EYWA
Early Warning System
for Mosquito Borne Diseases

Earth Observation for Epidemics
of Vector-borne Diseases /
EuroGEO Action Group

EuroGEO

BEYOND
Centre of EO Research
and Satellite Remote Sensing

Operational Unit "BEYOND Centre of EO
Research & Satellite Remote Sensing"

An Early Warning Tool to the epidemics arsenal

Unveiling the EYWA System
From the challenge...to the solution

Haris Kontoes
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www.beyond-eocenter.eu
On behalf of EYWA team

Scan me to find more

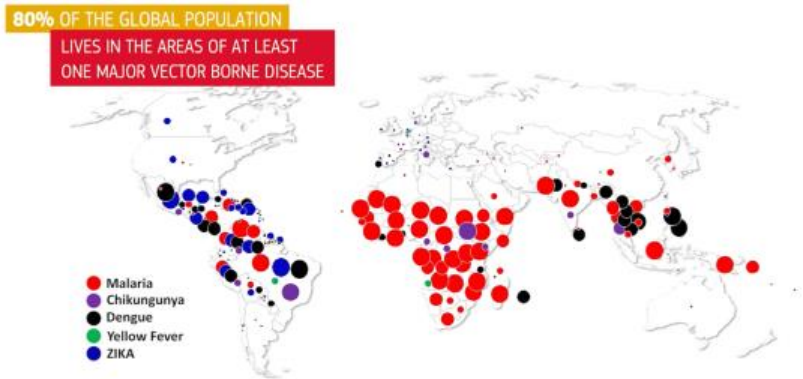
e-shape

EARLY WARNING FOR EPIDEMICS prize

European Commission

Winner of the first "EIC Horizon Prize
on Early Warning for Epidemics"

Introduction | MBDs: A global problem to be addressed



Re-emergence of significant mosquito born disease, including outbreaks, reported native and imported cases (2017-2019)

- **Climate Change**, **globalisation** and other drivers are altering ecological conditions for **mosquitoes**.
- Mosquito-Borne Diseases (MBDs) are present in **over 100 countries**.
- 700,000 deaths per year.
- **Malaria**, most lethal for kids aged under five in the sub-Saharan regions.
- **Europe** a "hot spot" of **West Nile Virus**.
- **Chikungunya** and **dengue fever** increased 40% over 1950[1].

1. https://www.thelancet.com/action/showPdf?pii=S0140-6736(20)32290-X

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EYWA & West Nile Virus in Europe

Greece

- **1702 cases and 227 deaths** in the past 12 years.
- **EYWA** supports **4 regions** with a total of **2500 settlements** and **3.8M people**. Entomological risk predictions powered by the **BAd (Ecodev)** and **MAMOTH (BEYOND/NOA)** models. Epidemiological risk predictions powered by the **BAr (Ecodev)** and **MIMESIS (Uni of Patras)** models.

Italy

- **EYWA** supports **2 regions** with a total of **757 municipalities** and **540K people**.
- Entomological risk predictions powered by the **MAMOTH (BEYOND/NOA)** model.
- Epidemiological risk predictions powered by the **BAr (Ecodev)** and **MIMESIS (Uni of Patras)** models.

Serbia

- **Vojvodina region 37 municipalities** and **1.9M people**.
- Entomological risk predictions powered by the **MAMOTH (BEYOND/NOA)** model.

- **West Nile Virus** outbreaks have been registered in all of **southern Europe**.
- Starting to register cases in 2010, the disease had extreme outbreaks in multiple countries in **2018** with **1549** cases and **166** deaths in a year.
- In 2022 there is another outbreak ongoing in cases with **939** cases and **68** deaths so far.
- Overall **4989 cases and 437 deaths** in the past **12 years**.
- EYWA supports 11 regions in Europe for a total of **10.909 municipalities** and more than **34M people** living in them.

Germany

- **Baden-Württemberg region 74 municipalities** and **11.1M people**.
- Entomological risk predictions powered by the **MAMOTH (BEYOND/NOA)** model.

BNITM
Bernhard Nocht Institute for Tropical Medicine

France

- **3 regions / 9935 municipalities** and **~12 M people**.
- Entomological risk predictions powered by the **MAMOTH (BEYOND/NOA)** model.

EID MÉDITERRANÉE
OPÉRATEUR PUBLIC EN ZONES HUMIDES

EYWA supported European regions

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EYWA & MBDs in Ivory Coast

Mosquito Threats in Ivory Coast:

- Aedes Aegypti spread Dengue Fever, Chikungunya, Yellow fever, Zika fever and more disease agents
- Anopheles spread Malaria

Malaria in 2020:

- 26.378.275 **population at risk**, 7.434.595 **suspected** cases, 4.587.859 **confirmed** cases, 2.252.312 in **children under 5**, 103.947 **severe** cases, 1.315 **deaths**.

Dengue fever outbreaks:

- 2017[3]: 623 **suspected** cases, 2 **deaths**
- Outbreaks in **Abidjan** with a P… **6.321.017**.

MAMOTH EYWA model already established operationally.

1. https://www.cdc.gov/globalhealth/countries/cote-d-iv…htm#malaria
2. https://www.sciencedirect.com/science/article/pii/S03…X14002054
3. https://www.who.int/emergencies/disease-outbreak-news/item/04-august-2017-dengue-cote-d-ivoire-en
4. https://www.africanews.com/2022/05/04/dengue-fever-outbreak-one-dead-11-cases-recorded-in-ivory-coast//

EYWA & MBDs in Thailand

Dengue fever:

- Dengue is hyper-endemic and all 4 serotypes are in active circulation in Thailand (home to around **69 million individuals**).
- Two dominant dengue mosquito vectors, **Aedes aegypti** and **Aedes albopictus**
- Each of the 77 provinces in Thailand have on average, non-zero reported dengue case counts over the past 10 years[1].
- Large outbreaks in 2013, 2015 and 2019 with 153.765, 141.375 and 128,964 respectively[2].

Chikungunya:

- Thailand experienced outbreaks in 2008-2009 (49.069 cases[3]), and 2018-2019 (approximately 15.000 cases[4]).

Transferable MAMOTH EYWA model enabled cooperation with Thailand and Ghana stakeholders

1. https://bmcinfectdis.biomedcentral.com/articles/10.11…05666-4
2. http://outbreaknewstoday.com/thailand-infectious-diseas…measles-dengue-and-melioidosis-30041/
3. https://www.ajtmh.org/view/journals/tpmd/90/3/article-p41…
4. https://pubmed.ncbi.nlm.nih.gov/33690657/

MBDs in Ghana

Malaria (2020 data):

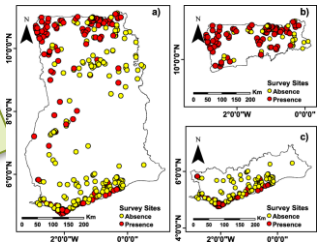
- 31.072.945 **population at risk**, 5.879.506 **suspected & confirmed** cases, 12.084 **estimated deaths**.

Lymphatic Filariasis (2017 data):

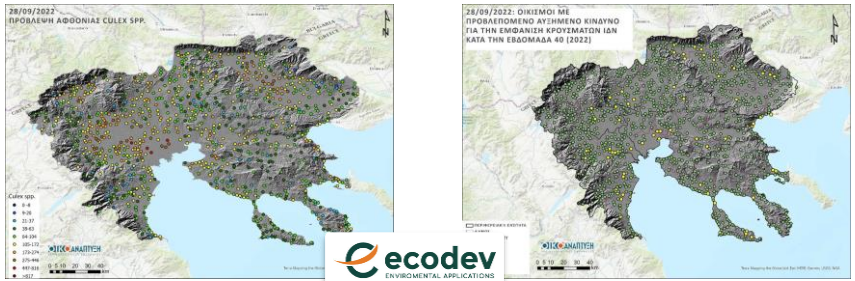
- A cumulative total of over 74M people were treated, giving an estimate of large number of people affected.
- 22 districts defined as "hotspots" (even after mass drug administration programs) with virus prevalence above the recommended 1% level.
- Vector control has been shown to greatly impact the transmission of LF[1,2] , with vector control strategies.
- EYWA can make an impact by guiding these strategies.

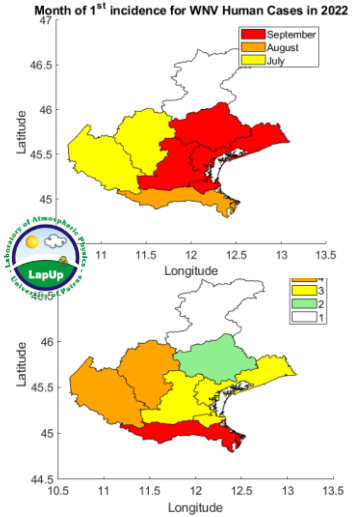
1.https://www.annualreviews.org/doi/10.1146/annurev.ento.54.110807.090626

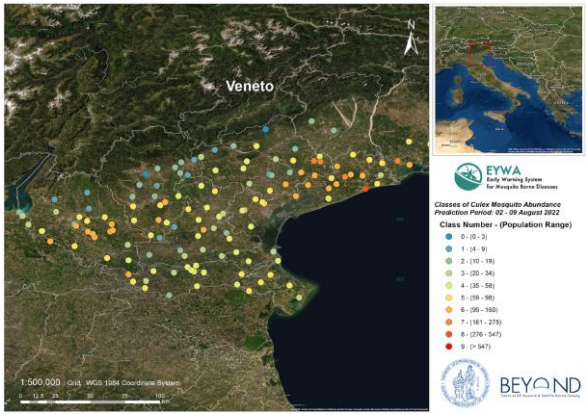
2.https://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0005280#

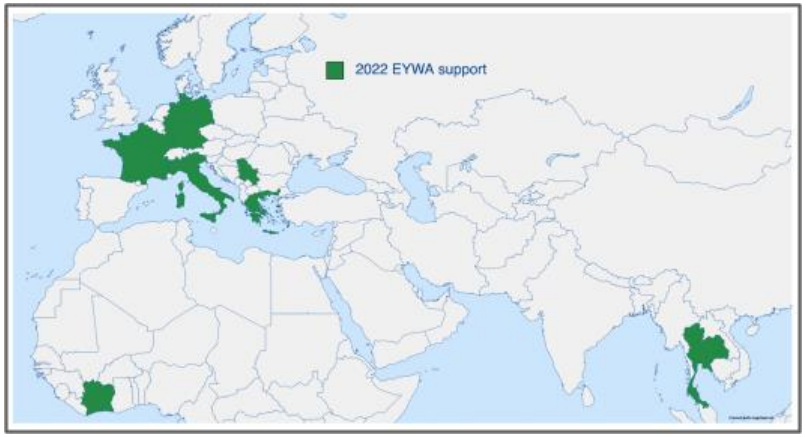


Working towards a solution









What does EYWA offer?

A couple of weeks/one month earlier it informs on mosquito abundance and pathogen transmission and suggests preventive and awareness door-to-door actions in the villages at risk

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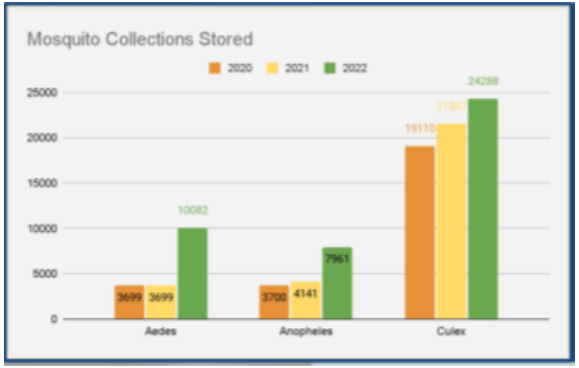
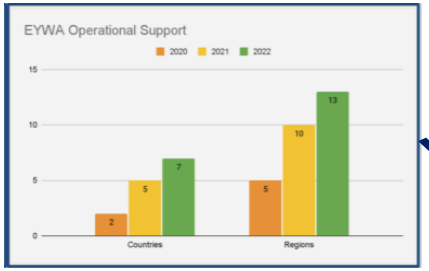
A fragmented landscape

After EYWA:

EYWA set the stage for:

- ❑ Data federation and organization in one system
- ❑ Open big features spaces with environmental, entomological, health, socio-economic, climatic, etc data/indicators
- ❑ Delivers Validated Transfer Learning and Forecasting Models for Risk Prediction





What is new in the concept of EYWA ?

Before EYWA:

- ❑ Siloed collections Entomological & epidemiological records
- ❑ Lack of indicators providing dynamics in the change of:
  - ○ Environment, weather, landscapes hosting areas mosquitoes
- ❑ No Standardization in feature engineering to feed AI/Dynamic forecasting models
- ❑ No robust/transferable solutions

The EYWA journey up to date… in a nutshell

2020

EYWA started its operations with 5 regions in 2 European Countries (Greece/Italy)

2021

EYWA expanded to include 10 regions in 5 European Countries (France, Germany, Greece, Italy, Serbia)

2022

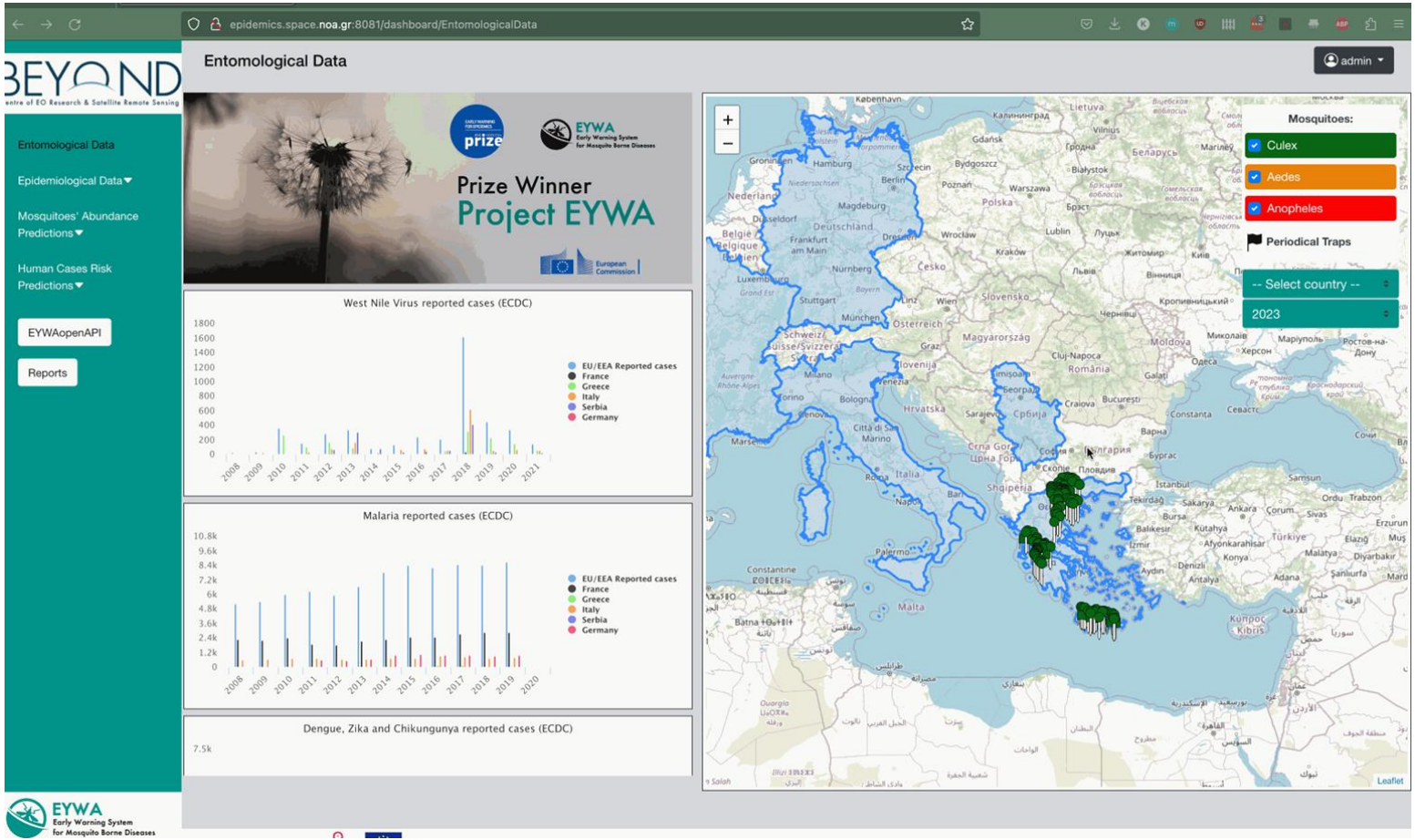
EYWA wins the 1st EIC Horizon Prize on Early Warning for Epidemics &
further expands to support another region in Italy and Cote d'Ivoire in Africa operationally and Thailand in Asia pre-operationally.

Winner of the first "EIC Horizon Prize on Early Warning for Epidemics"

2023

EYWA is on track to support:
Ghana
East Germany
Milan
Also planned cooperation with Pasteur Network to potentially expand to its member countries.

What does the feature-space look like?



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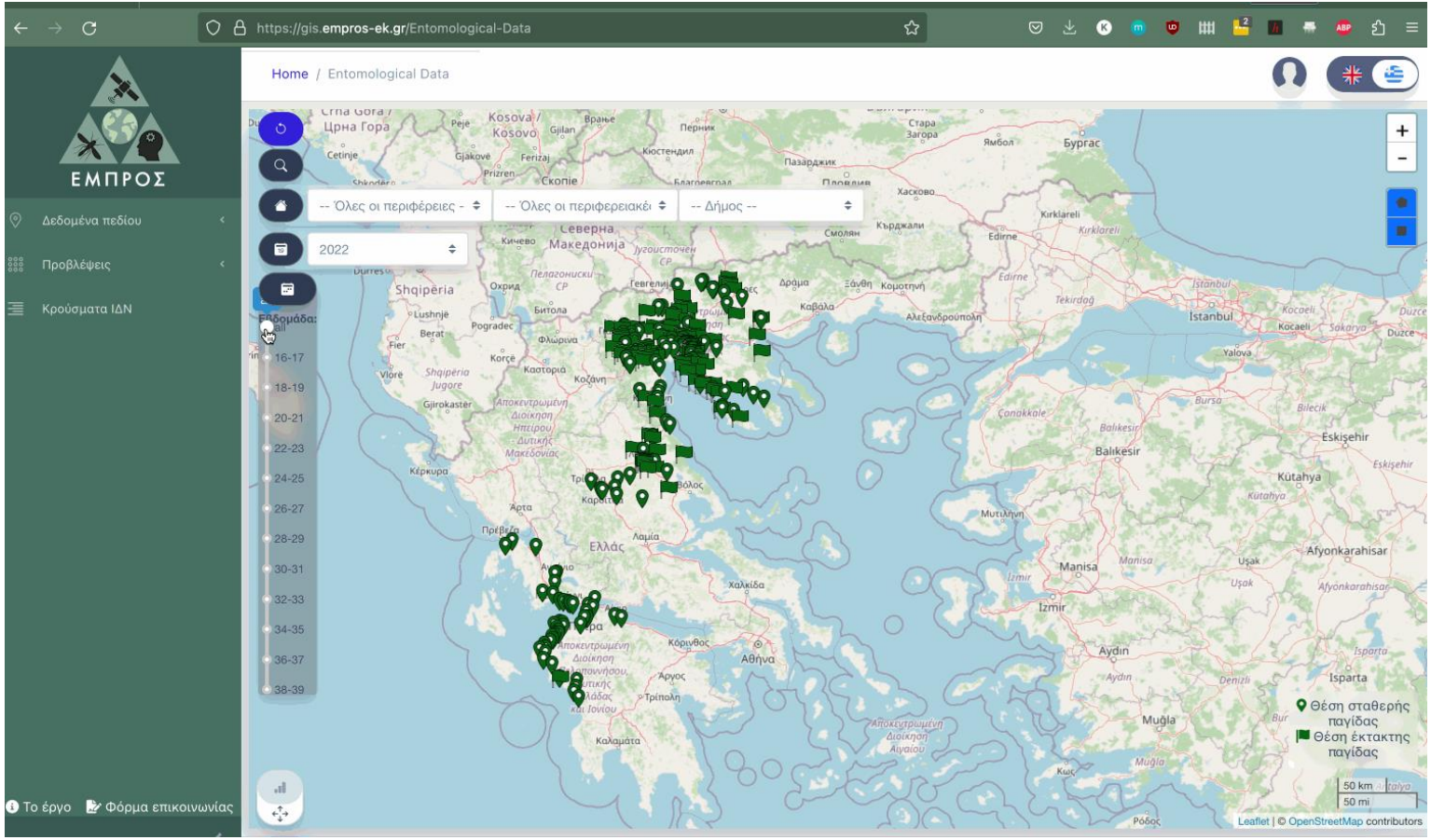
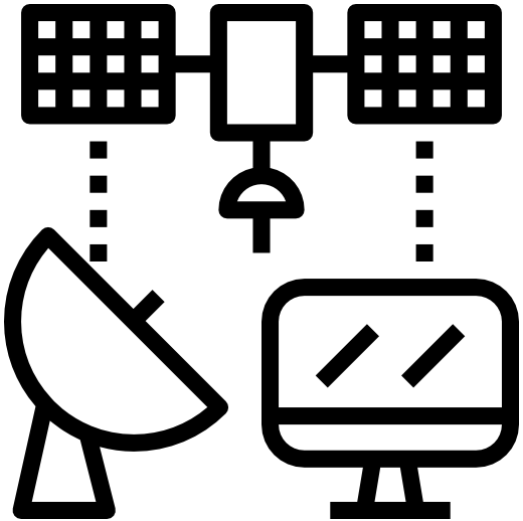
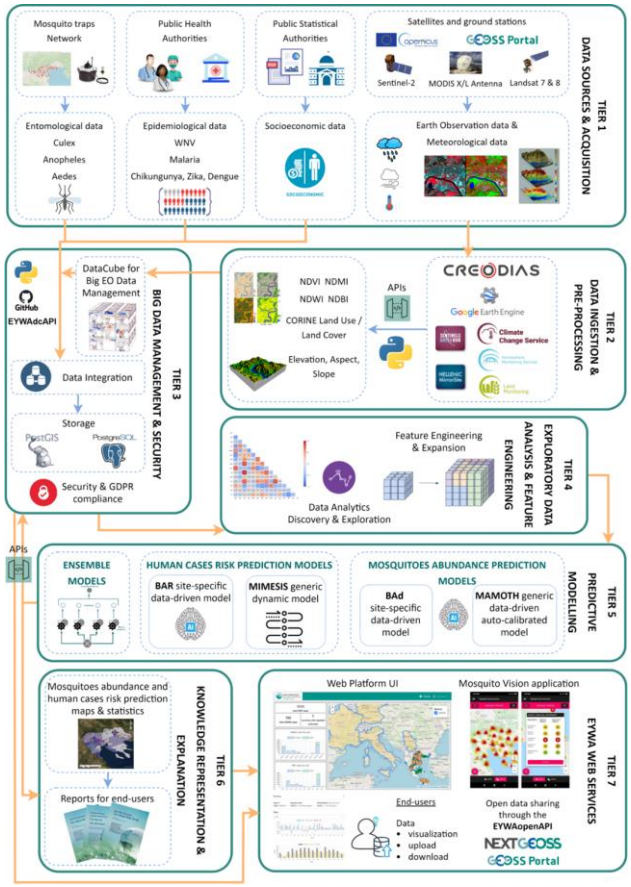

https://gis.empros-ek.gr/Entomological-Data
ΕΜΠΡΟΣ
Home / Entomological Data
Δεδομένα πεδίου
Προβλέψεις
Κρούσματα ΙΔΝ
-- Όλες οι περιφέρειες --
-- Όλες οι περιφερειακέ
-- Δήμος --
2022
Εβδομάδα:
16-17
18-19
20-21
22-23
24-25
26-27
28-29
30-31
32-33
34-35
36-37
38-39
Το έργο
Φόρμα επικοινωνίας
Θέση σταθερής παγίδας
Θέση έκτακτης παγίδας
50 km
50 mi
Leaflet | © OpenStreetMap contributors

Automated Platform



Building Automated Data Ingestion Pipelines:

- ❑ Starting with Greece, Ecodevelopment is using an API to upload the entomological data in the database on a weekly basis.
- ❑ An automated process kicks in that uses the DataCube to generate and update the database with the Earth Observation derived features.
- ❑ Similar APIs have been developed to upload the model predictions to the database.
- ❑ Ultimate goal is to have close to real-time updating of EYWA database with the latest information.



What/Where does EYWA provide as models for Early Warning?

WNV risk

❑ MIMESIS (Univ. of Patras)

- **Municipality** level.
- **Monthly** predictions.
- Dynamic Model.
- Available in Greece, Italy and Serbia (2023)
- Predicted probability/number of WNV cases & expected first week of registered case.

❑ BAr (ECODEV)

- **Settlement** level.
- **Weekly** predictions
- Neural Network based Model.
- Available in Greece.
- Predicted **probability WNV case**.

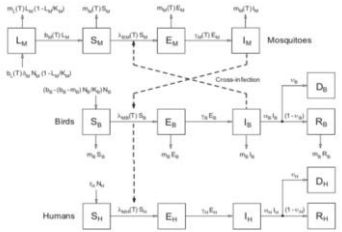
Mosquito Abundance

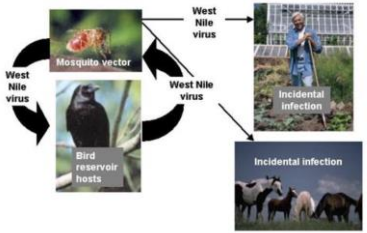
❑ BAd (ECODEV) abundance model

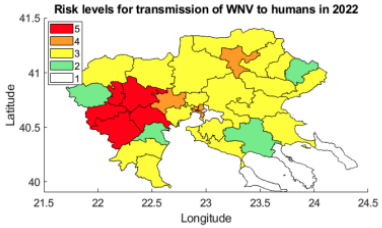
- **Settlement** level
- **XGBoost model**
- Available in 4 regions in Greece
- **Weekly** predictions

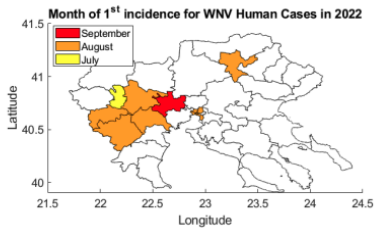
❑ MAMOTH (NOA)

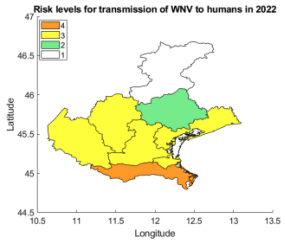
- **2x2km grid cell**.
- Neural Network model.
- Available in **Cote d'Ivoire, France, Germany, Greece, Italy, Serbia**
- **Biweekly/Monthly** predictions.











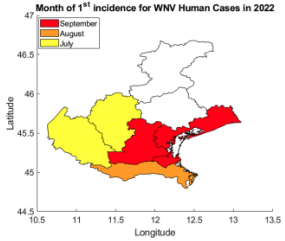


Figure 6. (Left) Map of the risk level of occurrence of WNV human cases in Veneto, (Right) Map with the month of incidence for WNV human cases in Veneto.

MIMESIS (Univ. of Patras)

MIMESIS (spatial dynaMIcal Model for wESt nIle viruS)

- Developed by the Laboratory of Atmospheric Physics of the University of Patras.
- Climate dependent epidemiological (deterministic) model that works on a ensemble probabilistic frame that provides West Nile Virus risk maps.
- The model operates spatially at the meso-scale and temporarily at the monthly to seasonal scale.
- Supports 4 regions in Greece and 1 region in Italy.
- Average detection probability exceeds 74% (reforcasts).
- During the 2022 operational season:
  - In April, in the region of Central Macedonia the model predicted 11 municipalities as high risk areas of registering WNV cases.
  - In 10 of those cases were later indeed registered (91% accuracy).

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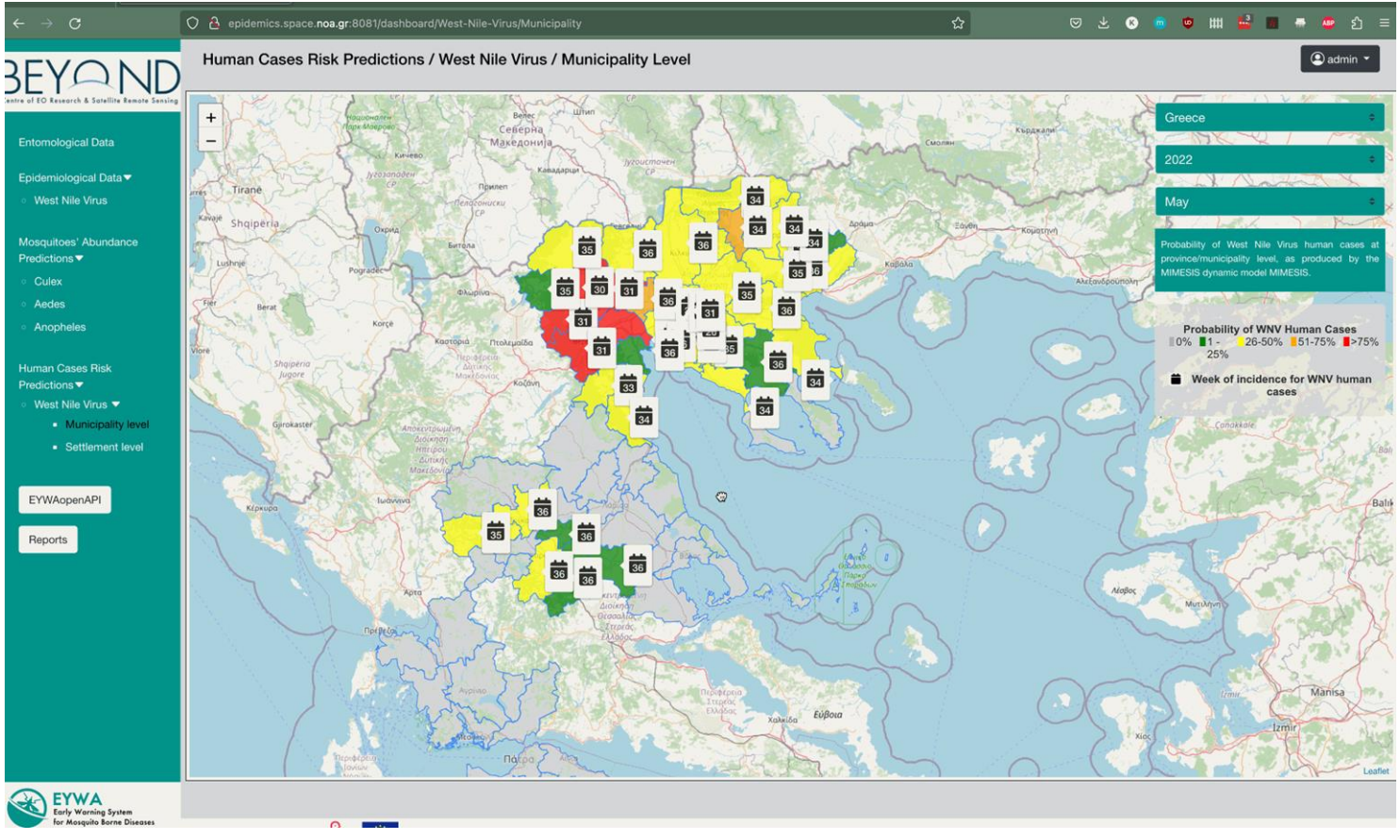
MIMESIS (Univ. of Patras)



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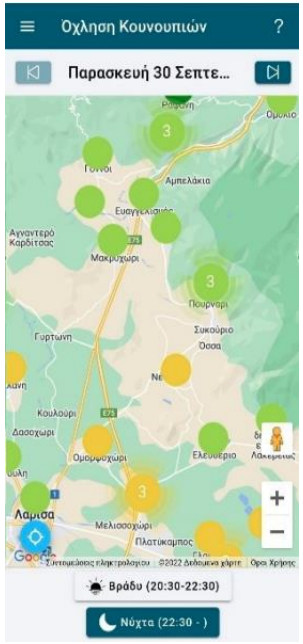
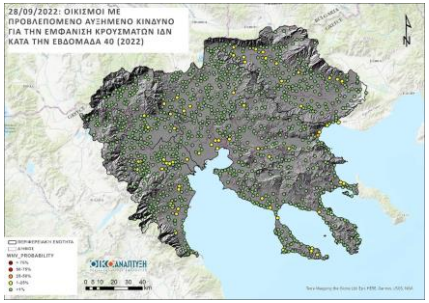
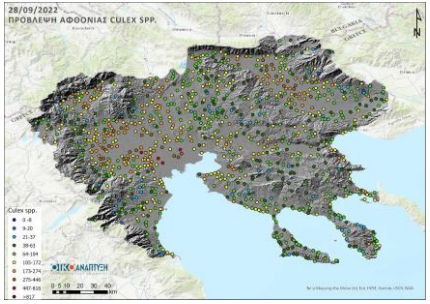
BAd & BAR (ECODEV)



Mosquito Vision app
BAd predictions / nuisance levels



BAR22 predictions
Settlement level WNV risk



BAd predictions
Culex Mosquito Abundance

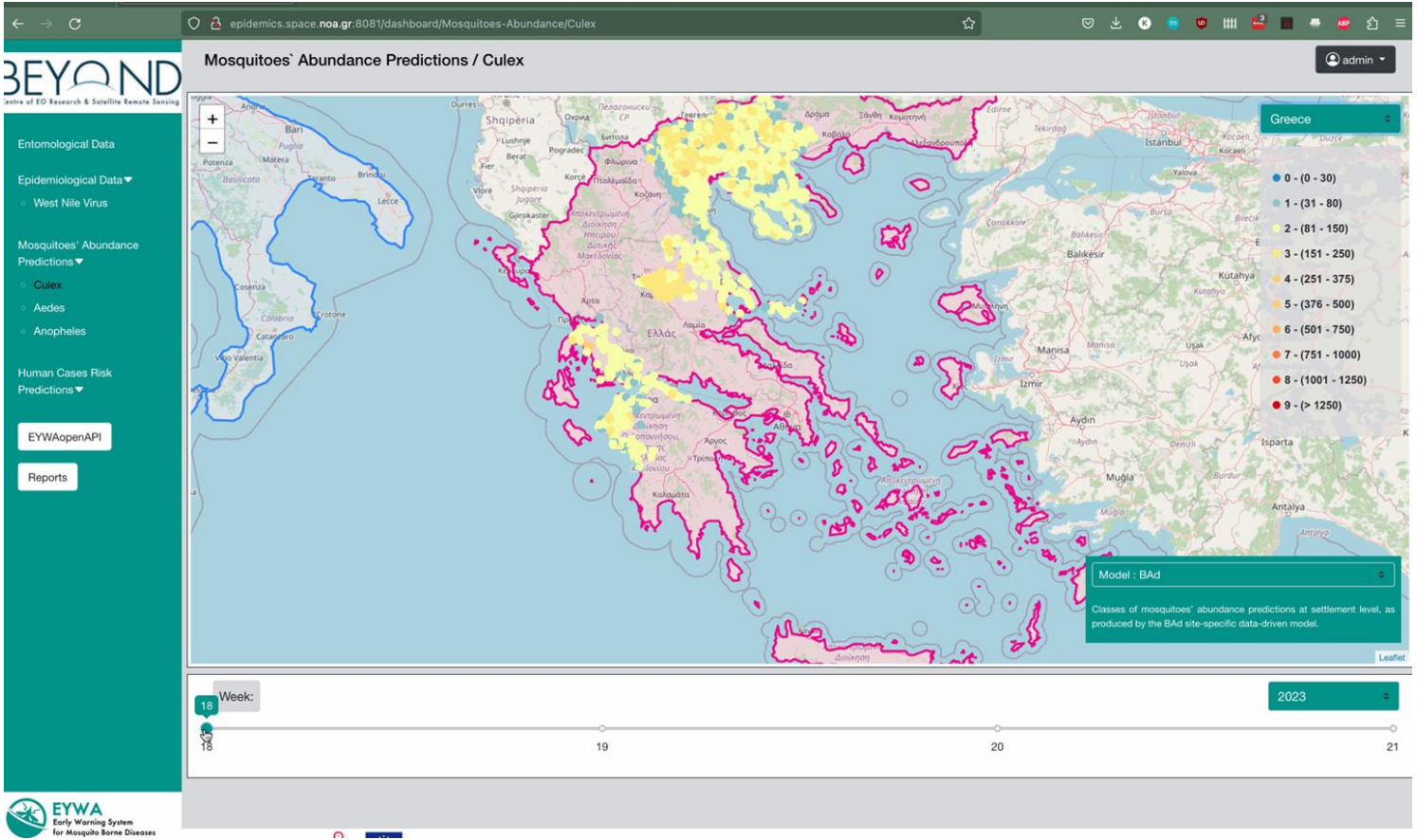
BAd (Big data technologies' model for Adult mosquitoes)

- ❑ Developed by Ecodevelopment S.A.
- ❑ Daily forecasts of mosquito abundance on a settlement level.
- ❑ Available in 4 regions in Greece.
- ❑ Outputs 10 equiprobable classes of populations
- ❑ A data driven regression machine learning model, using the XGBoost implementation of the boosted trees algorithm.
- ❑ Trained using data from 11.138 mosquito collections.
- ❑ It is fed with another model that provides predictions on mosquito larvae.
- ❑ The model accuracy is calculated with the Mean Absolute Error, and the validation error has been calculated to 1.27 classes.
- ❑ Powers the Mosquito Vision app that provides the model output as nuisance level available in more than 2400 settlements.

BAR22 (Big Data Technologies model for the Assessment of Risk)

- ❑ Developed by Ecodevelopment S.A.
- ❑ Weekly forecasts of West Nile Virus risk on a settlement level.
- ❑ A data driven neural network model.
- ❑ Outputs risk on 5 levels (0-4, very low to very high)
- ❑ Available in the Central Macedonia region.
- ❑ Supports larviciding actions.
- ❑ Updated version of the older BAR model works on providing predictions on zones of settlements.
- ❑ Operational since 1st August 2022.
- ❑ For 46 out of 54 zones (covering 888 settlements) the risk level was off by 1 level on average for cases registered in the August/September period, for an accuracy of 85%.

BAd (ECODEV)


epidemics.space.noa.gr:8081/dashboard/Mosquitoes-Abundance/Culex
Mosquitoes` Abundance Predictions / Culex
admin
Entomological Data
Epidemiological Data
West Nile Virus
Mosquitoes' Abundance Predictions
Culex
Aedes
Anopheles
Human Cases Risk Predictions
EYWAopenAPI
Reports
Greece
0 - (0 - 30)
1 - (31 - 80)
2 - (81 - 150)
3 - (151 - 250)
4 - (251 - 375)
5 - (376 - 500)
6 - (501 - 750)
7 - (751 - 1000)
8 - (1001 - 1250)
9 - (> 1250)
Model : BAd
Classes of mosquitoes' abundance predictions at settlement level, as produced by the BAd site-specific data-driven model.
Leaflet
Week:
18
2023
18
19
20
21
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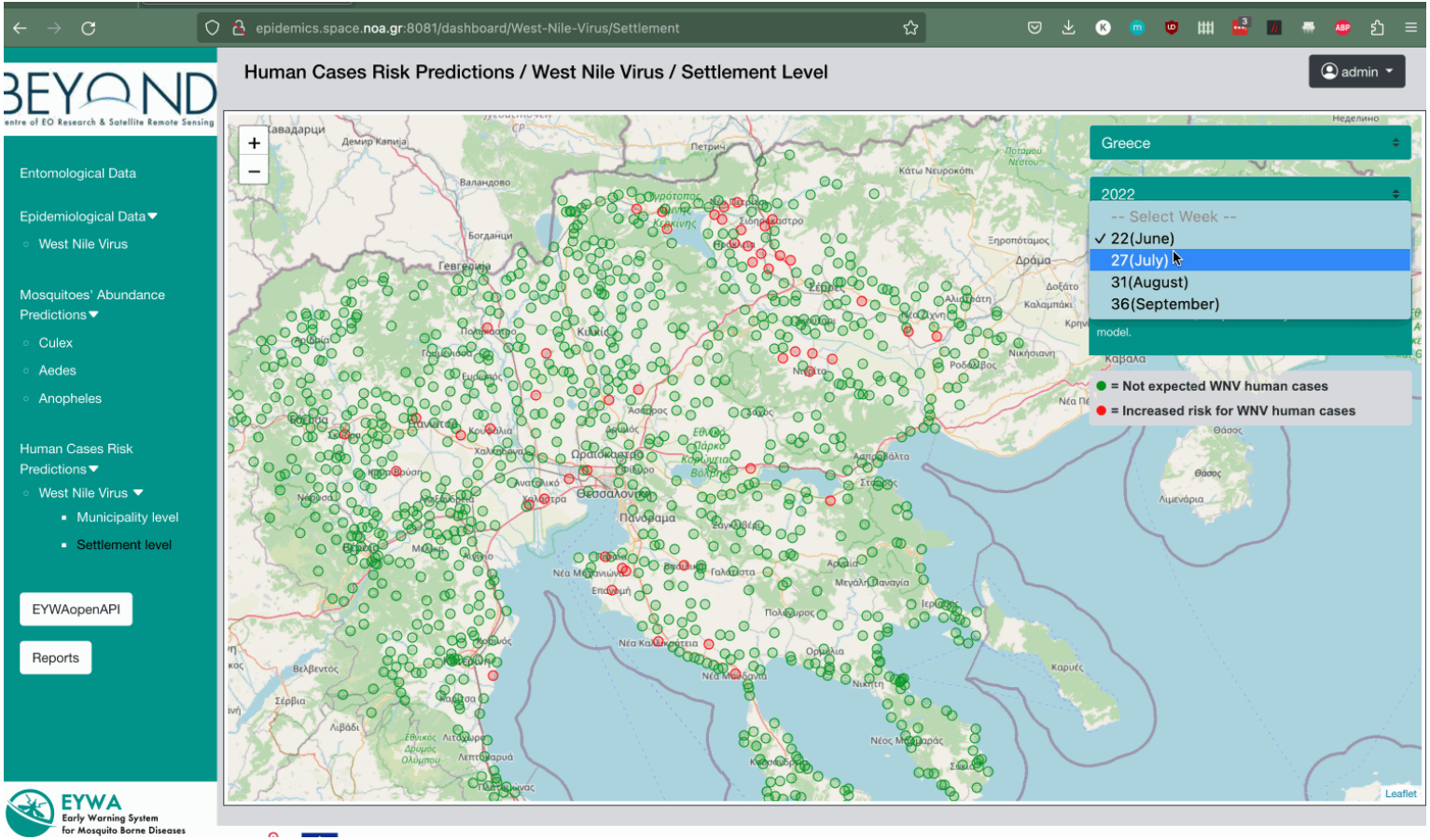
BAR22 (ECODEV)



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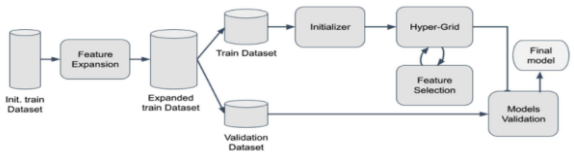
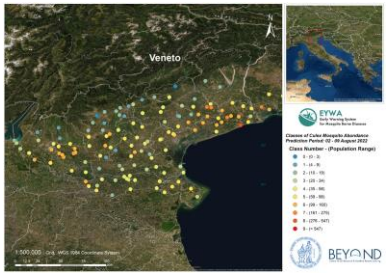
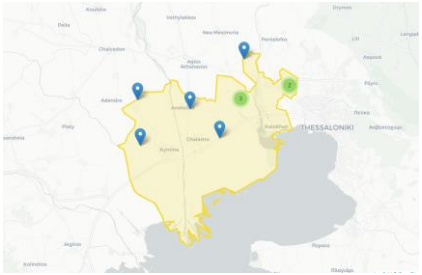
MAMOTH (NOA)



Model Training Pipeline



Operational predictions
(Veneto region)



Mosquito abundance aggregate statistics
(color represents mean value)
Delta municipality, Central Macedonia

Robustness, Scalability, Transferability, Site & Mosquito type agnostic, Transfer Learning capability

MAMOTH (**M**osquitoes **A**bundance prediction **M**odel aut**O**-calibrated from features ple**TH**ora)

- Data driven model, developed by the Beyond Operational Unit of the IAASARS/National Observatory of Athens using the 12-year series of tabular entomological data (42.400 collections) from multiple countries, based on the neural networks.
- The model takes as input all available entomological data and the EO generated features in each region & species, and using a train/validation pipeline selects the best features, then predicts the expected mosquito population on any point for the next 15-30 days (customizable).
- Works with the Aedes, Anopheles & Culex mosquitoes in all EYWA supported countries, supporting all mosquito-borne diseases.
- Accuracy of > 93% in predicting high/medium/low risk of mosquitoes.
- Implementation available to provide complete entomological risk map of a whole region in a 2x2km grid.
- Has been extended to provide area level (province / municipality / settlement) aggregate statistics of mosquito populations, by sampling the area of interest to generate random points then predicting for each point and aggregating.
- Work is being undertaken for the MAMOTH model to feed predictions on a municipality level (aggregate statistics) into the MIMESIS model beginning in the coming 2023 operational season.

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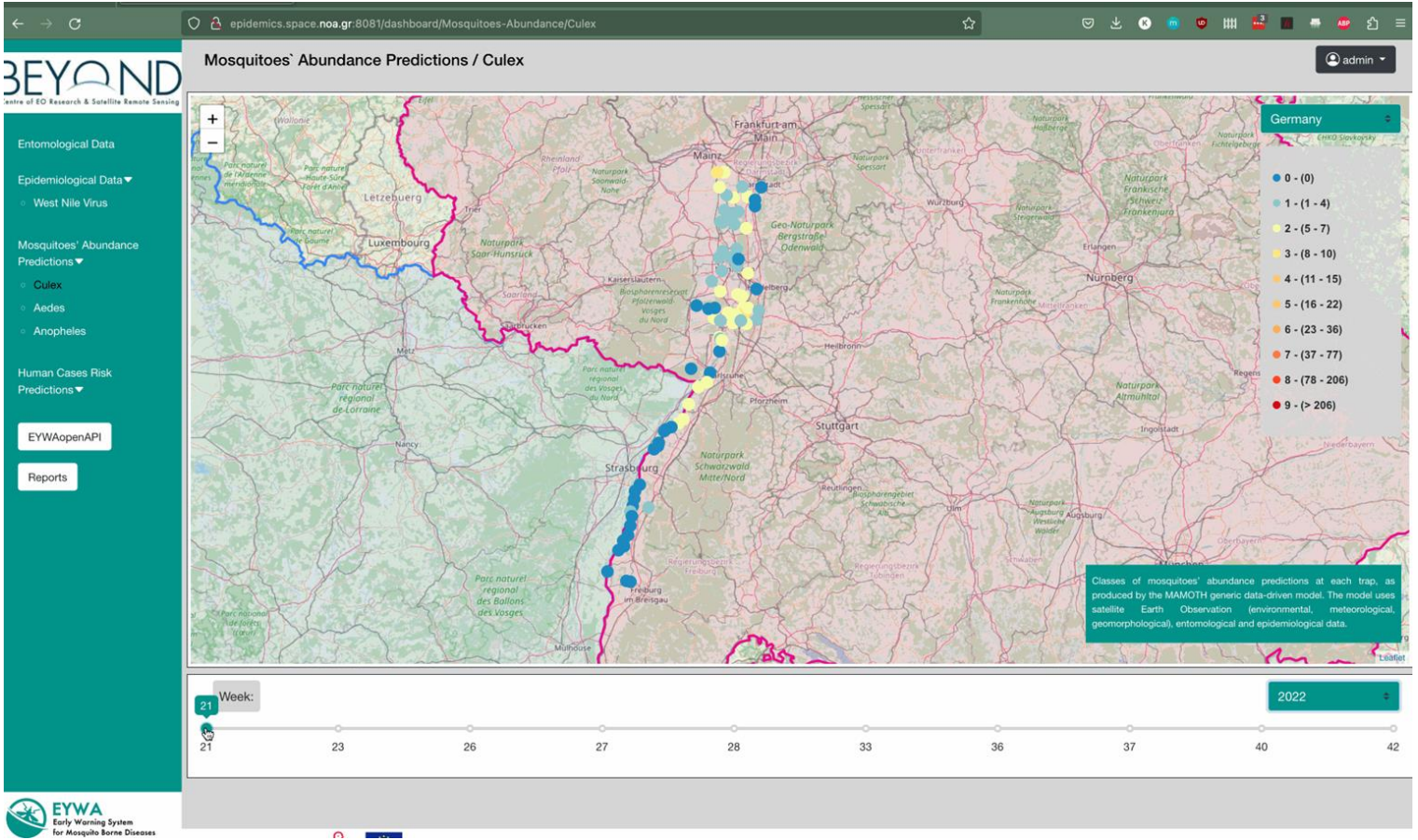
Remote Sensing"

EYWA
Early Warning System
for Mosquito Borne Diseases

Earth Observation for Epidemics
of Vector-borne Diseases /
EuroGEO Action Group

EuroGEO

MAMOTH (NOA)



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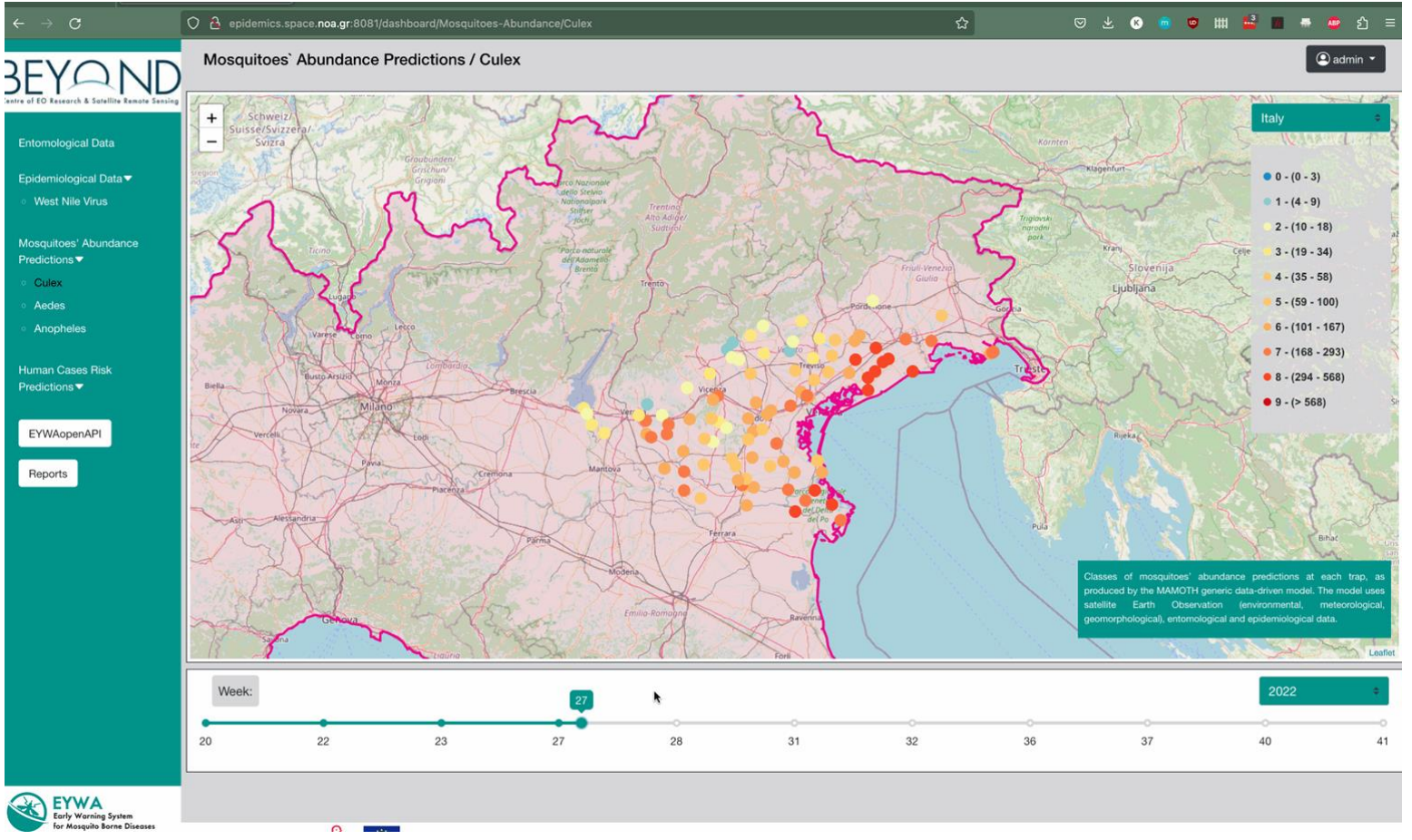

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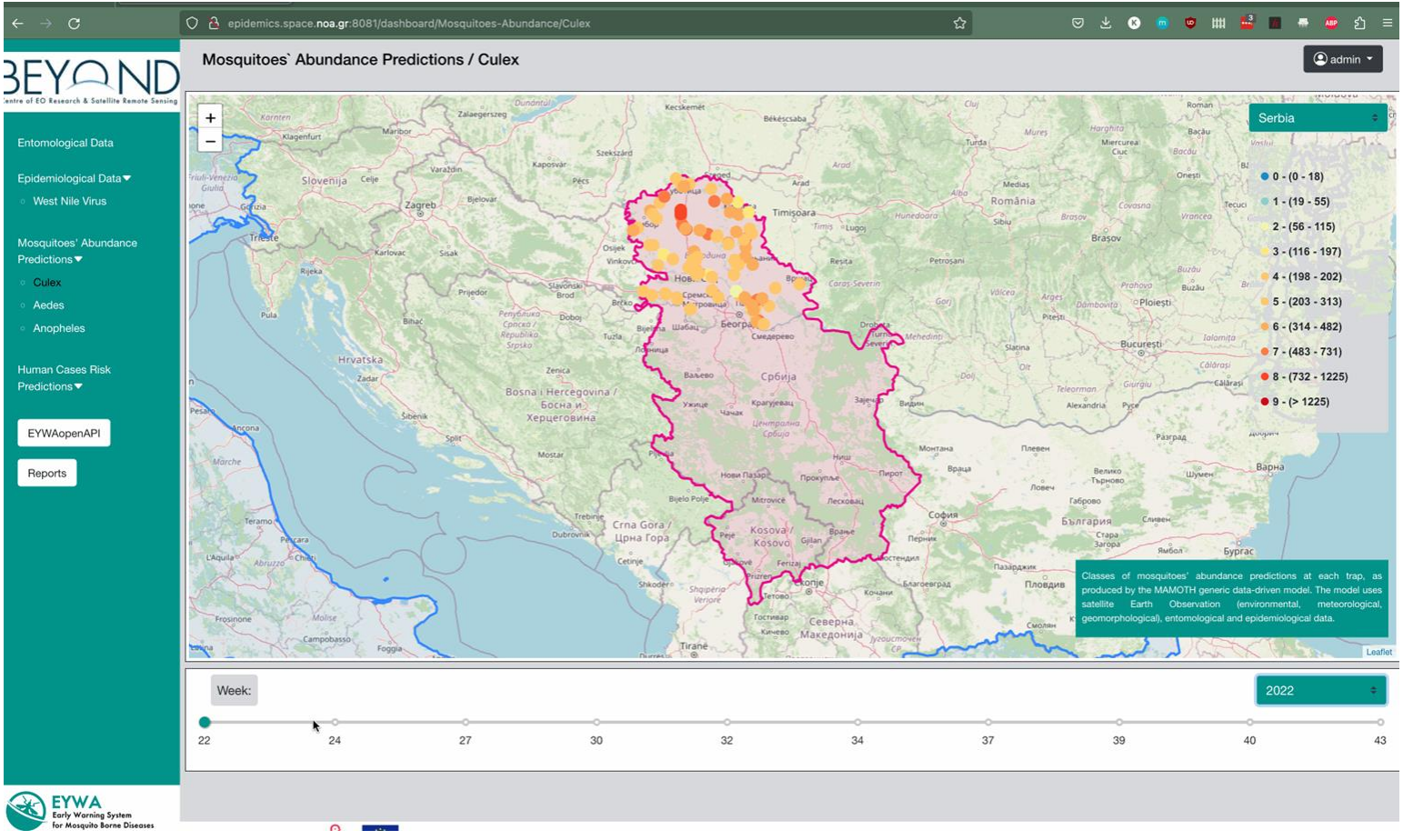

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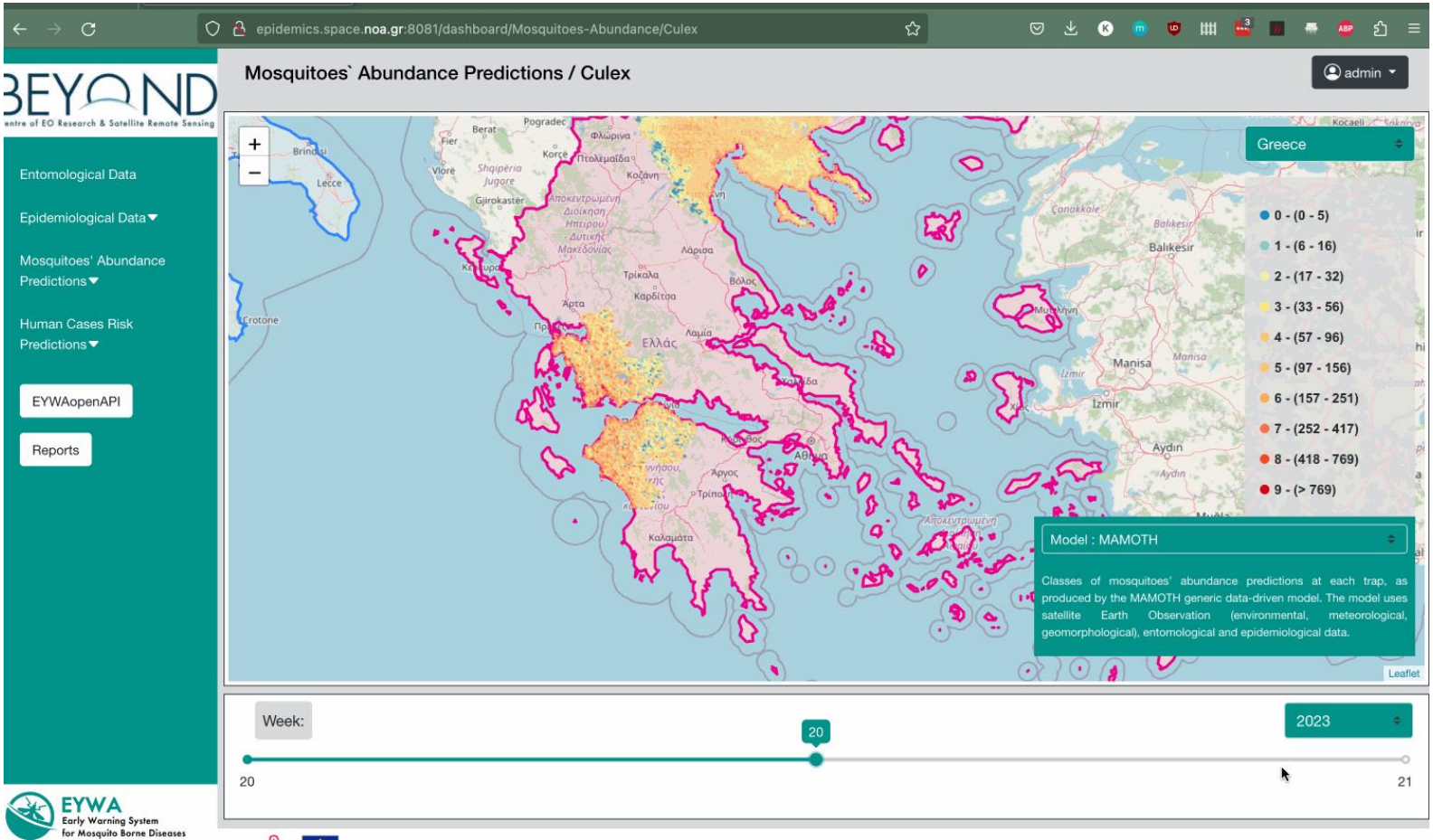

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MAMOTH:Climate Change Research

Visualization of the per decade expected increase in mosquito populations, 2020-2100, Veneto, Italy

RCP 2.6
Mosquito populations are expected to increase to a maximum of 6.5% in the 2080s compare to 2010s baseline.

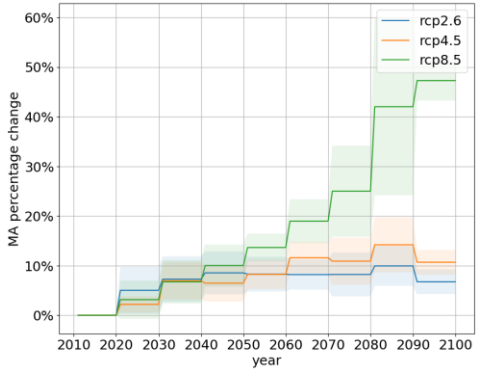
RCP 4.5
Mosquito populations are expected to increase to a maximum of 10% in the 2080s compare to 2010s baseline.

RCP 8.5
Mosquito populations are expected to increase to a maximum of 41%! in the 2090s compare to 2010s baseline.

- Research was conducted into how climate change is going to affect the mosquito populations in the current century.
- The **Land Surface Temperature** and **Rainfall** are among the most important features in the MAMOTH model according to the feature importance metrics.
- Using leading research into climate change projections the **Representative Concentration Pathway (RCP)** trajectory which is adopted by the **Intergovernmental Panel on Climate Change** was selected as the best fit for the work.
- These projections have been generated by the panel using an consistent set of socioeconomic assumptions, and provide different scenarios of emissions and the expected change in mean temperature and rainfall.
- The selected scenarios are:
  - **RCP 2.6**: Extreme measures are taken to reduce CO2 emissions which start declining by 2020 and fall to 0 by 2100.
  - **RCP 4.5**: Some measure are taken and CO2 emissions peak at 2040 then start declining to reach half the levels of 2050, in 2100.
  - **RCP 8.5**: No measures are taken and CO2 emissions continue to increase through 2100.

Climate Change Long Term Forecasting

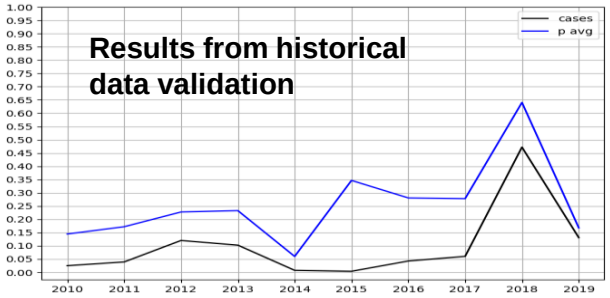
- The projected values for the Temperature and Rainfall from each scenario are adjusted by adding the changes into the input data which are then fed into the MAMOTH model and predictions are generated for the future.
- For the Veneto region which is one of the study areas, the expected population changes are for each scenario:
  - **RCP 2.6**: a maximum of 6.5% increase in population numbers is expected in the 2080s decade compared to the 2010s baseline.
  - **RCP 4.5**: a maximum of 10% increase in population numbers is expected in the 2080s decade compared to the 2010s baseline.
  - **RCP 8.5**: a maximum of 41%! increase in population numbers is expected in the 2090s decade compared to the 2010s baseline.



MAMOTH: Expanding to West Nile Virus Human Risk

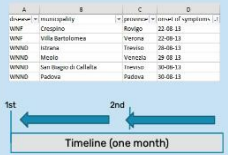
Proposed Solution:

- Gather historical **data on WNV diseases** for previous years
- Build a **machine learning model** for case prediction
- Use the model **to predict the probability of case appearance** in a designated area
- Produce risk map of an entire region to be used as **early warning system** for prevention



Data Wrangling - Manipulation

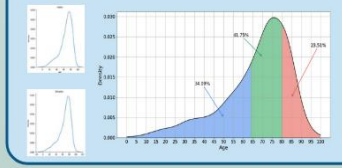
Spatio-temporal Harmonization:



- Data on **WNV cases**
- **Bi-weekly** prediction timeline
- Convert case **location** to [x,y] coordinates
- **Aggregate** cases over location and date
- Add **negative** examples
- Fill dataset with features

Feature Aggregation:

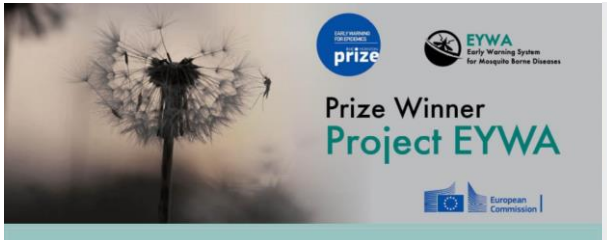
- Three **population groups** based on KDE plot
  - Group1: [0-64] 83% of total population
  - Group2: [65-80] 14% of total population
  - Group3: [81-99+] 3% of total population
- **Area** in sq. km for all municipalities
- **Mosquito population** based on MAMOTH predictions



- **Week** number (1-52), **Season**, and **cyclical encoding** of variables: day, month, week, season
- **distance** of municipality from the equator
- Cumulative mosquitos **from previous 30 days**
- case existence from **previous period** and **previous month**
- Number of **hot fortnights** (>30C^0) from previous month and from the 1st day of year

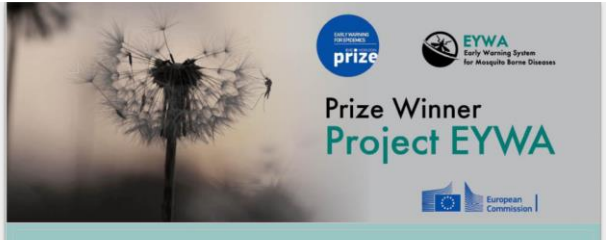
Dataset	Date / Location	EO Data (ndvi, ndwi, temperature, rainfall..)	Geomorphological	Demographics / Area	Entomological - Mosquitos	**Target (case)**

EYWA reports



Baden – Wuerttemberg Region, Germany

Report period 01/05/2023 - 31/05/2023



Occitanie, Grand-Est and Corsica Regions, France

Report period 01/05/2023-31/05/2023

Veneto and Trentino Regions, Italy

Report period 01/05/2023 - 31/05/2023

Περιφέρεια Κεντρικής Μακεδονίας, Ελλάδα

Περίοδος Αναφοράς 01/05/2023- 31/05/2023

Περιφέρεια Θεσσαλίας, Ελλάδα

Περίοδος Αναφοράς 01/06/2023- 30/06/2023

Vojvodina Region, Serbia

Report period 01/05/2023 - 31/05/2023

In a nutshell

- **EYWA** is an established **impactful** & **transferable** Early Warning System.
- The system is **expanding** each year **to new regions** dealing with different climatic & socioeconomic conditions.
- The **sustainability** issue per use case is carefully examined and justified only if Institutional users are actively involved as co-designers
- Models are adapted in providing **early warning** and guiding **targeted** larviciding and **door to door** awareness based on **user feedback** at the end of each mosquito season
- The identification of **means/channels/networks** to disseminate the EYWA products are a high priority
- Established and **standardized collection and access** to EO and in-situ entomological and health records are key aspects of EYWA
- Highlights the power of **EO** in supporting **Communities** and **Health Systems** around the world.
- As part of the EuroGEO Action Group, EYWA **seeks for synergies** with on-going projects and initiatives (e.g. EO4Health).

Operational Unit "BEYOND Centre of EO Research & Satellite Remote Sensing"

EYWA Early Warning System for Mosquito Borne Diseases

Earth Observation for Epidemics of Vector-borne Diseases / EuroGEO Action Group

Thank you!

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(Coordinator of EuroGEO Action Group for Epidemics)
(Lead Partner of EYWA)

18 Partners | 7 Countries

Greece
National Observatory of Athens (NOA) – BEYOND Centre of EO Research & Satellite Remote Sensing
Ecodevelopment S.A
University of Patras – Physics Department - Laboratory of Atmospheric Physics (LapUP)
Dimitrios Vallianatos (IDCOM)
Aristotle University of Thessaloniki
University of Thessaly, Medical School. Laboratory of Hygiene and Epidemiology

Italy
Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe)
Edmund Mach Foundation
University of Trento

Serbia
University of "Novi Sad", Faculty of Agriculture, Laboratory for Medical and Veterinary Entomology
Scientific Veterinary Institute "Novi Sad"
University of Novi Sad, Faculty of Medicine

Germany
German Mosquito Control Association (KABS)
Bernhard Nocht Institute for Tropical Medicine

France
EID Méditerranée

European Commission
Joint Research Center

Ivory Coast
Centre Suisse de Recherches Scientifiques en Côte d'ivoire

Thailand
Vector Biology and Vector Borne Disease Research Unit, Department of Parasitology, Faculty of Medicine, Chulalongkorn University