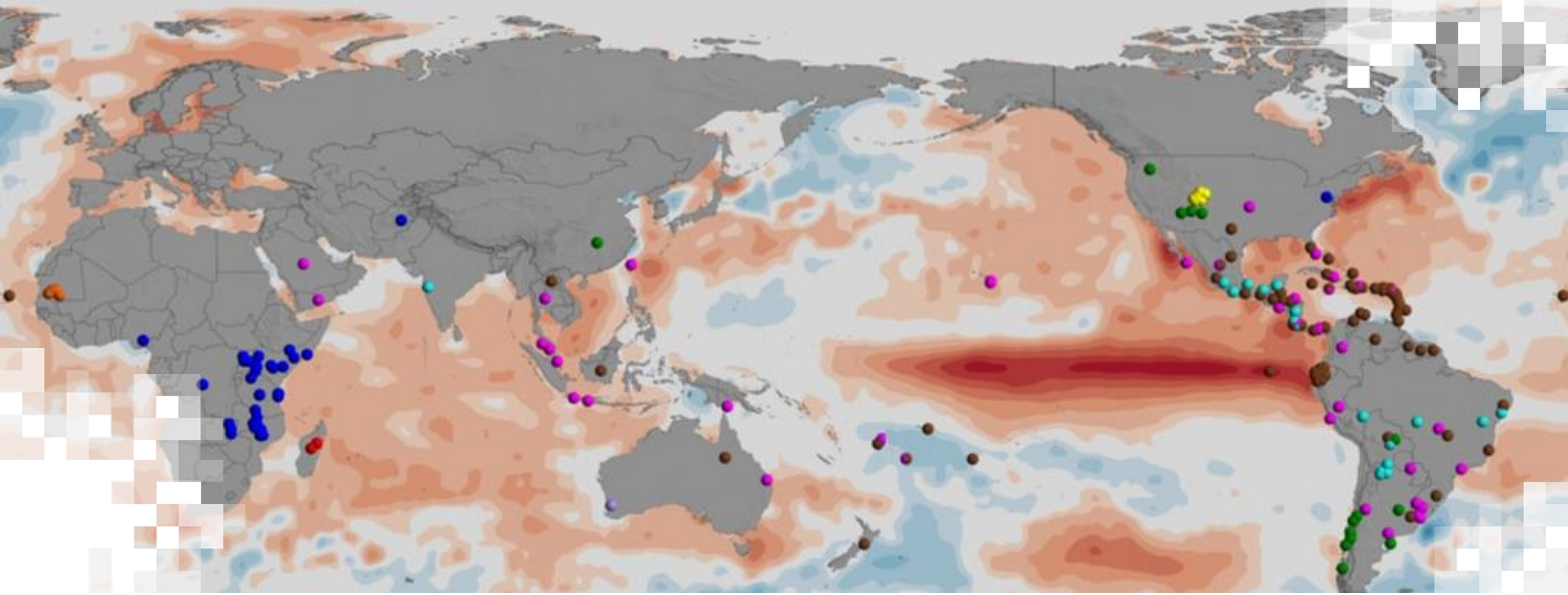
- Wall-to-Wall Model of Malaria Burden Potential
  - 250m resolution
  - 8-day update
  - 1– 2 months forecast

- Executed: 2016-2020



Tracking Temporal Variability in Malaria Burden Potential in High-Burden States of Myanmar

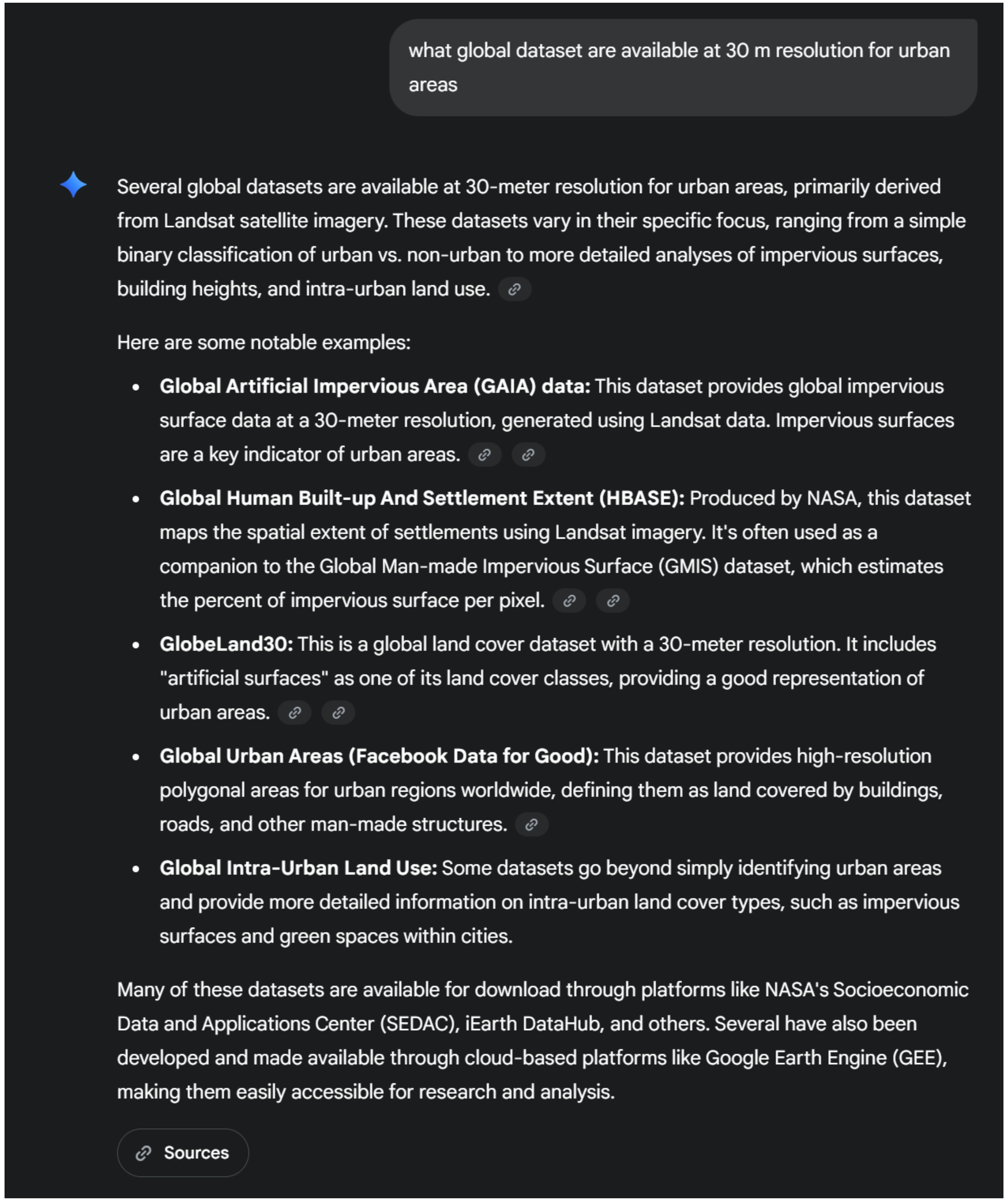




Common Challenges of Working with Remotely Sensed Data and How to Tackle Them

Data Search and Discovery

- Earthdata Search
- Known archives or data repositories, e.g.:
  - Global Forest Watch
  - Pangea
  - NASA DAACs
- Simply search the web or use AI



Data Assessment

- Explore published uncertainties
- Conduct an assessment for a specific component in your particular region

Table 4.

Results of MAX and RIGHT functions.

Map Strata	Total Samples (n)	Correct Samples Defined by MAX Function (n)	MAX (M) Function	Correct Samples Defined by RIGHT Function (n)	RIGHT (R) Function	Improvement in Accuracy when Fuzziness Is Considered (R-M)	Area Weights
Perennial water	75	44	58.67%	56	74.67%	16.00%	0.007
Impervious surface	75	34	45.33%	50	66.67%	21.33%	0.002
Villages	75	33	44.00%	63	84.00%	40.00%	0.003
Croplands	152	90	59.21%	118	77.63%	18.42%	0.190
Managed forests	75	24	32.00%	48	64.00%	32.00%	0.048
Natural forests	393	256	65.14%	332	84.48%	19.34%	0.489
Ephemeral water	75	19	25.33%	35	46.67%	21.33%	0.029
Shrub and grass	184	17	9.24%	62	33.70%	24.46%	0.229
Bare surfaces	75	23	30.67%	31	41.33%	10.67%	0.003
Total	1179	540	45.80%	795	67.43%	21.63%	
Total weighted accuracy			48.20%		69.22%	21.02%	

Table 4 in Chen et al. (2021). A disease control-oriented land cover land use map for Myanmar. Data (Basel), 6 (6):63.

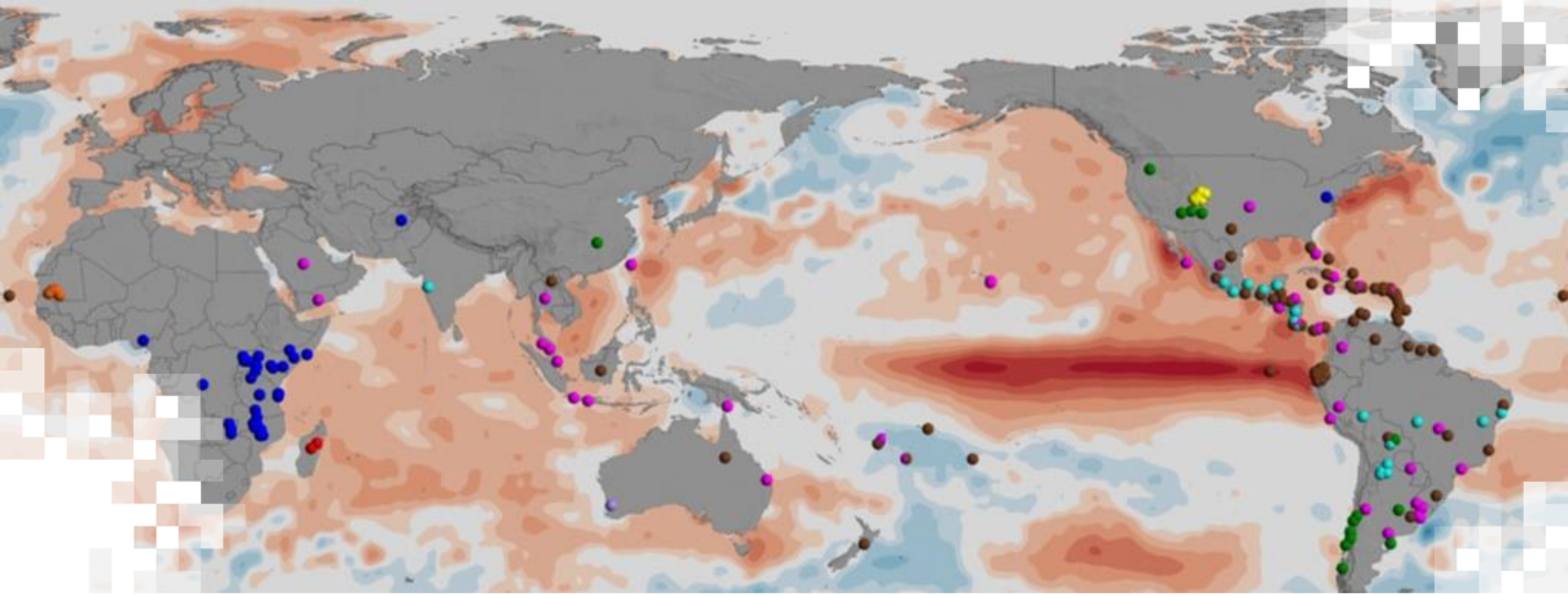
Data Preprocessing

- Apply QA Bits
- Gap-Fill Data
  - Compositing
  - Interpolating
  - Modeling
- Re-Grid to a Common Resolution
  - Aggregate to coarser grid cells
  - Downscale to finer grid cells
- Convert to a Common Projection
  - Select a projection that will be best for your final product

Table 9. 250 m Level 3 Surface Reflectance Band Quality Description (16-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	sur_refl_qc_250m
0-1	MODLAND QA bits	00	corrected product produced at ideal quality all bands
		01	corrected product produced at less than ideal quality some or all bands
		10	corrected product not produced due to cloud effects all bands
		11	corrected product not produced due to other reasons some or all bands may be fill value [Note that a value of (11) overrides a value of (01)].
2-3	Spare (unused)	--	--
4-7	band 1 data quality four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds
8-11	band 2 data quality four bit range		SAME AS BAND 1 ABOVE
12	atmospheric correction performed	1	yes
		0	no
13	adjacency correction performed	1	yes
		0	no
14	different orbit from 500 m	1	yes
		0	no
15	spare (unused)	-	---

Table 9 in Vermote et al. (2015). MODIS Surface Reflectance User's Guide. *Collection 6*.



Part 1:
Summary

ARSET Summary

- Satellite observations provide diverse, comprehensive, repeated observations of the environment, including both direct and indirect or proxy measurements, which can improve the assessment and forecasting of climate-sensitive infectious disease outbreaks by monitoring the disease econiche.
- Environmental parameters relevant to climate-sensitive infectious disease econiches, such as temperature, precipitation, vegetation, and land cover, can be observed from space.
- Satellite data might be used to inform the hazard, vulnerability, and/or exposure aspects of the disease risk. Different considerations apply to each aspect of the risk.
- Incorporating remote sensing data into the study of climate-sensitive infectious diseases involves identifying remote sensing data with suitable parameters, coverage, and resolution, and then evaluating these data for suitability in the specific context of their application. Existing datasets may be suitable for use, or new, locally-specific datasets may need to be created.
- Gaps in satellite data may be addressed using gap-filling approaches such as compositing, interpolating, or modeling.
- Satellite data preprocessing involves quality filtering, gap-filling, re-gridding, and conversion to a common projection.

Looking Ahead to Part 2

- Dr. Michael Wimberly (University of Oklahoma) will present a case study of the application of satellite remote sensing data to Malaria forecasting in Ethiopia.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 10/09/2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 10/23/2025**

- **Certificate of Completion:**
  - Attend all live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- Dr. Tatiana Loboda
  - loboda@umd.edu

- ARSET Website
- ARSET YouTube

Thank You!