Cornell AgriTech New York State Agricultural Experiment Station

The plant disease triangle as a framework for constructing disease surveillance systems with remote sensing

Katie Gold
Assistant Professor of Grape Pathology
Cornell University
ICPP Episense Satellite Event
July 19, 2023

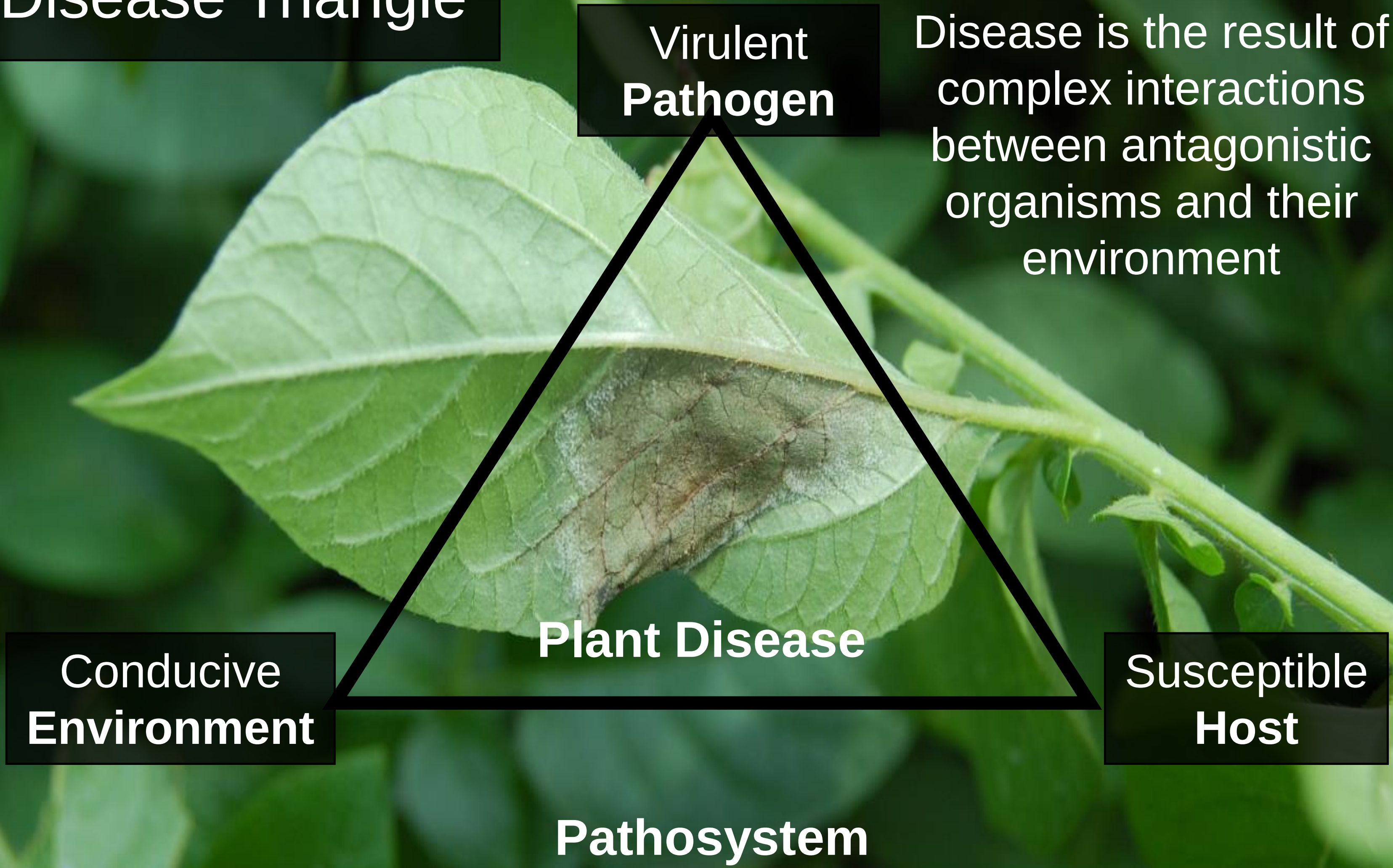
Cornell CALS College of Agriculture and Life Sciences

Space Grapes Art by Matthias Grunewald, 2000

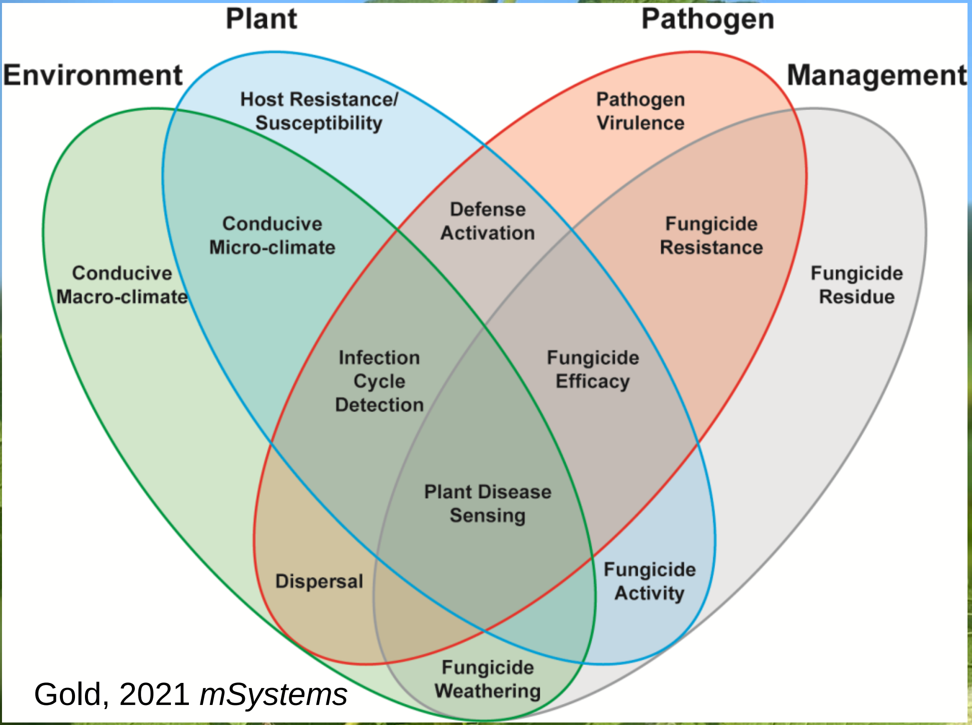

Disease is the result of complex interactions between antagonistic organisms and their environment

The Disease Triangle

Disease is the result of complex interactions between antagonistic organisms and their environment



Remote sensing is the only ***scalable*** detection method in our disease control toolbox that can transcend historical limitations to provide *actionable* early warning and detection.



Gold, 2021 *mSystems*

Cotton Root Rot infected field in College Station, TX **1929**

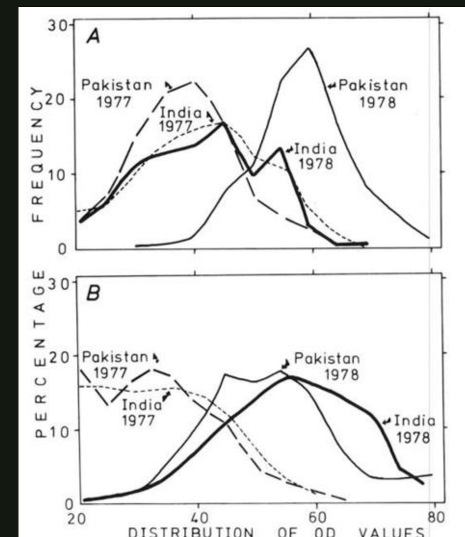
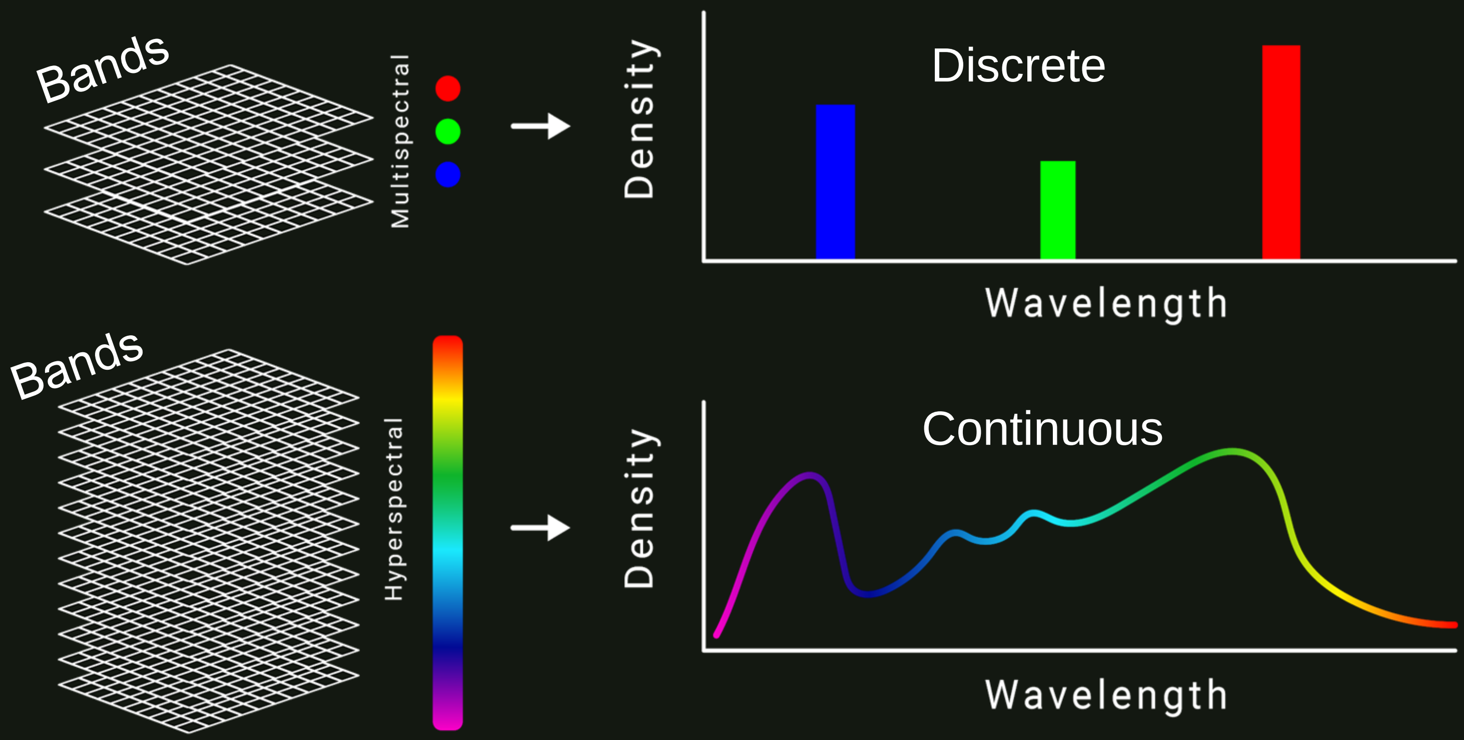


Fig. 2. Frequency distribution of optical density (OD) data for adjacent areas studied in India and Pakistan for the years 1977 and 1978 by the Landsat-2 multispectral scanner on **A,** channel 6 and **B,** channel 7. On the Indian side of the border the wheat crop was healthy and there were similar frequency distributions during both years. Note that in Pakistan (A) marked spectral differences were observed between nonepidemic (1977) and epidemic (1978) years.

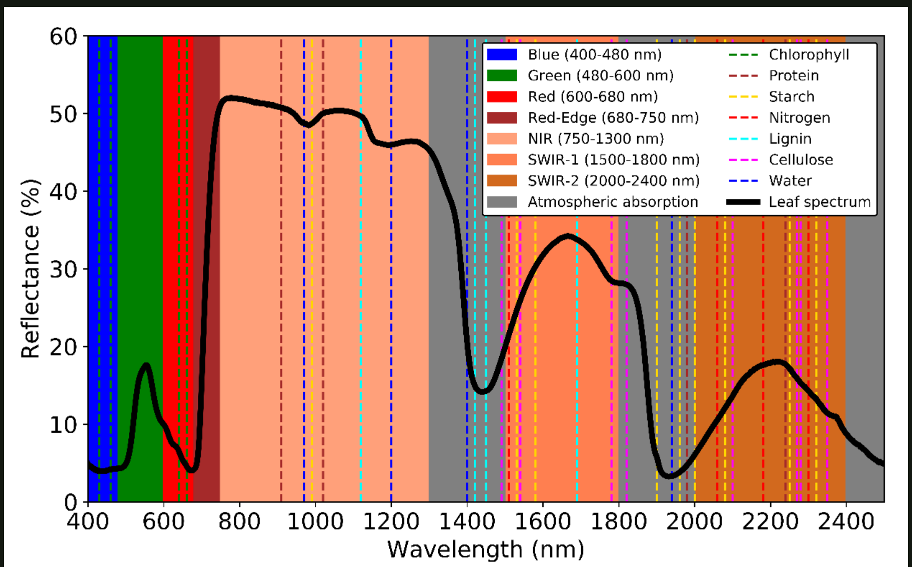
First use of satellite data to monitor a plant disease epidemic in **late 1970s**

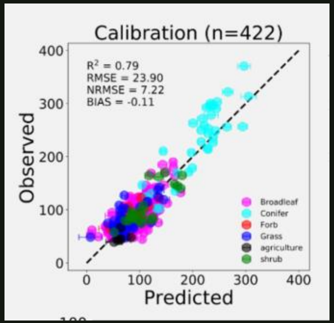
Imaging spectroscopy measures light near continuously

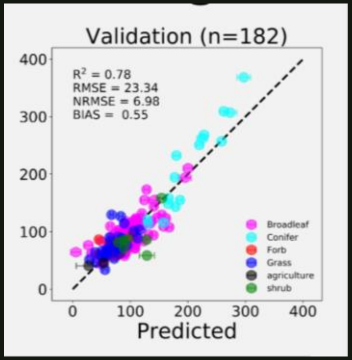


VIS: Visible Light, ~450-750nm
NIR: Near Infrared, ~800-1200nm
SWIR: Shortwave Infrared, ~1200-2400nm

Plant chemistry changes light reflectance

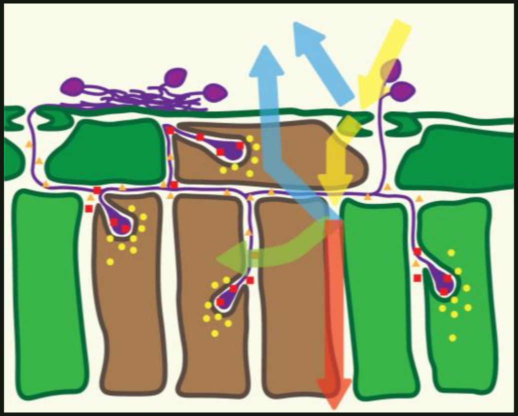






Slide content from Townsend Lab, UW-Madison

Spectroscopy offers more information about plant-microbe interactions than our eyes alone can see



Art by Eric Larson

Plant pathogens physically and chemically change plant constitution

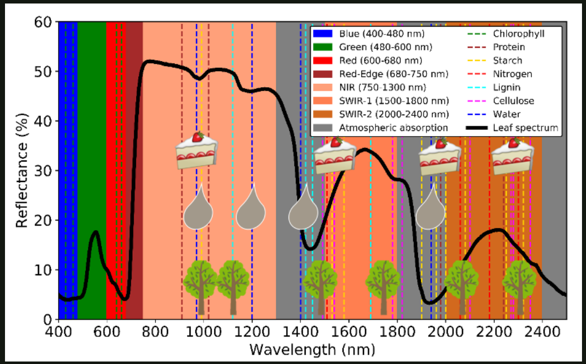


Figure by Phil Townsend

Known biochemical & physiological plant constituents affect spectral reflectance

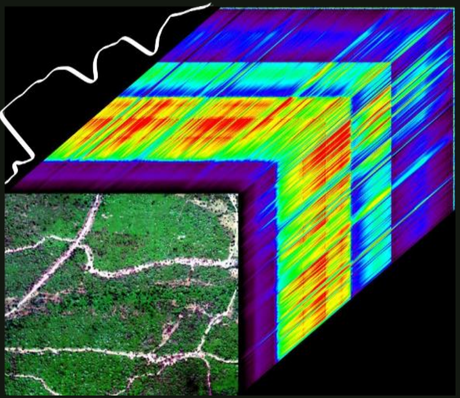


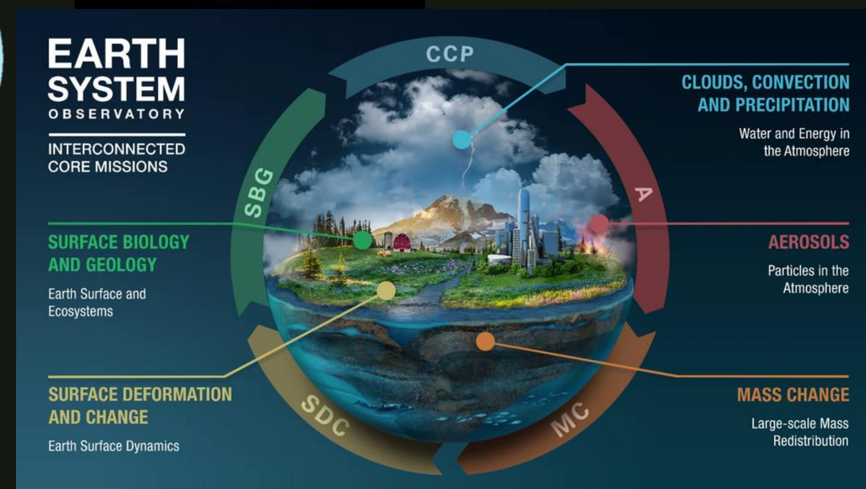
Figure by Phil Townsend

Imaging spectroscopy allows us to study plant disease at scale

Underlying disease physiology and pathogen biology drives our ability to sense and detect with imaging spectroscopy

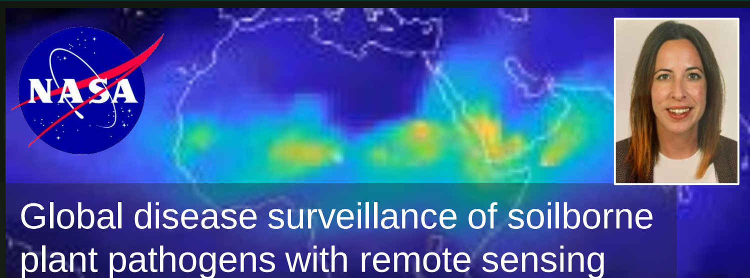
Surface, Biology, and Geology

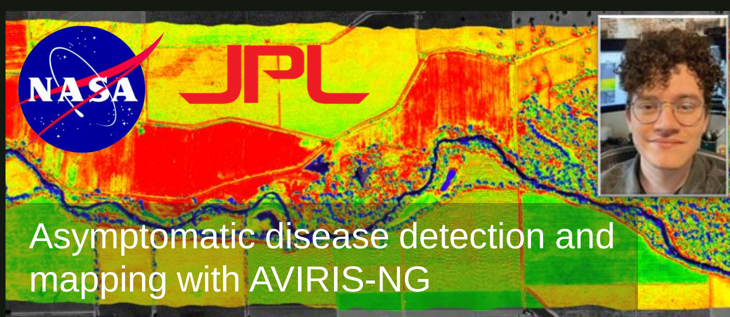
Global VSWIR Imaging Spectrometer Launching ~2028

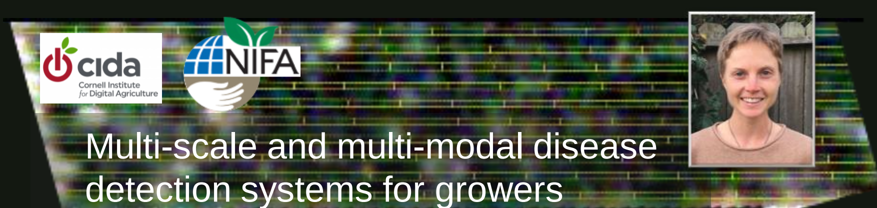


Advances in sensor design and constellation satellite architecture design have converged to put us at the precipice of an unprecedented era of agricultural monitoring

The Gold Lab studies the fundamental and applied science of **plant disease sensing** across scales to improve early detection & intervention.







Global disease surveillance of soilborne plant pathogens with remote sensing

Fusarium oxysporum (Fo)

- Causes Fusarium Wilt (FW)
- Endemic to all six crop producing continents, 100+ susceptible crops
- Survives in soil for 20+ years
- Annual yield losses ~10-60%
- Range will expand with climate change (Shabani et al. 2014)

Soil dwelling fungi are capable of aerosolization and transport in global dust plumes.

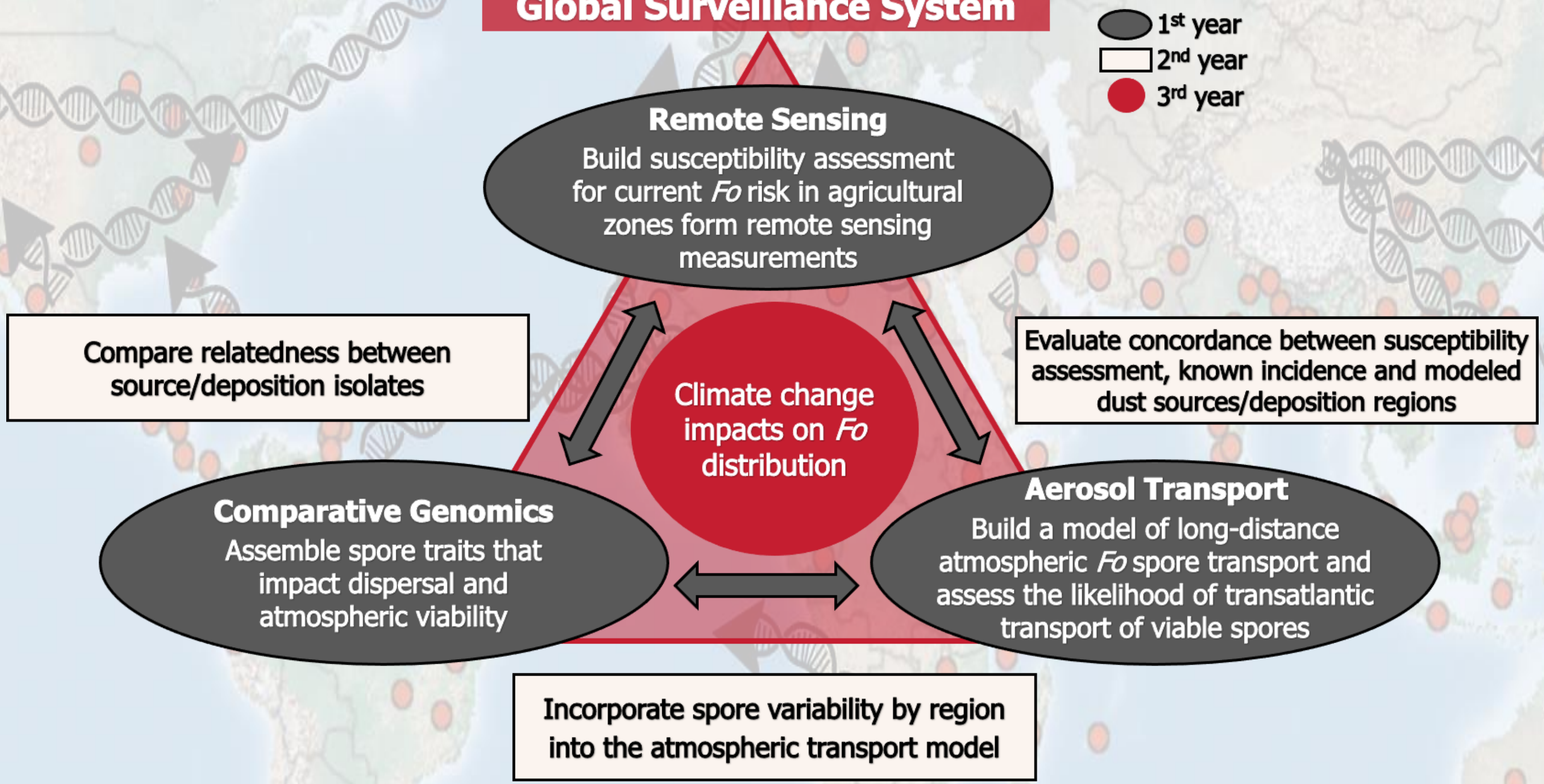
Griffin 2001, Kellogg 2004, Barberan 2015

Infectious *F.oxy* spores and DNA have been isolated from North African and Asian dust samples.

Yeo & Kim 2002, Palmero 2011, Giongo 2013, Gonzalez-Martin 2014

IDS Award #80NSSC20K1533

Fusarium oxysporum Global Surveillance System



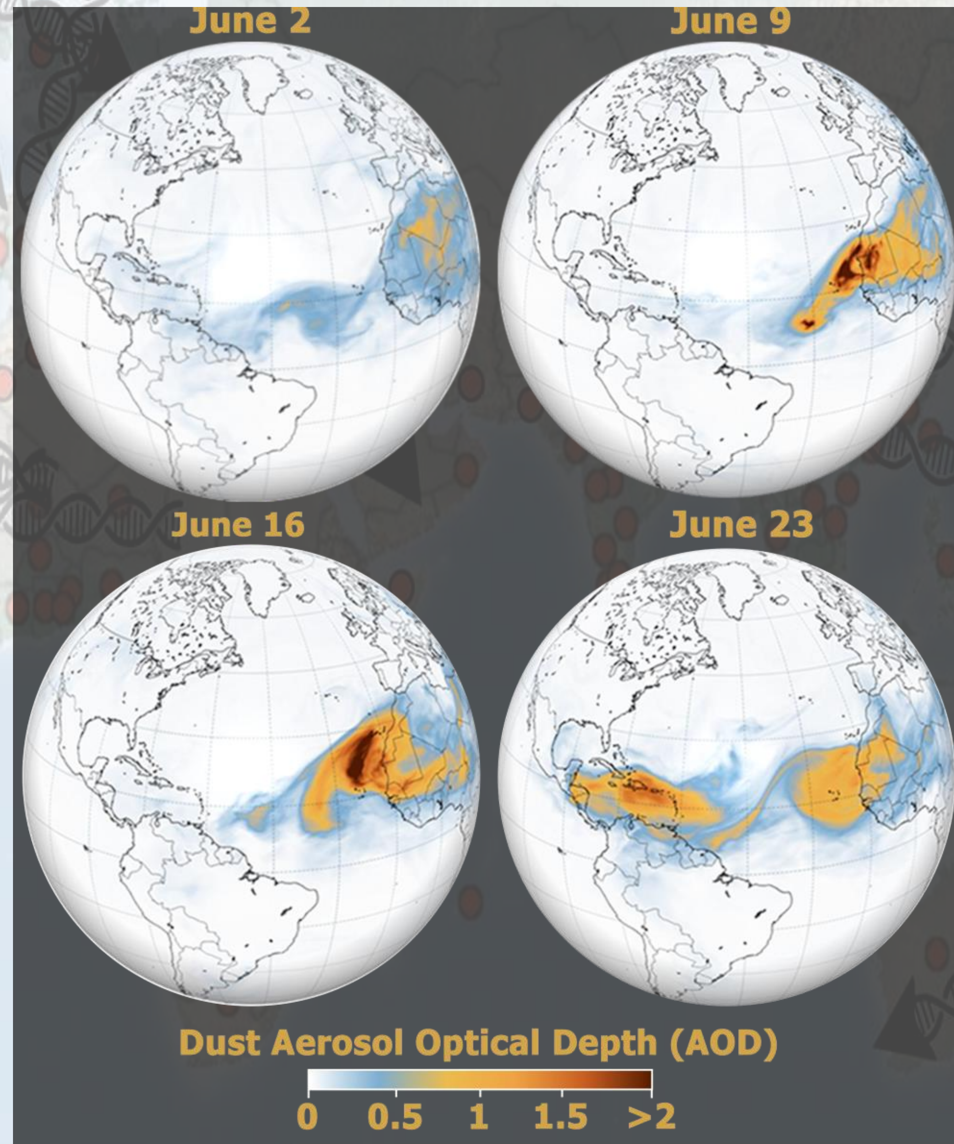
IDS Award #80NSSC20K1533

Aerosol Transport

Build a model of long-distance atmospheric *Fo* spore transport and assess the likelihood of transatlantic transport of viable spores

In order to ask "**Can viable Fo spores be transported across the Atlantic?**" We first had to….

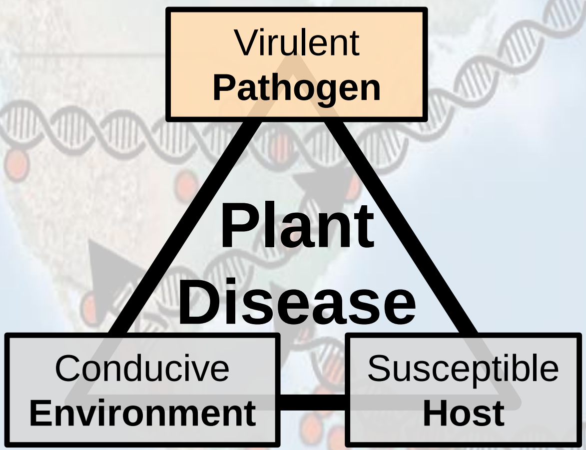
1) …accurately simulate the "Godzilla" dust event of Summer 2020
2) …adapt the CESM-CAM6-MIMI to include **agricultural dust**
3) …adapt the step 2 model to include **spore transport** with uniform concentration and fixed properties (e.g. size, weight) and an exponential decay function to kill off 99% of spores in 3 days

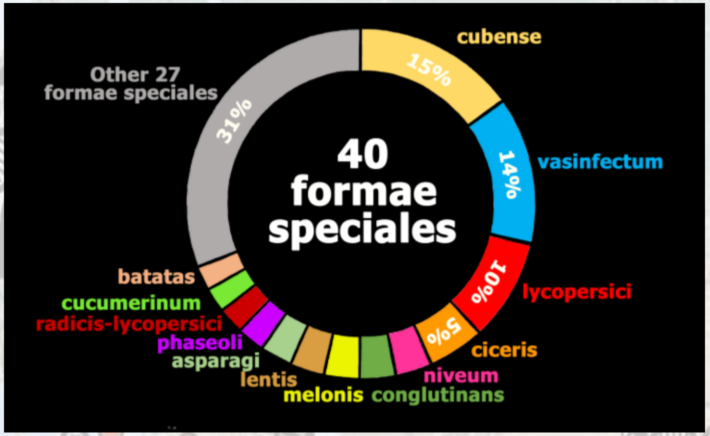


Global dust current *Fusarium oxysporum*

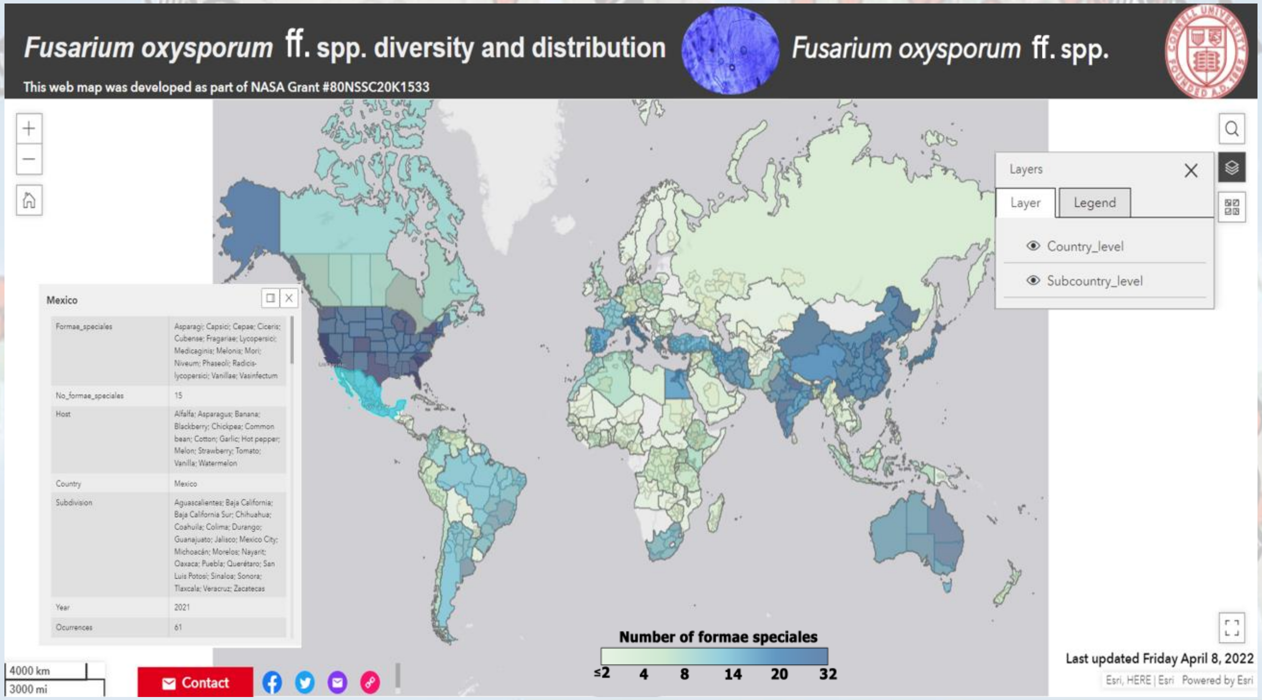
Brodsky et al. *accepted, Environmental Research Letters*

Remote Sensing
Build susceptibility assessment for current *Fo* risk in agricultural zones form remote sensing measurements





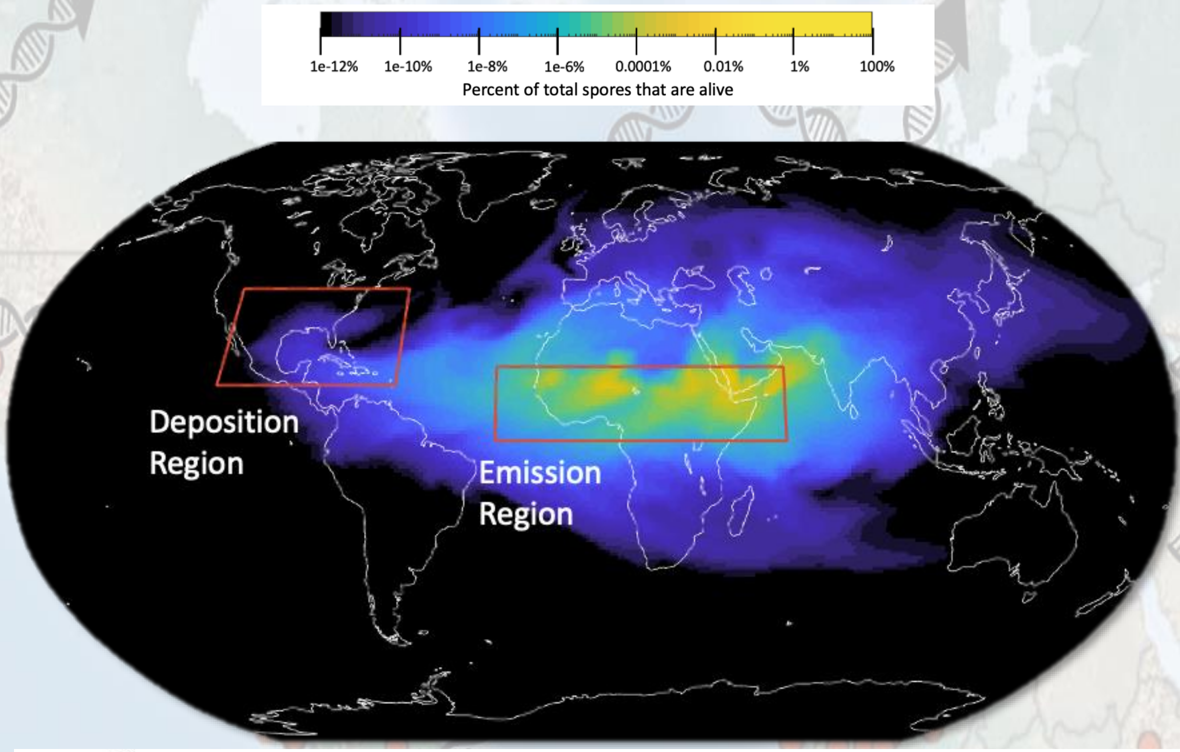
3980 *Fo* incidence reports at country and sub-country level derived from 1180 references



SCAN ME
to visit the online web map

Global dust current
Fusarium oxysporum

Calderón et al. 2022, *Plant Disease*

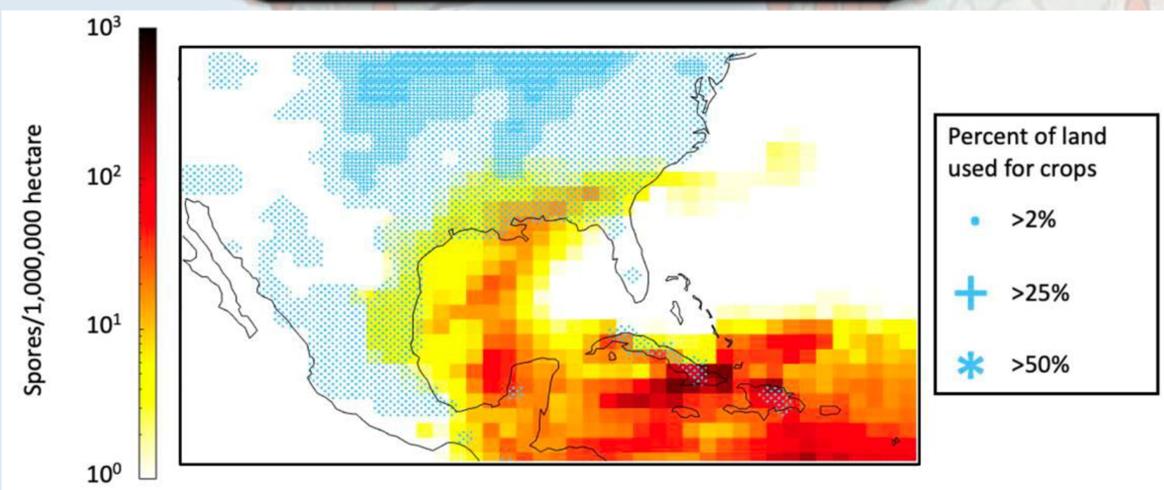



Almost all spores lose viability before reaching Americas….

<u>but not all!</u>

→ Our model indicates that **~4 million live spores** could have been deposited in North America in June 2020

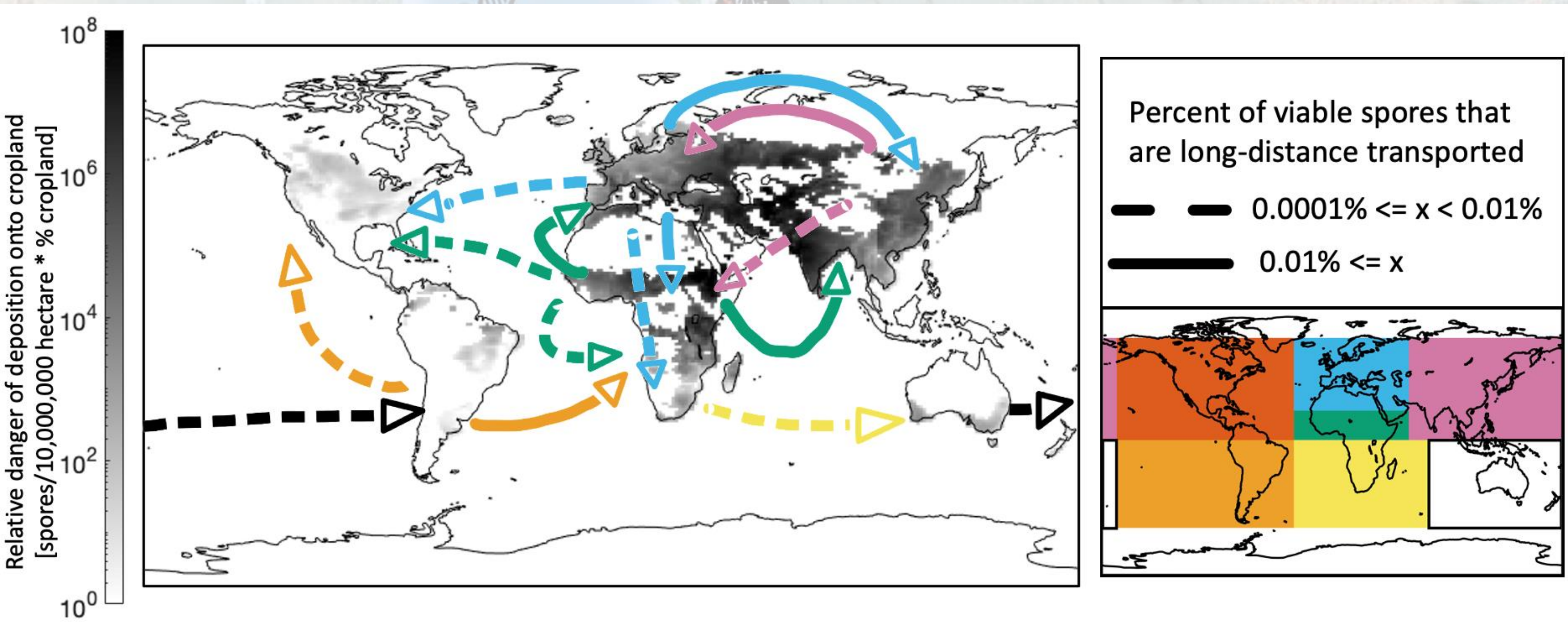
→ Theoretically, if there is substantial fungal infestation in North Africa, a big dust event like Godzilla could carry millions of live spores to the Americas.



Aerosol Transport
Build a model of long-distance atmospheric *Fo* spore transport and assess the likelihood of transatlantic transport of viable spores

Brodsky et al. *accepted, Environmental Research Letters*

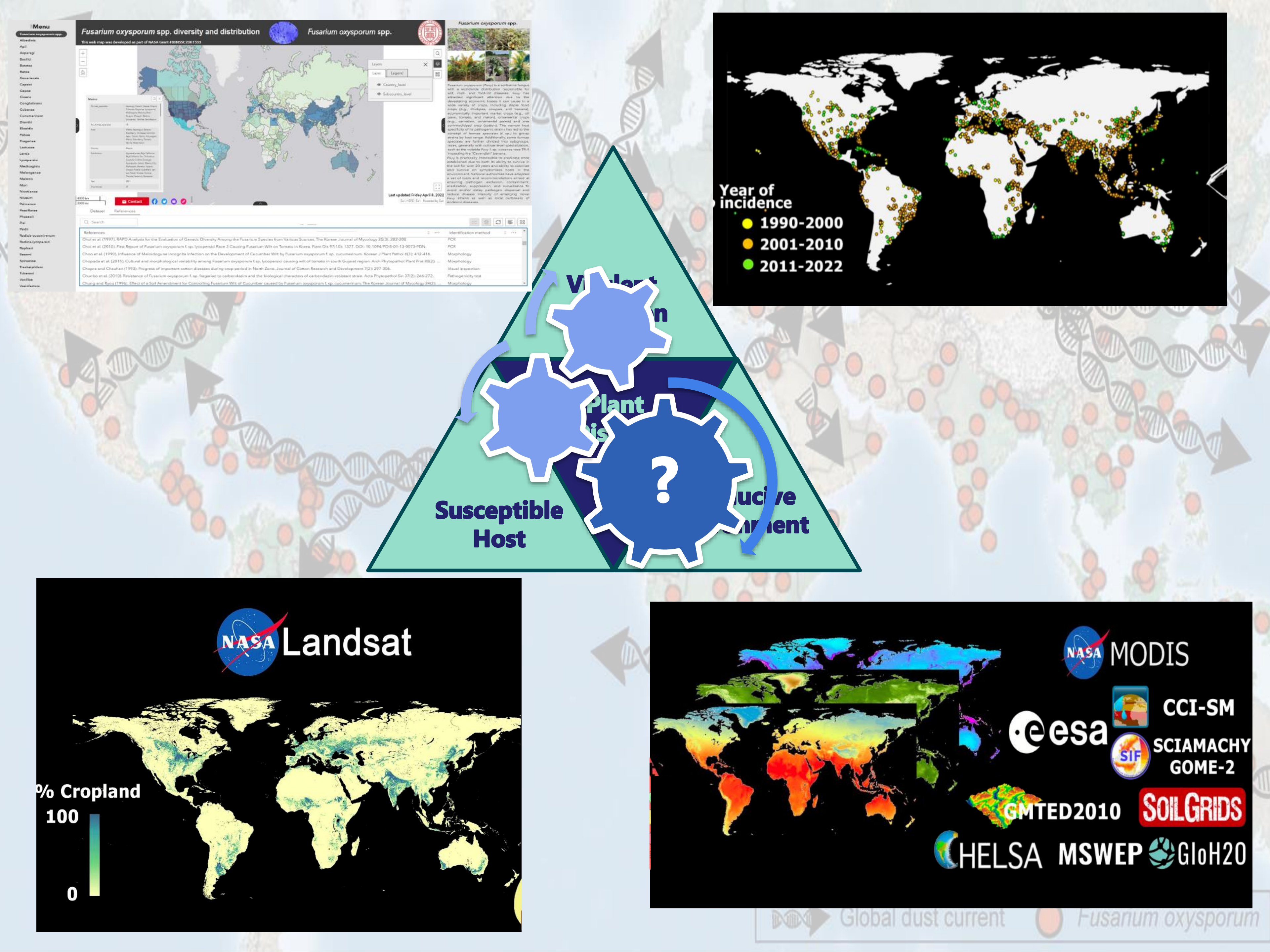
- **Poster: This afternoon here**
- **Talk: C3.5-5, Tues 3:10PM, Salon Tête d’Or**



While transoceanic transport of viable spores appears possible, **intercontinental** transport between Europe/Africa/Asia is more likely, and potentially of greater risk.

Aerosol Transport
Build a model of long-distance atmospheric *Fo* spore transport and assess the likelihood of transatlantic transport of viable spores

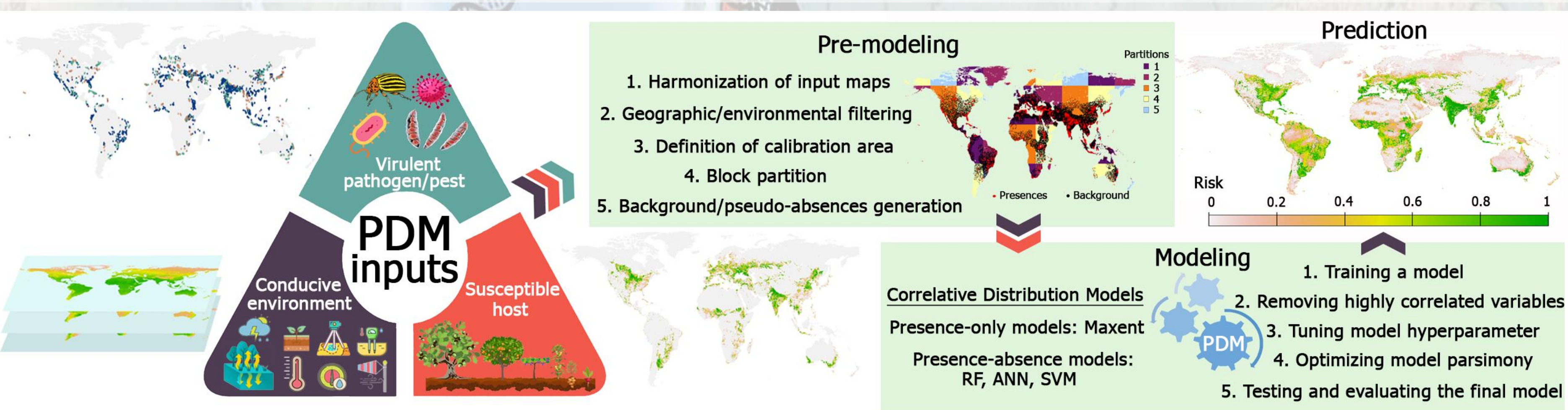
Brodsky et al. *accepted, Environmental Research Letters*

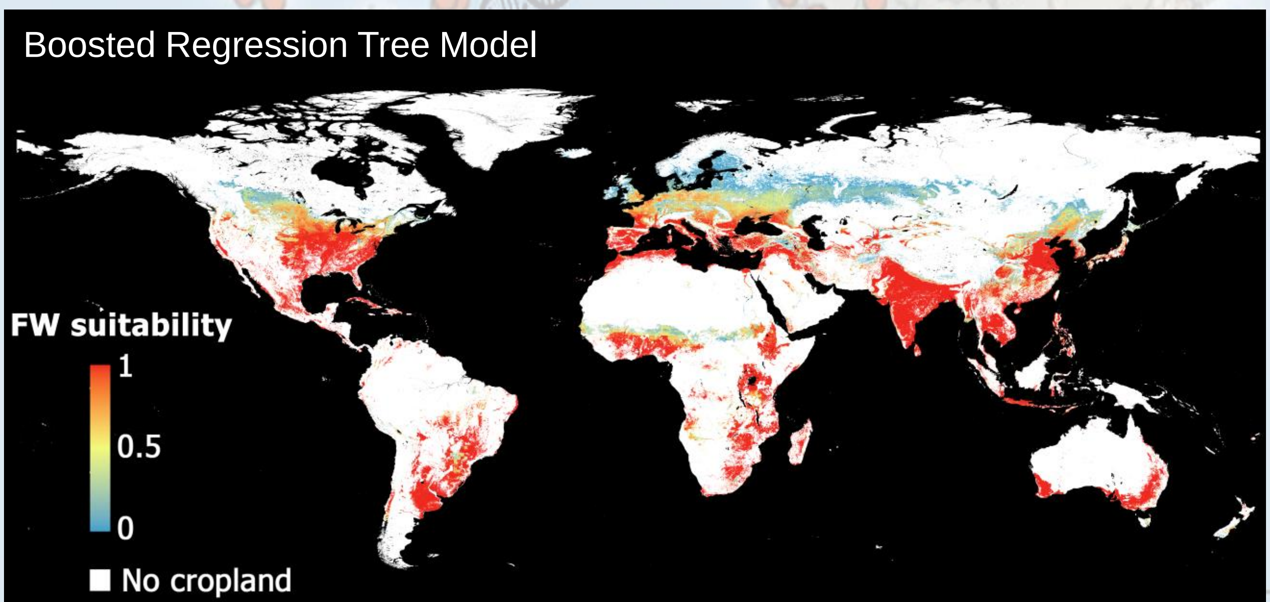


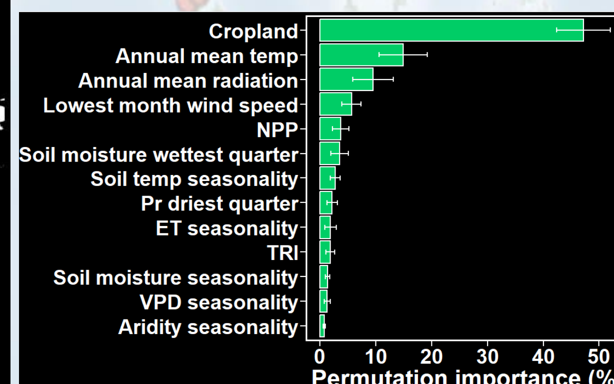
Menu
Fusarium oxysporum spp. diversity and distribution
Fusarium oxysporum spp.
Year of incidence
1990-2000
2001-2010
2011-2022
Plant
Susceptible Host
?
NASA Landsat
% Cropland
100
0
NASA MODIS
esa
CCI-SM
SIF
SCIAMACHY
GOME-2
GMTED2010
SOILGRIDS
CHELSA
MSWEP
GloH2O
Global dust current
Fusarium oxysporum

Pathosystem Distribution Modeling

SPECIES DISTRIBUTION MODELING Estimate statistical reletionships between species presence and environmental variables, thus predicting the geographical suitability for its establishment. Based on machine-learning methods: MaxEnt (Maximum Entropy), Artificial Neural Networks, Random Forests, Boosted Regression Trees, and Support Vector Machines





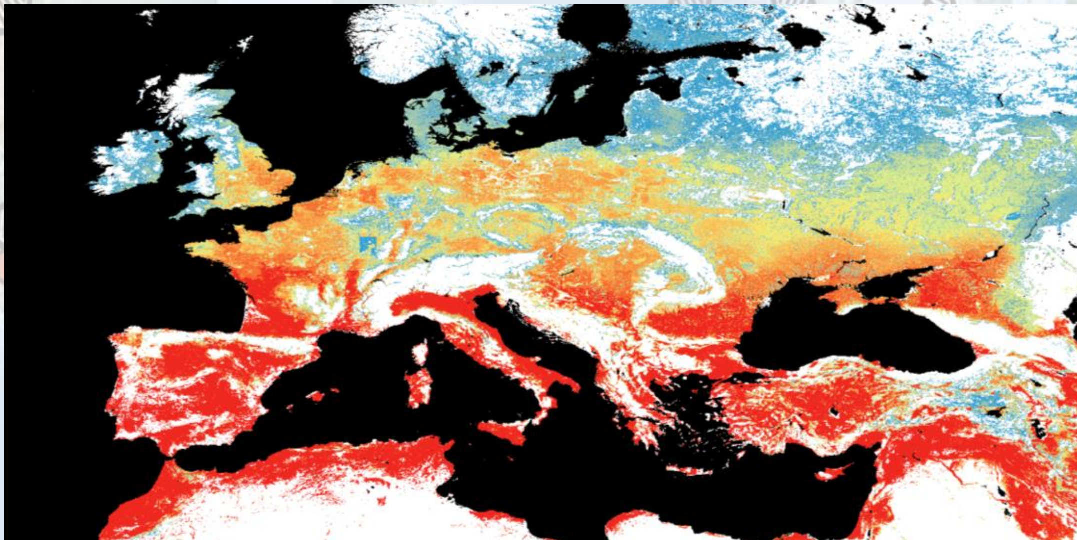


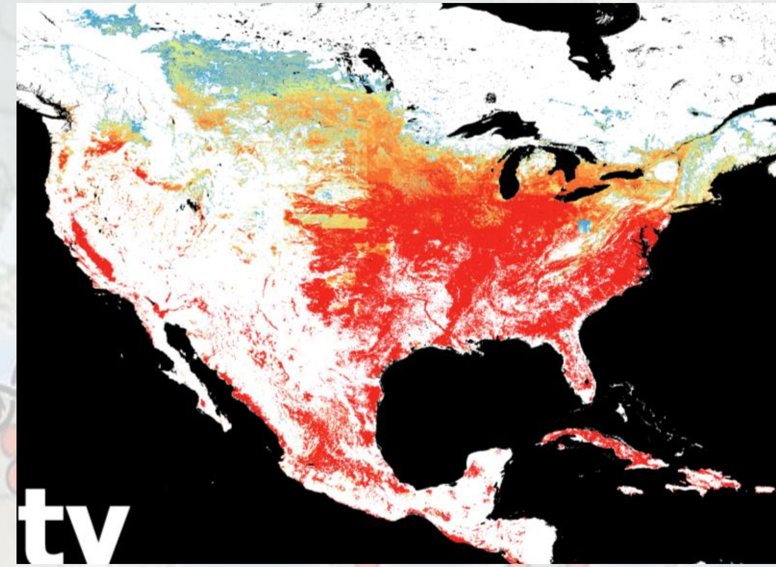
Remote Sensing

Build susceptibility assessment for current *Fo* risk in agricultural zones form remote sensing measurements

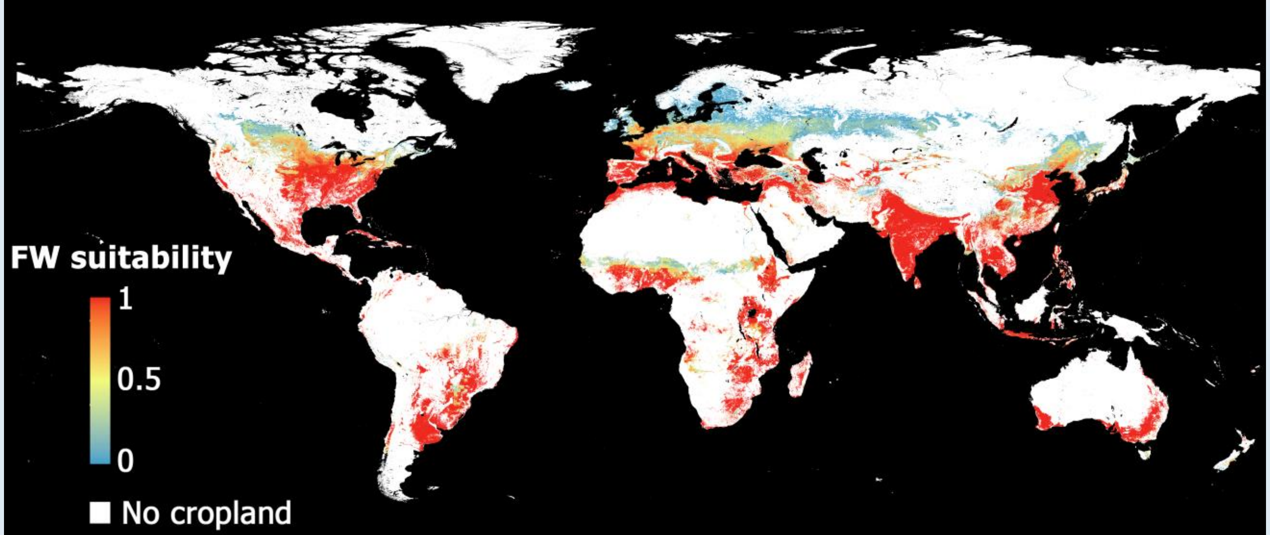
Calderón et al in prep, no photos please

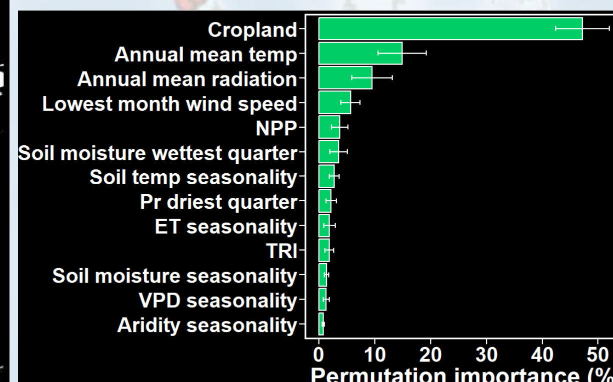
Pathosystem Distribution Modeling





Boosted Regression Tree Model

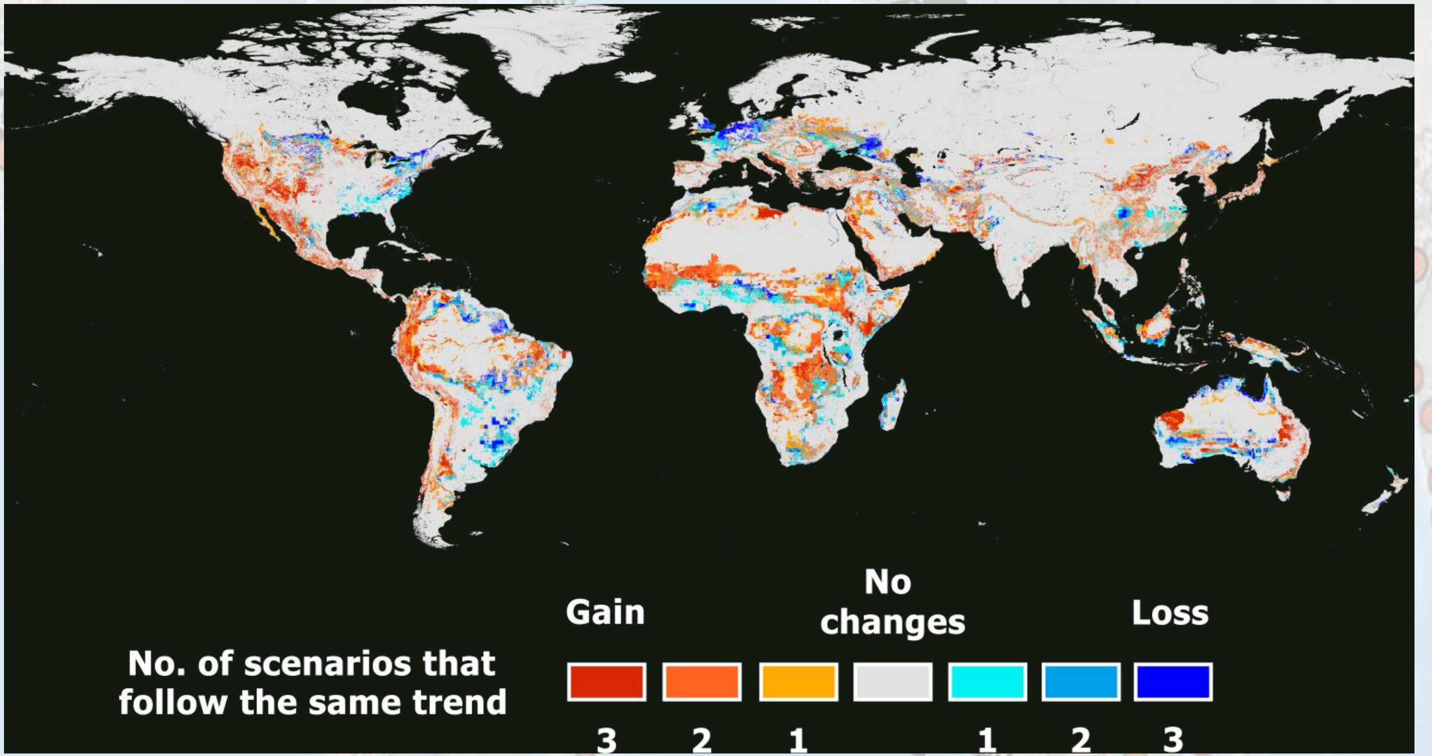


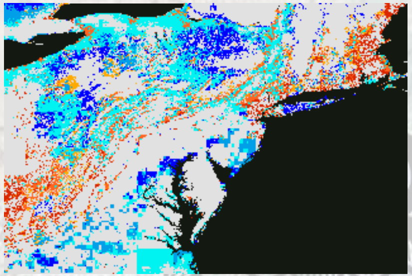


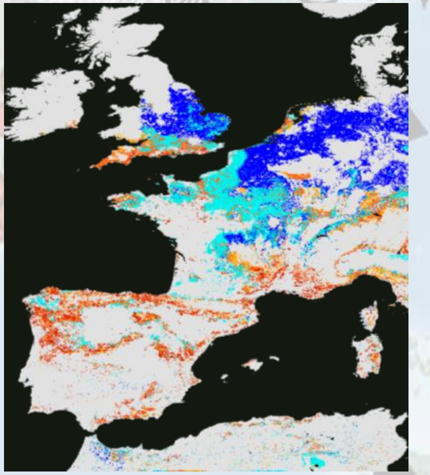
Remote Sensing
Build susceptibility assessment for current *Fo* risk in agricultural zones form remote sensing measurements

Calderón et al in prep, no photos please

Predicting disease suitability in the future under various climate change scenarios





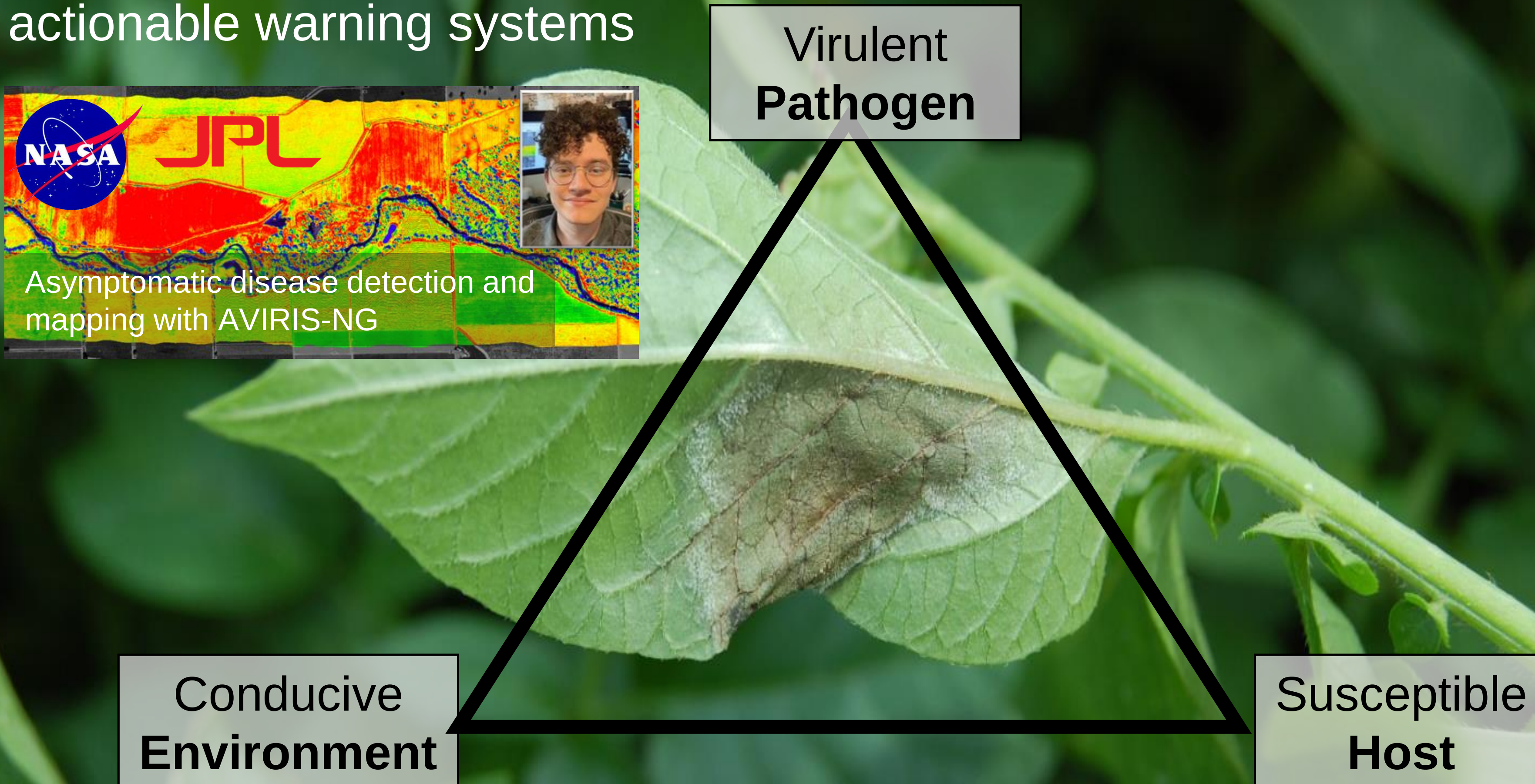


- Talk, Sun 10:10 AM (here)
- Poster, Mon 21st - Tues 22nd
- Flash Talk, Tues 6:40 PM, Agora

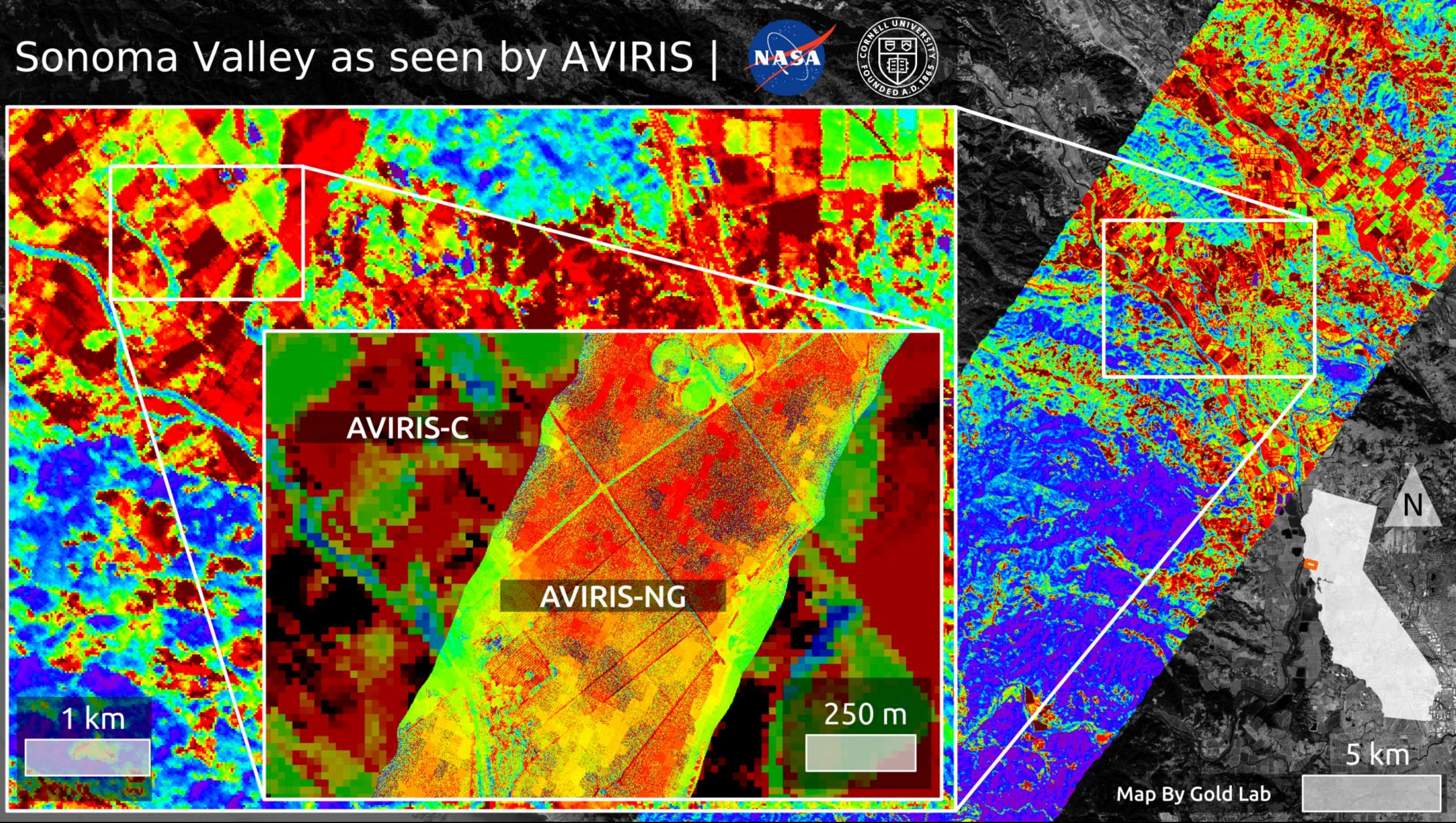
Climate change impacts on *Foxy* distribution

Calderón et al in prep, no photos please

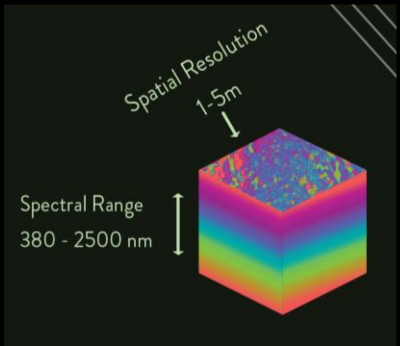
Accurate pathogen distribution is the bottleneck in building actionable warning systems



Sonoma Valley as seen by AVIRIS |



High spectral and spatial resolution
Low temporal resolution
Ideal for <u>long latent</u> phase diseases
Ideal for <u>zero tolerance</u> management thresholdx



GLRaV-3: A major threat to grape production

- Decreases yield, vine lifespan, & grape quality
- Long latent period: vine can be infected for 12mo before showing foliar symptoms (Blaisdell 2016)
- Symptoms (when present) primarily in lower canopy, red varieties only
- No cure, only treatment is removal. Recommended once incidence >30%

Testing is expensive…

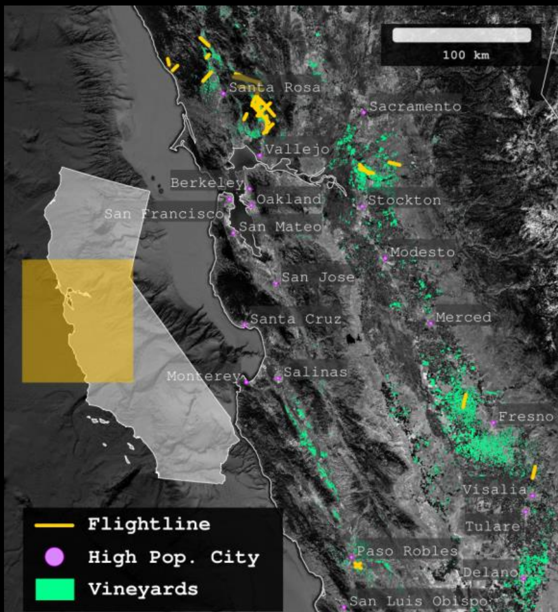
- 1 Vine for 1 virus: $40-50

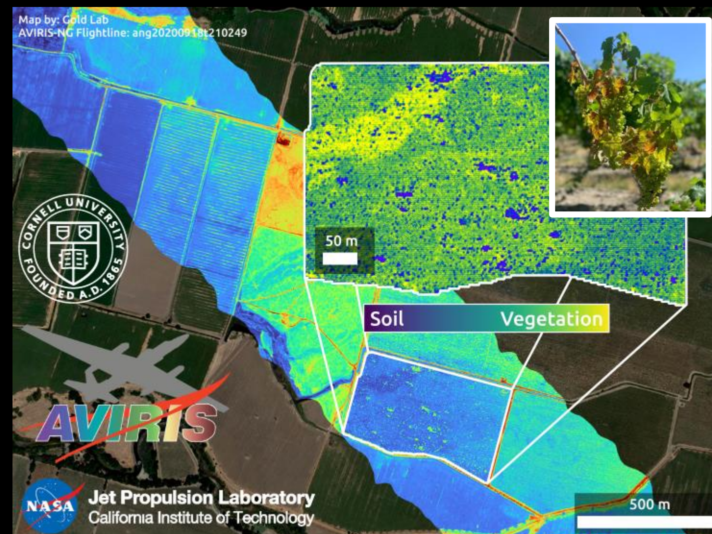
…And so is the cost of disease

- Viral disease cost the grape and wine industry over **$3 billion** annually

2020 AVIRIS-NG “Wine Tour”

Air and ground campaign funded by emergency allocation from NASA Biodiversity office





37,000 acres total captured

10—15 highly trained scouts swept 300ac vine by vine to flag and geotag GLRV infected vines in September 2020 and 2021

Subset tested to validate scouts: 100% accurate

Harvest occurred within 1wk of AVIRIS-NG flight

Visibly symptomatic in 2020 = Sy

Visibly symptomatic in 2021 = latently infected in 2020 = aSy

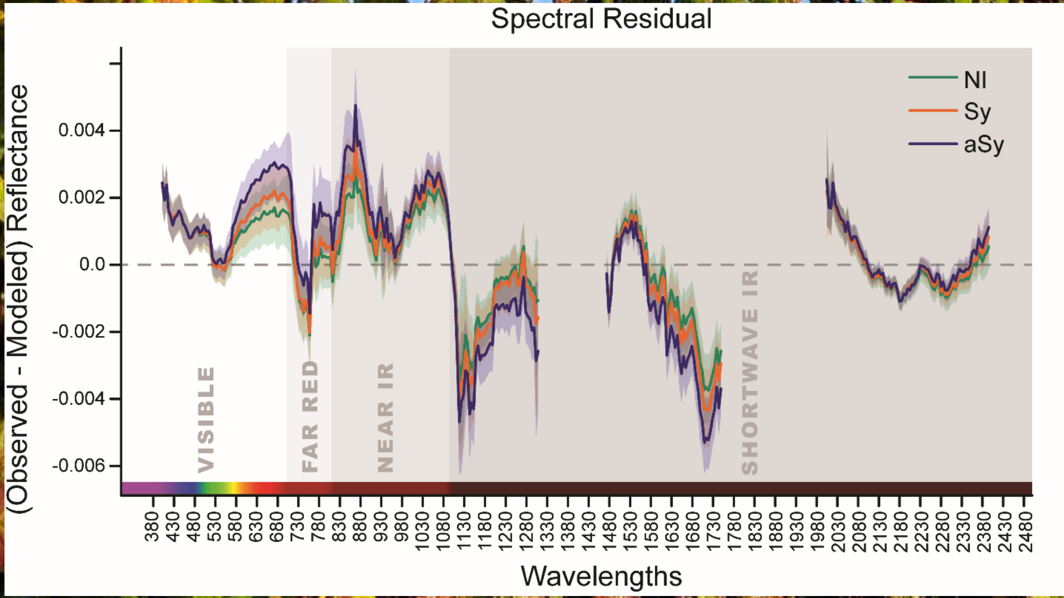
E&J Gallo Winery

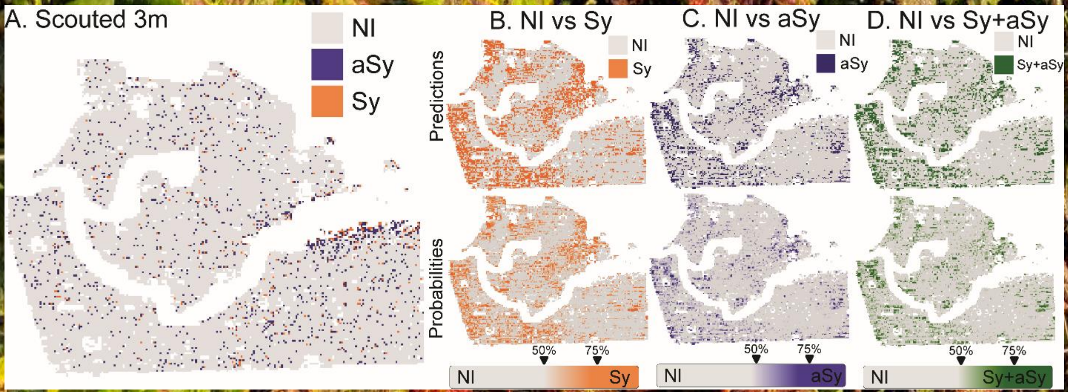
LODI WINE GROWERS

Starr & Storm Crop Solutions

Asymptomtatic virus detection with NASA AVIRIS-NG

Romero Galvan et al. 2023, *Phytopathology*





Visibly symptomatic in 2020 = Sy

Visibly symptomatic in 2021 = latently infected in 2020 = aSy

Classification	Random Forest + SMOTE + Smoothing + Unmixing (3m)	
	Test Accuracy	Test Kappa
NI vs (Sy + aSy)	**85%**	**0.71**
NI vs Sy	81%	0.62
NI vs Sy vs aSy	67%	0.51
NI vs aSy	**87%**	**0.73**

NASA JPL SURP and NASA Award #80NSSC21K1605

Asymptomtatic virus detection with NASA AVIRIS-NG

Romero Galvan et al. 2023, *Phytopathology*

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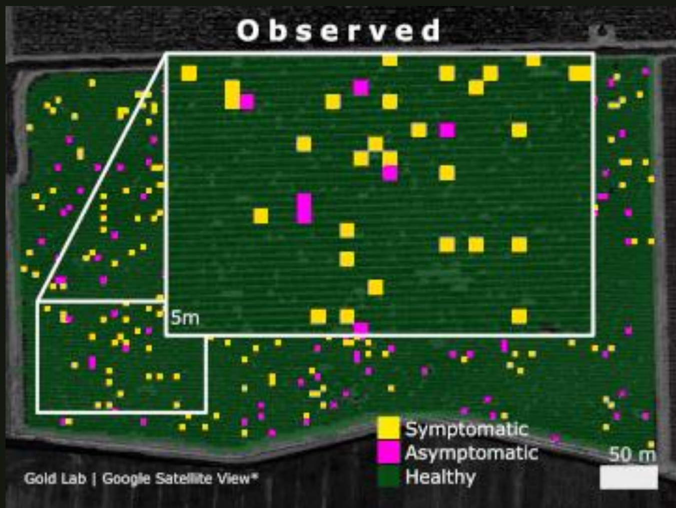
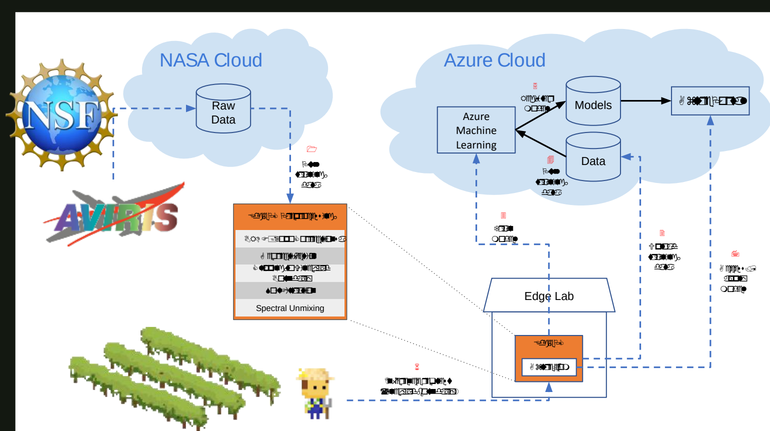


To reduce misclassifications and deploy at scale with SBG, we need to:

1. Address biological confounders: variety + abiotic stress
2. Implement a more powerful analysis platform
3. Collect more ground validation



WineGuard

P9.4-020, Wed Aug 23-Thu 24

Rubambiza & Romero Galvan et al. 2023, JGR Biogeo

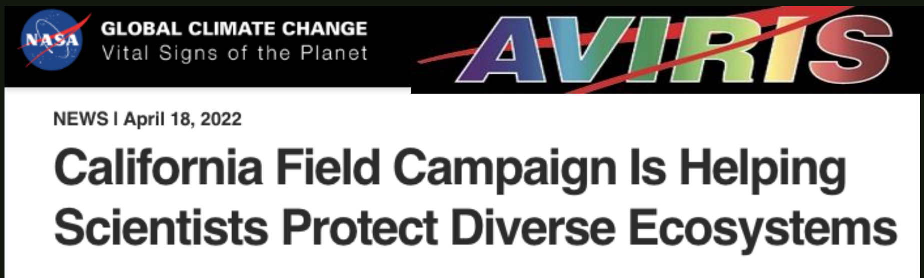
The PhytoPatholoBot:

A fully autonomous, vision guided vineyard robot

C9.4-5, Fri Aug 25 9:40am Rhone 3A

Liu et al. 2022, IROS

Up next: untangling confounding factors to improve disease detection

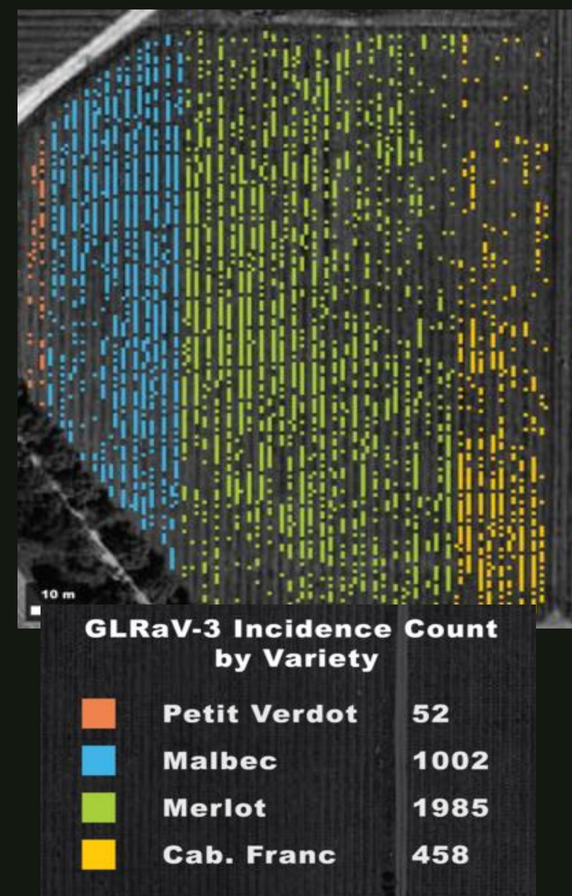


NEWS | April 18, 2022

California Field Campaign Is Helping Scientists Protect Diverse Ecosystems

GLRV		Error	Accuracy (1-Error)
	Mis-detection	5.94%	**94.06%**
	False positive	11.30%	**88.70%**

Liu et al. 2023, *IEEE proceedings*



NASA ACRES: A New Consortium to Grow NASA's Investment in U.S. Agriculture

Alyssa Whitcraft

25 initial projects at 12 principal institutions

implemented across the US through a transdisciplinary, multisectoral, and diverse Consortium

Objectives

- Support a deeper understanding of US agricultural land use, productivity, and sustainability
- Develop and transition on-farm decision support tools for smart agronomy
- Empower human, environmental, and human resilience to climate change and global hazards
- Increase diversity, equity, inclusion, and justice in agtech, and through Acres work

Right sizing spectral and spatial resolution on a pathosystem by pathosystem basis

Diseases with long latent phases and/or zero-tolerance management thresholds benefit the most from high spectral and spatial resolution and can tolerate low temporal resolution

Diseases with short latent phases and/or non-zero tolerance management thresholds benefit the most from high temporal and spatial resolution and can tolerate lesser spectral resolution (*to an extent)*

What makes for a meaningful intervention and on what time scale?

Who are your decision makers?

What is the minimum viable data product to inform a meaningful intervention?

Virulent **Pathogen**

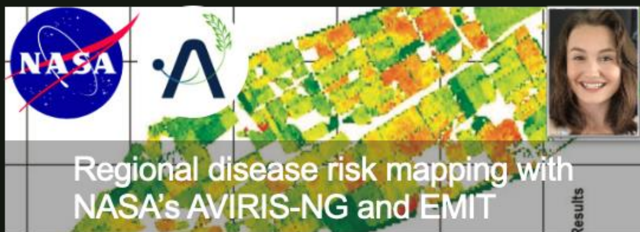
Plant Disease

Conducive **Environment**

Susceptible **Host**

Right sizing spectral and spatial resolution on a pathosystem by pathosystem basis

P9.4-009, Wed Aug 23 & Th 24

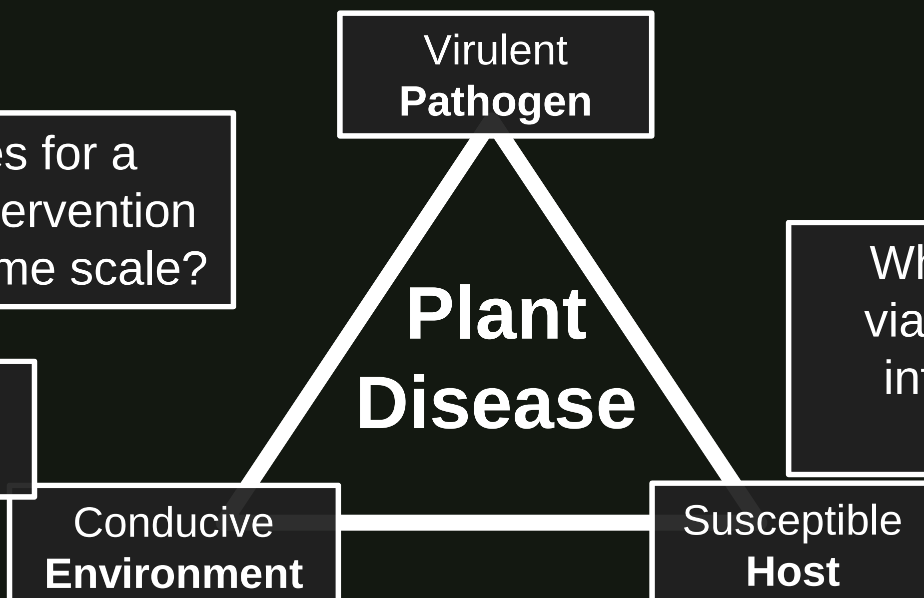


P9.4-005, Wed Aug 23 & Th 24

P9.4-013 , Wed Aug 23 & Th 24
Published last week in *Phytopathology!*

What makes for a meaningful intervention and on what time scale?

Who are your decision makers?



What is the minimum viable data product to inform a meaningful intervention?

Cornell AgriTech
New York State Agricultural Experiment Station

LODI WINE GROWERS
E&J Gallo Winery
Starr & Storm Crop Solutions

Questions?

kg557@cornell.edu

Twitter: @kaitlinmgold

JPL
NASA
cida Cornell Institute for Digital Agriculture
NSF

Cornell CALS
College of Agriculture and Life Sciences

Space Grapes Art by Matthias Grunewald, 2000