KELLY CAYLOR

IMPACTS OF AGRICULTURAL DECISION MAKING & ADAPTIVE MANAGEMENT ON FOOD SECURITY IN AFRICA

SESYNC Seminar, October 2015

PEI
PRINCETON ENVIRONMENTAL INSTITUTE

ACKNOWLEDGEMENTS

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Shahzeen Attari, Indiana U.
Justin Sheffield, Princeton U.
Eric Wood, Princeton U.
Lyndon Estes, Princeton U.
Adam Wolf, CEO Pulsepod

DISTRIBUTION OF WATER ON EARTH

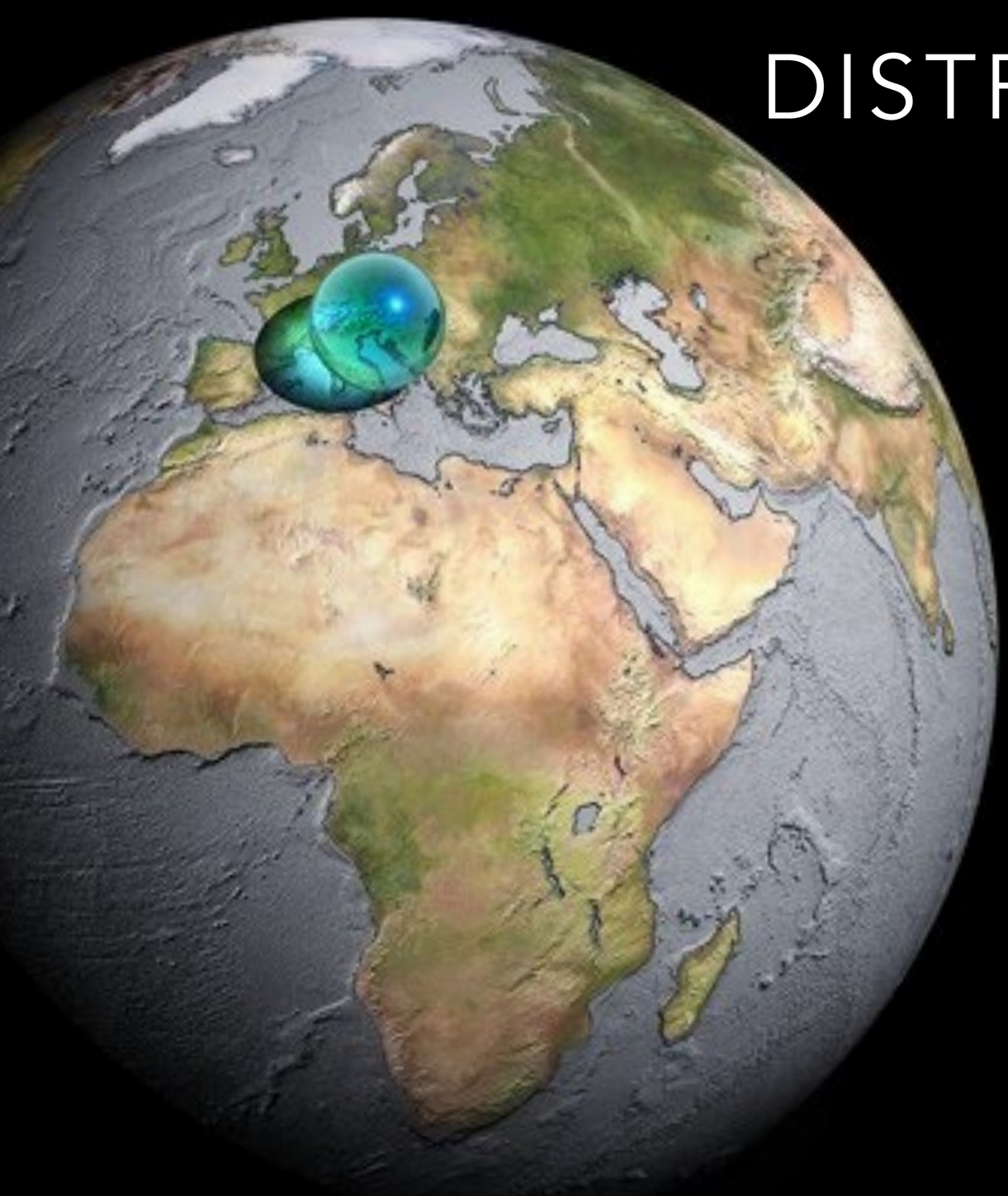
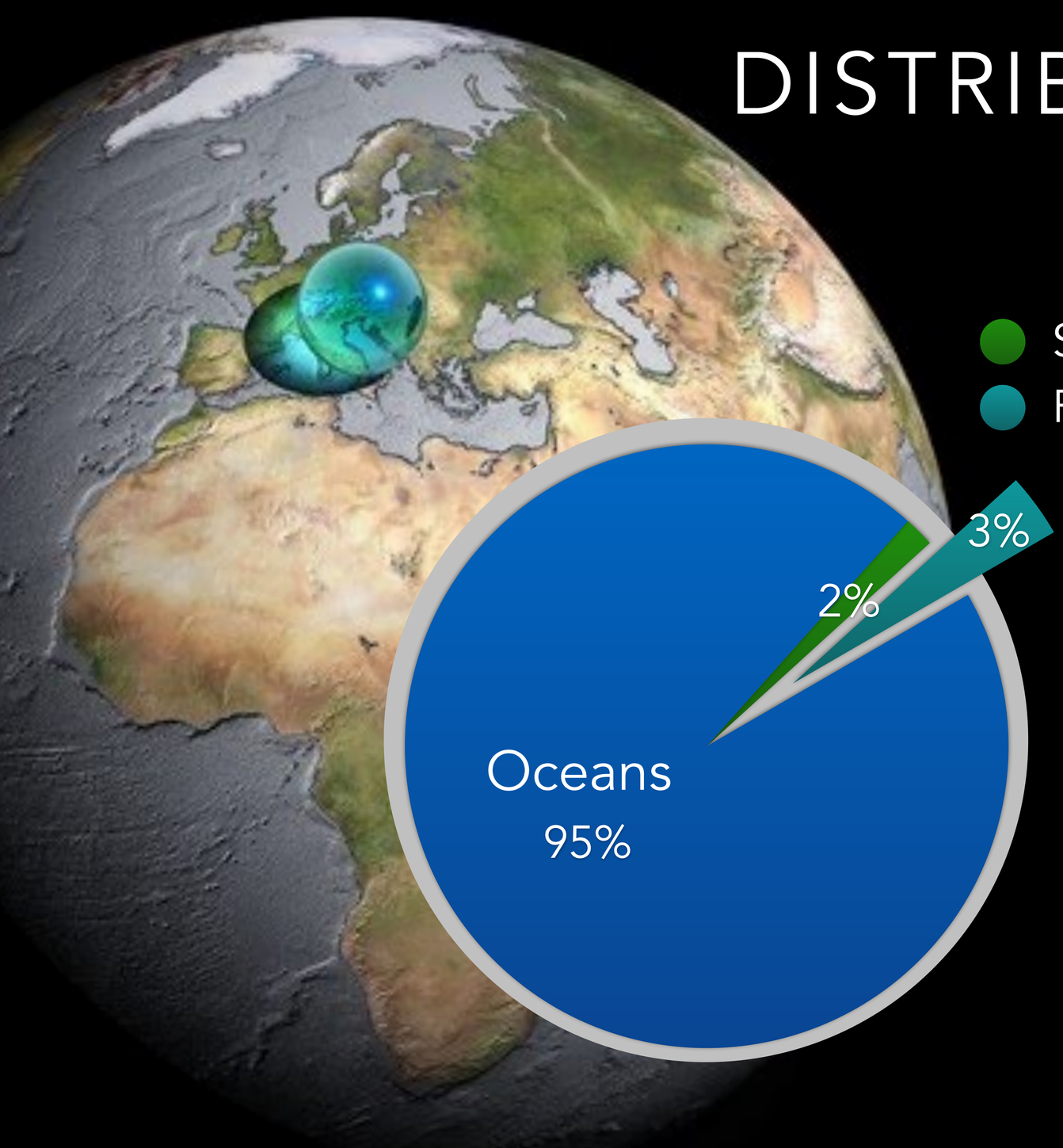


Image Credit: Adam Nieman

DISTRIBUTION OF WATER ON EARTH



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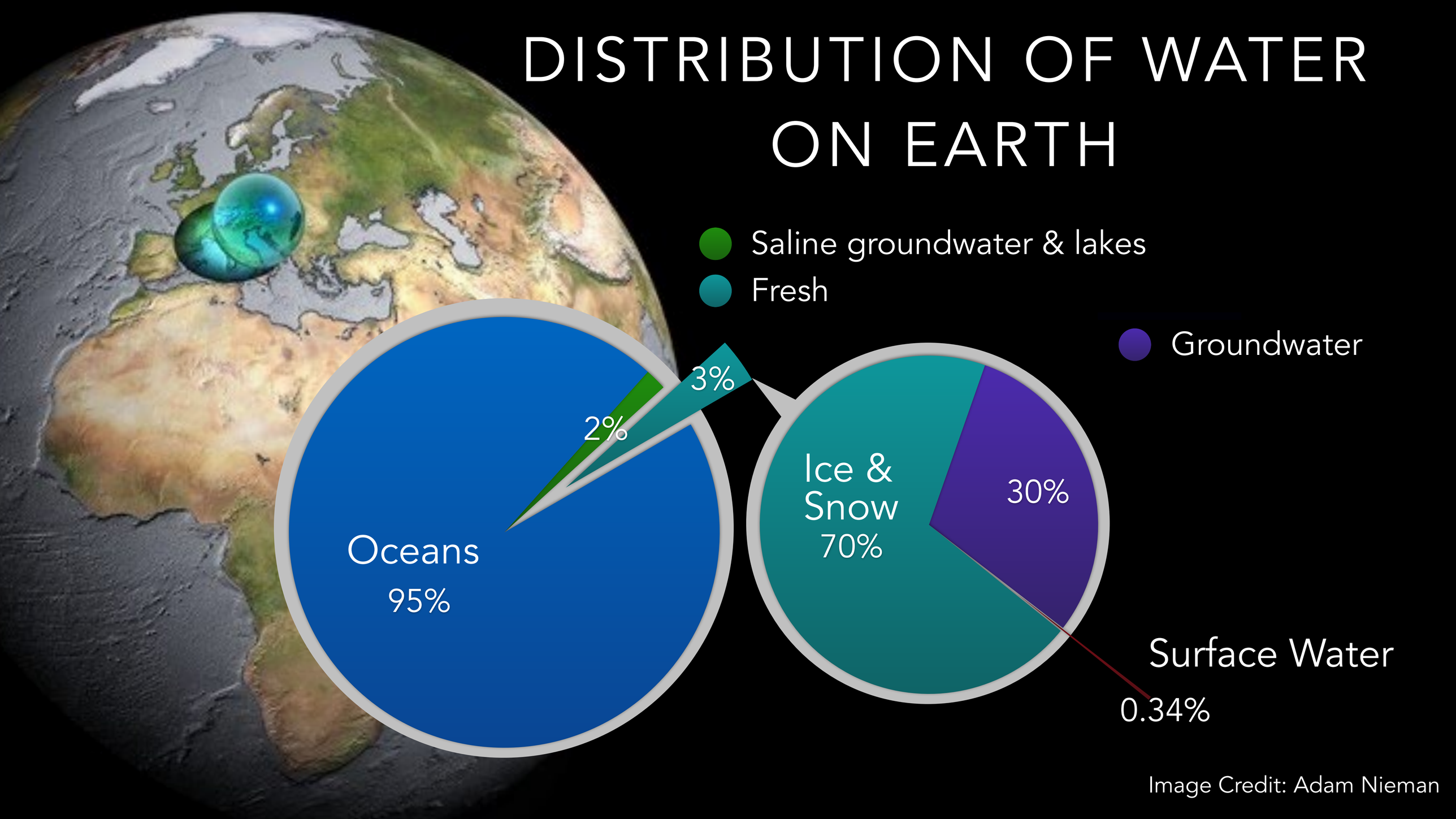

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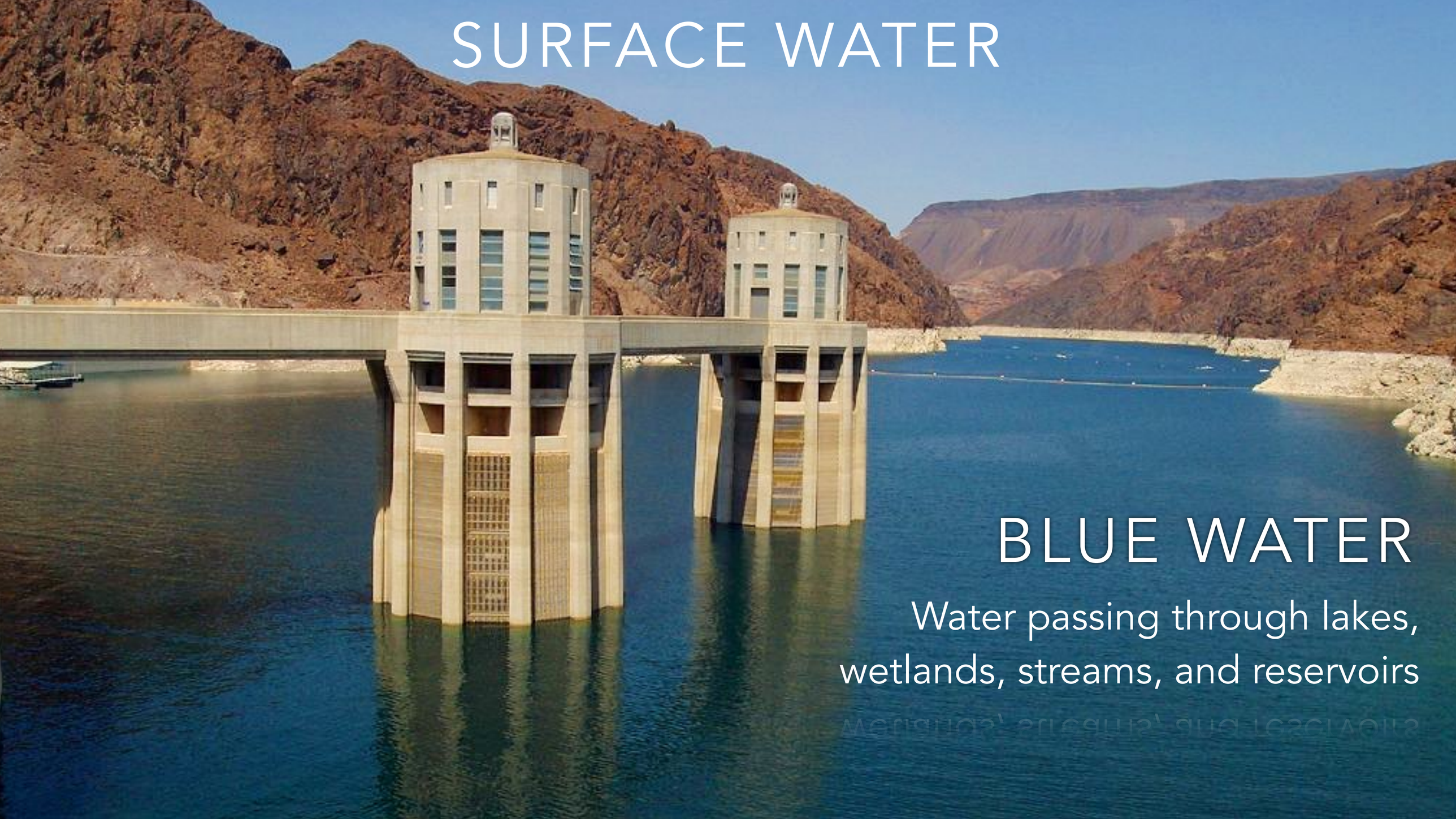
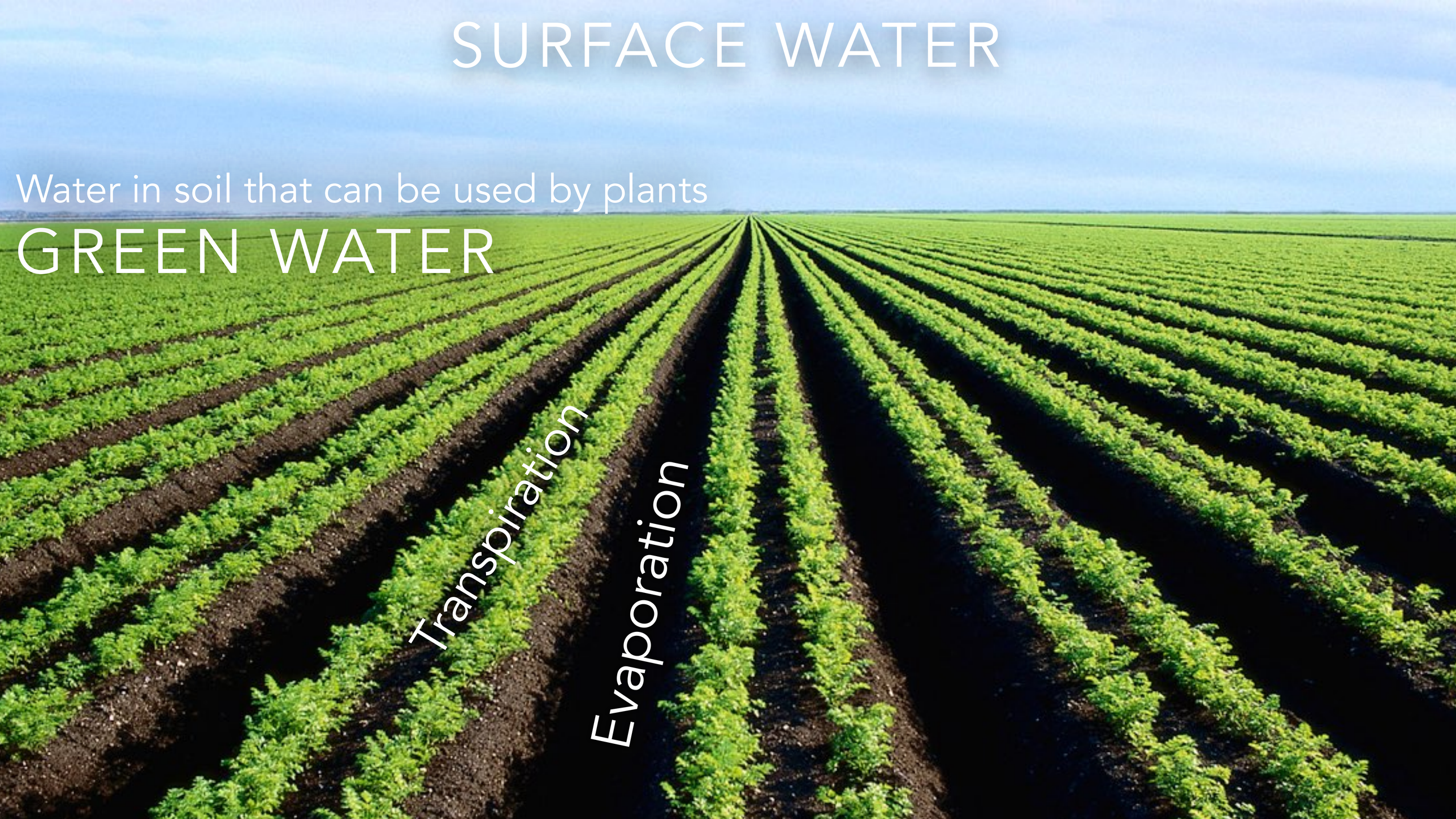
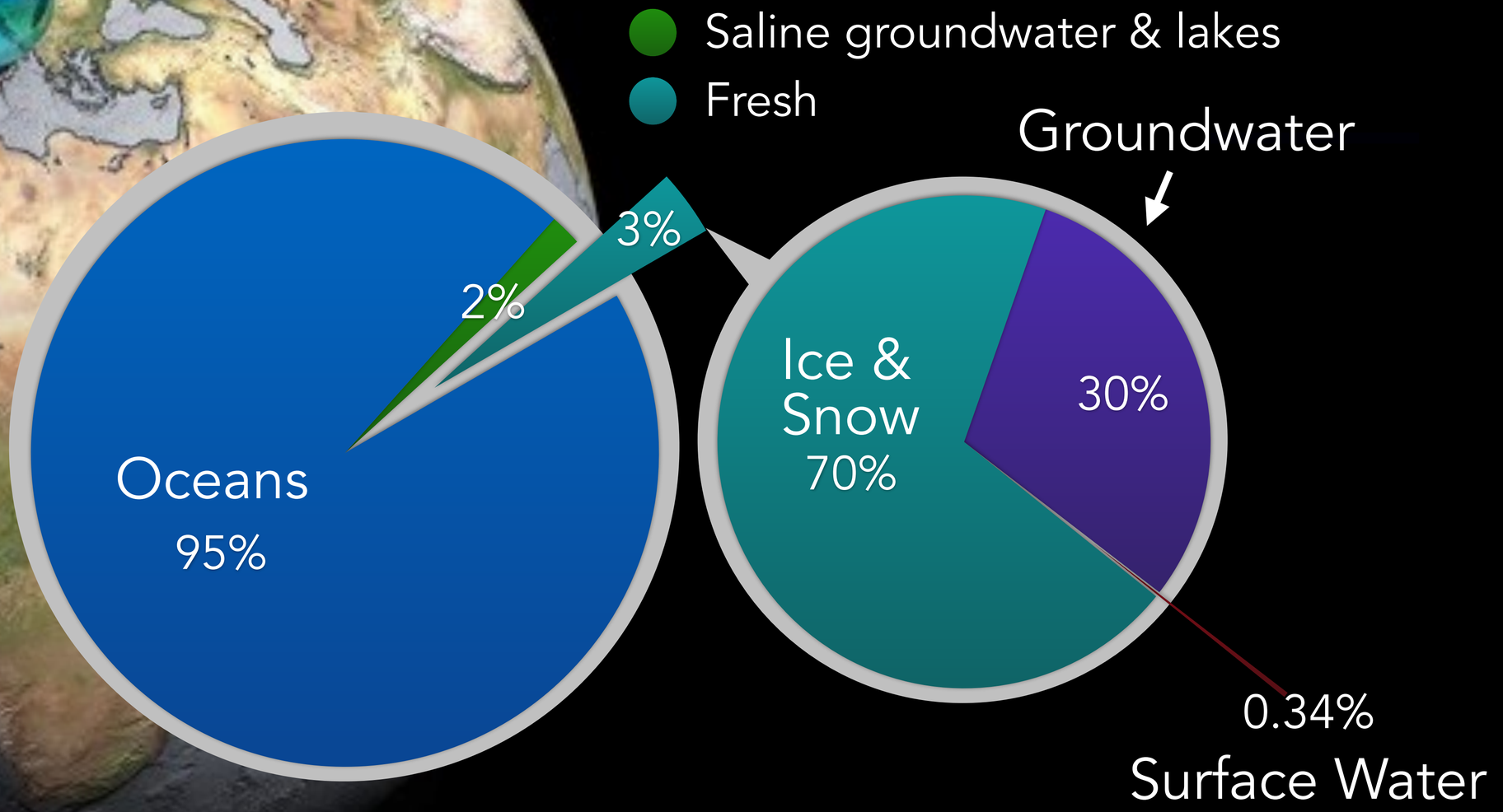

SURFACE WATER
BLUE WATER
Water passing through lakes, wetlands, streams, and reservoirs


SURFACE WATER
Water in soil that can be used by plants
GREEN WATER
Transpiration
Evaporation

DISTRIBUTION OF WATER ON EARTH



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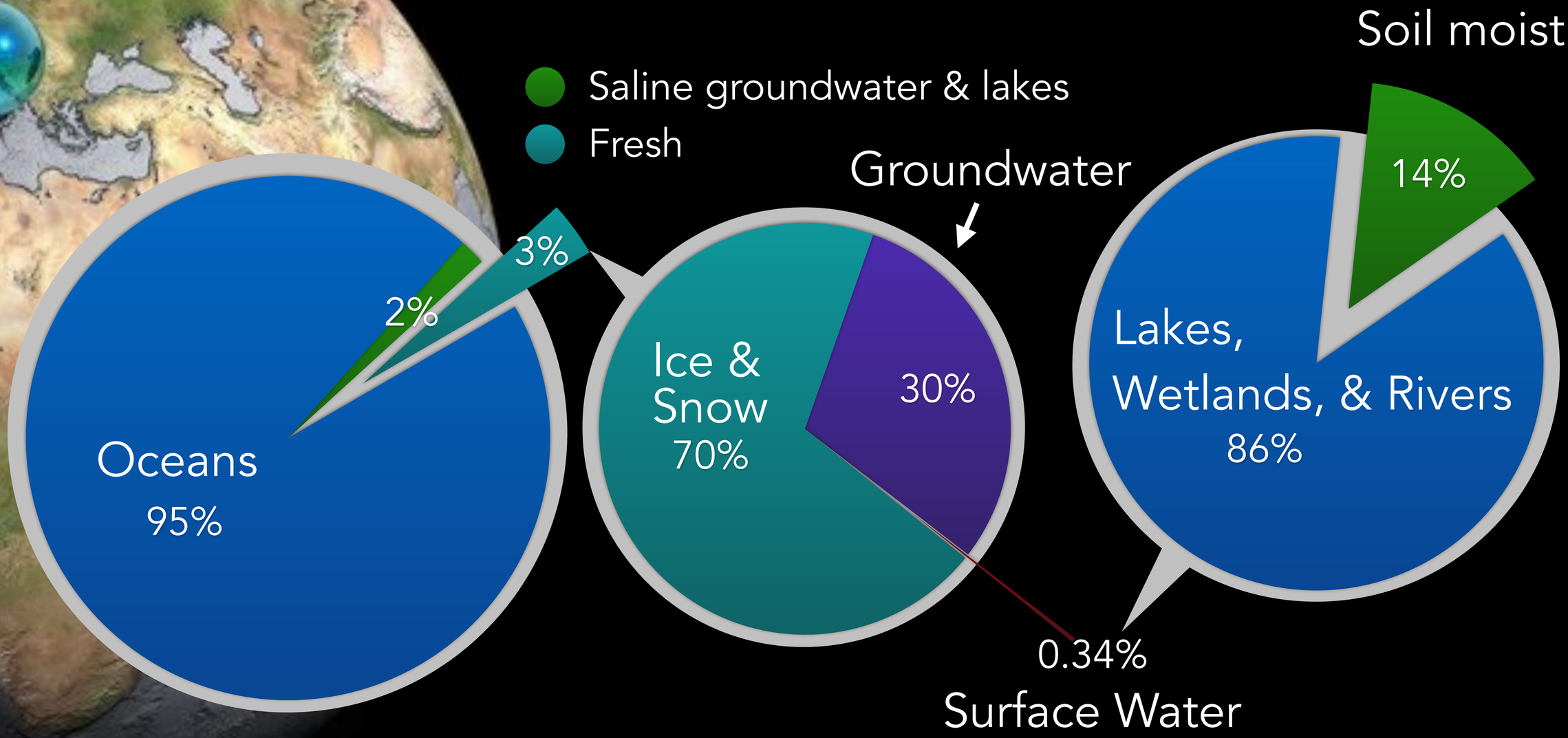
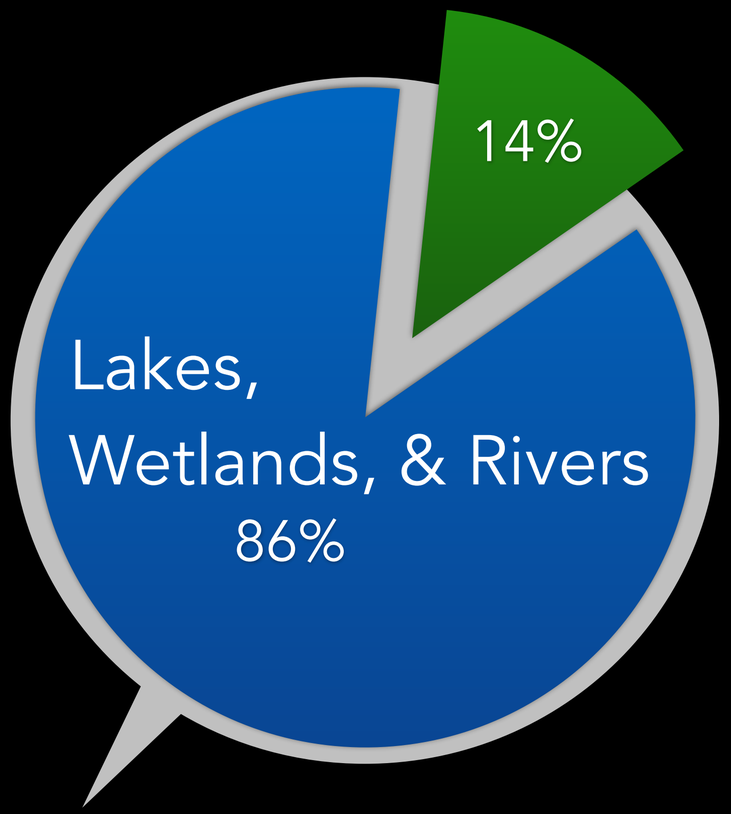


DISTRIBUTION OF WATER ON EARTH

Soil moisture fuels the productivity of all terrestrial ecosystems.
It makes up only 0.001% of all water on Earth.



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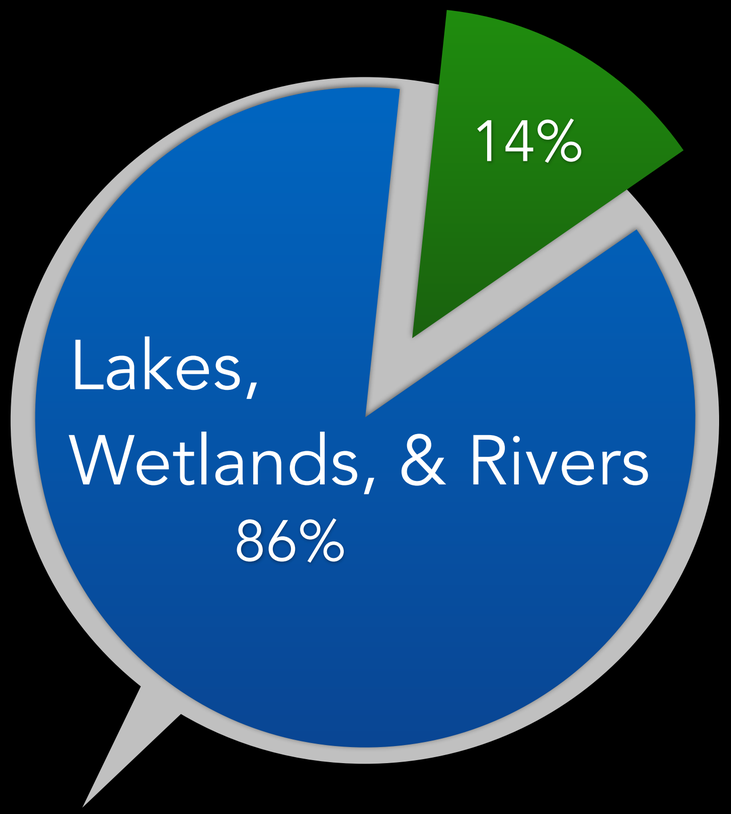
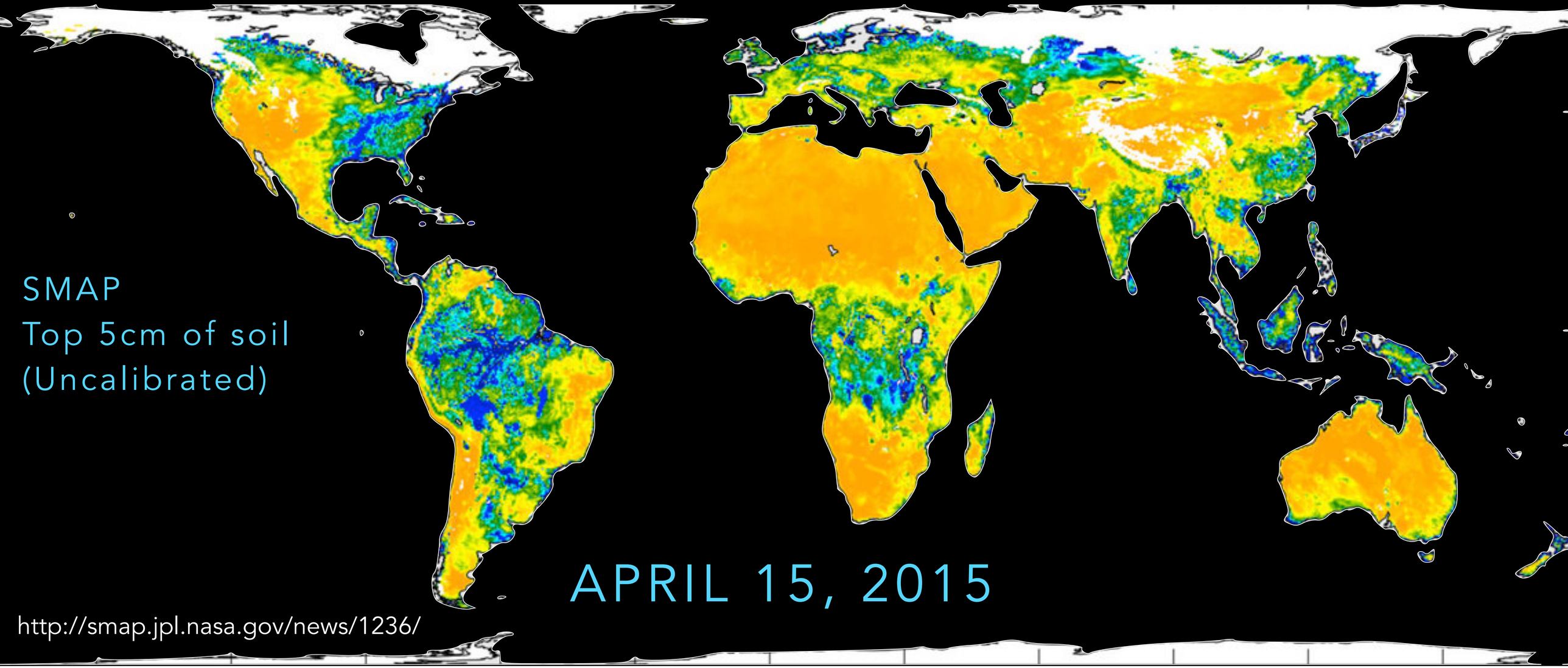
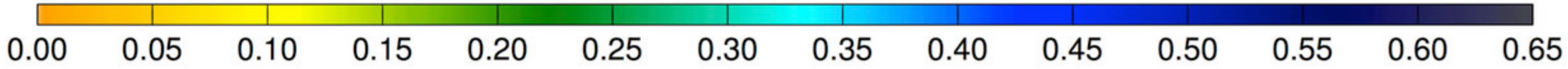


NSF 2015 Budget ($7.3B) is 0.187% of total 2015 US Budget request ($3.9T)

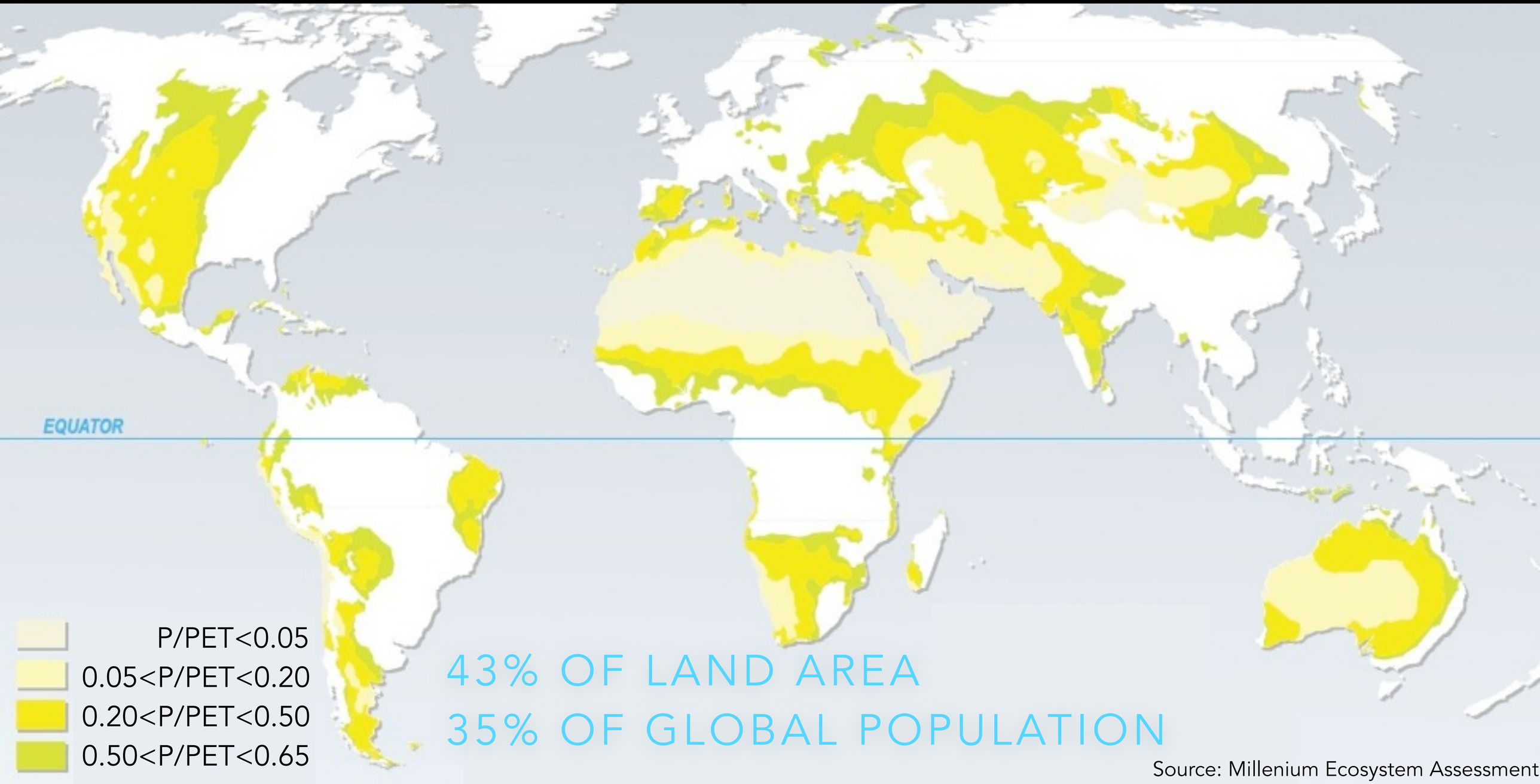
GLOBAL DISTRIBUTION OF SOIL MOISTURE



SOIL MOISTURE CM^3/CM^3



GLOBAL DISTRIBUTION OF DRYLANDS

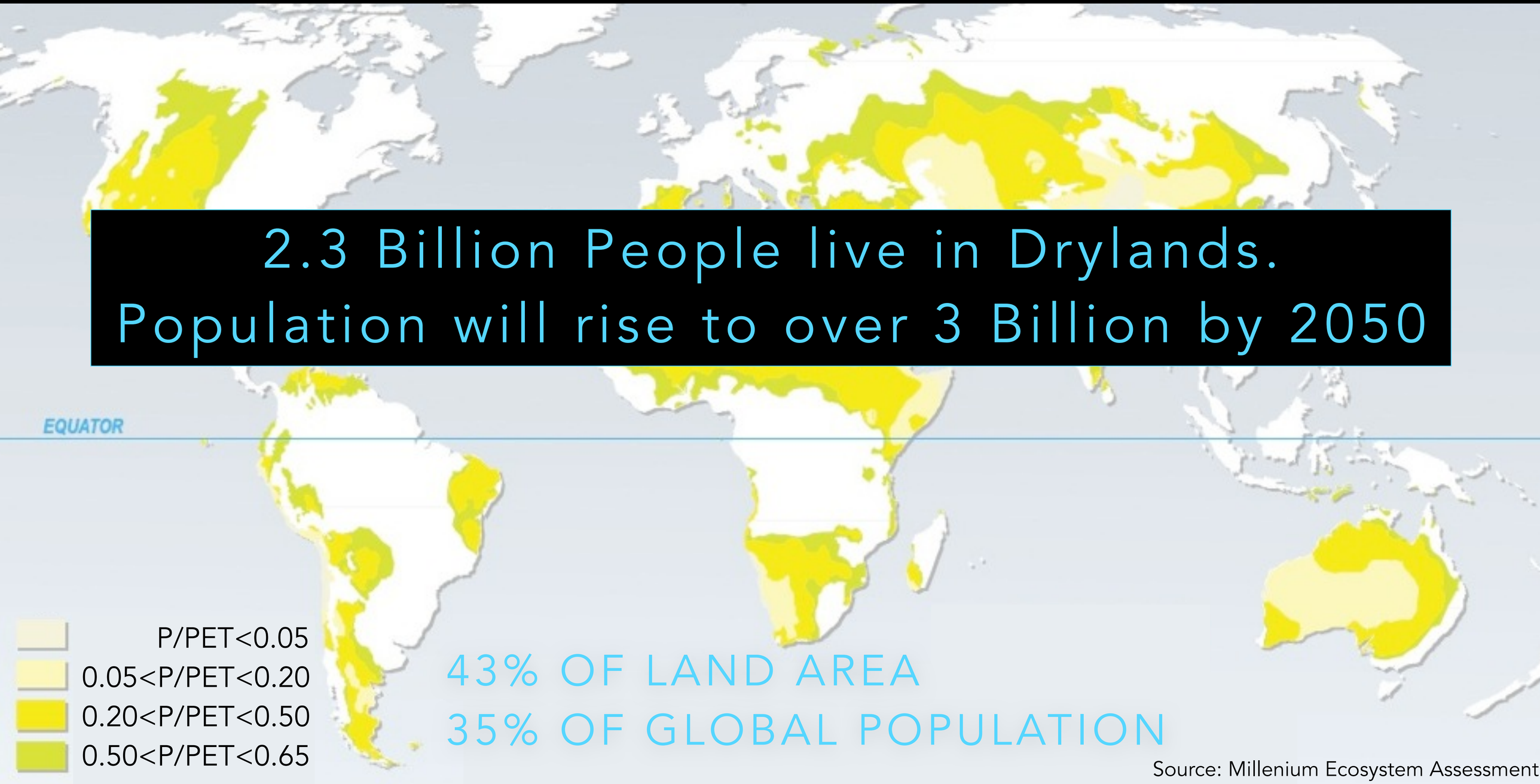


43% OF LAND AREA

35% OF GLOBAL POPULATION

Source: Millenium Ecosystem Assessment

GLOBAL DISTRIBUTION OF DRYLANDS



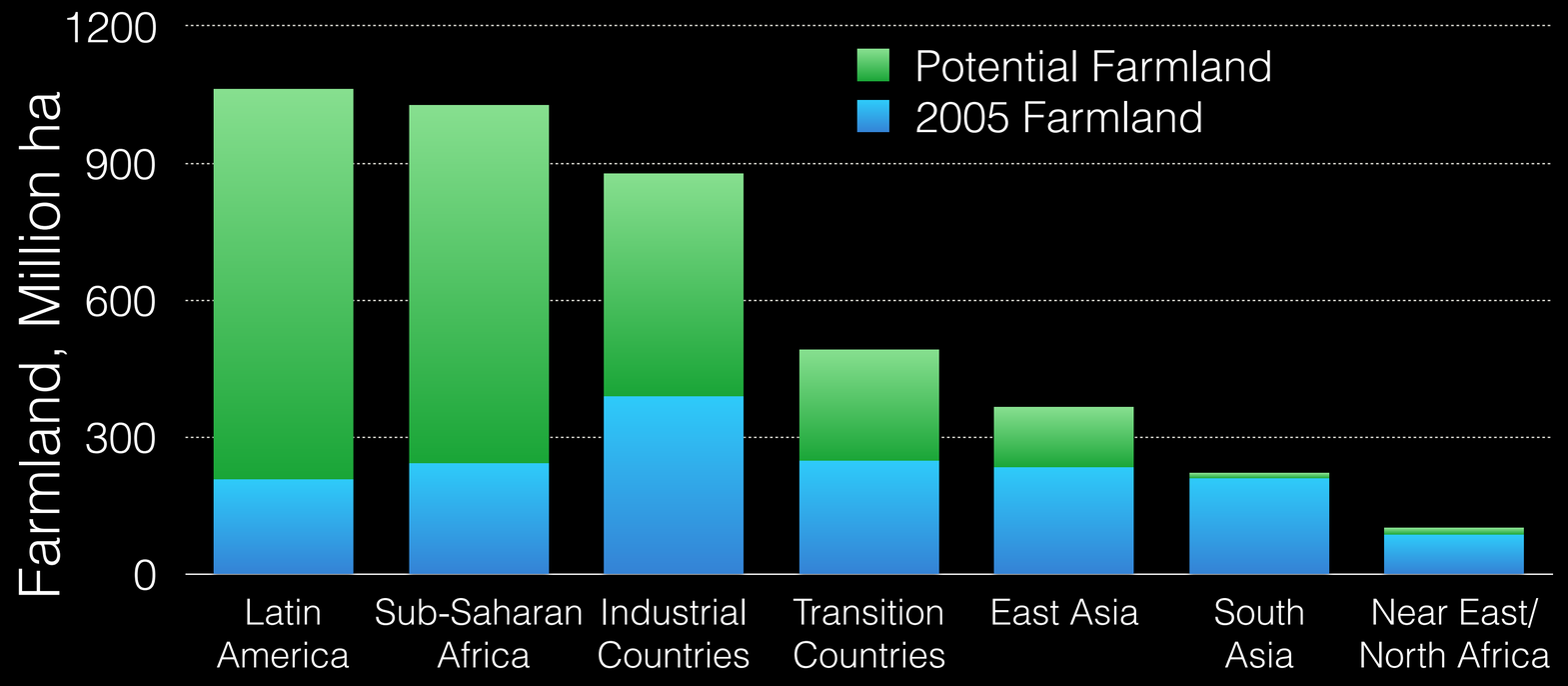
2.3 Billion People live in Drylands.
Population will rise to over 3 Billion by 2050

43% OF LAND AREA
35% OF GLOBAL POPULATION

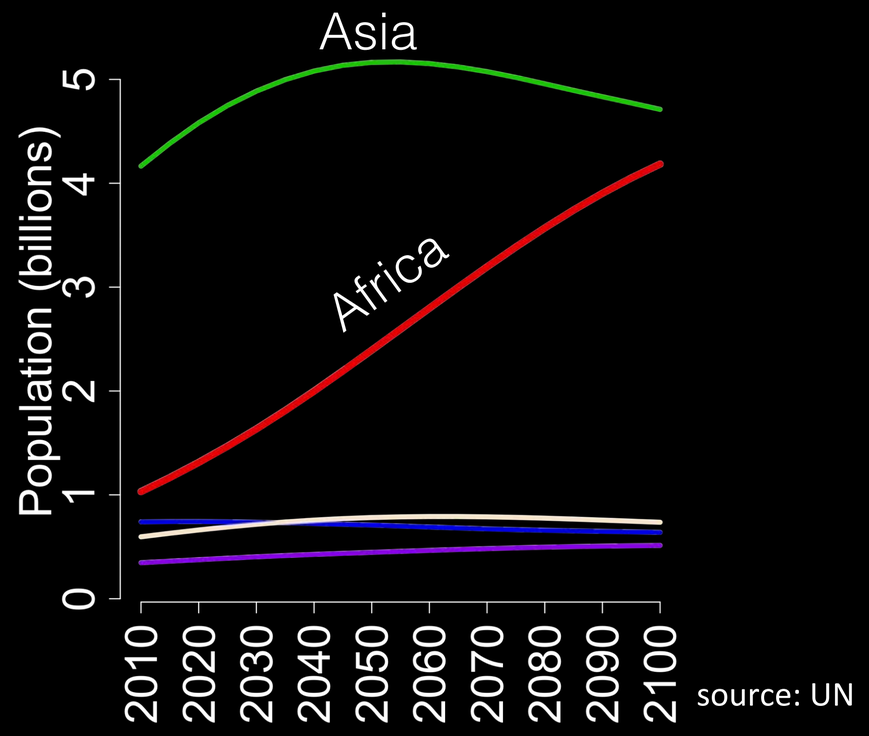
Source: Millenium Ecosystem Assessment

IMPORTANCE OF SMALLHOLDER AGRICULTURE IN SUB-SAHARAN AFRICA

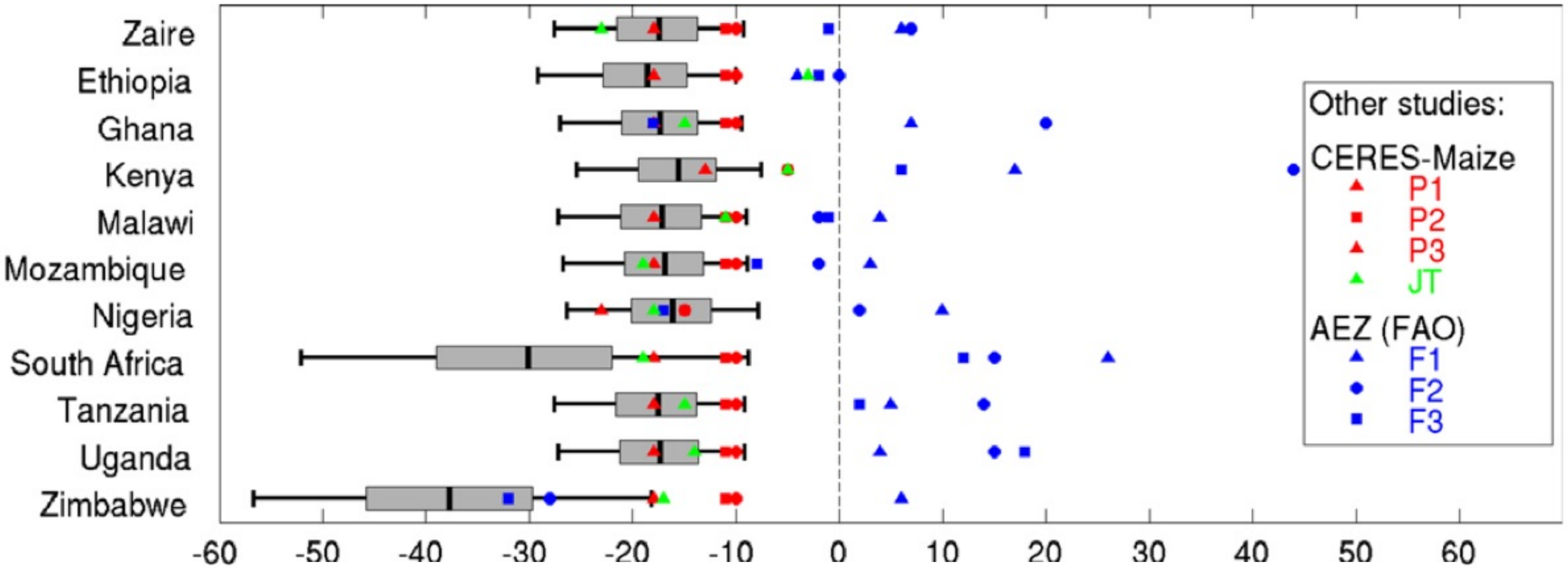
Sub-saharan Africa will experience almost all of the global population growth in the next 85 years, and contains 31% of the world's remaining potential farmland



Source: Bruinsma, 2009



CROP YIELDS TO DECLINE

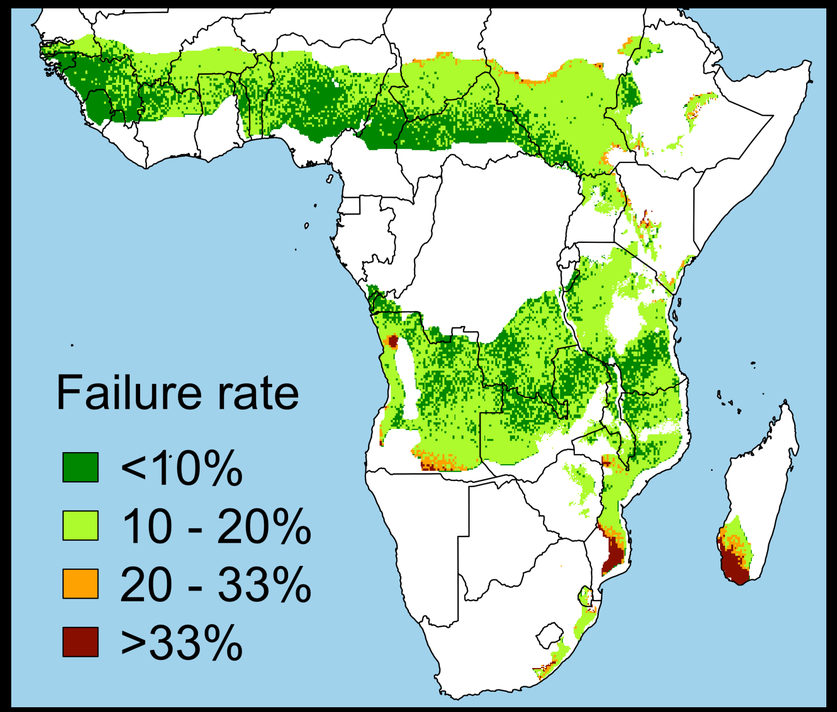


Percent change in maize yields by 2050

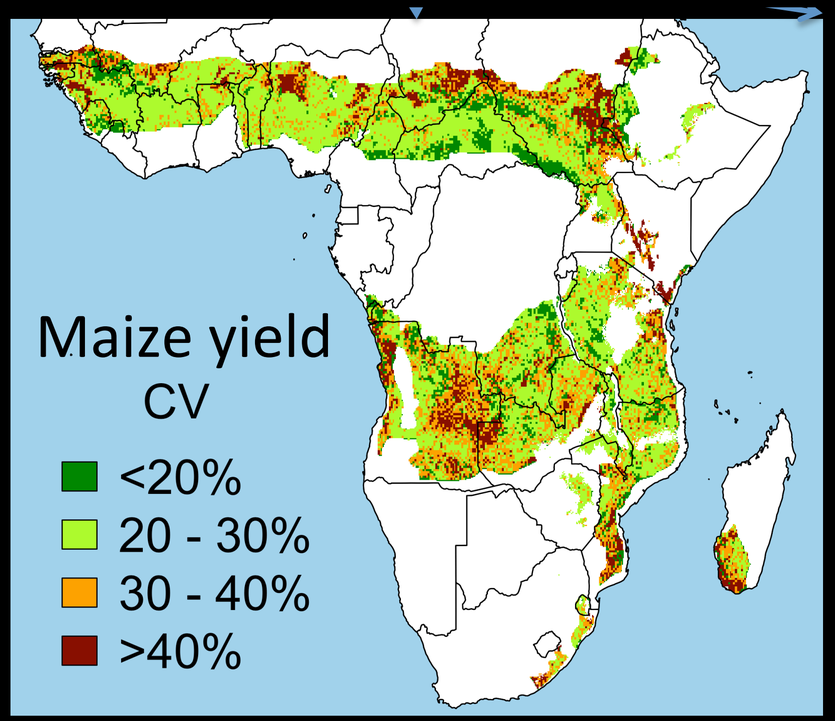
(Schlenker & Lobell, 2010)

CLIMATE VARIABILITY IS A CONSTRAINT ON AGRICULTURAL RESILIENCE

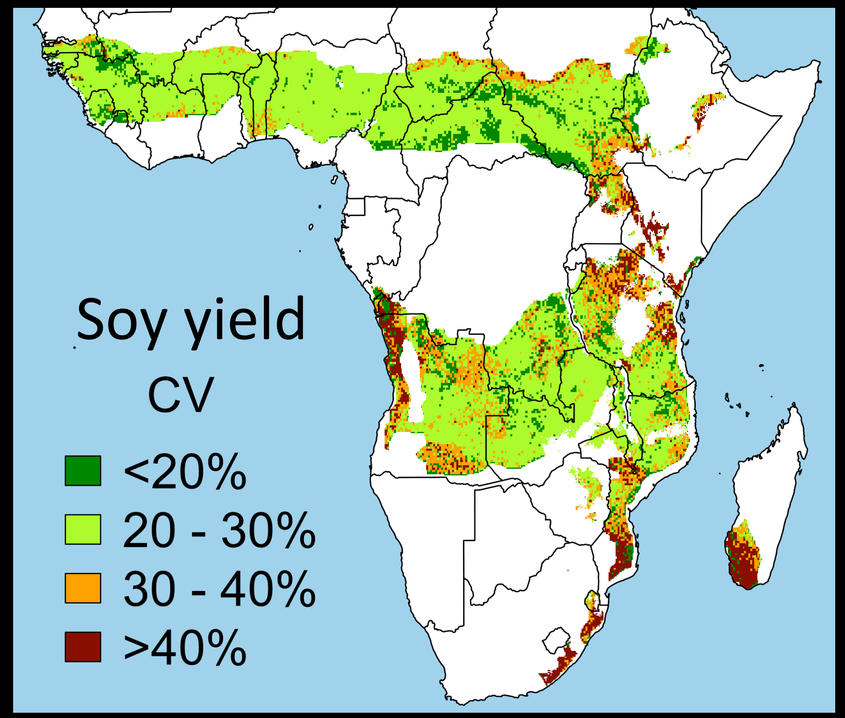
Probability of Failure



Variability in Maize Yields

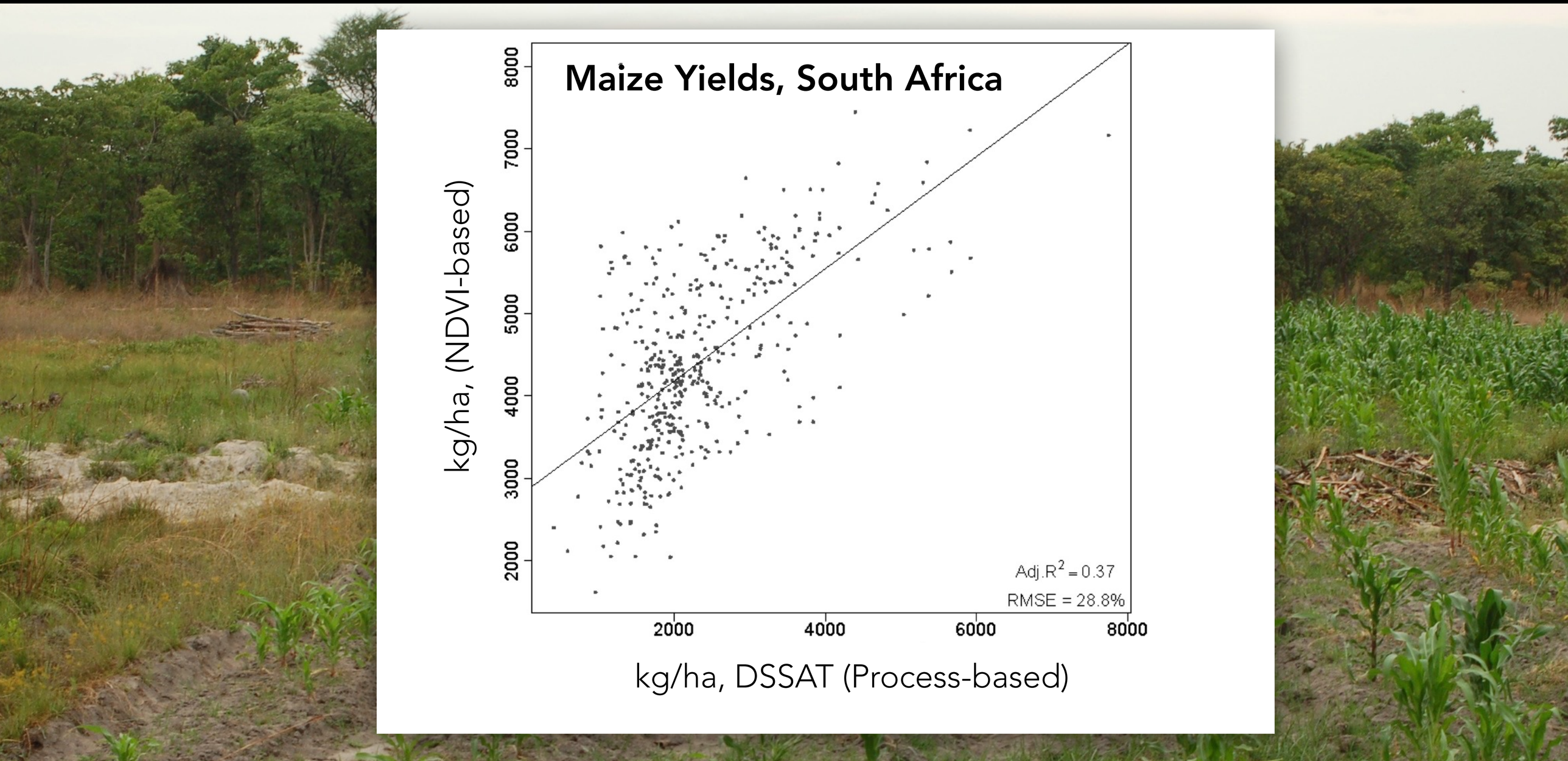


Variability in Soy Yields



Estes et al, Nature Climate Change

PROCESS-BASED MODELS OF CROP PRODUCTION OFTEN DO A POOR JOB, ESPECIALLY IN **LOW-YIELD SETTINGS**



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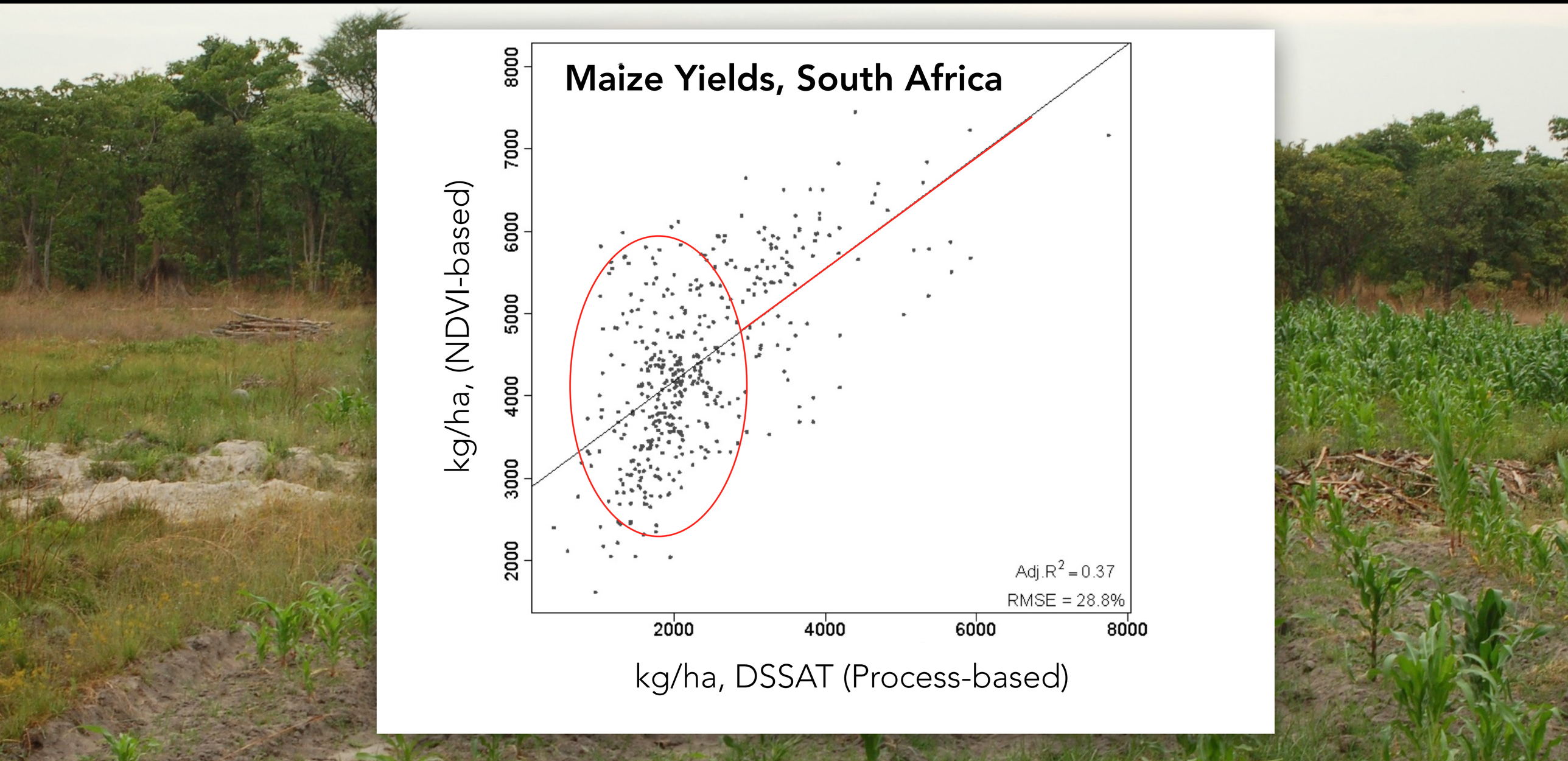

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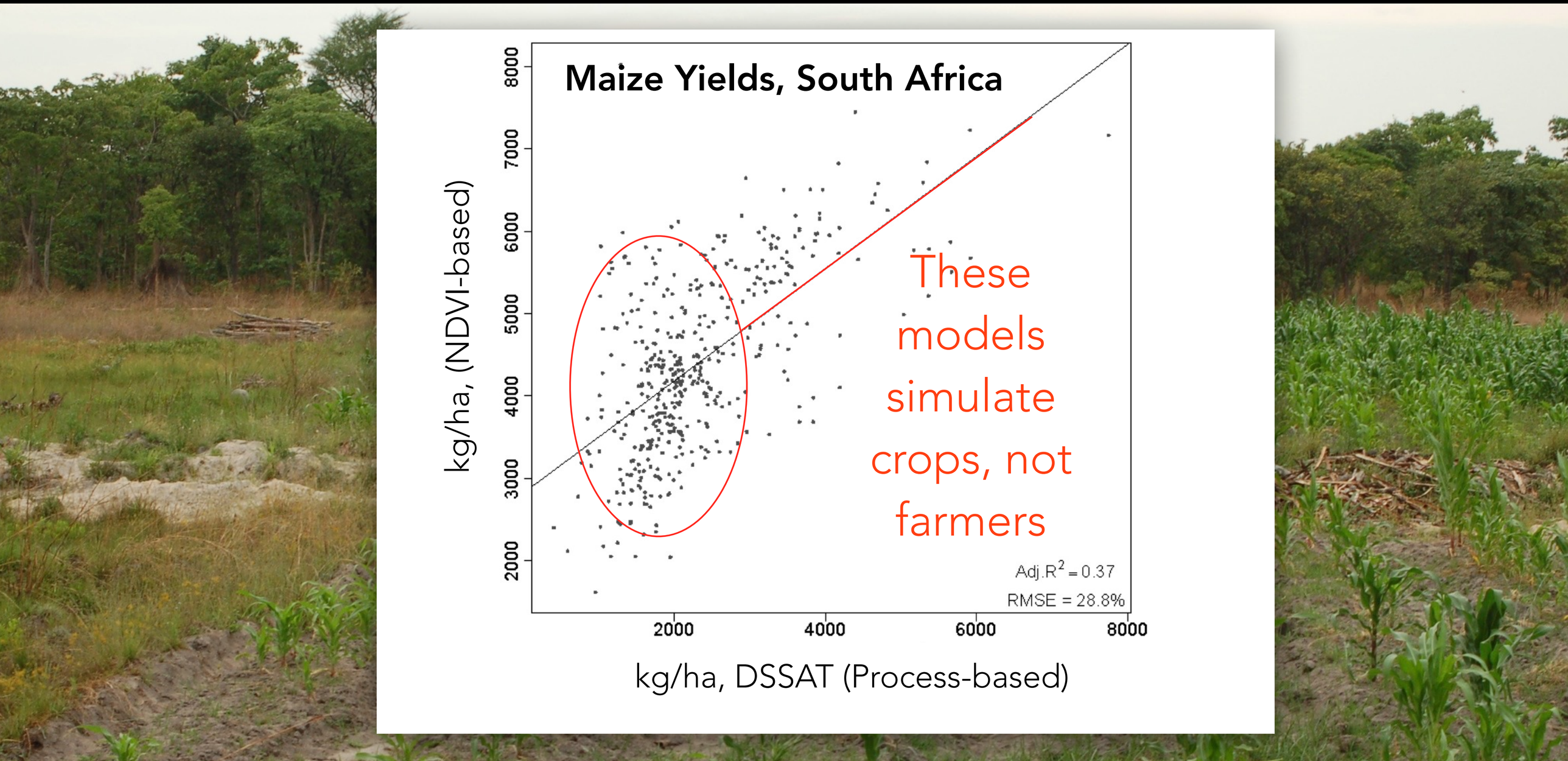
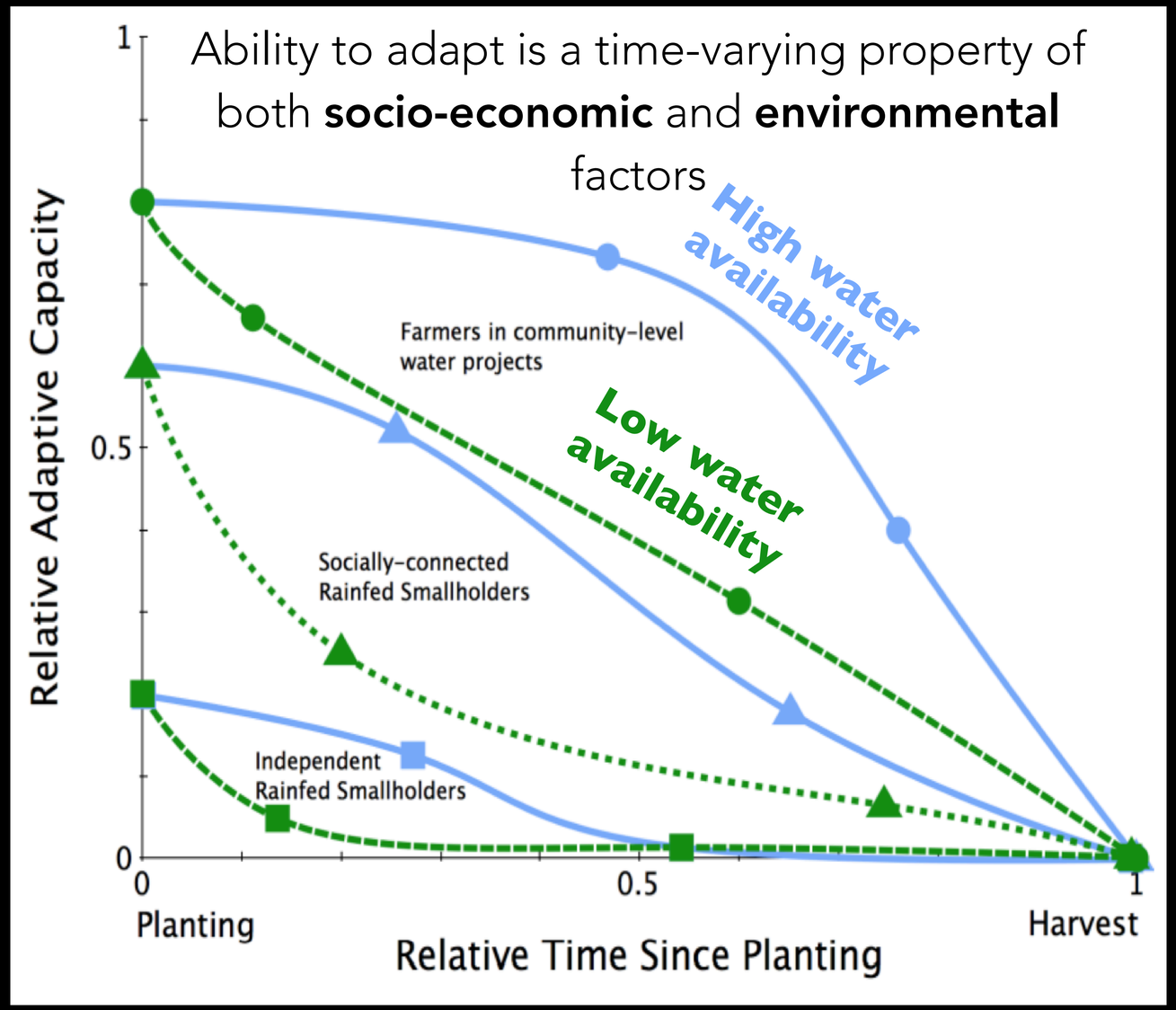


"Knowledge about agriculture and its impact on welfare and equity is limited by the lack of available, high quality, and consistent data on farm households."

FROM "THE EMPEROR HAS NO DATA! AGRICULTURAL STATISTICS IN SUB-SAHARAN AFRICA" - CARLETTO ET AL. 2013

SMALLHOLDER FARMERS VARY GREATLY IN THEIR CAPACITY TO RESPOND TO CLIMATE SHOCKS



Evans, Caylor, et al., in prep

RESEARCH QUESTIONS

How do **intra-seasonal dynamics** of environmental and social systems shape farmer adaptive capacity?

To what extent does **intra-seasonal decision-making** enable farmers to adapt to climate uncertainty?

How can **intra-seasonal data** improve the ability to model, predict, and enhance adaptation to climate variability in ways that increase food security?

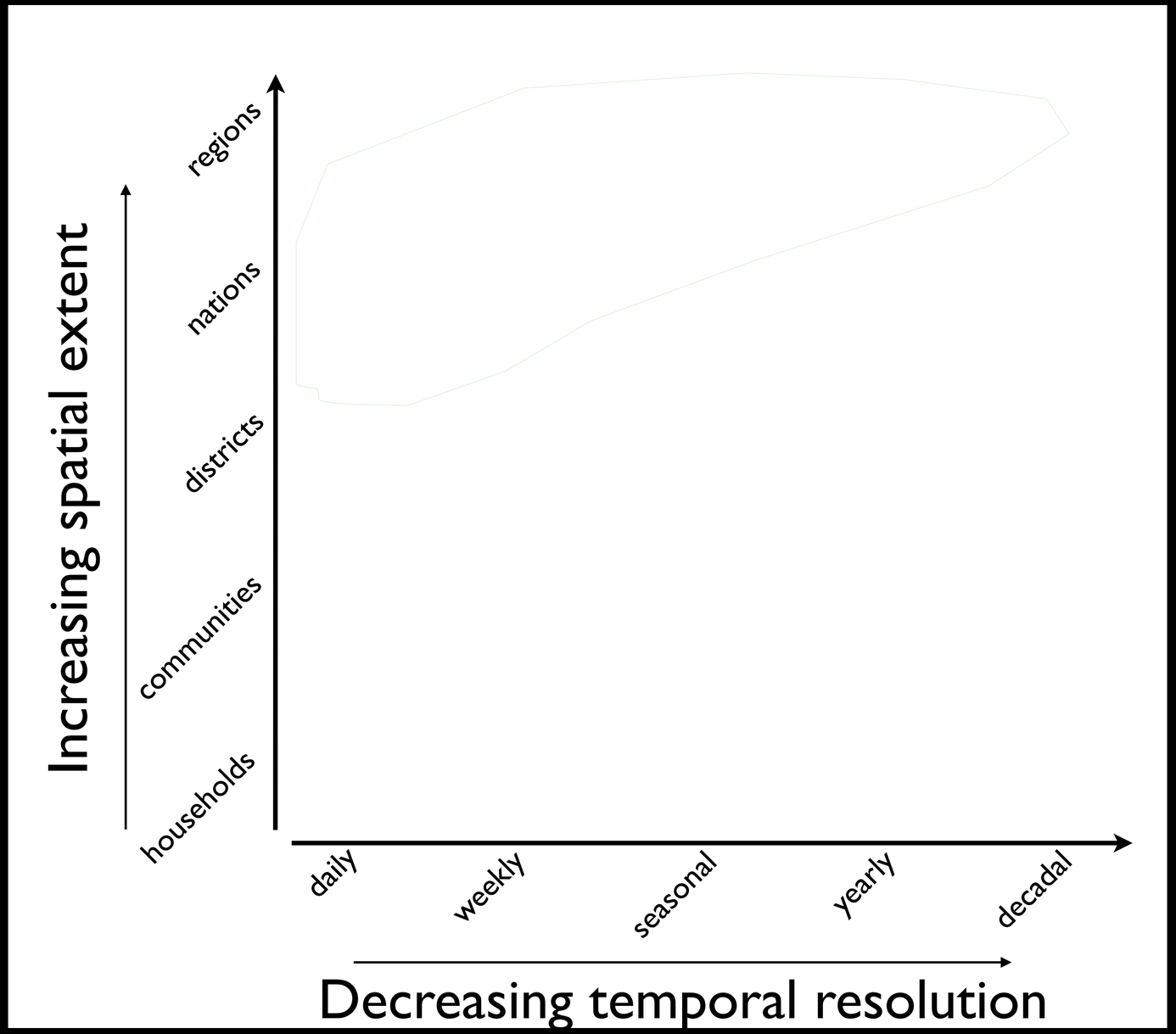
Examples of Inter-seasonal decision-making

What to plant.
Where to plant.

Examples of Intra-seasonal decision-making

Timing land operations.
Allocating labor.
Leveraging social connections.

SPATIO-TEMPORAL DOMAINS FOR COUPLED SYSTEM MODELING



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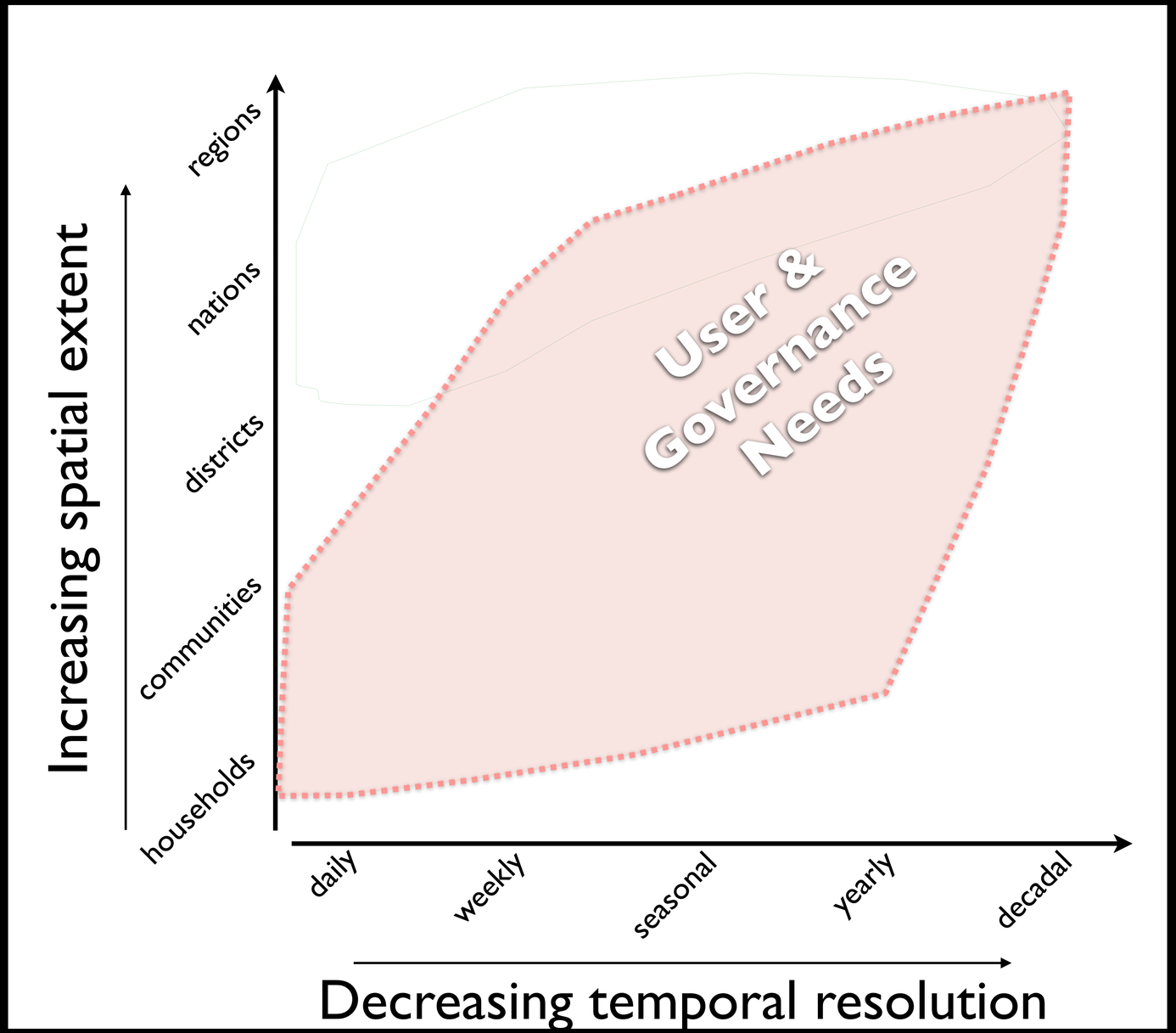

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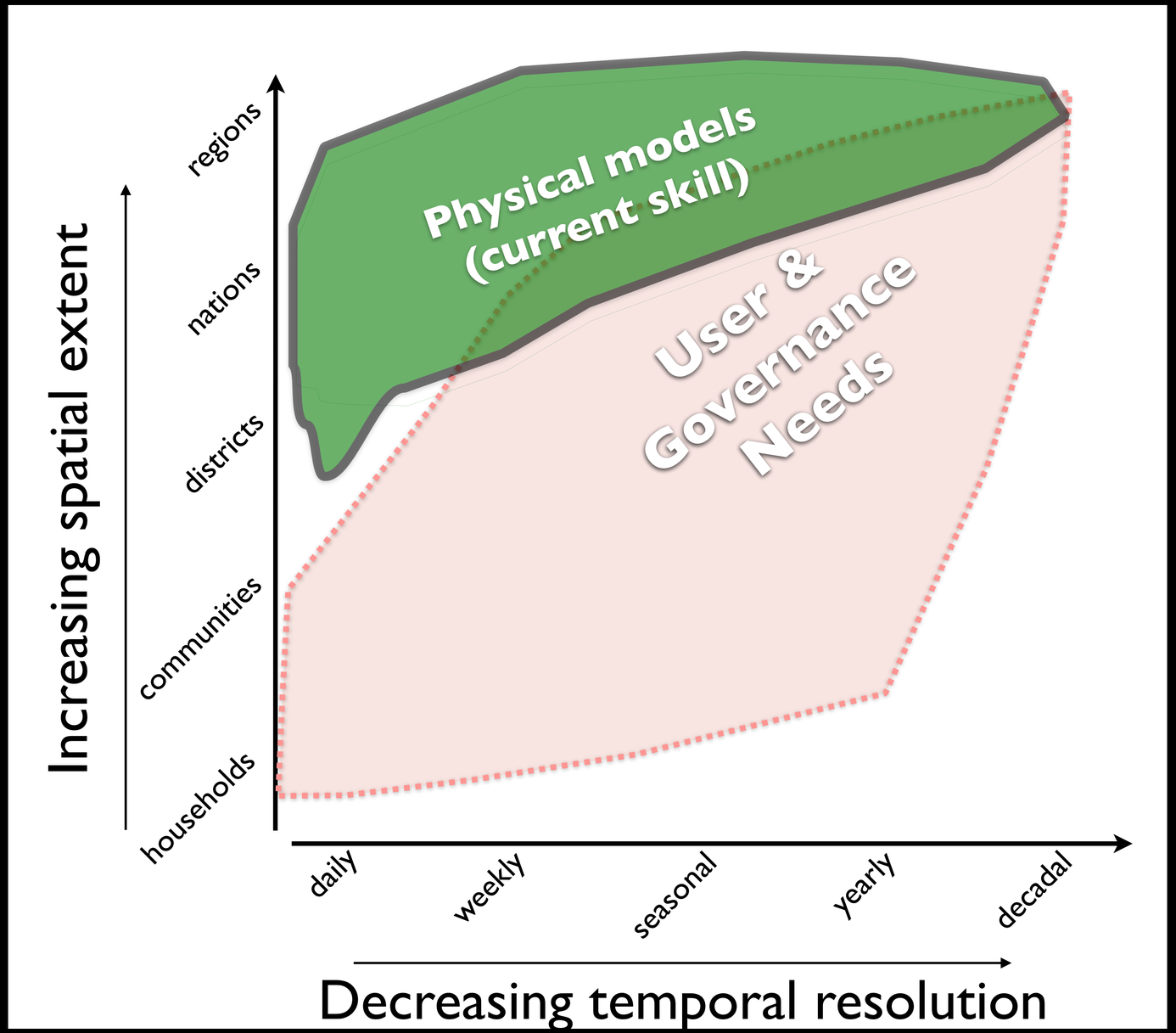

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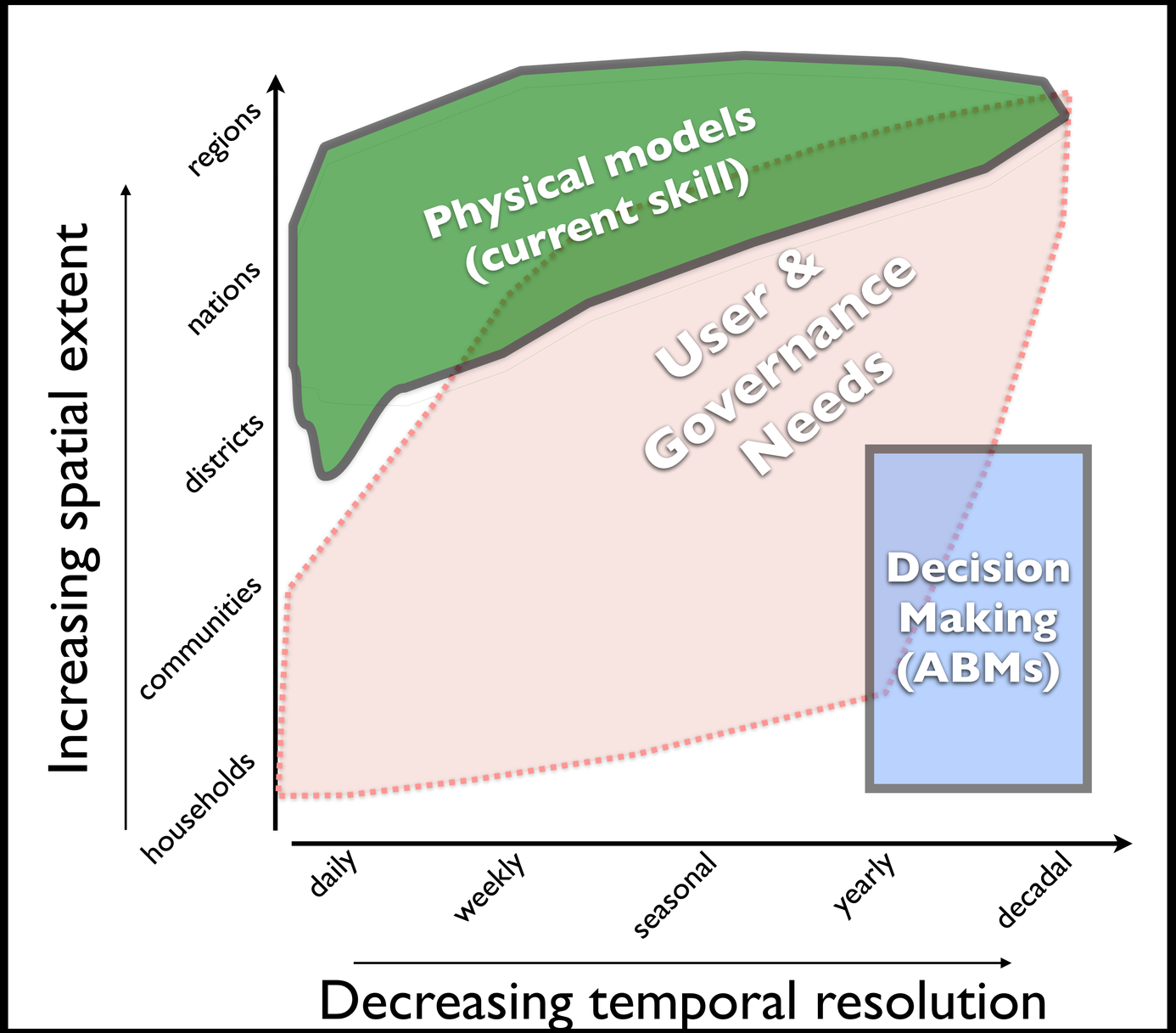

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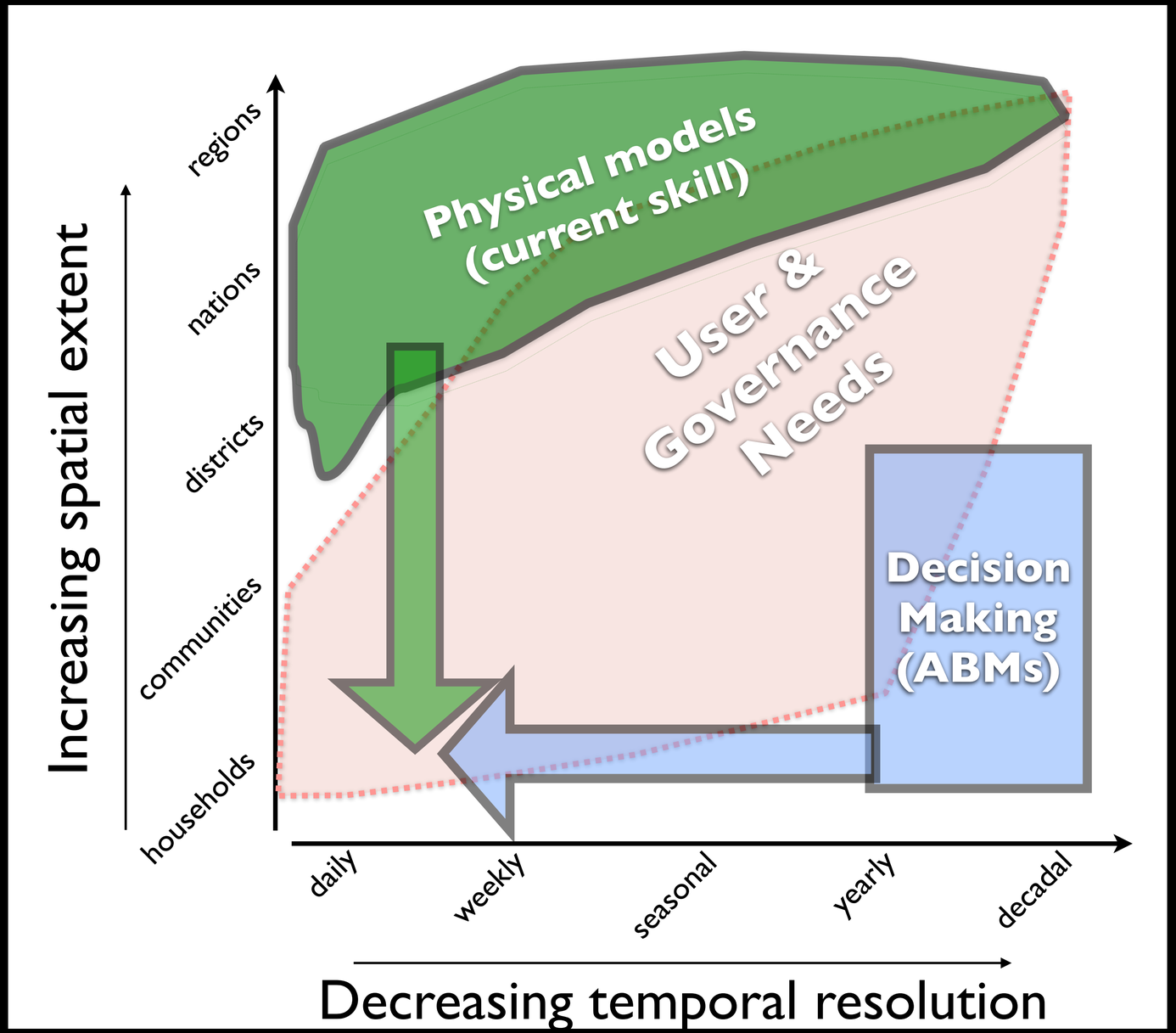

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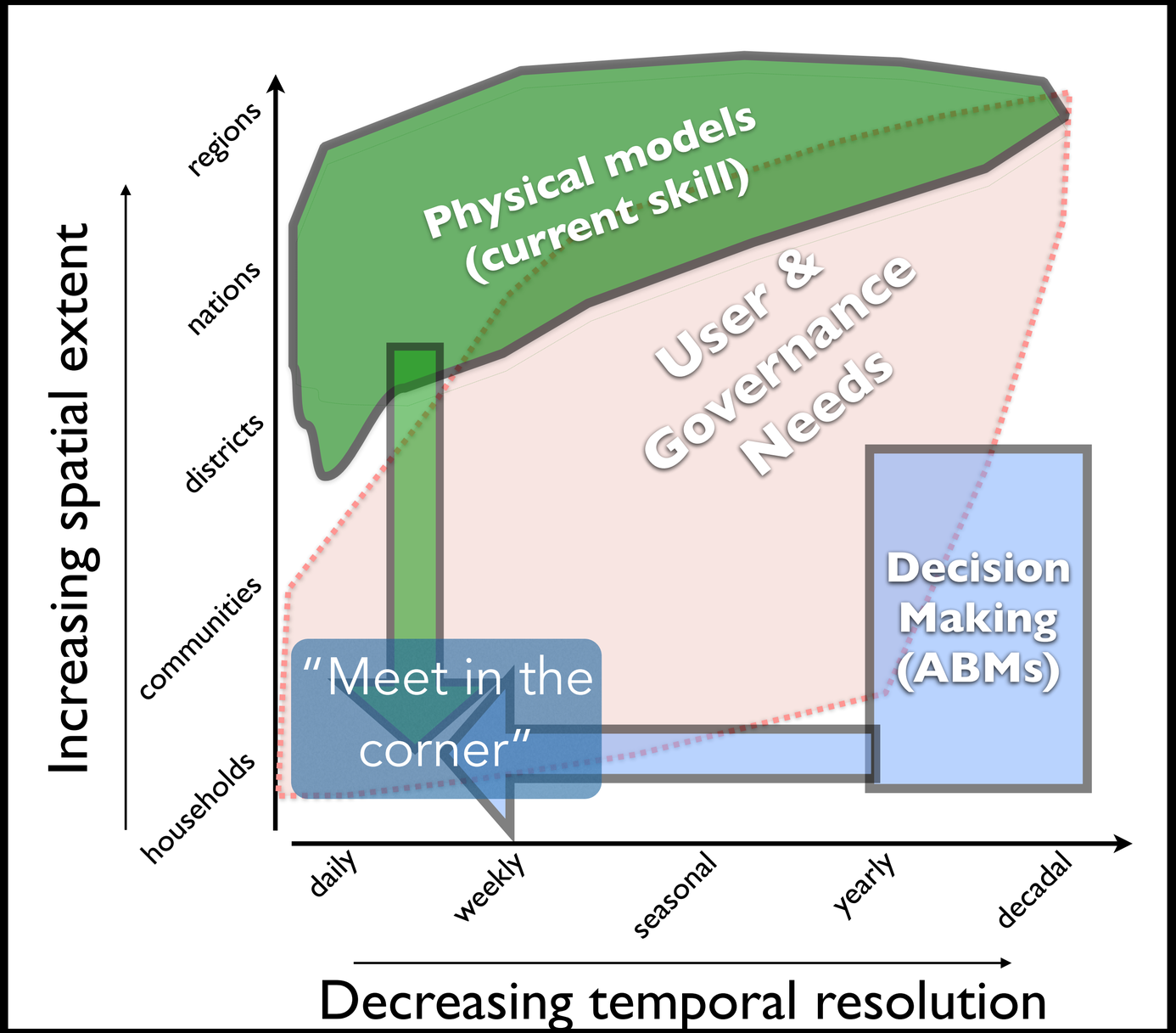

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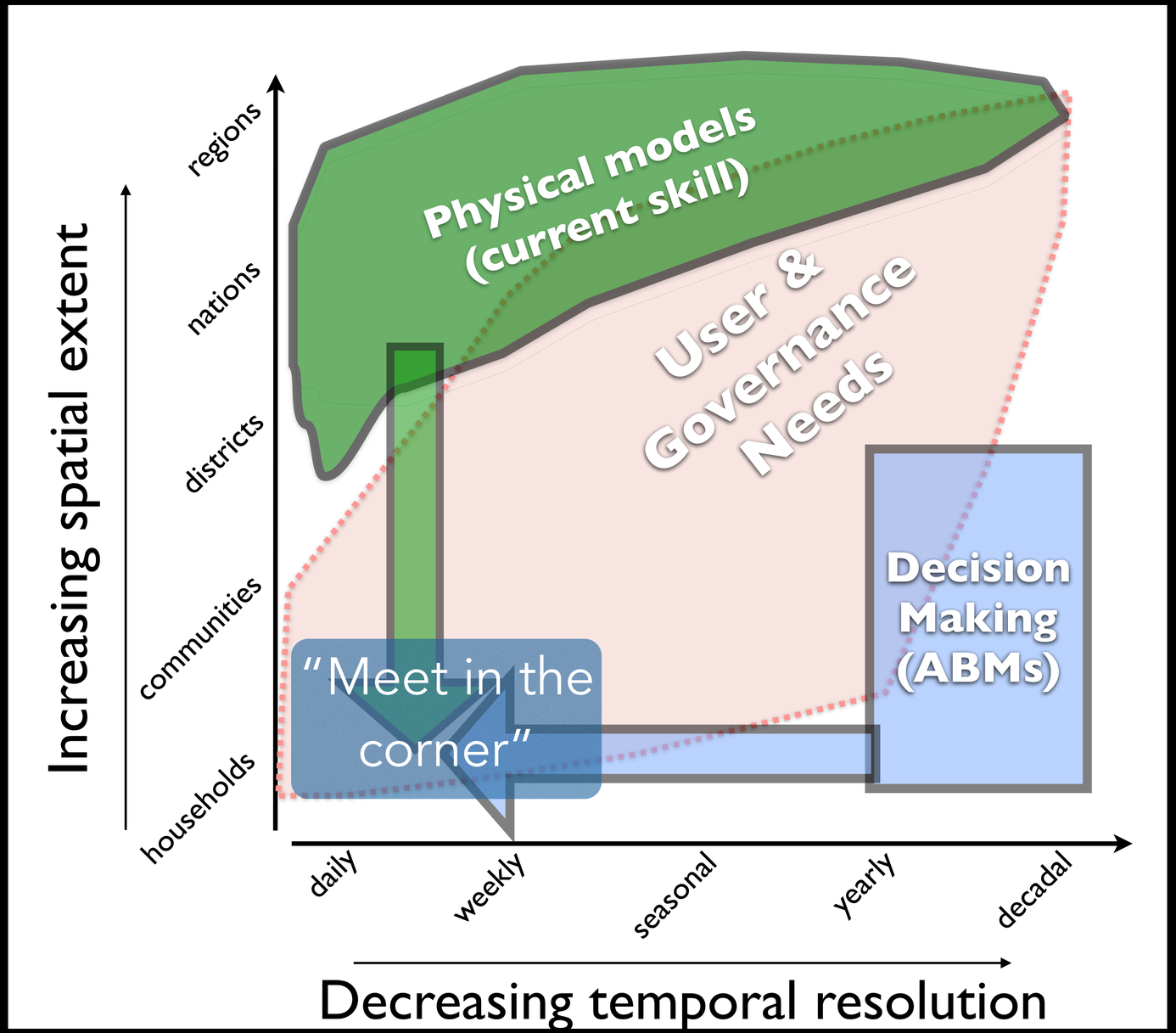
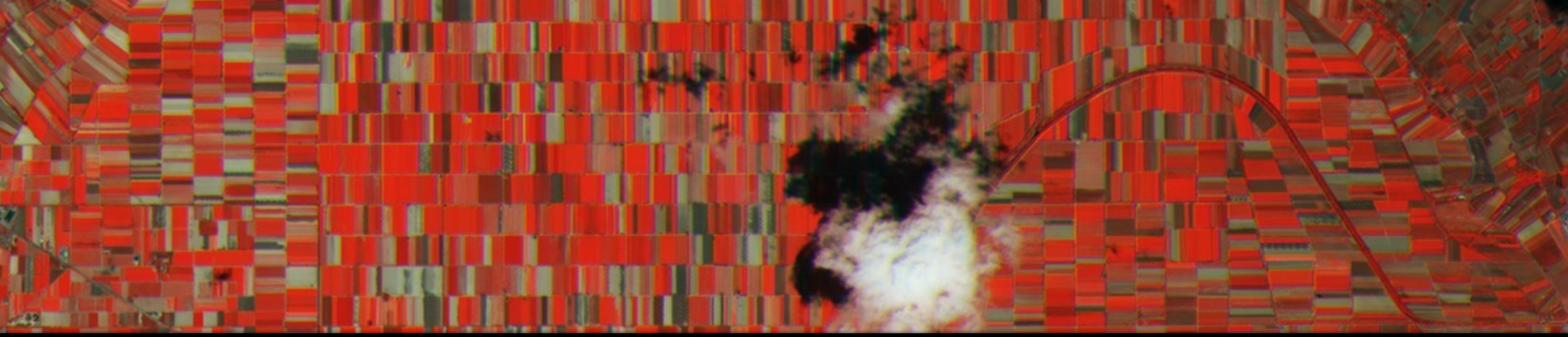


Three Obstacles to "Meeting in the Corner"

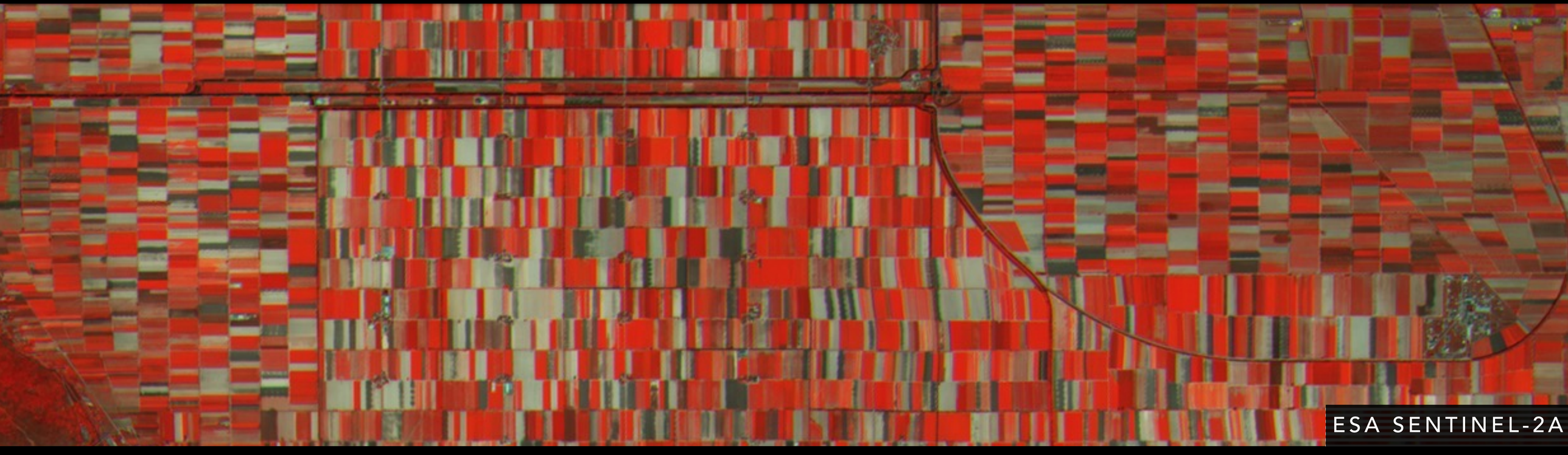
Resolving intra-seasonal agricultural **land-use at household scales**

Resolving intra-seasonal agricultural **decision-making at household scales**

Resolving intra-seasonal **ecohydrological dynamics household scales**

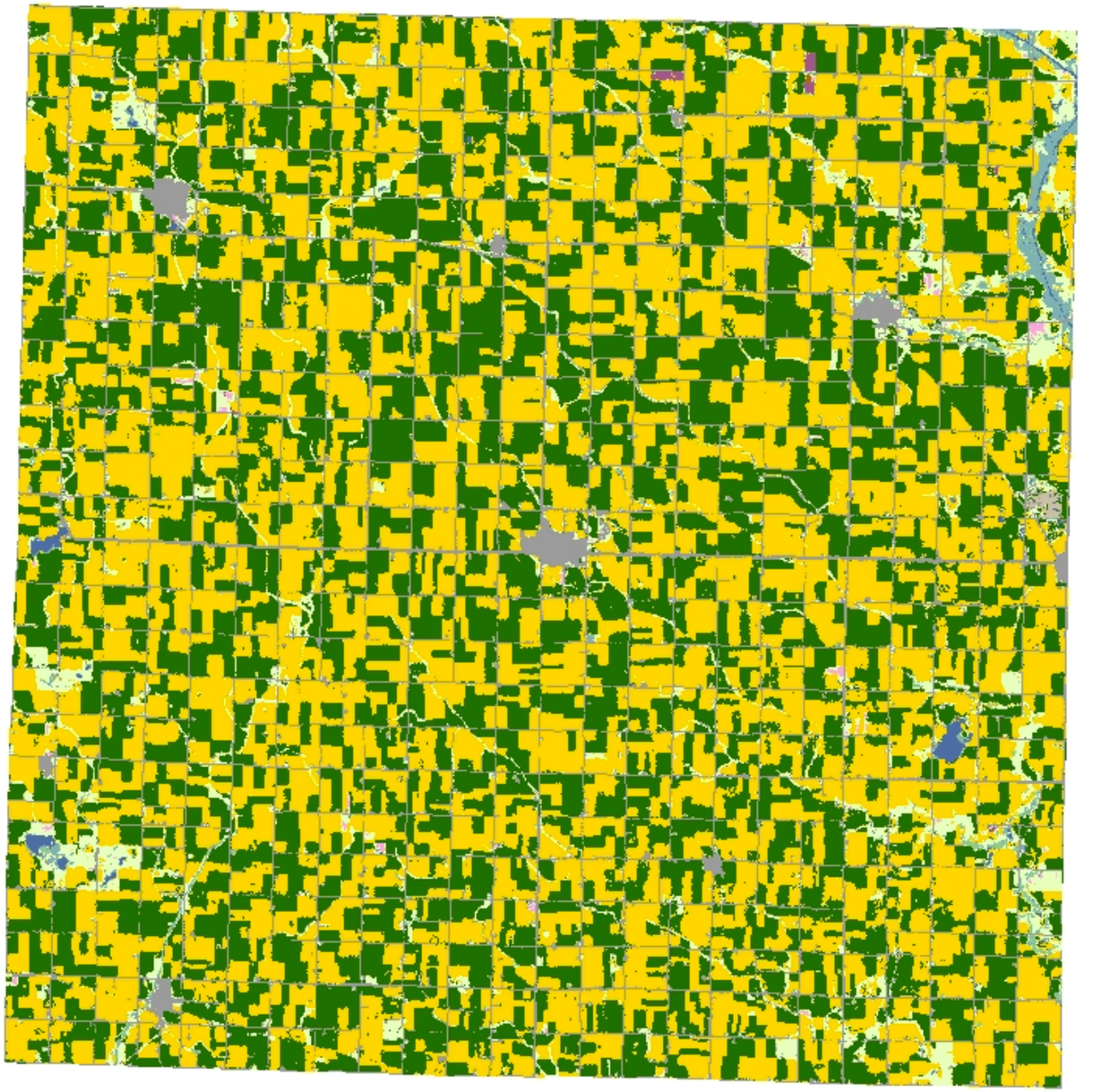


WHERE IS AGRICULTURE OCCURRING?



ESA SENTINEL-2A

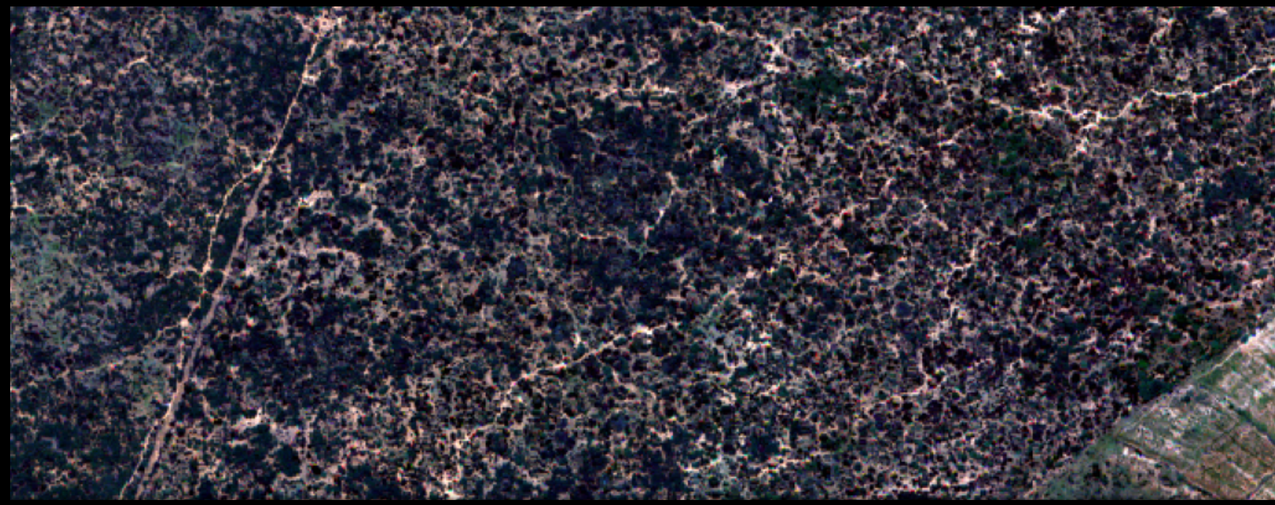
Pocahontas County, Iowa
2008 Cropland Data Layer



Land Cover Categories
(Ordered by Decreasing Acreage)

Agriculture
- Corn
- Soybeans
- Pasture/Grass
- Alfalfa
- Oats
- Winter Wheat
- Spring Wheat
- Clover/Wildflowers

Non-Agriculture
- Urban/Developed
- Wetlands
- Woodland
- Water
- Barren



WHERE IS **SUBSISTENCE** AGRICULTURE OCCURRING?

FIELD MAPPING

SMALLHOLDERS

2.5 billion smallholders managing 500 million small farms worldwide

Family farms constitute over 98% of all farms

Table 1: Estimated farm sizes of selected world regions (von Braun, 2004; FAO, 1997; Nagayets, 2005)

World region	Average farm size (hectares)
Africa	1.6
Asia	1.6
Western Europe	27.0
Latin America and Caribbean	67.0
North America	121.0

ALGORITHM DEVELOPMENT

RESEARCH GOAL

Design an algorithm to automatically map agricultural fields including smallholder agriculture in Sub-Saharan Africa

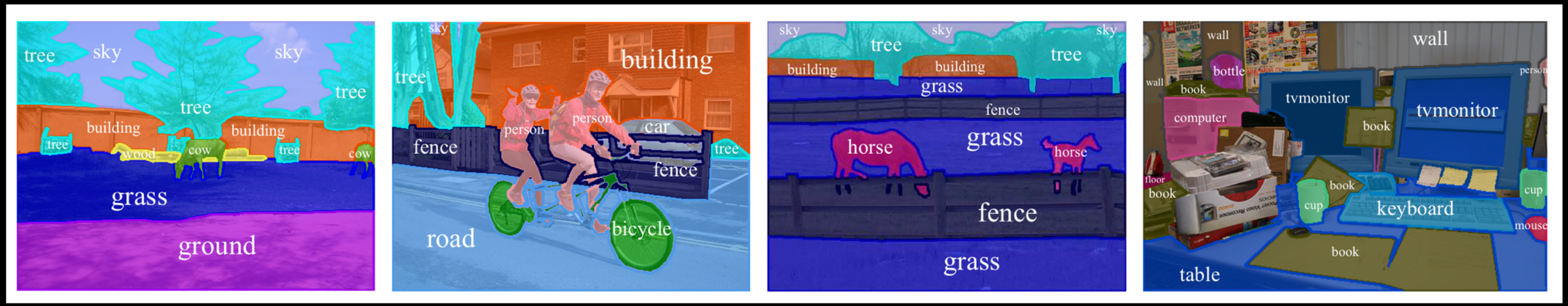
REMOTE SENSING

"[…] one of the main goals of remote sensing research in past decades has been ***semantic classification***. Despite large efforts over the last 30 years, this task remains ***largely unsolved***."

–TOKARCZYK ET AL., 2015

LINKS TO COMPUTER VISION

SEMANTIC CLASSIFICATION

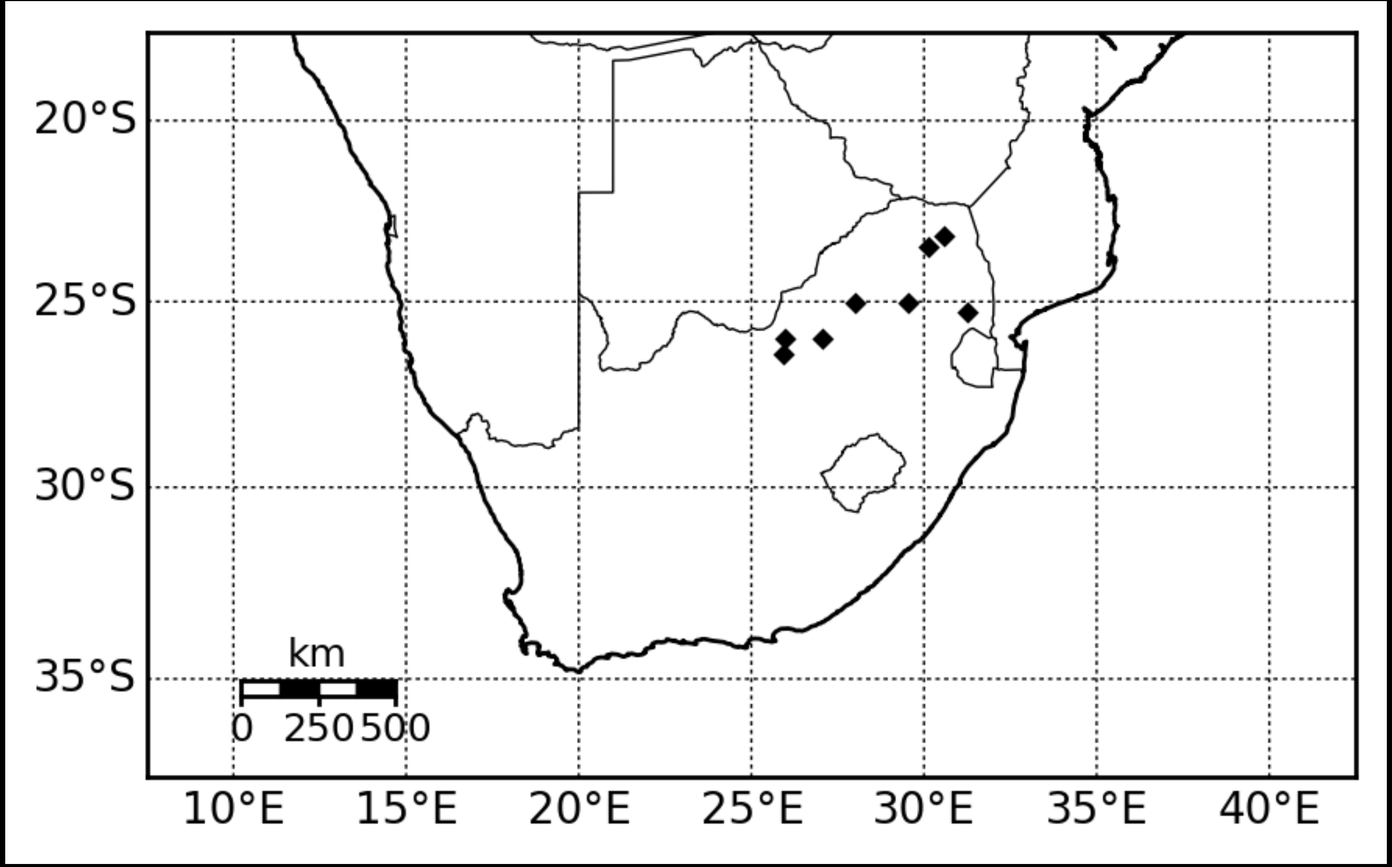


CREDIT: PASCAL-CONTEXT DATASET

3 Components: Training Data, Features, Classifier

LINKS TO COMPUTER VISION

TRAINING DATA

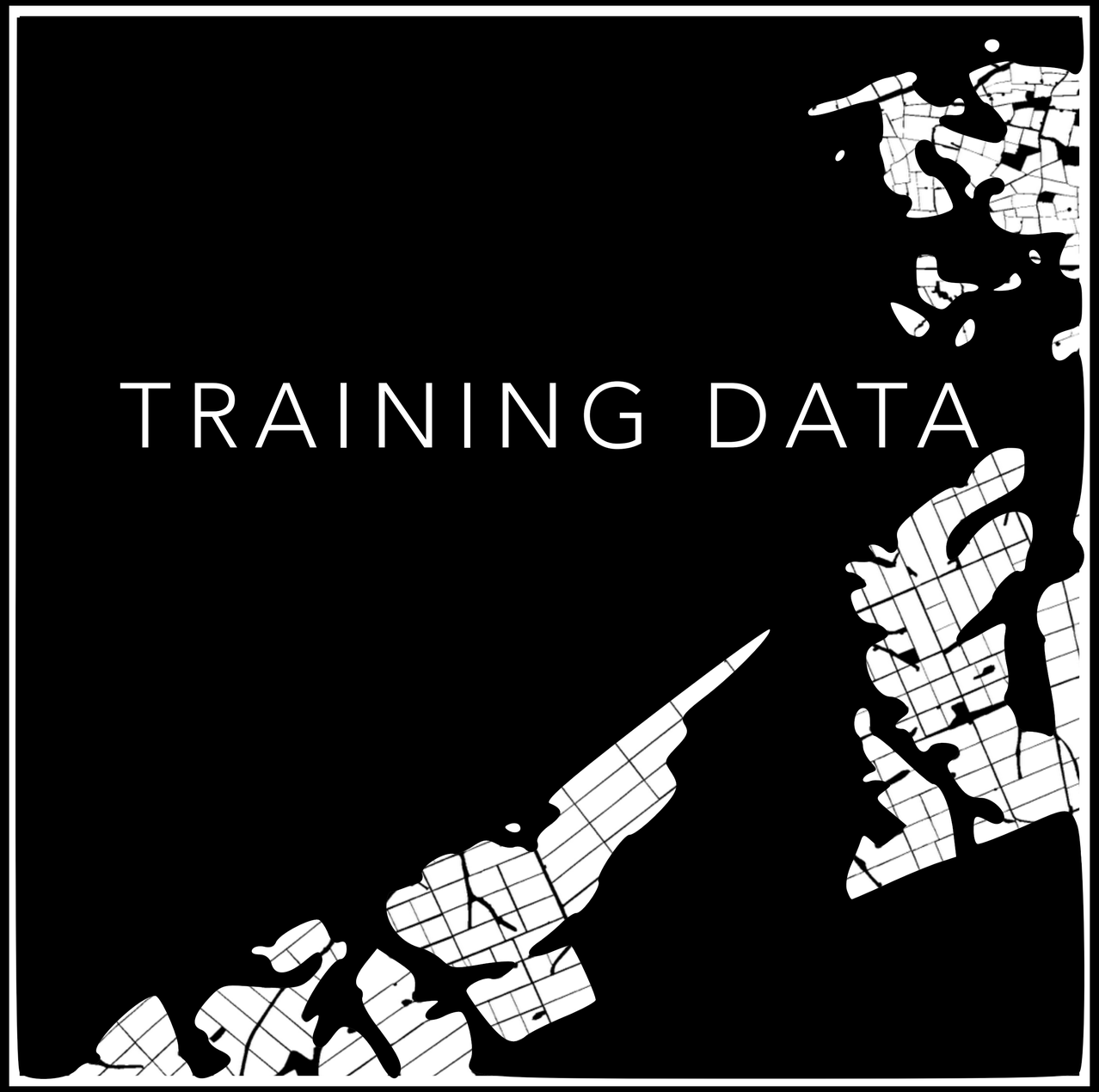


- 8 sites across South Africa
- WorldView-2 orthorectified panchromatic + 8-band multispectral images (2 m resolution)
- Growing season + off-season images

TRAINING DATA

OFF-SEASON

GROWING SEASON

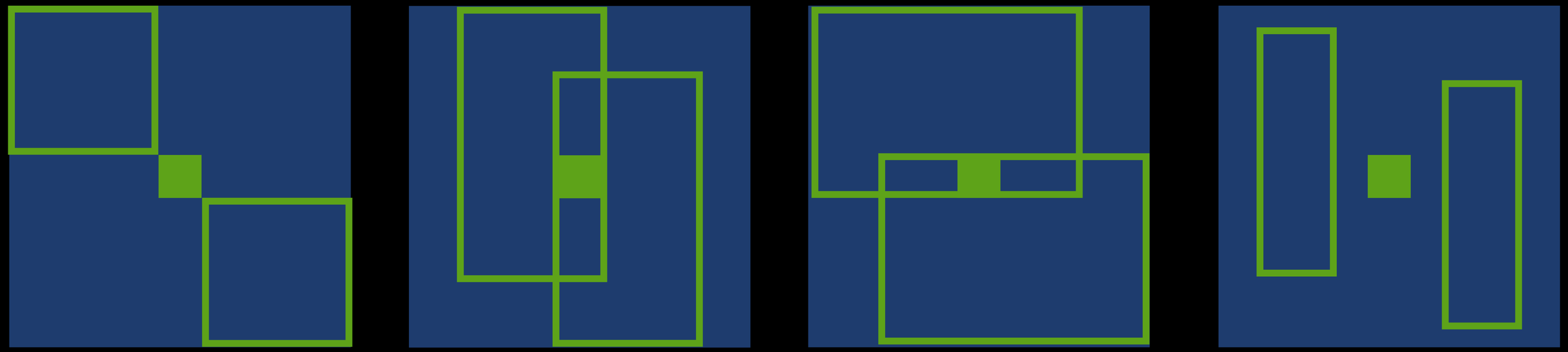


HAND-DIGITIZATION

Randomized Quasi-Exhaustive Features

Sliding window across image. Features defined relative to pixel of interest

RANDOMIZED PATCHES

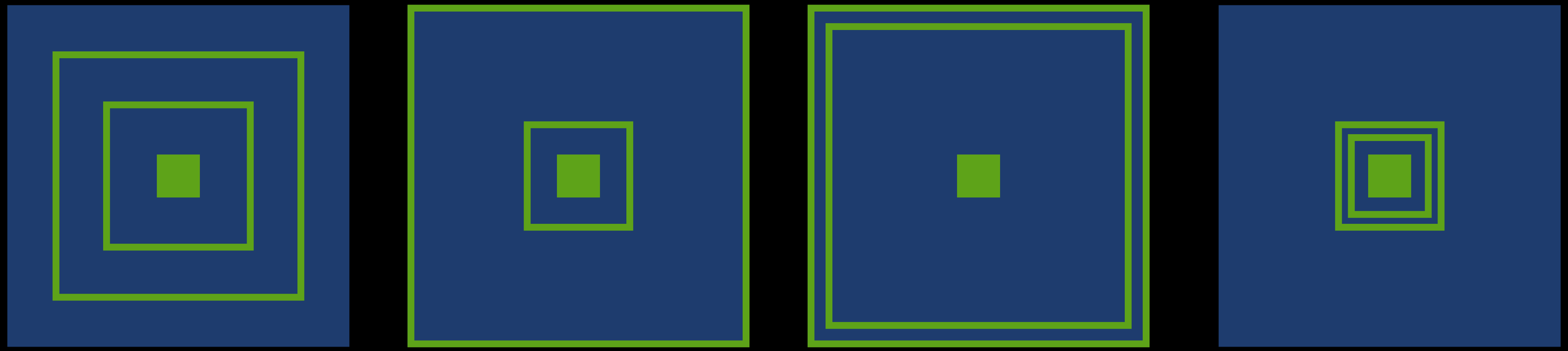


- Computer vision borrowing from machine learning & big data
- Thousands of simple features can outperform handful of complex features

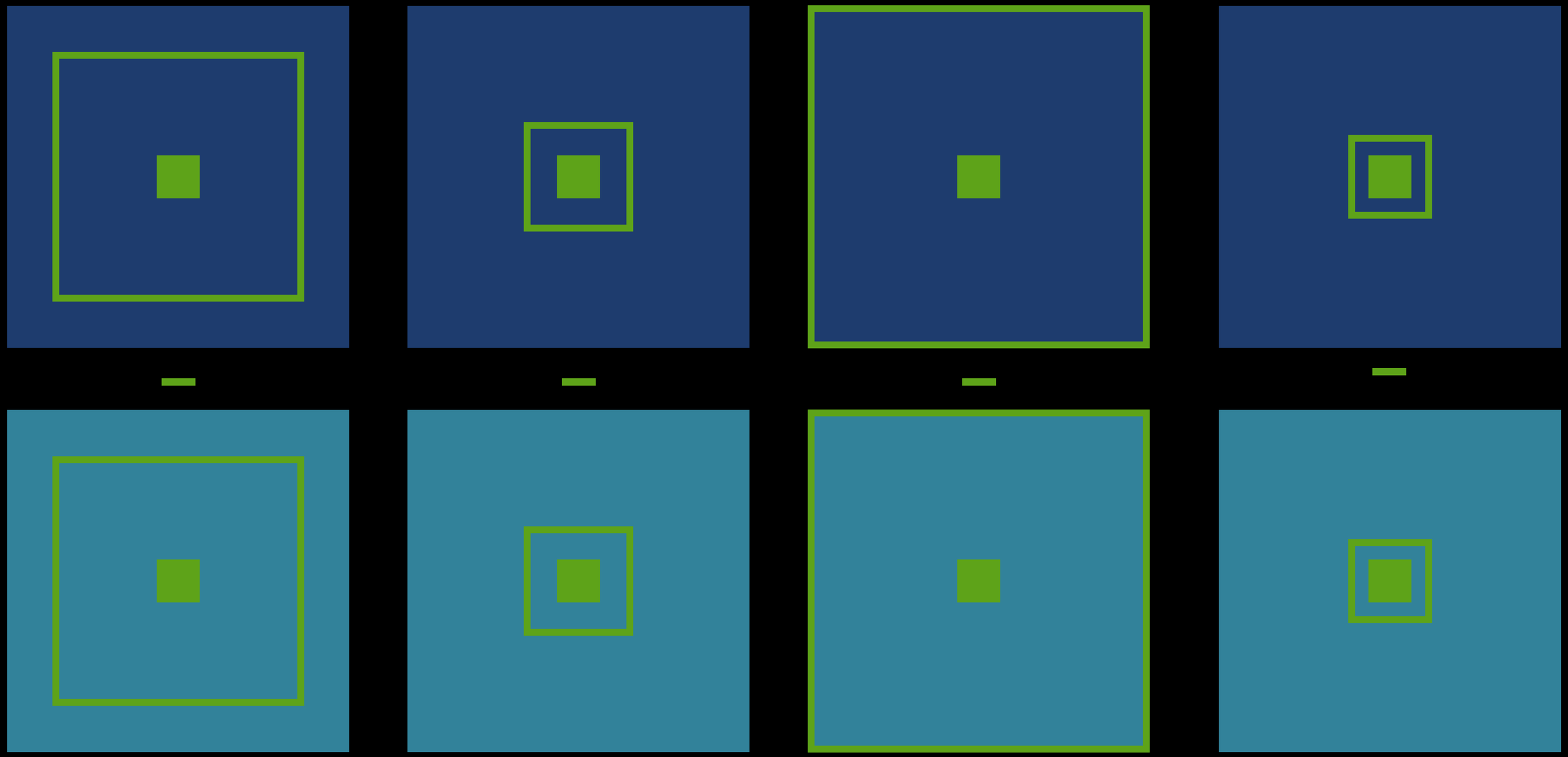
Randomized Quasi-Exhaustive Features

Sliding window across image. Features defined relative to pixel of interest

DIFFERENCE OF SQUARE PATCHES

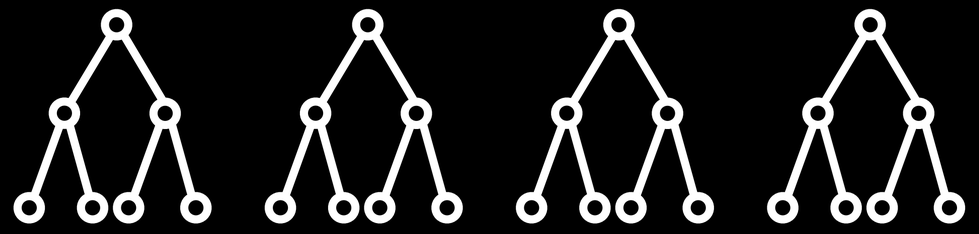


DIFFERENCE OF SQUARE PATCHES BETWEEN CHANNELS

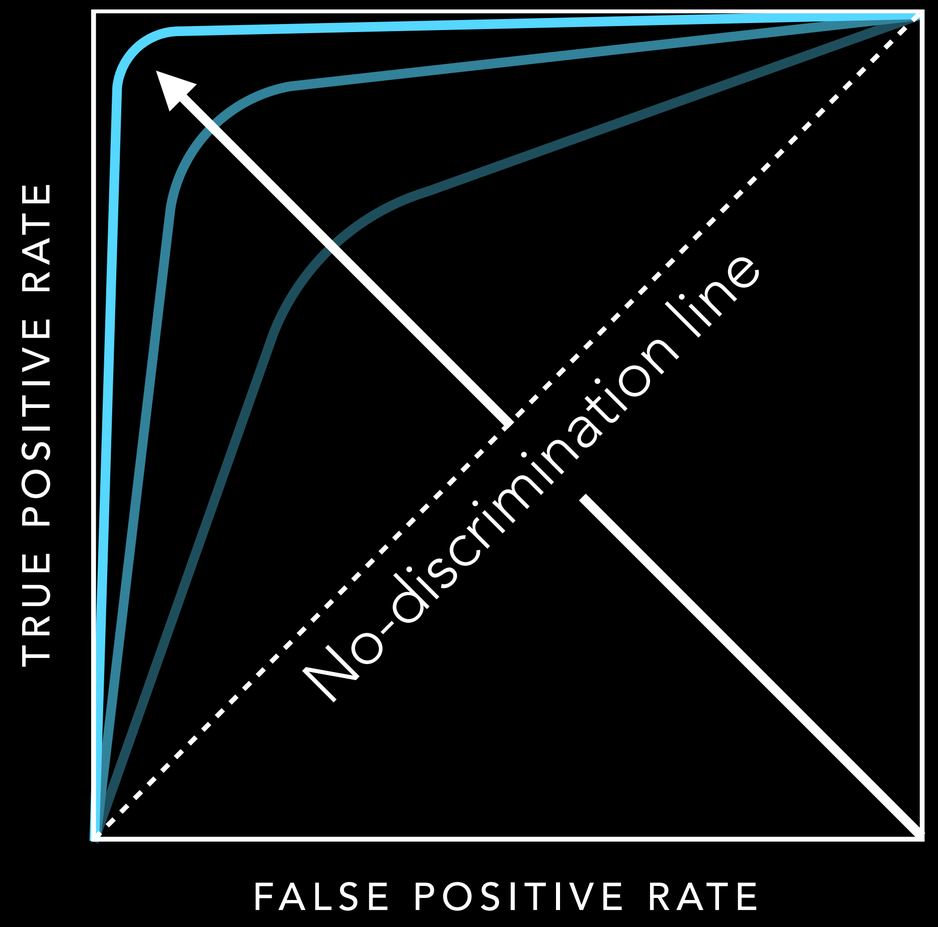


PIXEL-WISE CLASSIFIER

Random Forest (adapted from Hastle et al., 2009)



ROC CURVES & AUC



ROC: Receiver Operating Characteristic

True Positive Rate
(Sensitivity)

vs.

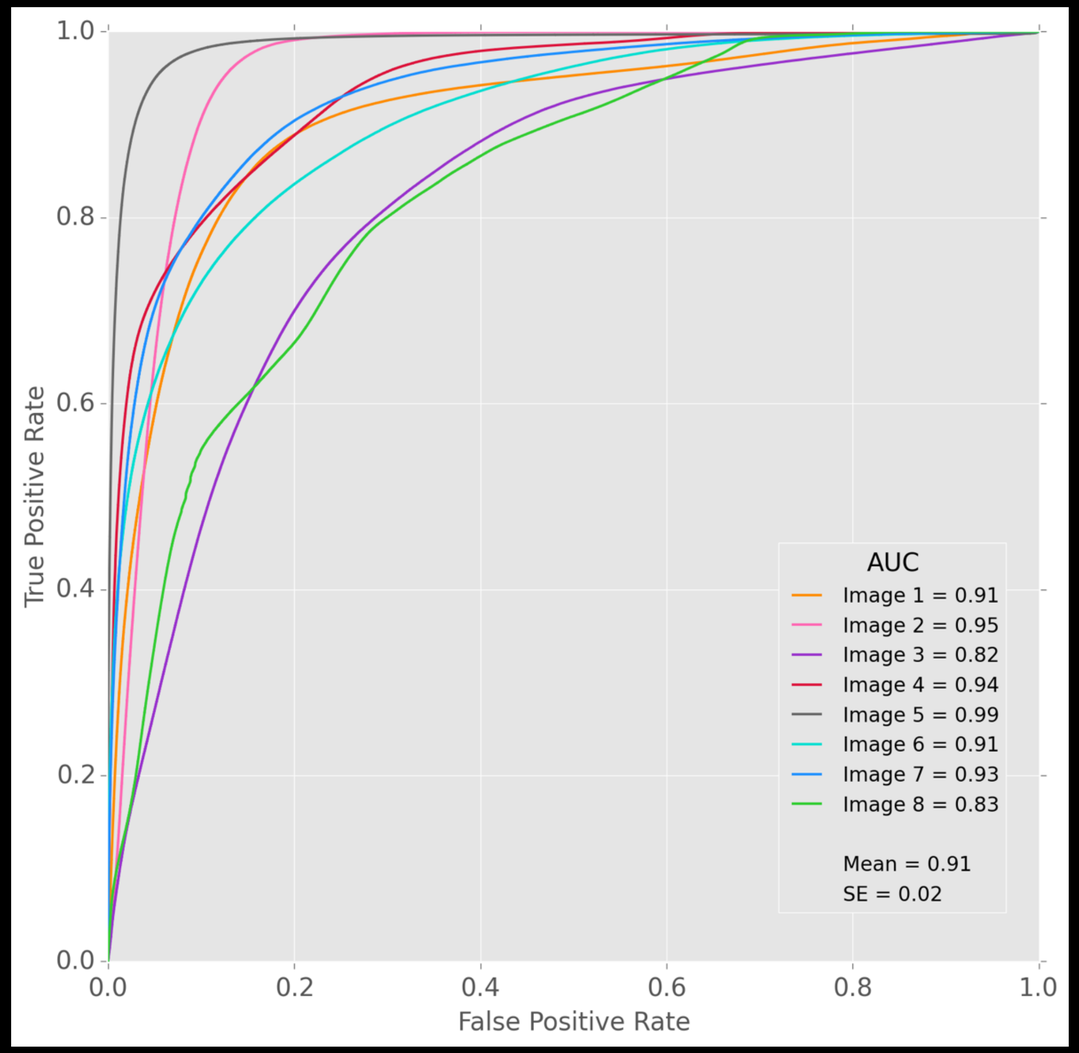
False Positive Rate or Fall-out
(1-Specificity)

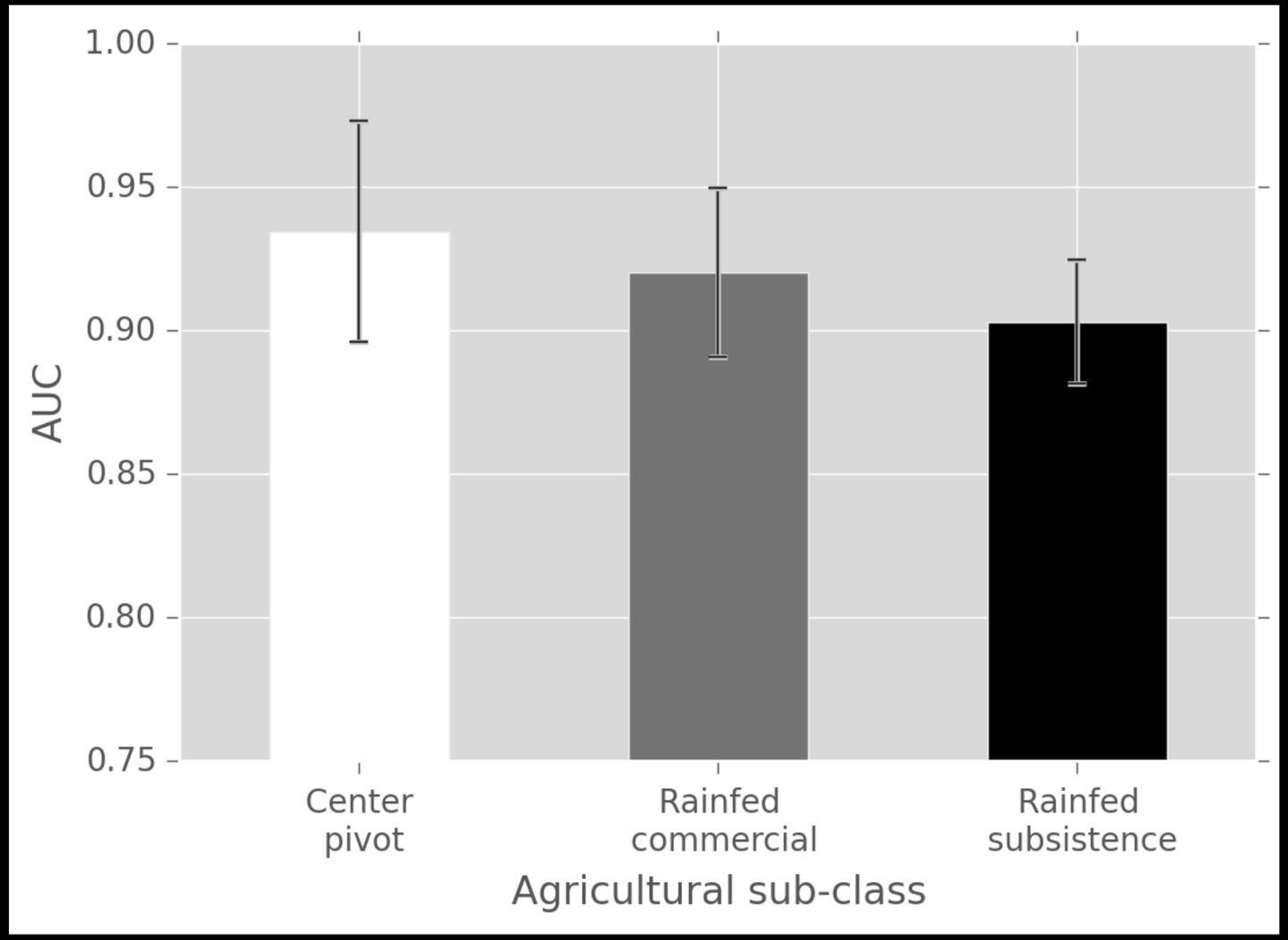
AUC- Area Under Curve

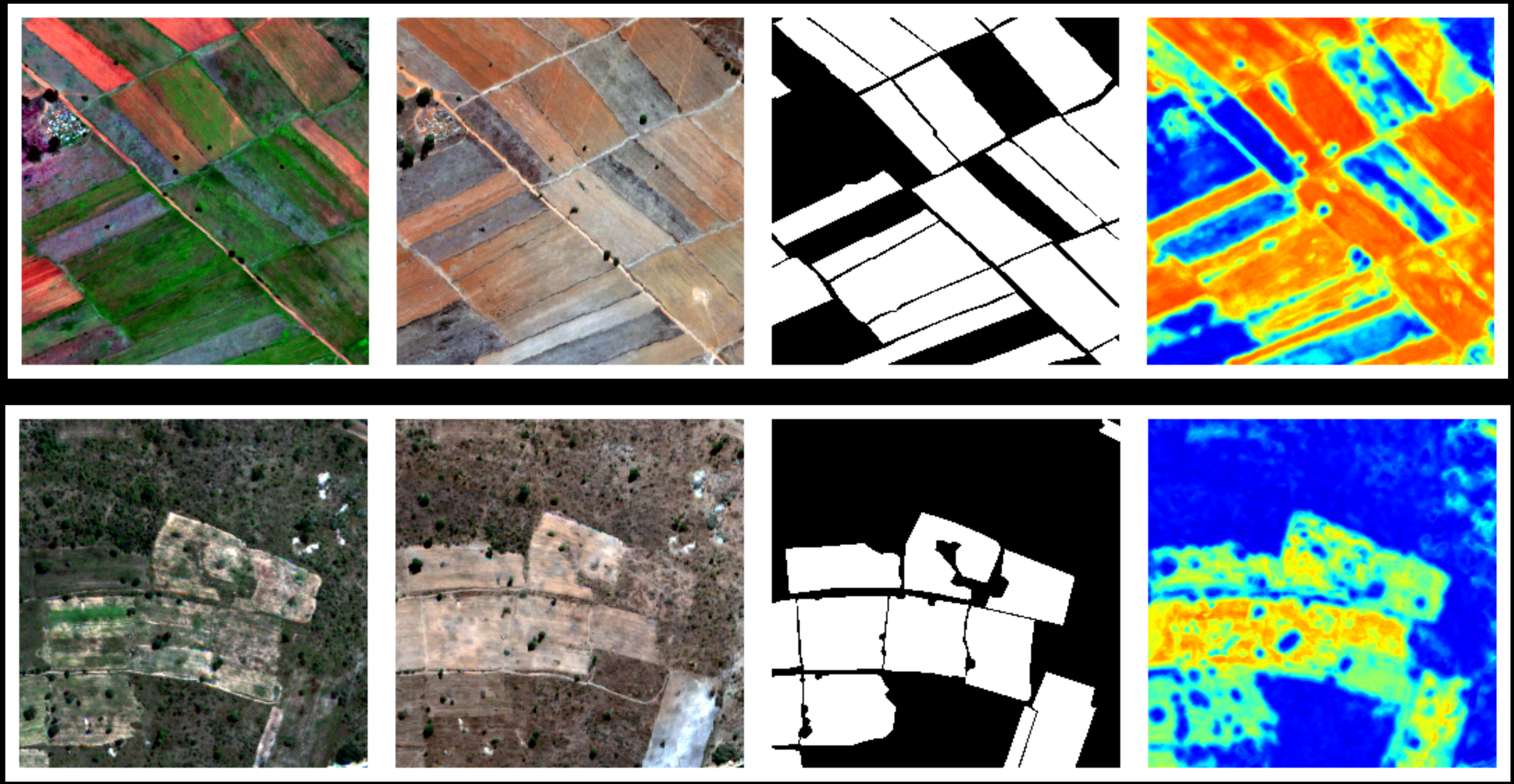
Probability that classifier will rank a randomly chosen positive instance higher than a randomly chosen negative instance

RESULTS

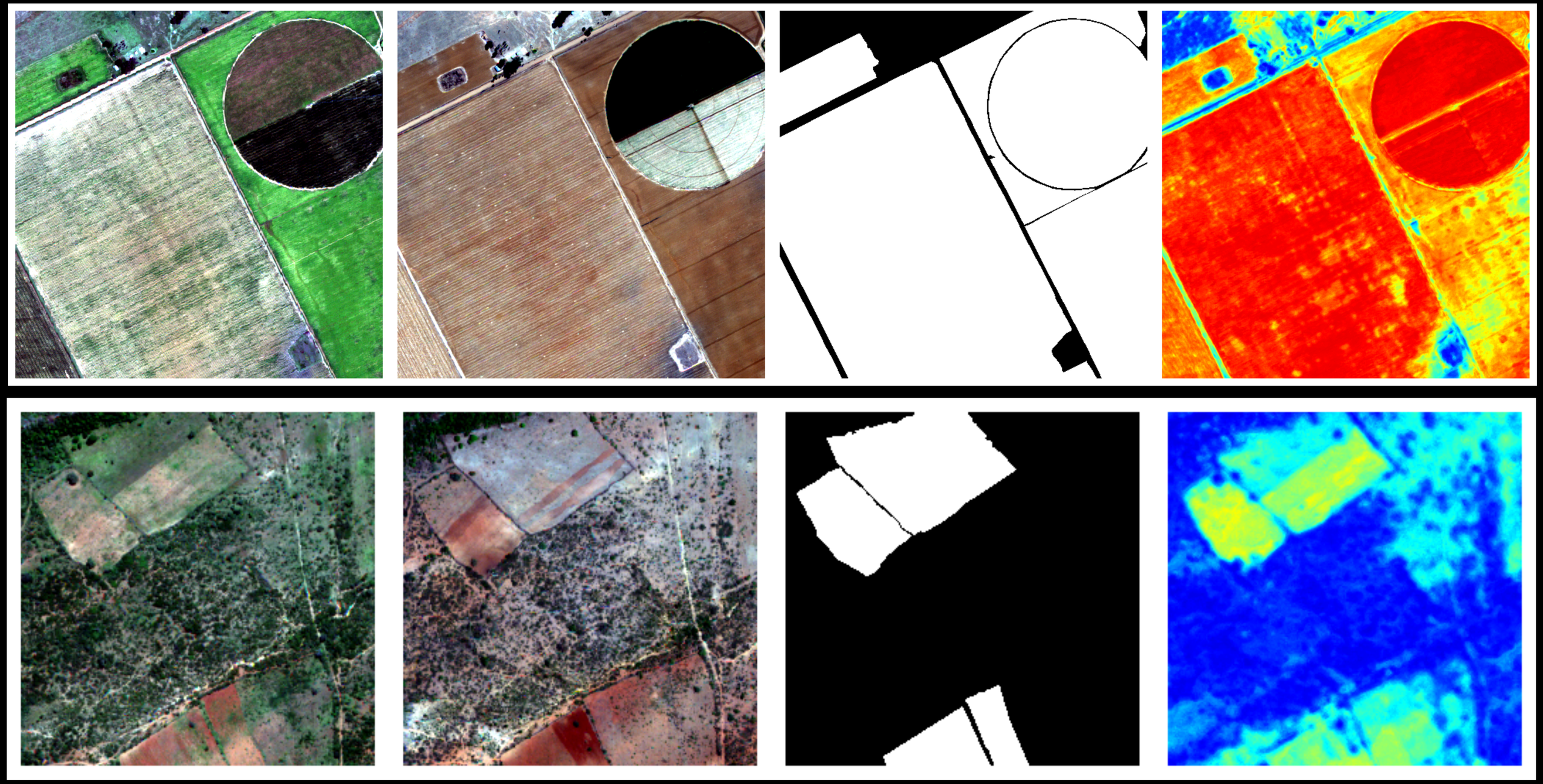
ROC CURVES



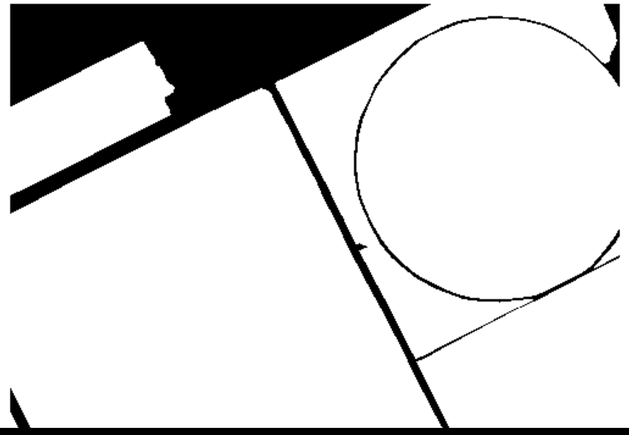
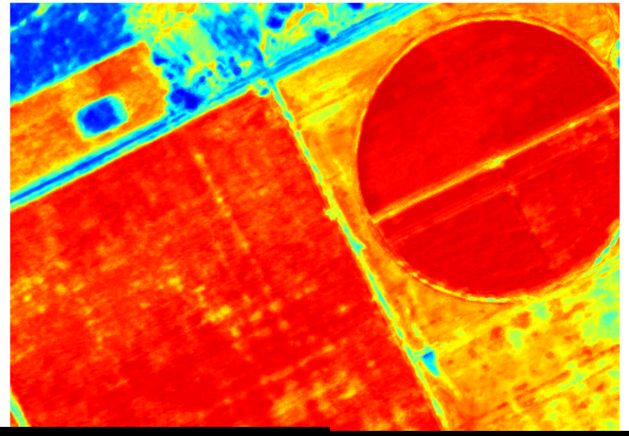




GROWING SEASON | OFF SEASON | HAND-DIGITIZED LABELS | POSTERIOR PROBABILITY

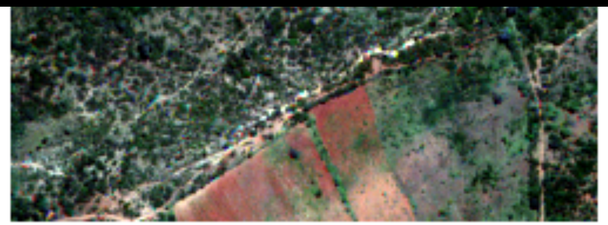
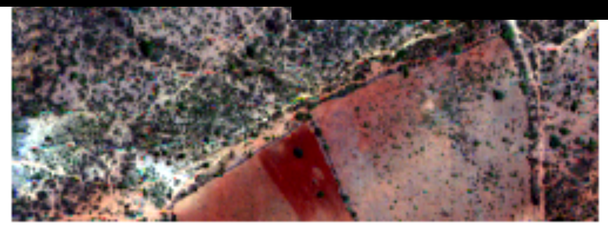


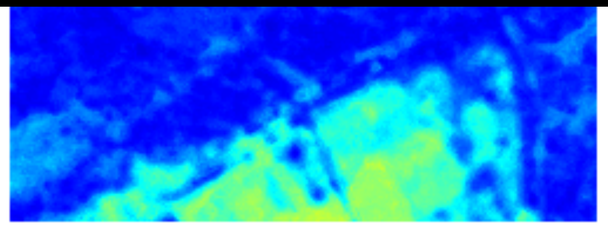
GROWING SEASON | OFF SEASON | HAND-DIGITIZED LABELS | POSTERIOR PROBABILITY

Debats S, Luo D, Estes L, Fuchs T, Caylor K (2015). A generalized computer vision approach to mapping crop fields in heterogeneous agricultural landscapes. PeerJ PrePrints 3:e1688. https://dx.doi.org/10.7287/peerj.preprints.1367v1

@stephaniedebats



GROWING SEASON

OFF SEASON

HAND-DIGITIZED LABELS

POSTERIOR PROBABILITY

CURRENT FARM-BASED APPROACHES FOR ASSESSING FOOD INSECURITY

Annual Crop Forecast Surveys & Post-Harvest Surveys

Household level samples of 3-4,000

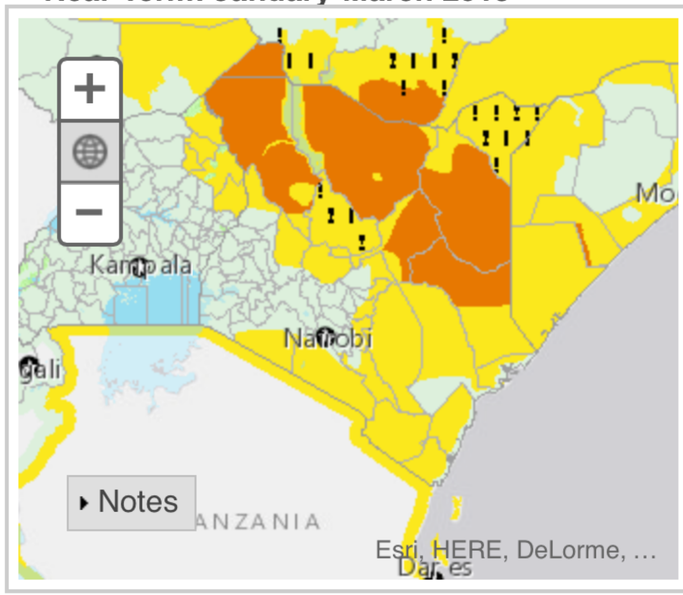
Incredibly expensive, relies on significant donor funds

Food Security Outlook Update

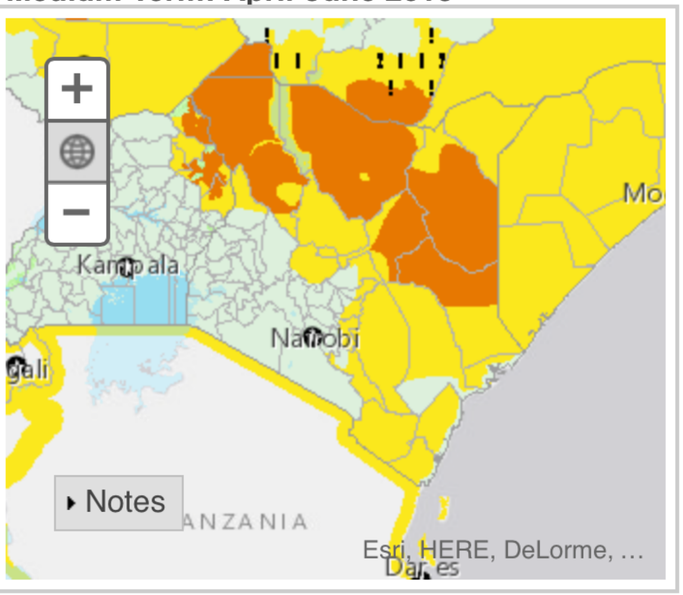
Assumptions for Quarterly Food Security Analysis

April 2015

Near Term: January-March 2015



Medium Term: April-June 2015



IPC V2.0 Phase of Acute Food Insecurity

Minimal	Stressed	Crisis	Emergency	Famine

Minimal	Stressed	Crisis or Higher

Would likely be worse without current or programmed humanitarian assistance

IDP Camps

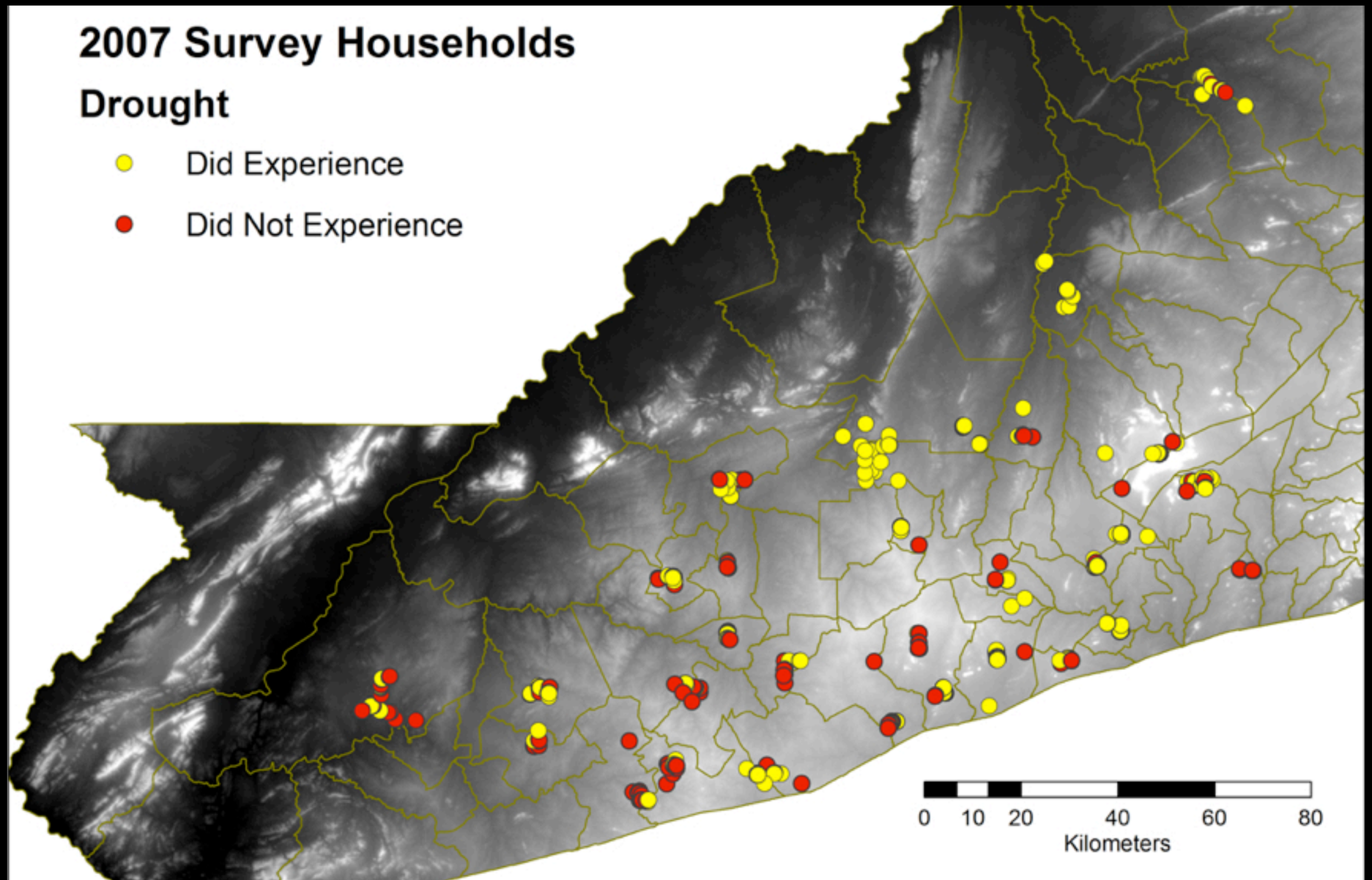
Region shapefile: http://shapefiles.fews.net/east-africa201501.zip

"Food insecurity is the result of complex interactions between physical and socio-economic factors that can overwhelm linear regression models. More sophisticated data-mining approaches could provide an effective way to model these relationships and accurately predict food insecure situations"

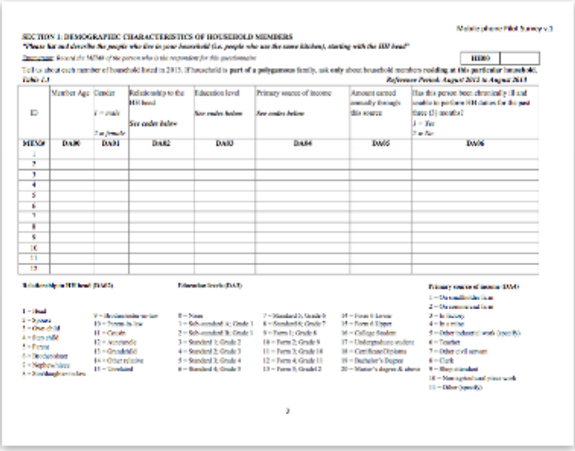
- SHORTRIDGE ET AL. 2015

IMPORTANCE OF LOCAL-LEVEL HETEROGENEITY

TOPOGRAPHIC, PRECIPITATION, FARM MANAGEMENT, MARKETS…



THE PAIN AND AGONY OF TRADITIONAL SURVEY DATA COLLECTION…



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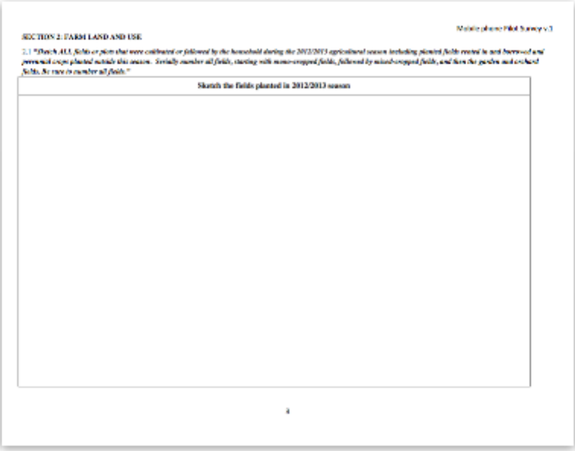

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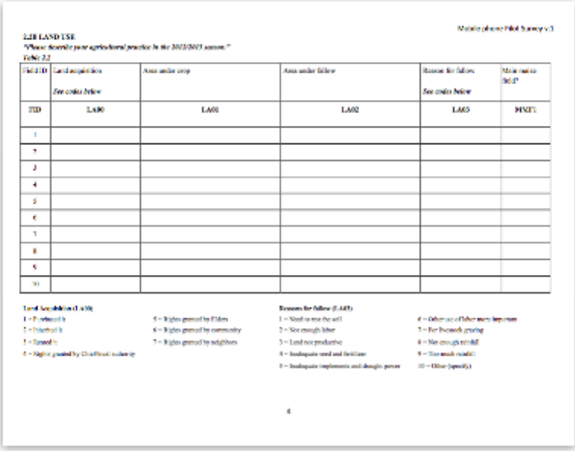

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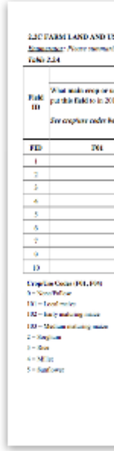
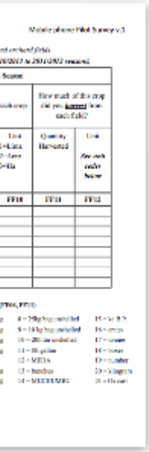
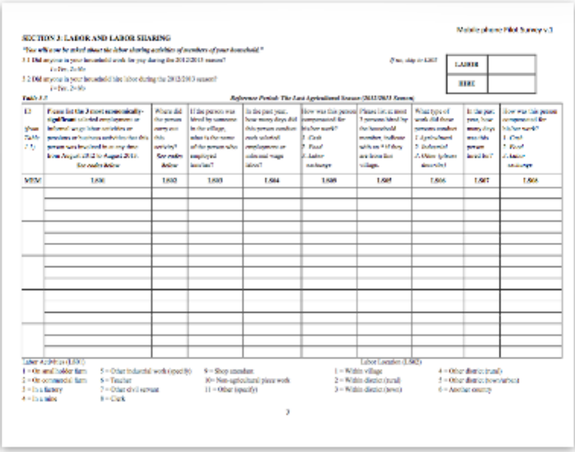


Not all surveys are so long, but half the challenge is just getting to the respondent…





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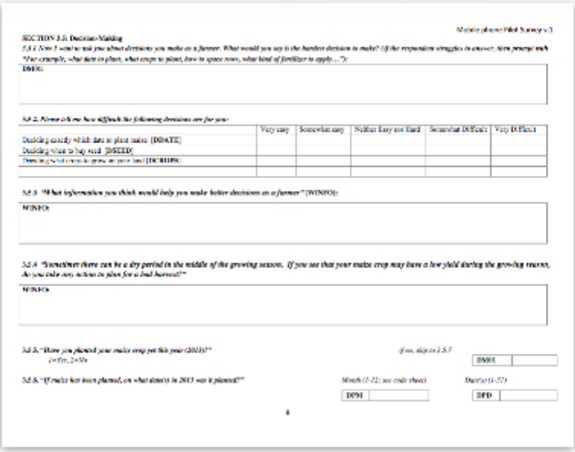

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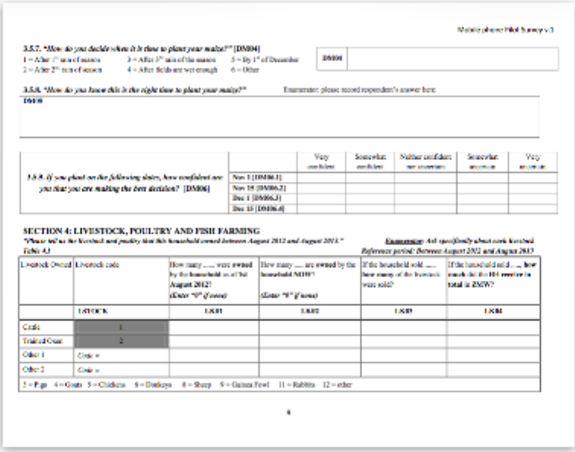

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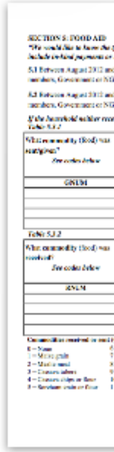

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

TRANSFORMATIONAL
ASSESSMENTS OF FOOD SECURITY

what farmers planted,

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,

where they planted it,

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,
how they manage it,

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,
how they manage it,
for **many, many farmers,**

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,
how they manage it,
for **many, many farmers**,
matched to **real-time**

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,
how they manage it,
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matched to **real-time ecohydrological data**

TRANSFORMATIONAL ASSESSMENTS OF FOOD SECURITY

what farmers planted,
where they planted it,
when they planted it,
how they manage it,
for **many, many farmers**,
matched to **real-time ecohydrological data**

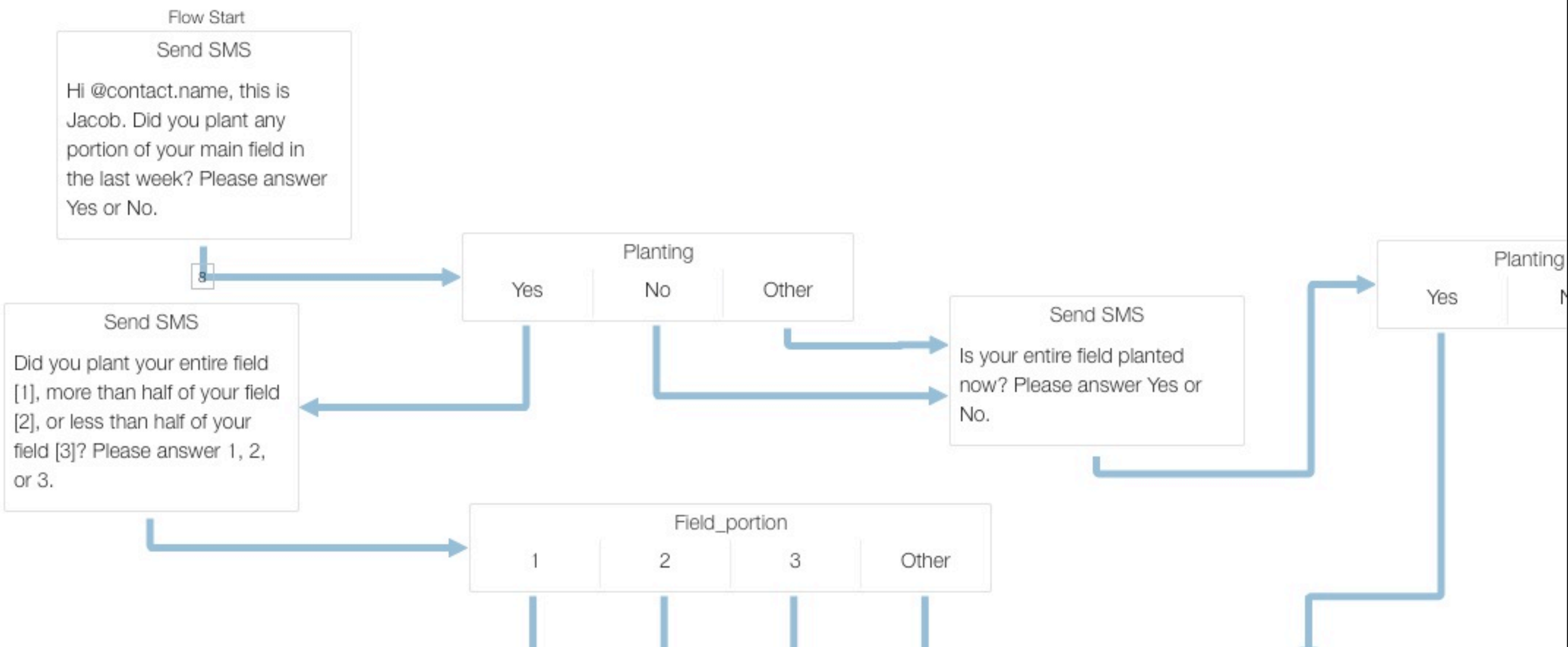
SAMSUNG
51%
16:08
+254715284076
Did it rain on your fields this week?
15:59
No
15:59
In the last 7 days, how many days did you irrigate your maize fields?
16:00
2
16:00
Thank you Stanley Wambugu. We will text you again next week.
16:01
Enter message

FLOWS… BRANCHES SELECTED BASED ON RESPONSES

CIPEC

textit

Planting period flow- Mulumbwa 4/15/14



Planting Season Flow

- Did you plant this week? If yes, what variety did you plant?
- What did you plant (local, early, medium, late maturing varieties)?
- What is your expected harvest at the end of the season?

Growing Season Flow

- Did you apply fertilizer?
- Did you weed?
- How tall is your maize?
- Did you do any piece work or wage labor?
- How many bags of maize do you have in storage?
- What is your expected harvest at the end of the season?

Harvest Season Flow

- Did you harvest this week?
- What is your total harvest so far?

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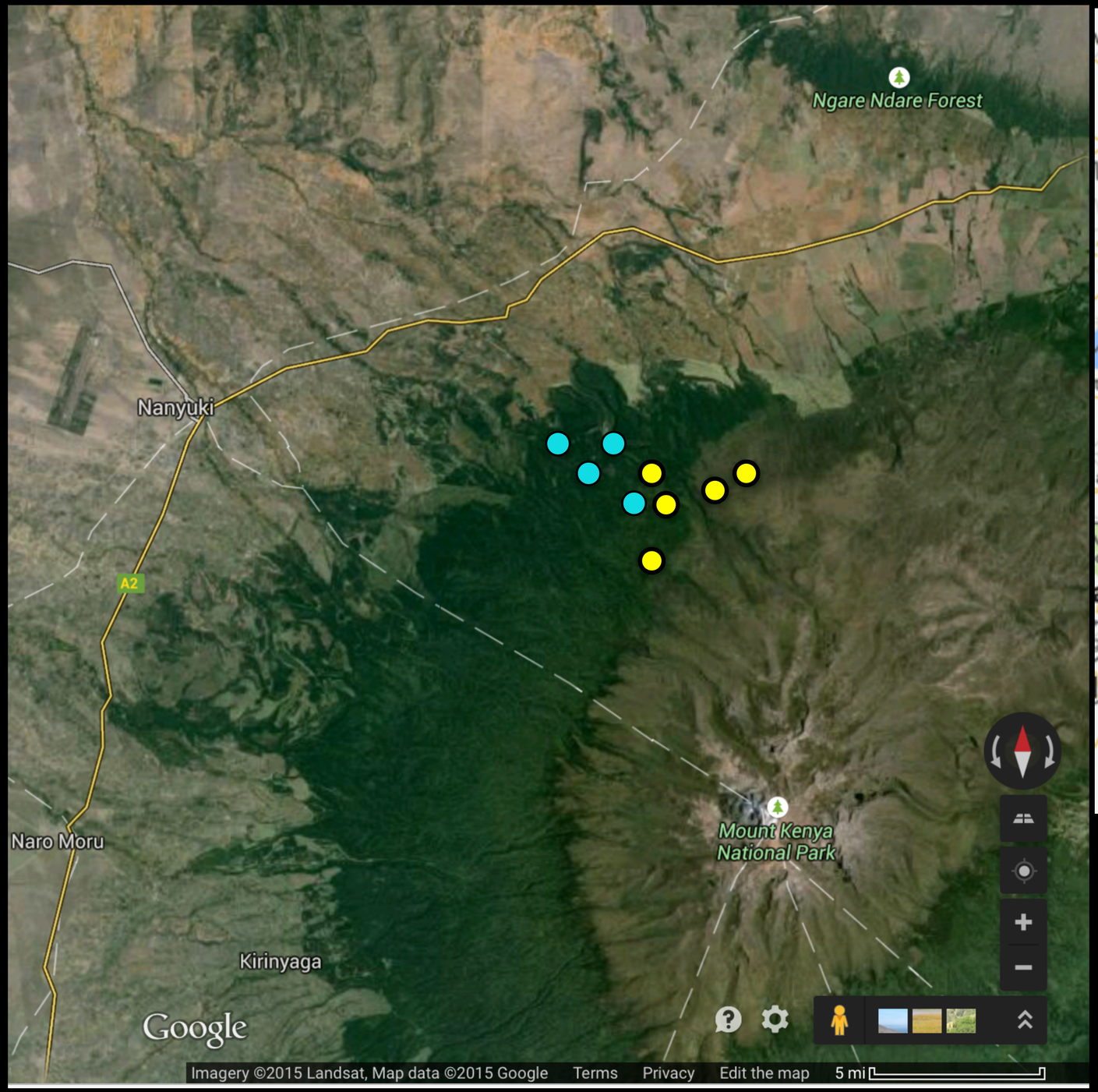
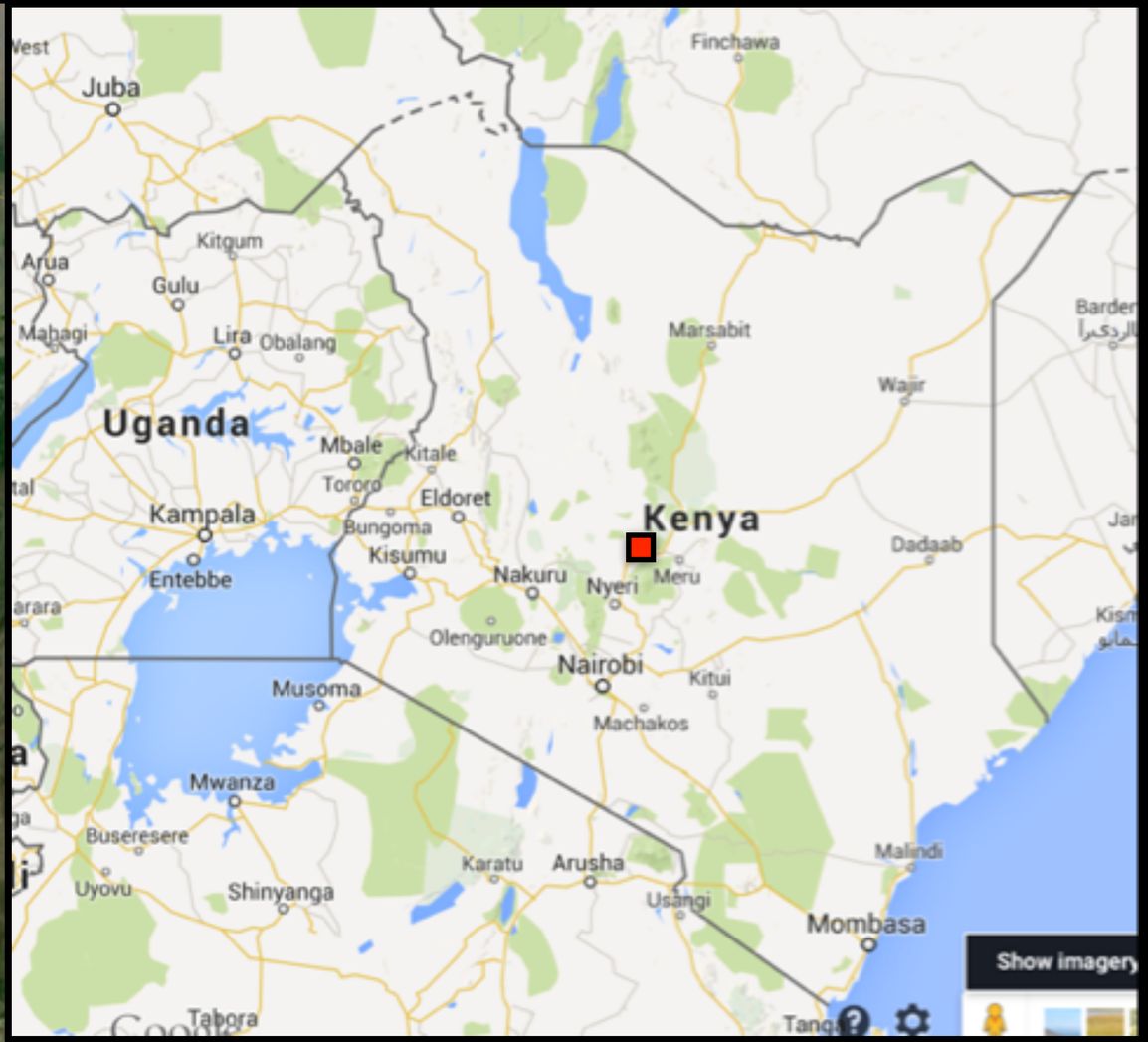

Ngare Ndare Forest
Nanyuki
A2
Naro Moru
Mount Kenya
National Park
Kirinyaga
Google
Imagery ©2015 Landsat, Map data ©2015 Google
Terms
Privacy
Edit the map
5 mi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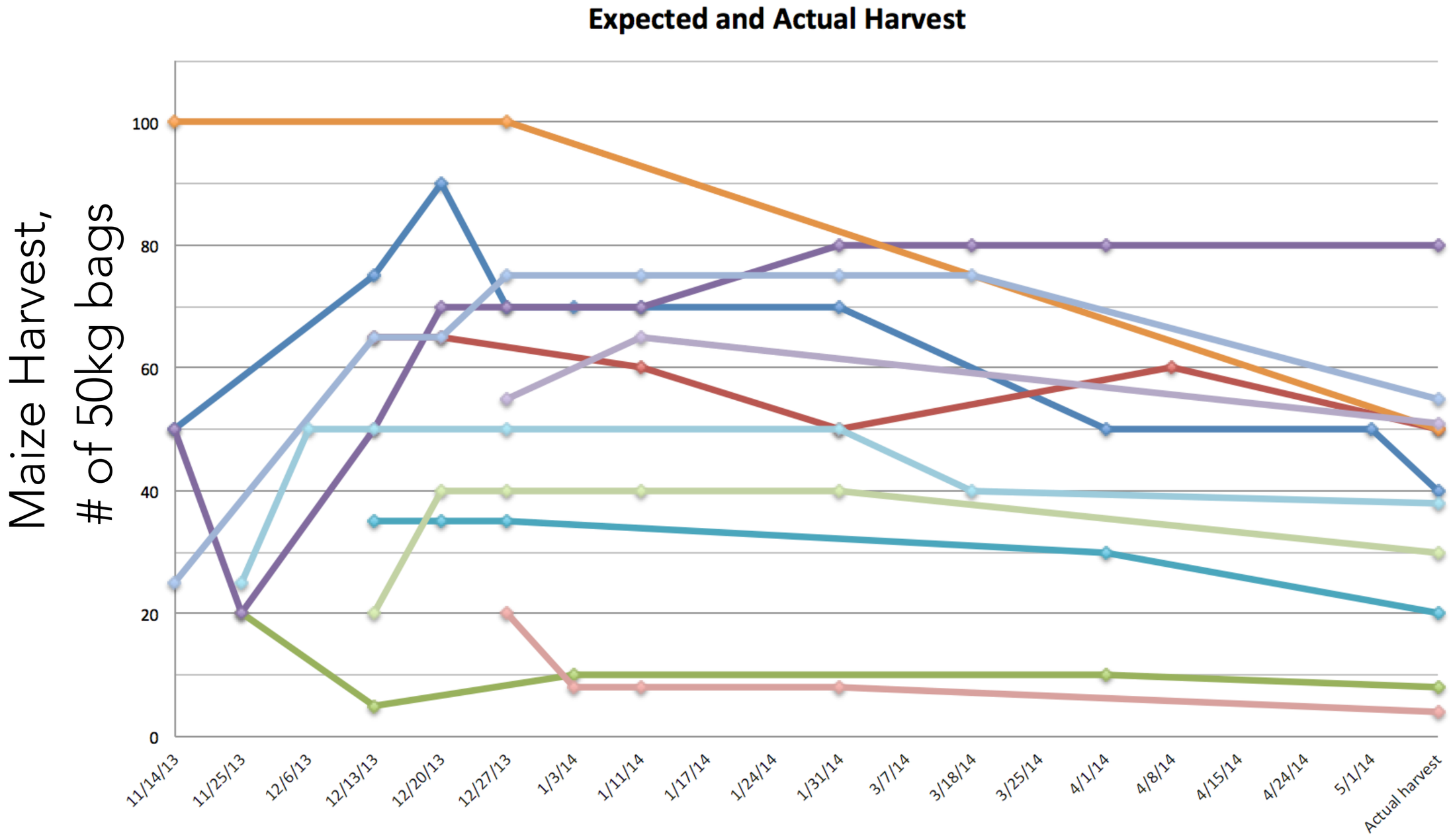
Finchawa
Kitgum
Arua
Gulu
Mahagi
Lira
Obalang
Marsabit
Wajir
Uganda
Mbale
Kitale
Tororo
Eldoret
Kampala
Bungoma
Kisumu
Kenya
Entebbe
Nakuru
Nyeri
Meru
Dadaab
Olenguruone
Nairobi
Kitui
Musoma
Machakos
Mwanza
Buseresere
Karatu
Arusha
Malindi
Uyovu
Shinyanga
Usangi
Mombasa
Tabora
Show imagery

CHANGING HARVEST EXPECTATIONS THROUGH GROWING SEASON



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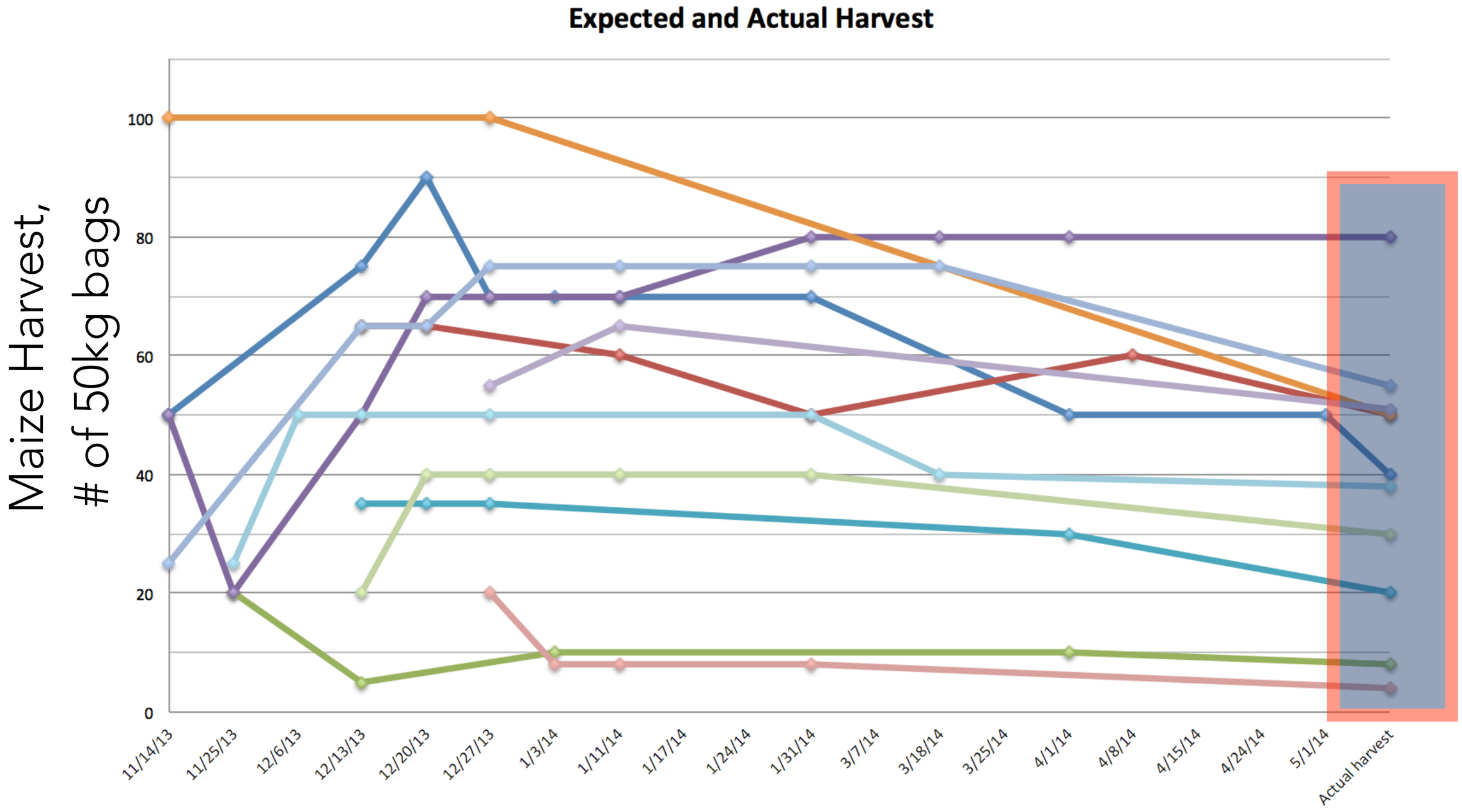
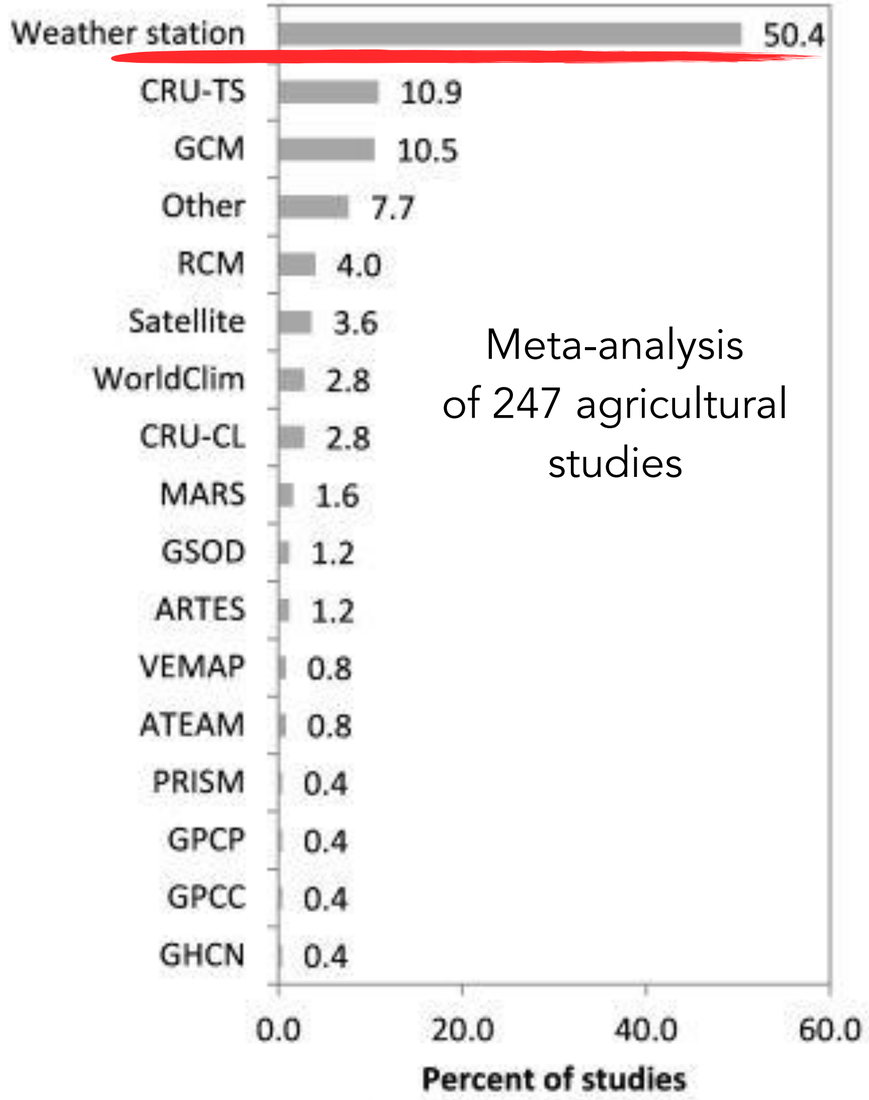


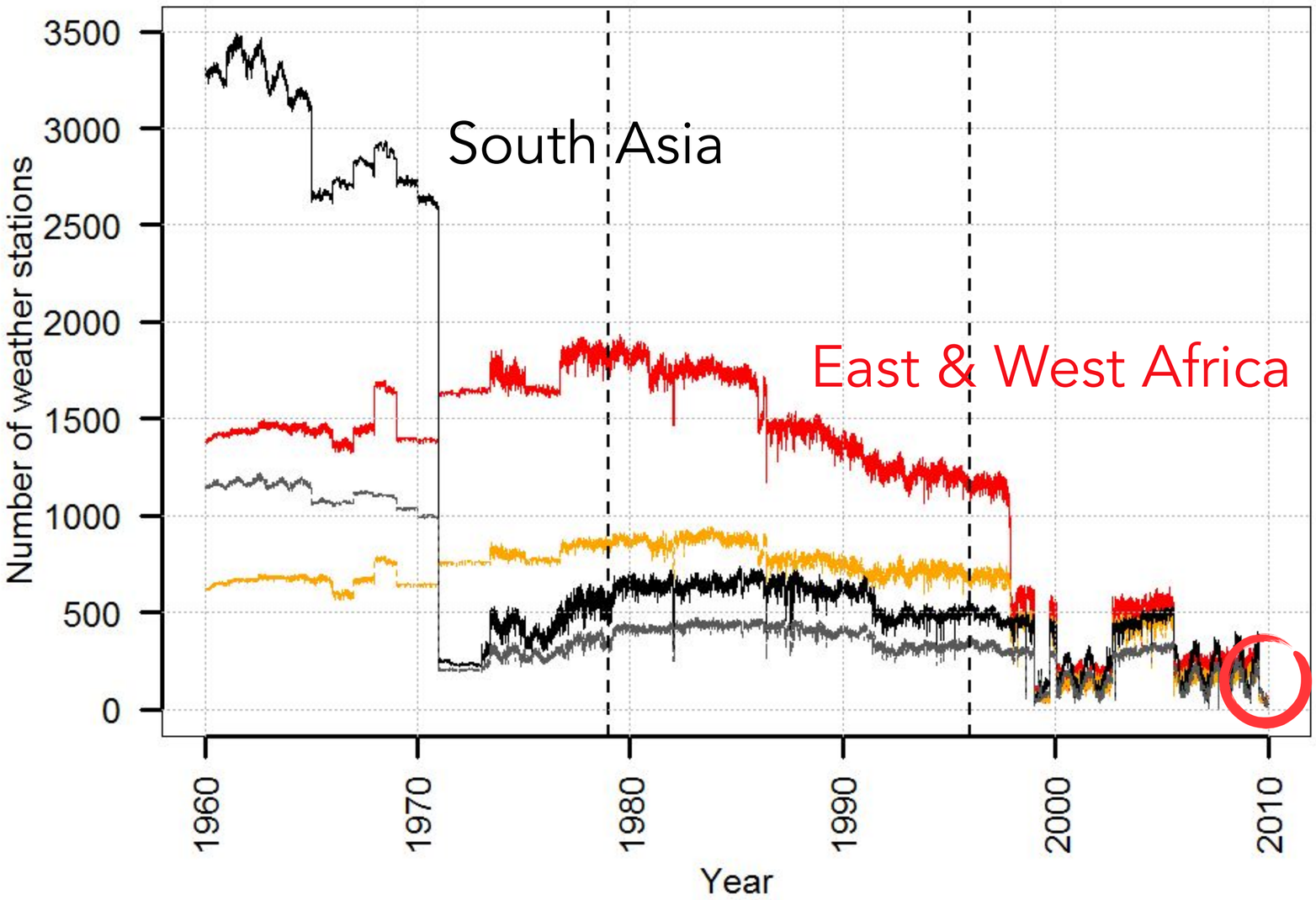
WHAT ENVIRONMENTAL DATA IS NEEDED?

ENVIRONMENTAL DATA SOURCE



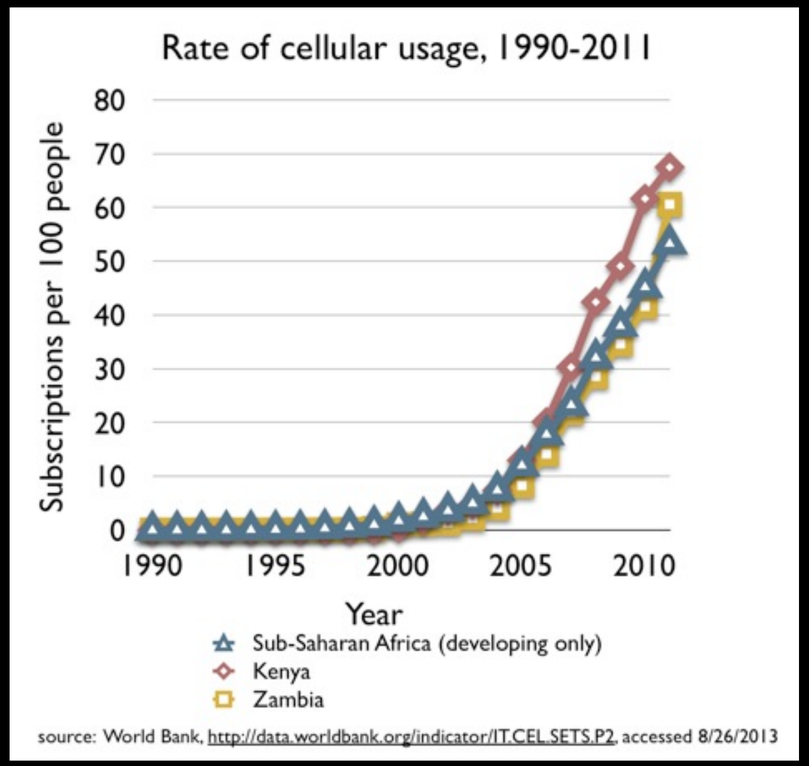
Source: Ramirez-Villegas & Challinor, 2012, Ag&ForMet

NUMBER OF AVAILABLE METEOROLOGICAL STATIONS



"LEAP-FROGGING" COUPLED SOCIAL-ENVIRONMENTAL SCIENCE IN THE DEVELOPING WORLD

1 Ubiquitous cellular



2 Cheap sensors, μCs, and cell modules

3 Open computing ecosystems

DaaS

PaaS

nexmo

twilio
CLOUD COMMUNICATIONS

textit

The "post-smartphone" era will soon become as defining as the "post-transistor" era.

PULSE Lab

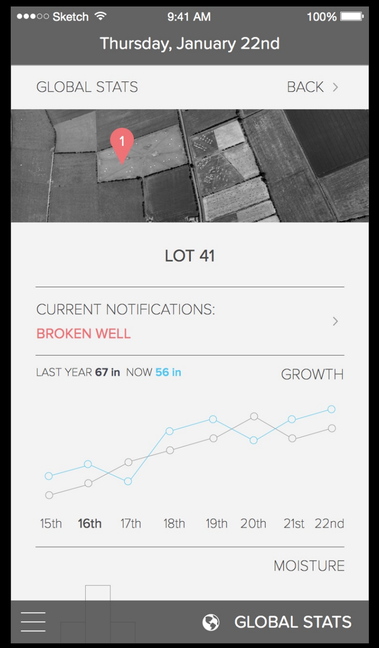
Princeton University Low-cost Sensors for the Environment

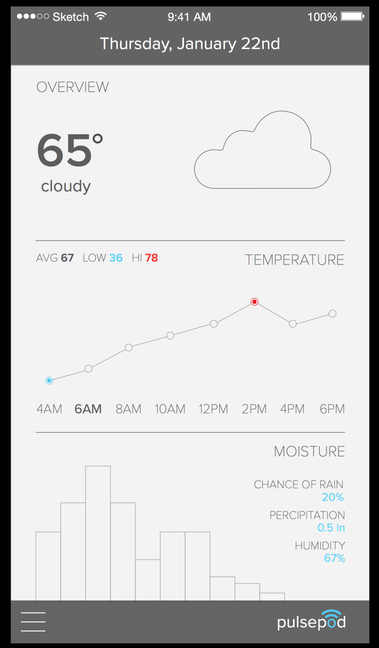
DEVELOP **LOW COST** SENSOR NETWORKS, COMMUNICATING IN **REAL-TIME**, STORING DATA IN AN **OPEN WEB-BASED API**

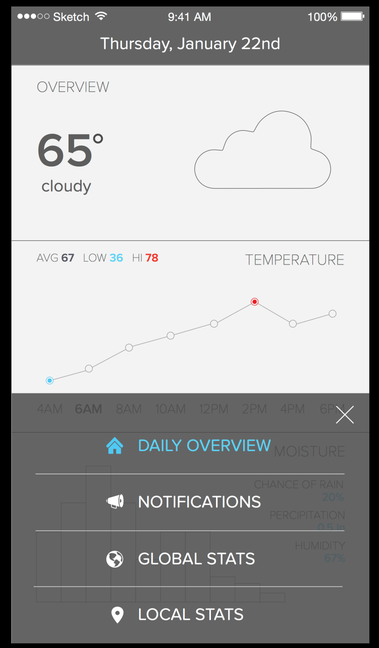
(APPLICATION PROGRAM INTERFACE)

Adam Wolf, Co-Founder

Lab Established	Spring 2012
Pulsepod Designs Inc. Founded	Oct 2014
NSF-ICorps	Jan-Feb 2015
Angel Investment Round	Sep 2015







Public Notebooks

Andre-Rothmaler-2779 data from unknown, Southern in ZM
536 4.1 Public Ben
Last updated 3 hours ago

Andre-McVaugh-9267 data from Choma, Southern in ZM
596 4.1 Public Ben
Last updated 3 hours ago

Traugott-Cordus-1569 data from unknown, Southern in ZM
1527 4.0 Public Ben
Last updated 3 hours ago

Chumvi cwp , Laikipia in KE
10980 4.1 Public Lyndon
Last updated 3 hours ago

Batian cwp, Meru in KE
12847 4.2 Public Lyndon
Last updated 3 hours ago

Eliza-Stebbins-3904 data from Princeton, NJ in US
6118 4.1 Public Lyndon
Last updated 3 hours ago

Gitaraga cwp, Meru in KE
12880 4.2 Public Lyndon
Last updated 3 hours ago

Nkando CWP, Laikipia in KE
16168 4.1 Public Ben
Last updated 4 hours ago

Tumaini CWP, Meru in KE
15273 4.1 Public Ben
Last updated 4 hours ago

Kaga CWP, Laikipia in KE
19670 4.2 Public Kelly
Last updated 4 hours ago

Wiumiririe cwp, Laikipia in KE
12090 4.1 Public Ben
Last updated 4 hours ago

Huku CWP, Nyeri in KE
13567 4.1 Public Kelly
Last updated 4 hours ago

PulsePodβ Notebooks Your Pods Admin Signed in as Kelly Sign out

Chumvi cwp , Laikipia in KE (last seen 2 hours ago)

Tags

Current Conditions

Powered by Forecast.io

It is currently mostly cloudy, with a temperature of 24°C. The relative humidity is 47%. Wind speed is 2.6 km/hr.

Today's Forecast

Powered by Forecast.io

Light rain starting in the afternoon, with a high temperature of 24°C and a low temperature of 13°C. There is a 55% chance of rain today.

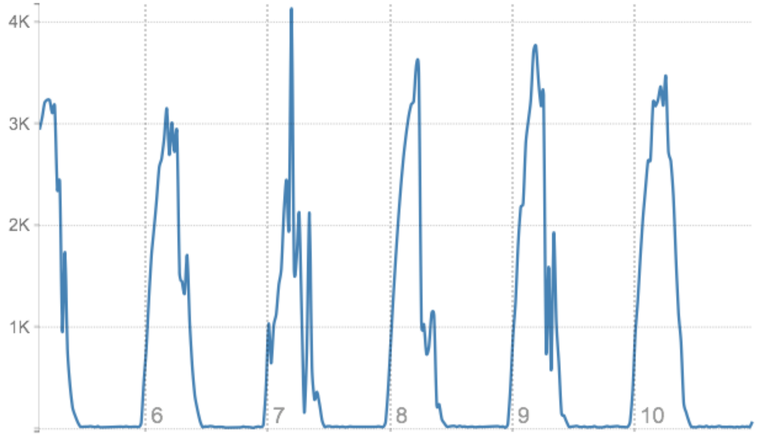
Data | Location | Pod Info | Notes | Downloads

Select a sensor to view your data. ×

Battery Voltage (4.06 V)	60 Minute Rainfall (0.25 mm)	Air Temperature (29.32 °C)	Air Relative Humidity (51.4 %)	Air Pressure (79.38 kPa)	Upwelling PAR (3480.54 µE/m2)	Downwelling PAR (273.83 µE/m2)

Index 648 nm Reflectance (0.12 %)	Index 830 nm Reflectance (0.14 %)

Chumvi cwp , Laikipia in KE, Upwelling Photosynthetically Active Radiation (µE/m2)



PulsePodβ Notebooks Your Pods Admin Signed in as Kelly Sign out

Kelly's Profile Page

kelly@pulsepod.io

Member since 12/31/2013. Last seen a few seconds ago.

Change Password

Notebooks 43 Pods 0 Data 62973

API Key: 12c0955bf35a4151a3cc9e9a362804d1 Reset API Key

Access the PulsePod API using your API key

From the command line:

Get all your data, plus any public data:

```
> curl --user 12c0955bf35a4151a3cc9e9a362804d1:empty https://api.pulsepod.io/data
```

Get all your notebooks, plus any public notebooks:

```
> curl --user 12c0955bf35a4151a3cc9e9a362804d1:empty https://api.pulsepod.io/notebooks
```

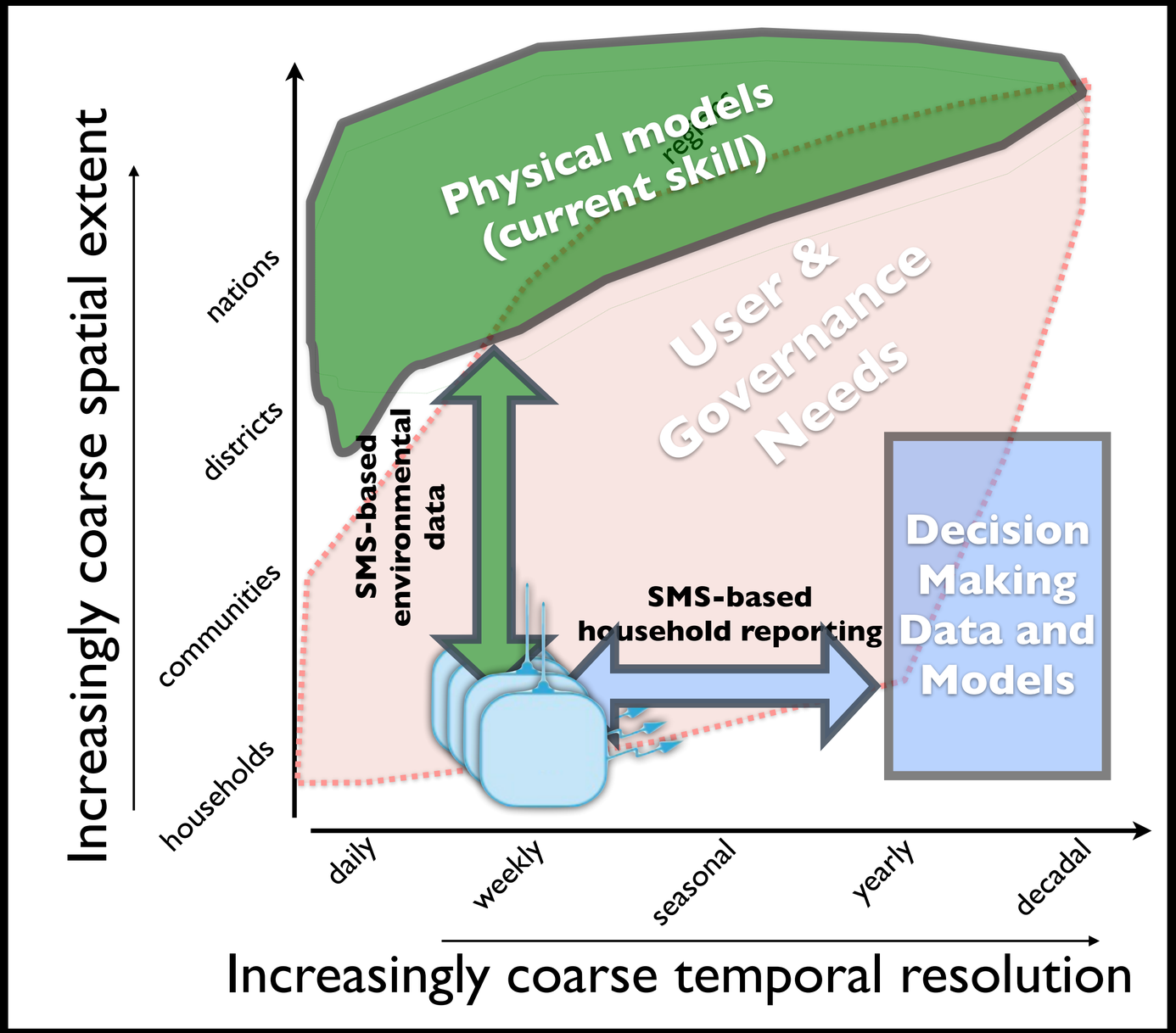
Get all your pods (only pods owned by you are returned):

```
> curl --user 12c0955bf35a4151a3cc9e9a362804d1:empty https://api.pulsepod.io/pods
```

Find all the data near a specific coordinate [longitude, latitude]:

```
> curl --user 12c0955bf35a4151a3cc9e9a362804d1:empty -X GET https://api.pulsepod.io/data --data 'where={"loc": {"$near
": {"$geometry":{"type": "Point", "coordinates": [-121.8, 38.55 ]}}}}'
```

SENSOR NETWORKS AND CELLULAR-BASED SURVEYS WILL ADDRESS AGRICULTURAL DATA AVAILABILITY & CONCURRENCY GAPS



COUPLED SYSTEM MODELS

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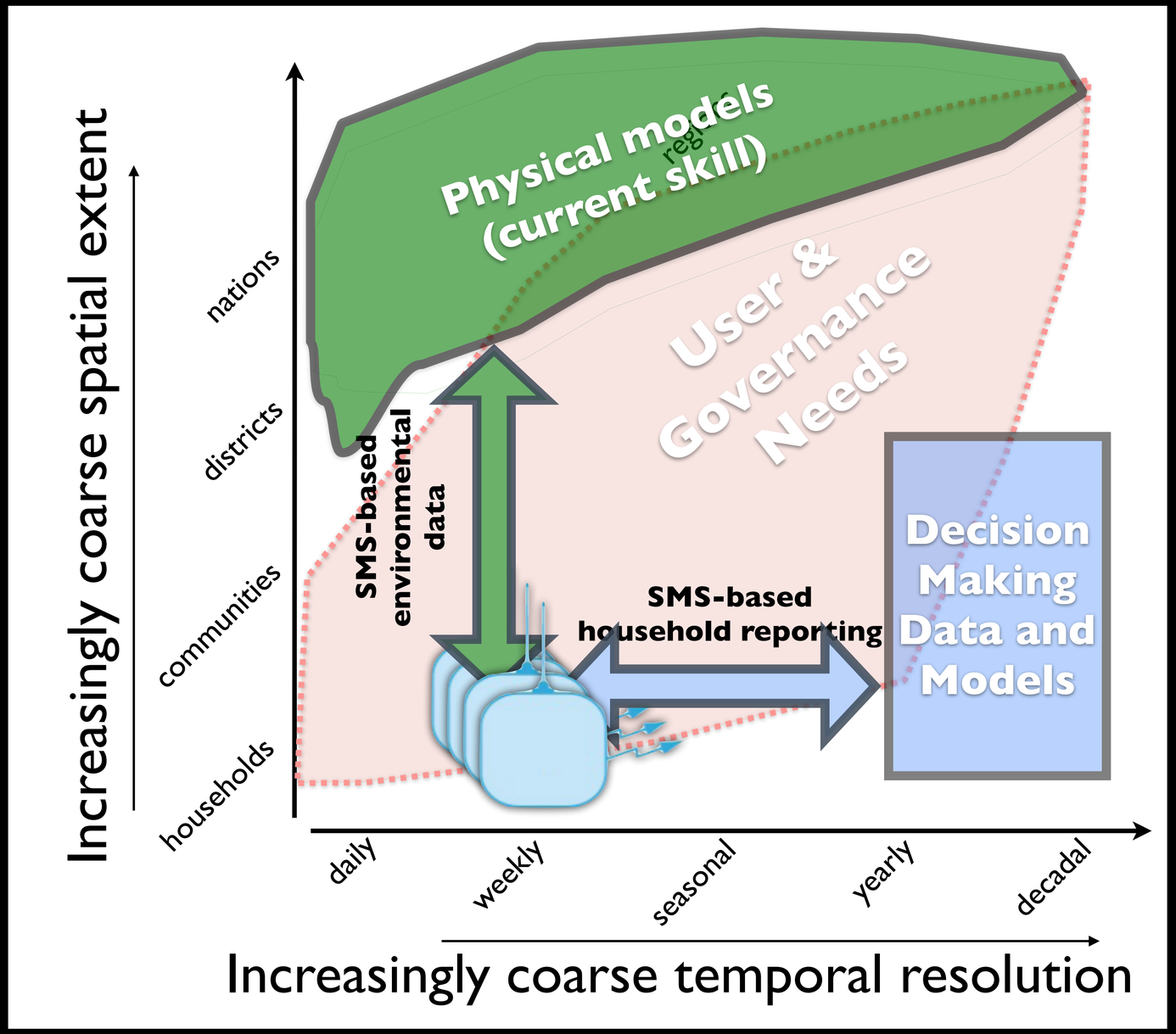
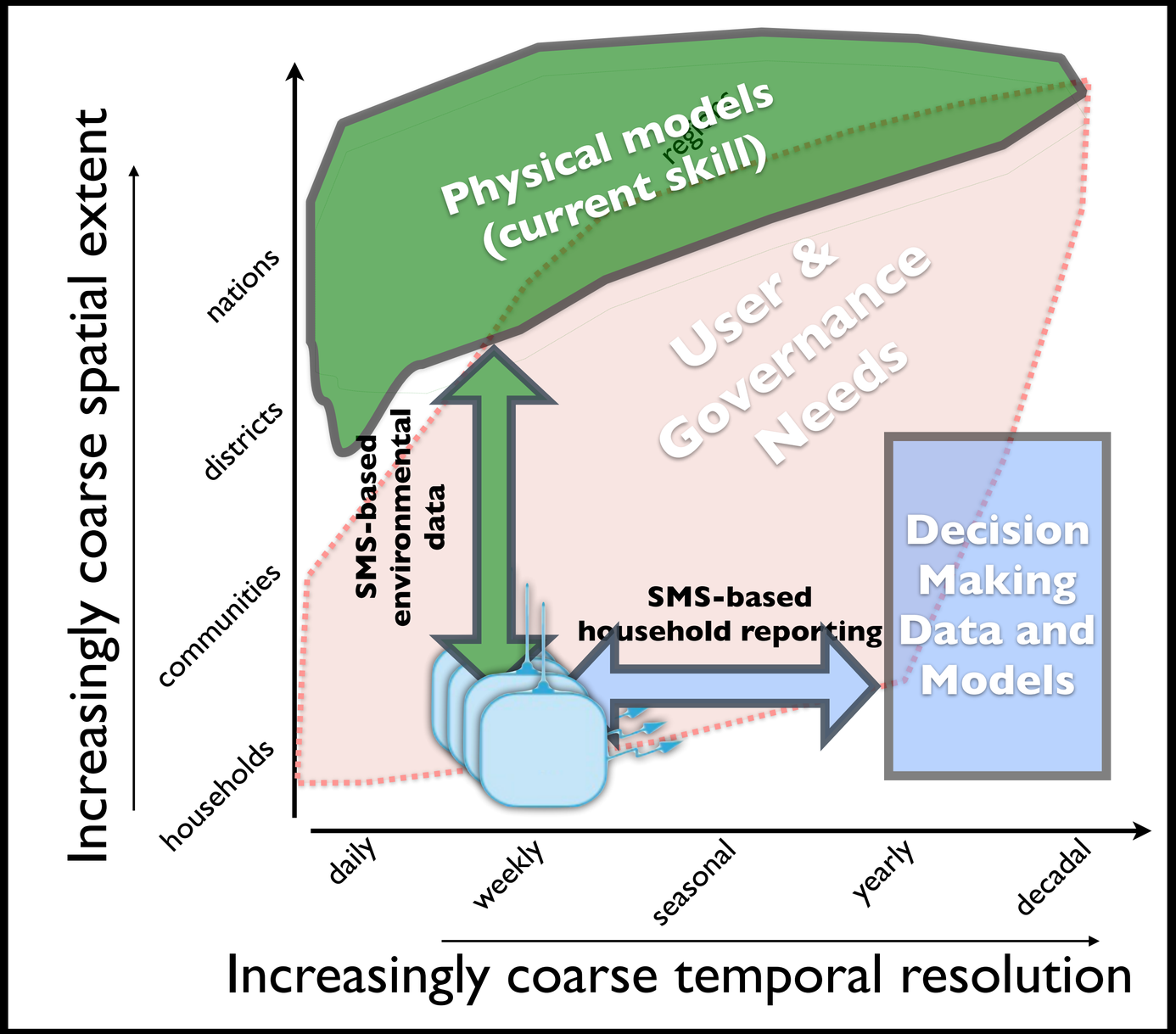


Measurements

COUPLED SYSTEM ~~MODELS~~

SENSOR NETWORKS AND CELLULAR-BASED SURVEYS WILL ADDRESS AGRICULTURAL DATA AVAILABILITY & CONCURRENCY GAPS



Measurements

COUPLED SYSTEM ~~MODELS~~

Novel approaches for characterizing **decision making** dynamics

Novel approaches for characterizing **environmental** dynamics

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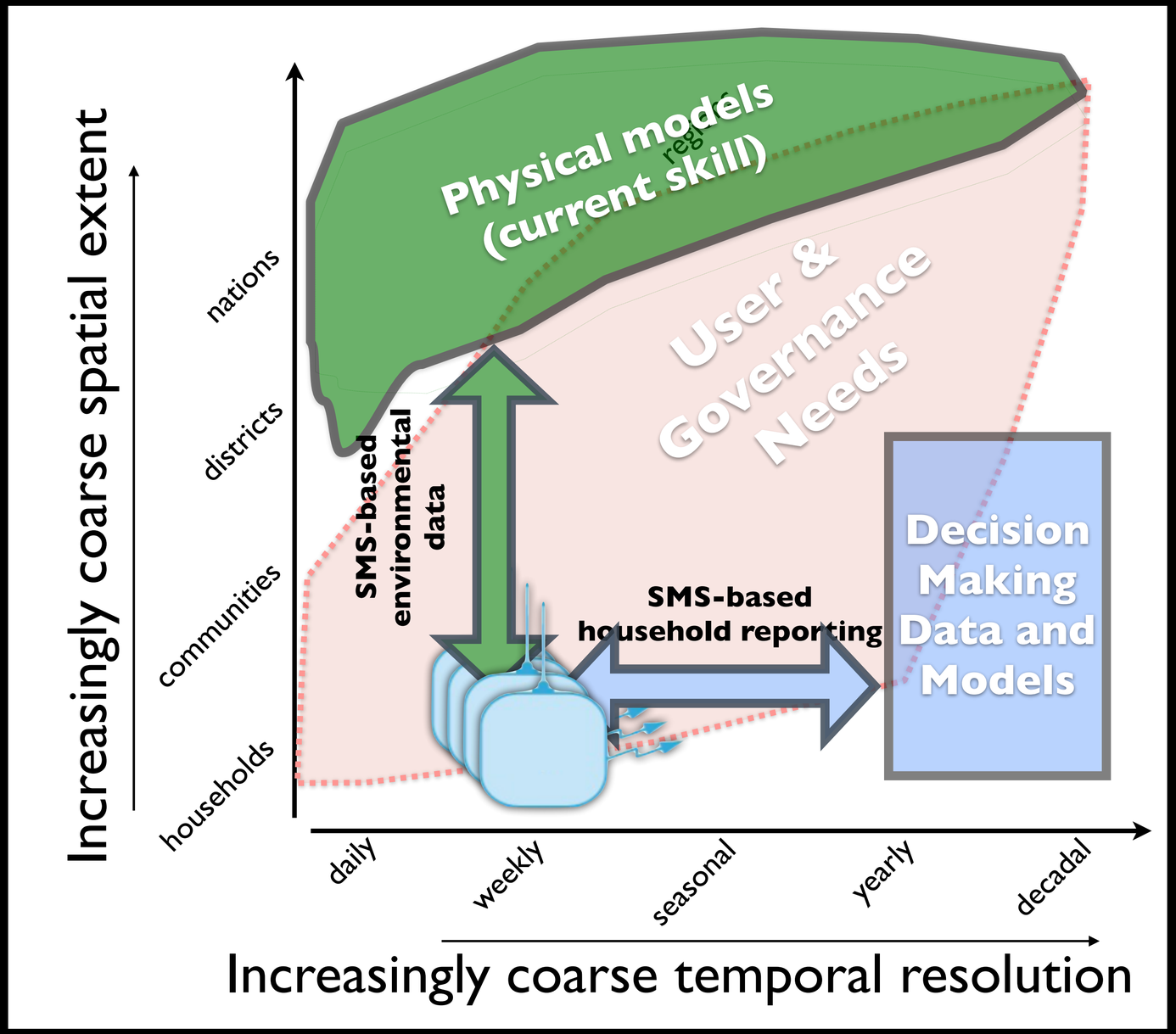
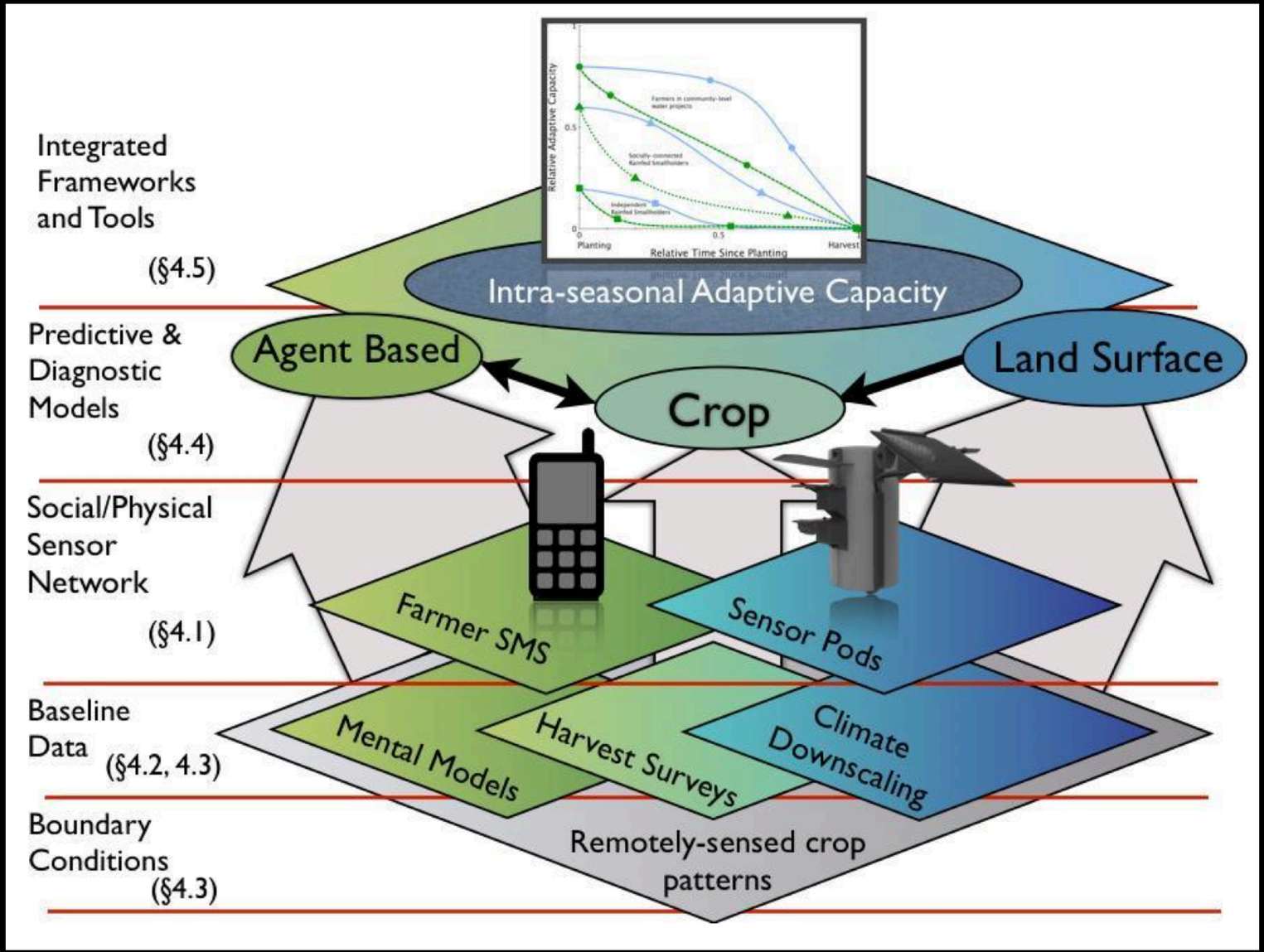


COUPLED SYSTEM ~~MODELS~~ Measurements

Novel approaches for characterizing **decision making** dynamics ⟷ Novel approaches for characterizing **environmental** dynamics

fanatical co-location and integration

THESE COUPLED DATA WILL YIELD IMPROVED SES FRAMEWORKS FOR ASSESSING INTRA-SEASONAL DETERMINANTS OF FOOD SECURITY



5 YEAR VISION

INDIANA UNIVERSITY BLOOMINGTON

PRINCETON UNIVERSITY

Weekly data from farmers, hourly or sub-hourly ecohydrological data

~15,000 farmers, ~1,000 pods

Feeding into improved seasonal forecast models for food security

Producing tools and products for improved and responsive agricultural decision-making

This research supported by National Science Foundation awards SES-1360463, BCS-1115009, BCS-1026776, the Princeton Environmental Institute, and an Indiana University Mellon Innovating International Research, Teaching and Collaboration (MIIRT) award.

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SCHOOL OF PUBLIC AND ENVIRONMENTAL AFFAIRS
SCHOOL OF INFORMATICS
OSTROM WORKSHOP

PRINCETON UNIVERSITY

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Project members:

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*Stephanie Debats (Princeton University)
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Kelly Caylor (Princeton University)
Lyndon Estes (Princeton University)
Justin Sheffield (Princeton University)
Shahzeen Attari (Indiana University)
Beth Plale (Indiana University)

We're looking for postdocs and graduate students to join our team!

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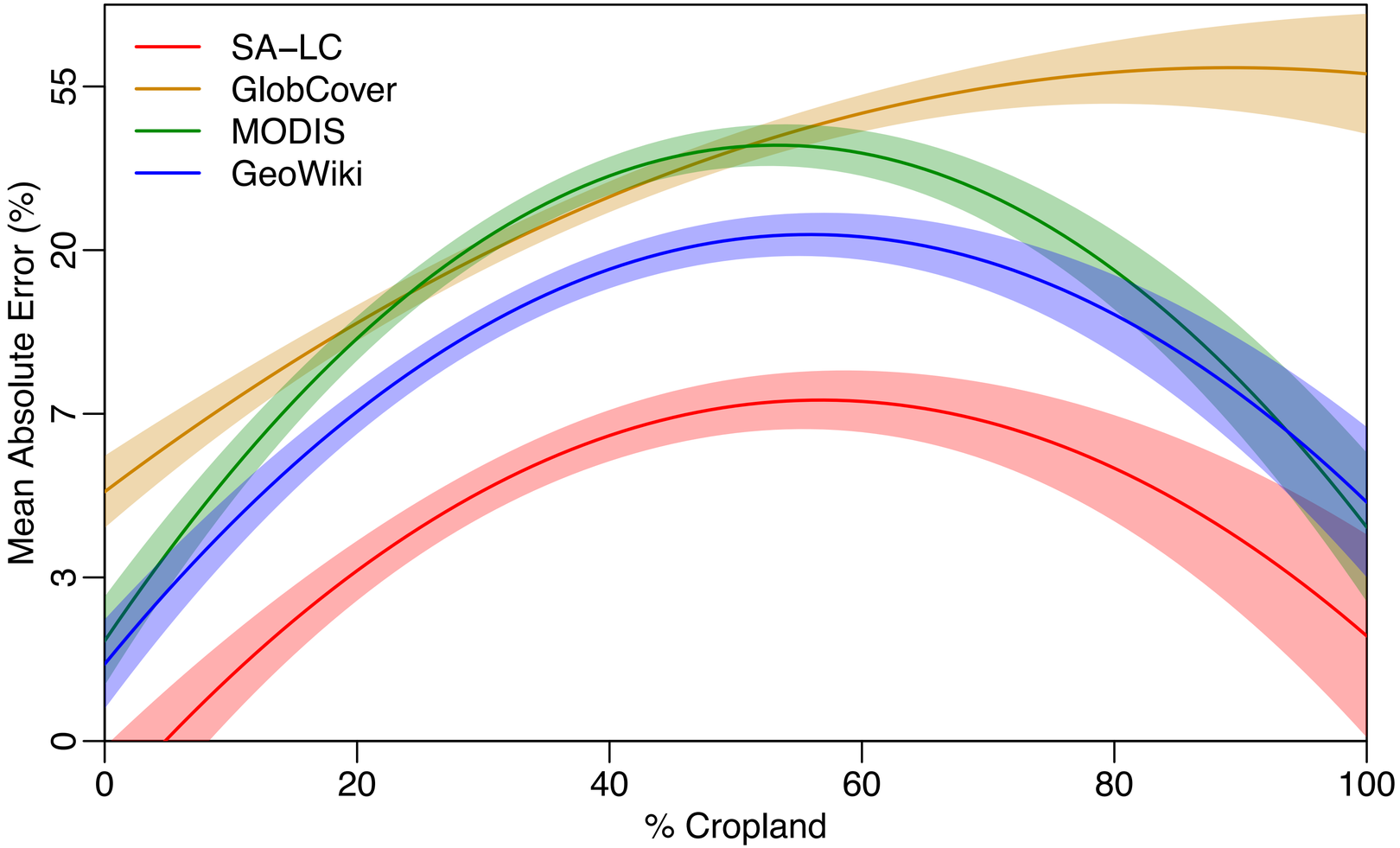
Mean absolute error (accuracy) in cropland fractional estimates in relation to actual cropland density