Using Satellite Data to Map Yields of Smallholder Farms

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I derive novel datasets on agricultural management and production using satellite data at high spatial resolutions and across large spatio-temporal scales

Yield

Jain et al. in review (3m^2, 2015-17)
Jain et al. 2016 (2 m^2; 2015)
Jain et al. 2017a (30 m^2; 2000-2015)

Cropped area

Jain et al. 2013 & Jain et al. 2017b (250 m^2; 2000 – 2016)
Smith et al. in prep. (3 m^2, 2017)

Sow date

Jain et al. 2017a (250 m^2; 2000-2016)

Crop Type

Rao et al. in prep. (3 m^2; 2017)

Google Earth Engine

planet.

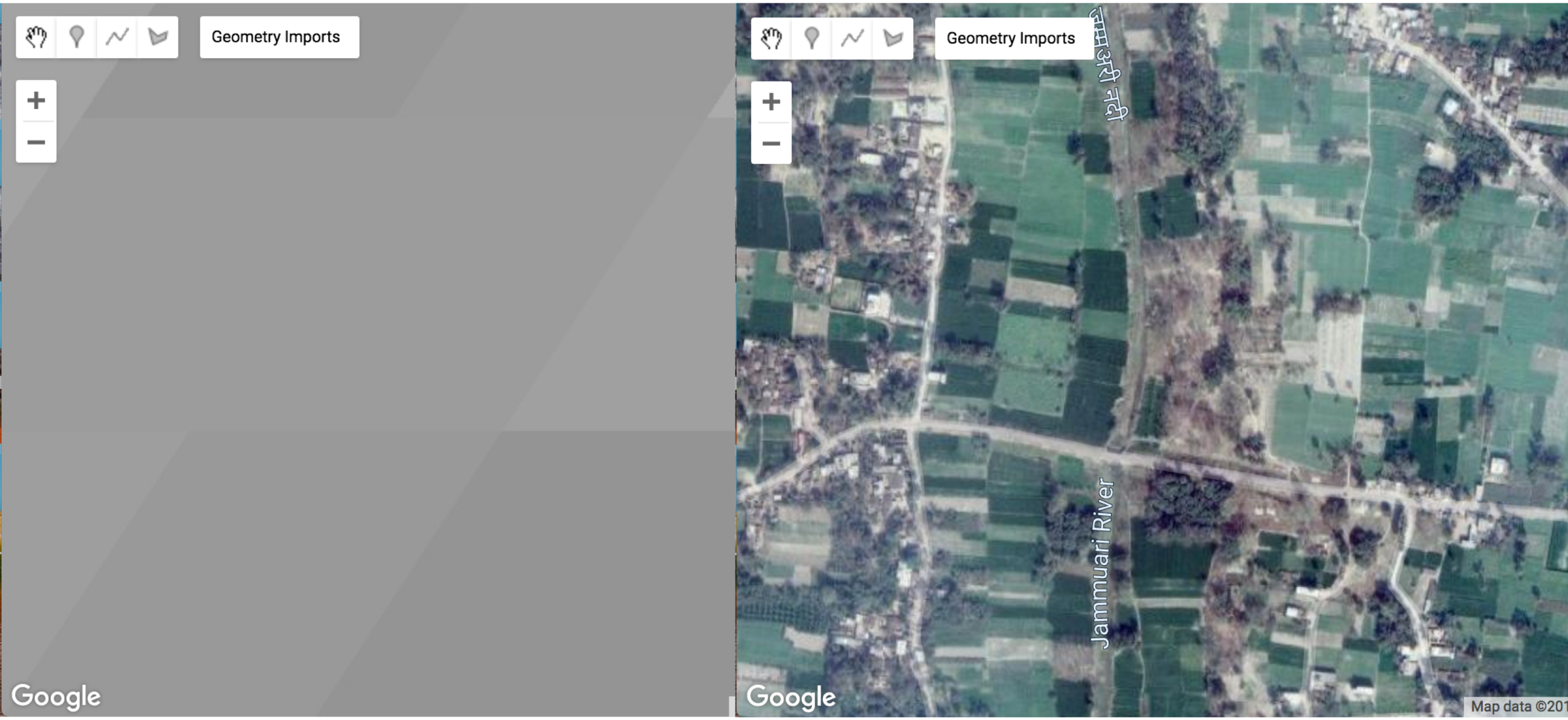
Outline

- Primer on satellite data products & potential pitfalls
- Work on mapping field-level yields of smallholder wheat fields in India

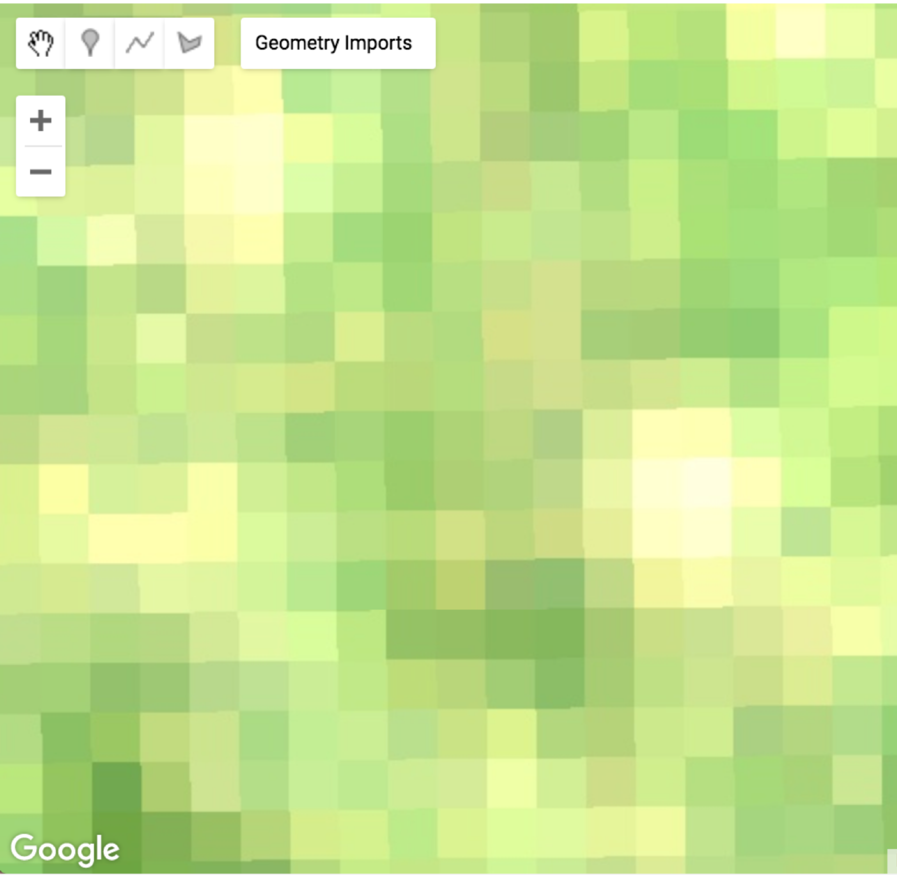
It is a really exciting time for using satellite data!

- There are new sensors, with higher spatial and spectral resolution so we can do much more!
- There are computational tools available to process data easily and quickly (e.g., Google Earth Engine)

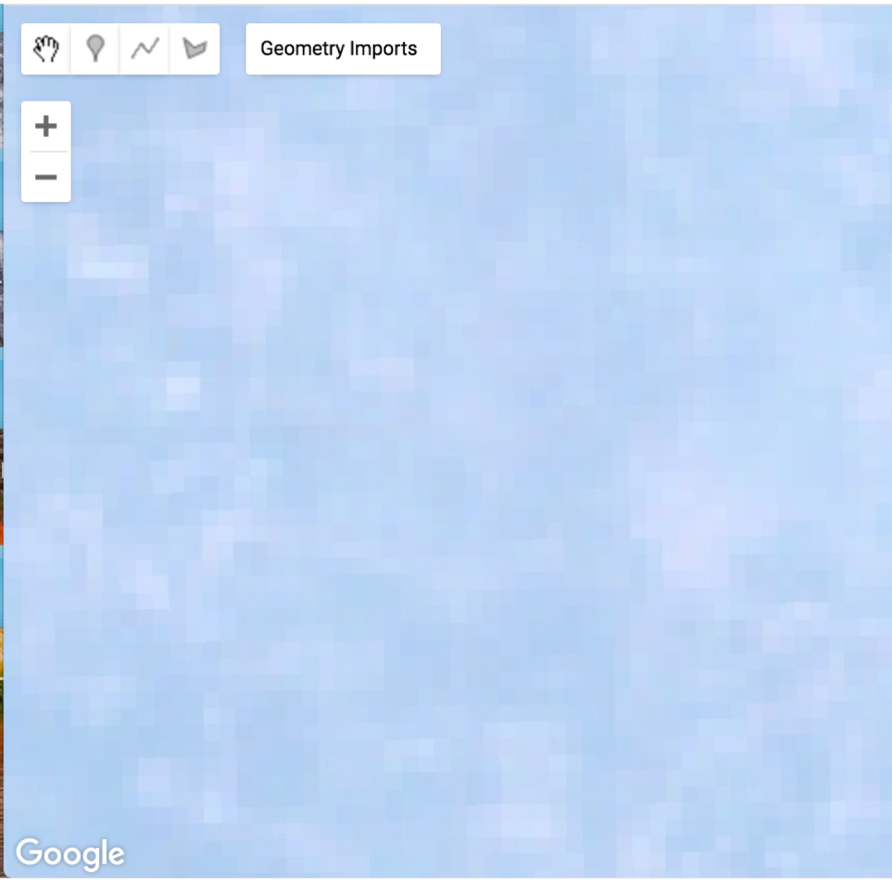
MODIS – 250 m^2; daily; 2000-present



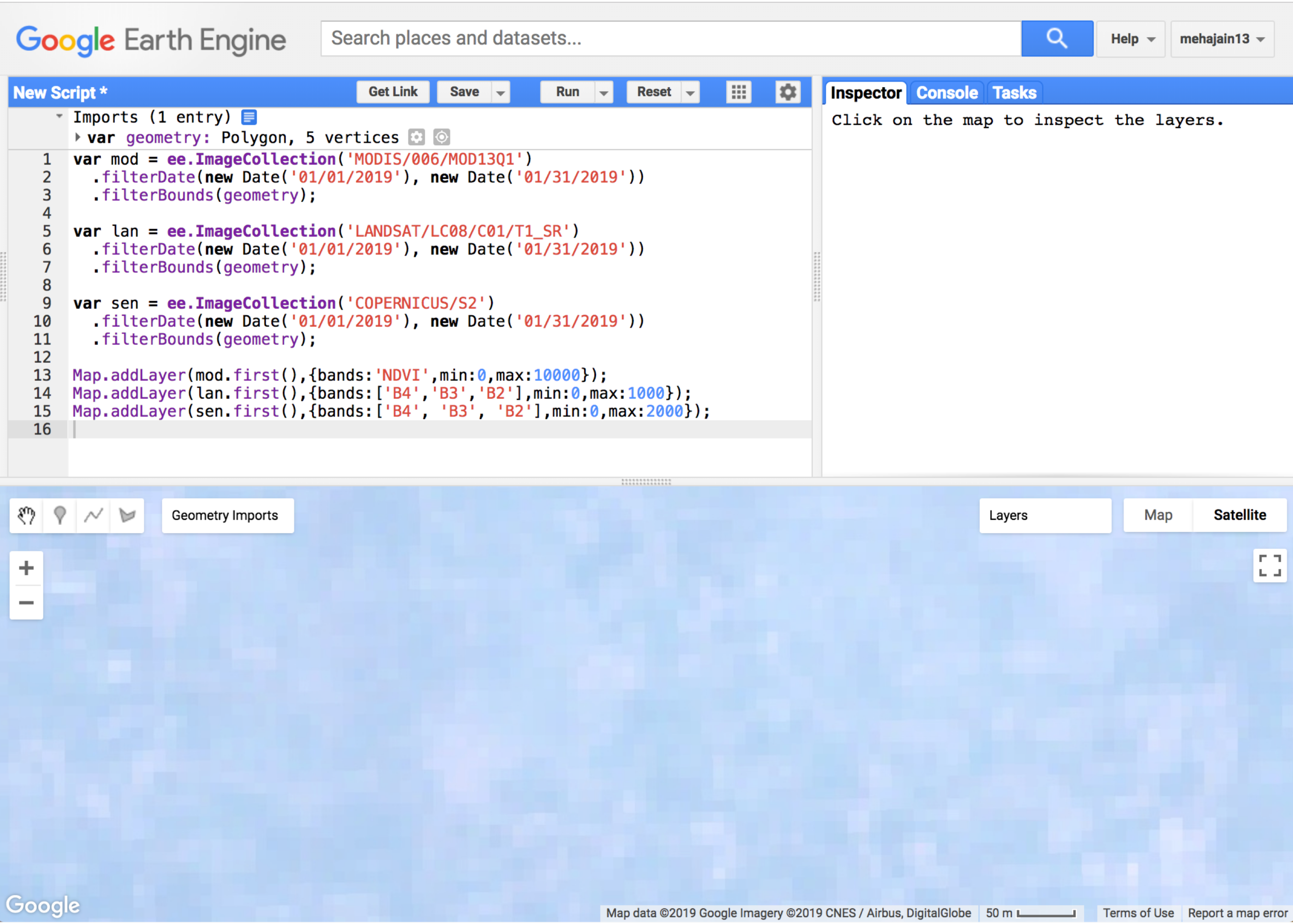
Landsat – 30 m^2; 16 days; 1970s-present



Sentinel 2 – 10 m^2; 5 days; 2015-present



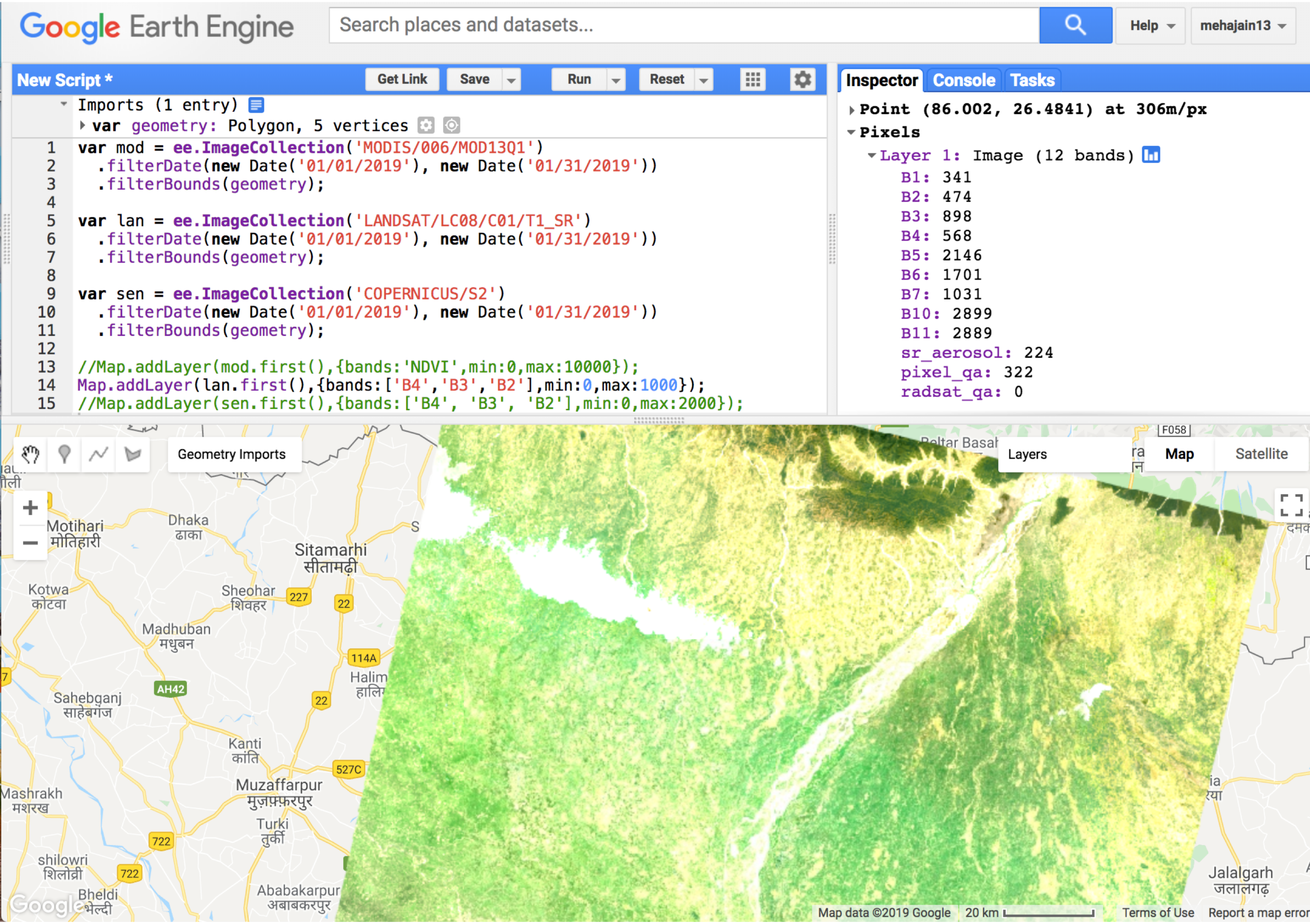
Planet – ~3 m^2; up to daily; 2015-present


Google Earth Engine
Search places and datasets...
Help
mehajain13
New Script *
Get Link
Save
Run
Reset
Inspector
Console
Tasks
Click on the map to inspect the layers.
Imports (1 entry)
var geometry: Polygon, 5 vertices
var mod = ee.ImageCollection('MODIS/006/MOD13Q1')
.filterDate(new Date('01/01/2019'), new Date('01/31/2019'))
.filterBounds(geometry);
var lan = ee.ImageCollection('LANDSAT/LC08/C01/T1_SR')
.filterDate(new Date('01/01/2019'), new Date('01/31/2019'))
.filterBounds(geometry);
var sen = ee.ImageCollection('COPERNICUS/S2')
.filterDate(new Date('01/01/2019'), new Date('01/31/2019'))
.filterBounds(geometry);
Map.addLayer(mod.first(),{bands:'NDVI',min:0,max:10000});
Map.addLayer(lan.first(),{bands:['B4','B3','B2'],min:0,max:1000});
Map.addLayer(sen.first(),{bands:['B4', 'B3', 'B2'],min:0,max:2000});
Geometry Imports
Layers
Map
Satellite
Google
Map data ©2019 Google Imagery ©2019 CNES / Airbus, DigitalGlobe
50 m
Terms of Use
Report a map error


Google Earth Engine
Search places and datasets...
Help
mehajain13
New Script *
CAUTION
Satellite
Map data ©2019 Google Imagery ©2019 CNES / Airbus, DigitalGlobe
50 m
Terms of Use
Report a map error

Be careful and mindful of how you are using these data!

- Cloud cover & haze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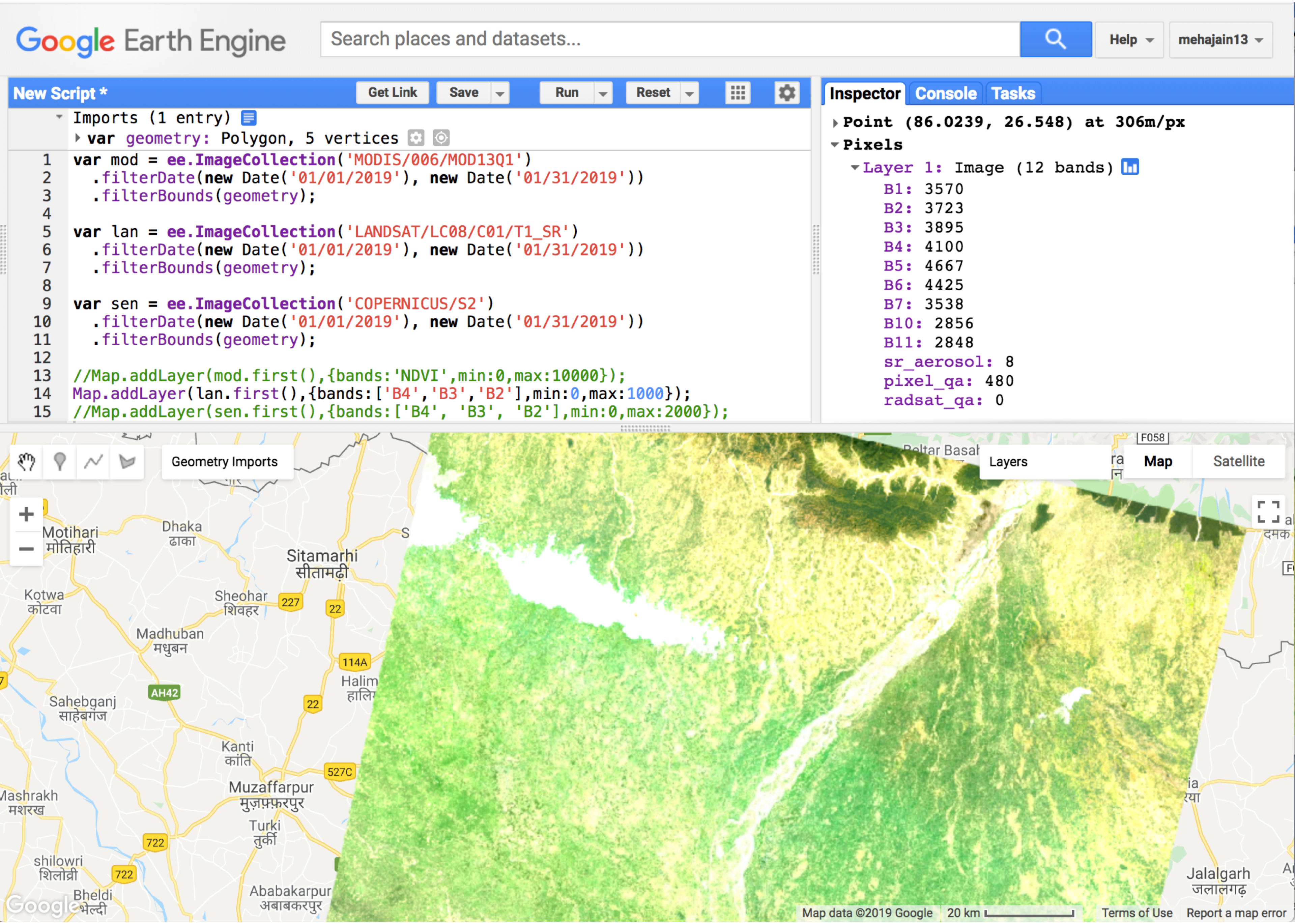
Inspector
Console
Tasks
Point (86.002, 26.4841) at 306m/px
Pixels
Layer 1: Image (12 bands)
B1: 341
B2: 474
B3: 898
B4: 568
B5: 2146
B6: 1701
B7: 1031
B10: 2899
B11: 2889
sr_aerosol: 224
pixel_qa: 322
radsat_qa: 0
Geometry Imports
Layers
Map
Satellite
Motihari
मोतिहारी
Dhaka
ढाका
Sitamarhi
सीतामढ़ी
Kotwa
कोटवा
Sheohar
शिवहर
Madhuban
मधुबन
Sahebganj
साहेबगंज
Kanti
कांति
Muzaffarpur
मुज़फ़्फ़रपुर
Mashrakh
मशरख
Turki
तुर्की
Ababakarpur
अबाबकरपुर
Bheldi
भेल्दी
Jalalgarh
जलालगढ़
227
22
114A
AH42
527C
722
F058
Map data ©2019 Google
20 km
Terms of Use
Report a map error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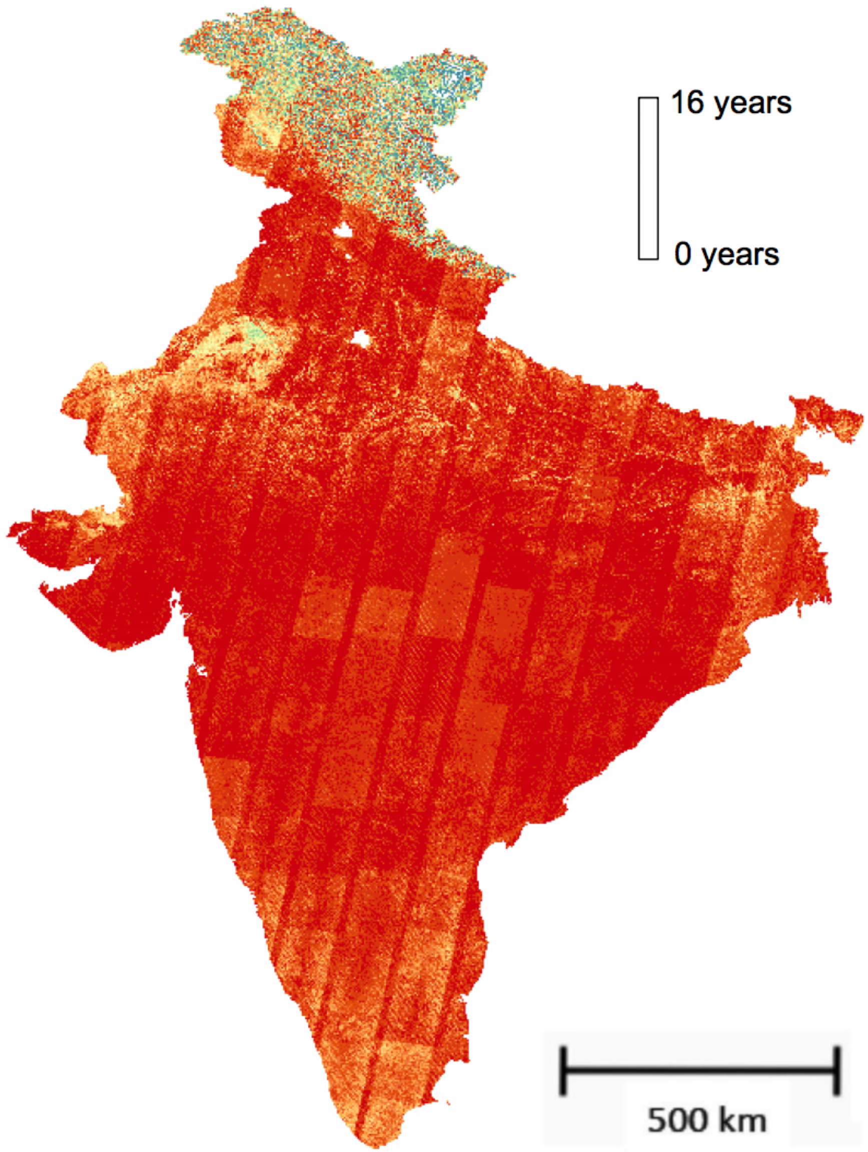
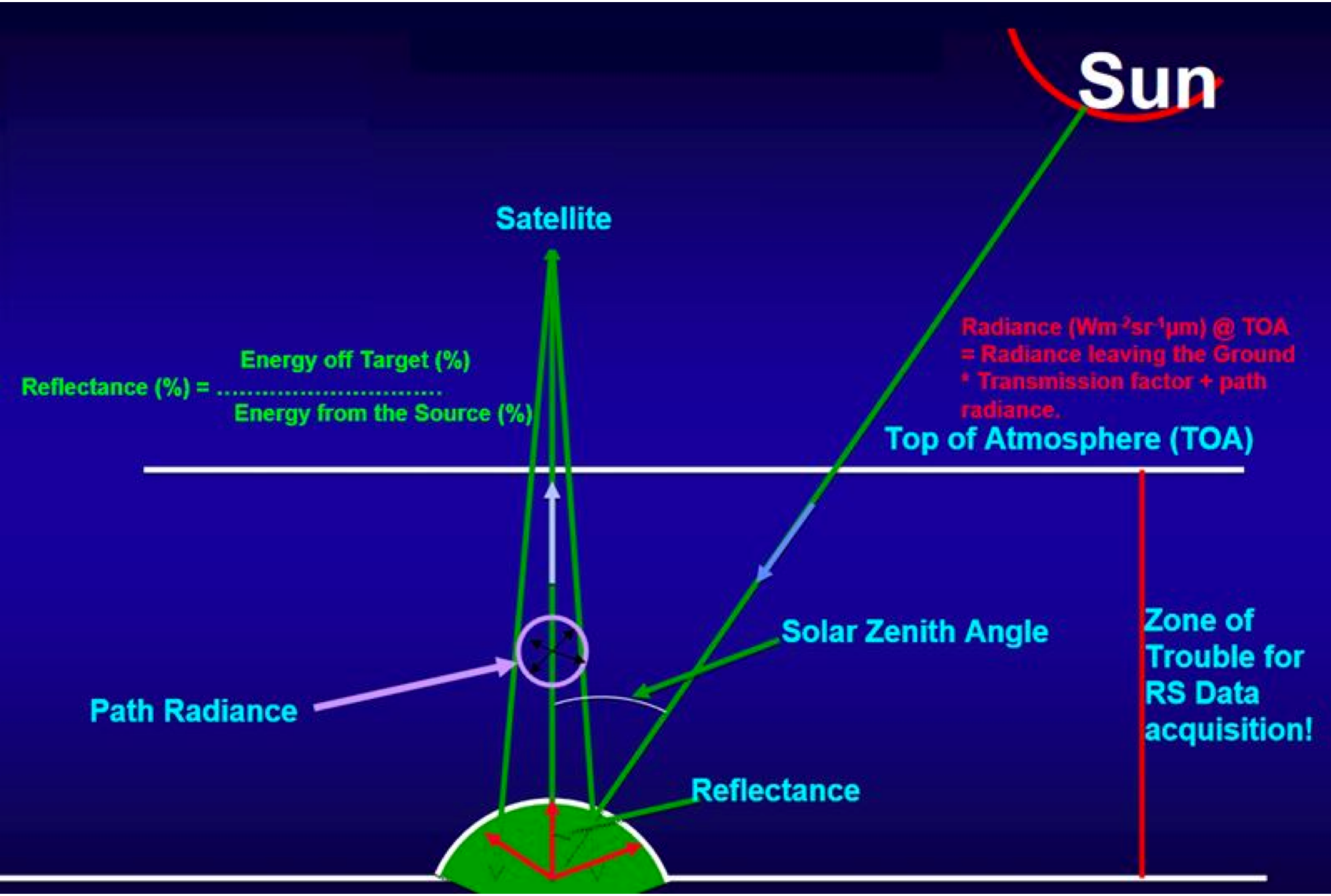
//Map.addLayer(sen.first(),{bands:['B4', 'B3', 'B2'],min:0,max:2000});
Inspector
Console
Tasks
Point (86.0239, 26.548) at 306m/px
Pixels
Layer 1: Image (12 bands)
B1: 3570
B2: 3723
B3: 3895
B4: 4100
B5: 4667
B6: 4425
B7: 3538
B10: 2856
B11: 2848
sr_aerosol: 8
pixel_qa: 480
radsat_qa: 0
Geometry Imports
Layers
Map
Satellite
Motihari
Dhaka
Sitamarhi
Sheohar
Madhuban
Kotwa
Sahebganj
Kanti
Muzaffarpur
Turki
Mashrakh
shilowri
Bheldi
Ababakarpur
Halim
Jalalgarh
Map data ©2019 Google
20 km
Terms of Use
Report a map error

Figure S1. Available Landsat imagery from 2000–2001 to 2015–2016. Number of years for which at least one cloud-free pixel is available during the main period of the winter growing season, January 1 to March 31. Pixels range from those where no imagery were available (blue) across the 16 years considered in our study (2000-2001 to 2015-2016) to pixels where imagery were available for all 16 years (red). A large proportion of the country has at least one missing year across time, highlighting the difficulty in relying on Landsat imagery to produce annual cropped area maps for much of the country.

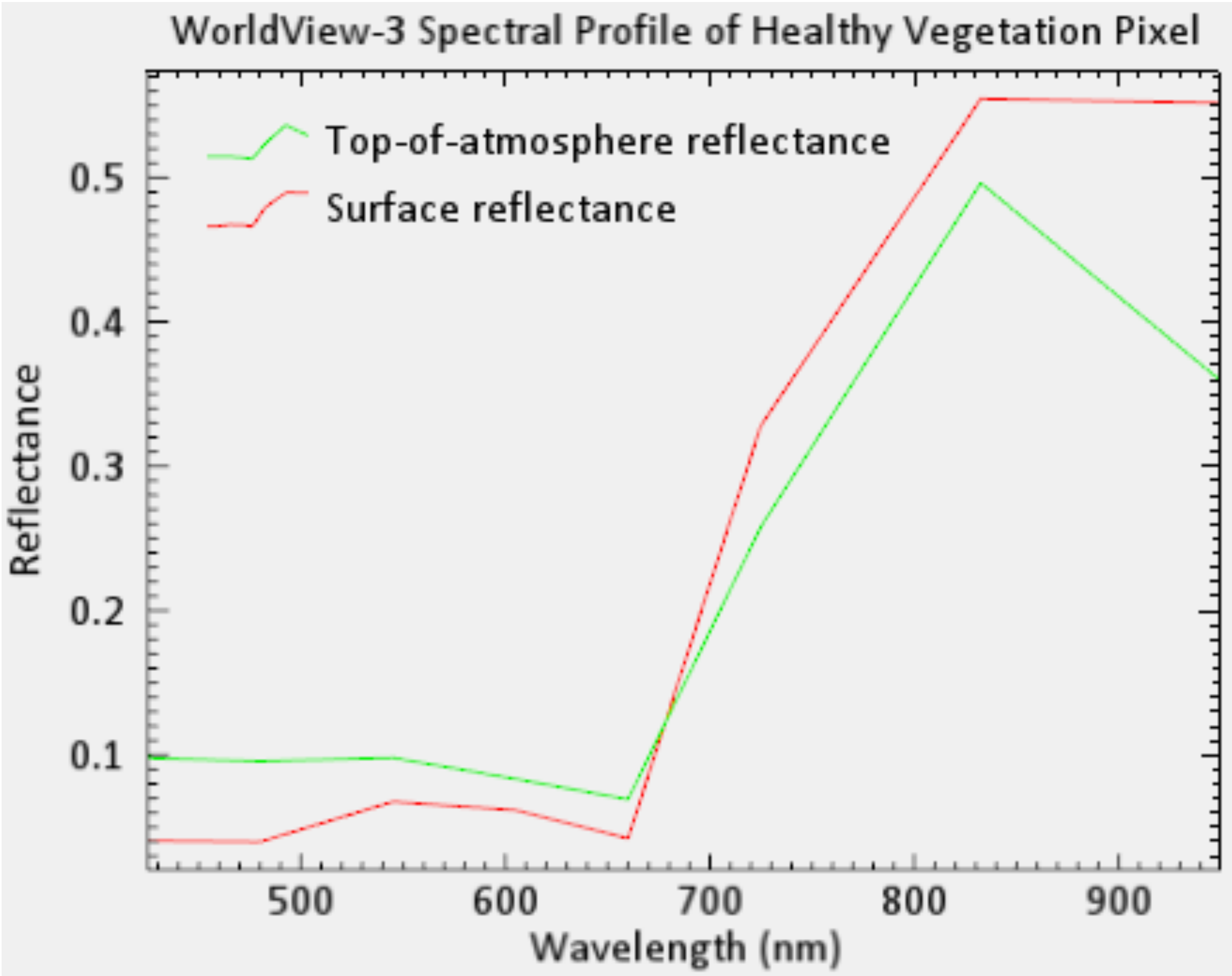


Be careful and mindful of how you are using these data!

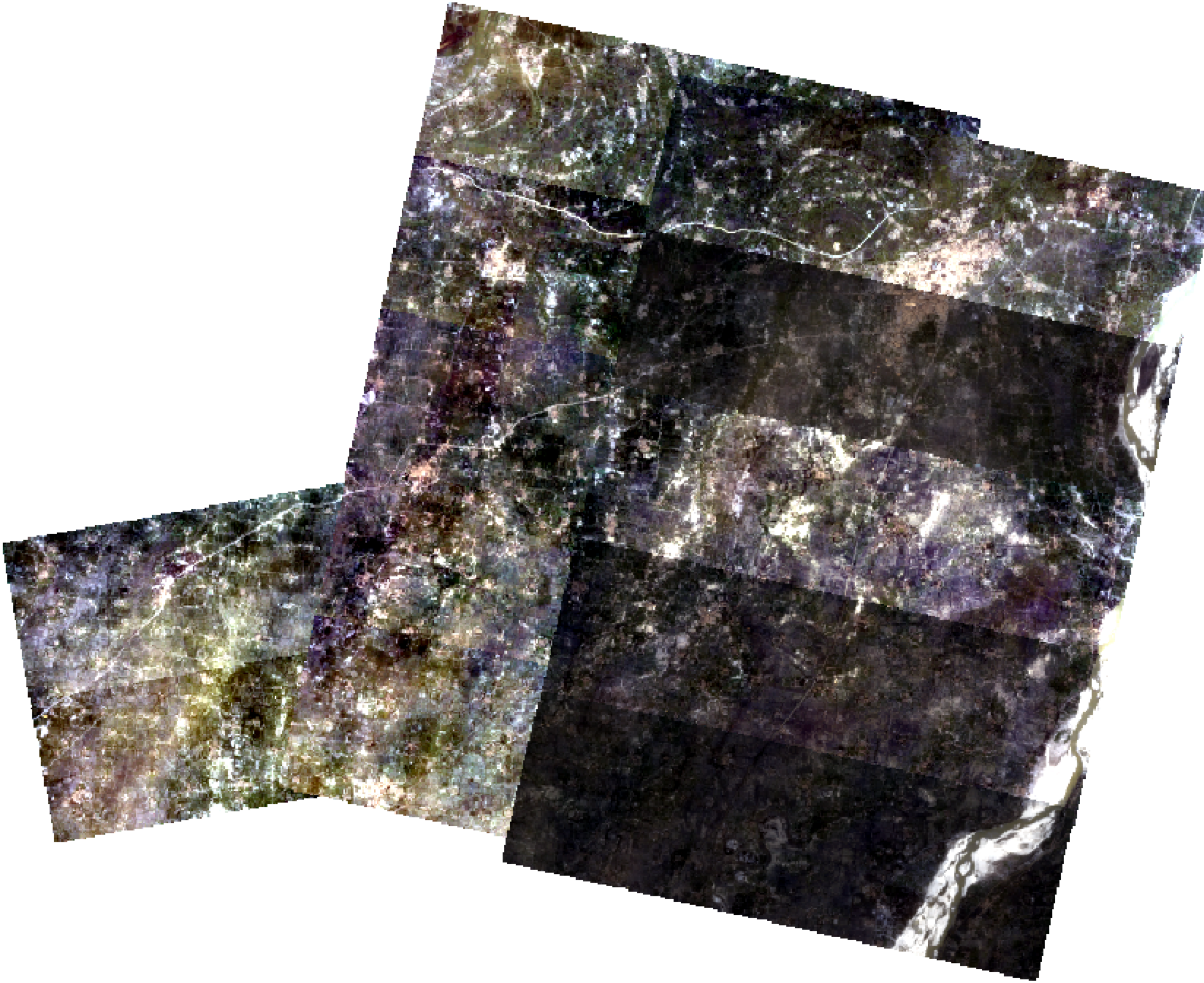
- Cloud cover & haze
- Surface reflectance corrections



www.un-spider.com



www.harrisgeospatial.com



Be careful and mindful of how you are using these data!

- Cloud cover & haze
- Surface reflectance corrections – you can get around this by using pre-processed data correct to surface reflectance:
  - MODIS – pretty good
  - Landsat – pretty good
  - Sentinel 2 – work in progress
  - Planet – current corrections are pretty poor!

Be careful and mindful of how you are using these data!

- Cloud cover & haze
- Surface reflectance corrections
- Make sure the sensor is the same through time (e.g., Landsat)

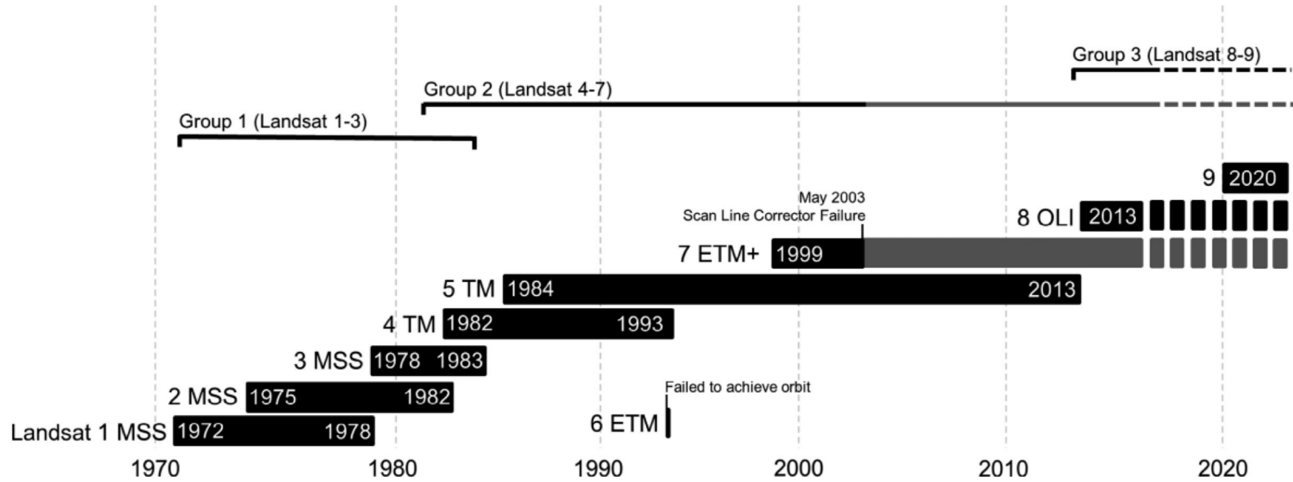


FIG. 1. A timeline of Landsat satellites and sensors. Landsat 9 launch date is based on recent congressional appropriations language.

TABLE 1. Summary of band designations and pixel size (m) for all Landsat satellites (LS) and sensors.

Landsat sensor	LS 1–5 MSS	LS 4–5 TM	LS 7 ETM+	LS 8 OLI/TIRS	Pixel size (m)
Coastal aerosol				B1 (0.43–0.45)	30
Blue		B1 (0.45–0.52)	B1 (0.45–0.52)	B2 (0.45–0.51)	30
Green	B1 (0.5–0.6)	B2 (0.52–0.60)	B2 (0.52–0.60)	B3 (0.53–0.59)	30 (60† for MSS)
Red	B2 (0.6–0.7)	B3 (0.63–0.69)	B3 (0.63–0.69)	B4 (0.64–0.67)	30 (60† for MSS)
NIR 1	B3 (0.7–0.8)				60
NIR	B4 (0.8–1.1)	B4 (0.76–0.90)	B4 (0.77–0.90)	B5 (0.85–0.88)	30 (60† for MSS)
SWIR 1		B5 (1.55–1.75)	B5 (1.55–1.75)	B6 (1.57–1.65)	30
SWIR 2		B7 (2.08–2.35)	B7 (2.09–2.35)	B7 (2.11–2.29)	30
Thermal		B6 (10.40–12.50)	B6‡ (10.40–12.50)	B10 (10.60–11.19) B11 (11.50–12.51)	30†
Pan-Chromatic			B8 (0.52–0.90)	B8 (0.50–0.68)	15
Cirrus				B9 (1.36–1.38)	30

Other important issues to consider

- Bias in the satellite data?
- Is it really measuring what you think (importance of validation data)?

What do I suggest?

- Talk to and/or collaborate with a remote sensing scientist!
  - E.g., Lobell, Burke, and Ermon
- Look at the data before you use it!!! Clouds and seams will often be visually apparent
- I’m writing a piece for REEP about the benefits and potential pitfalls of using satellite data – stay tuned!

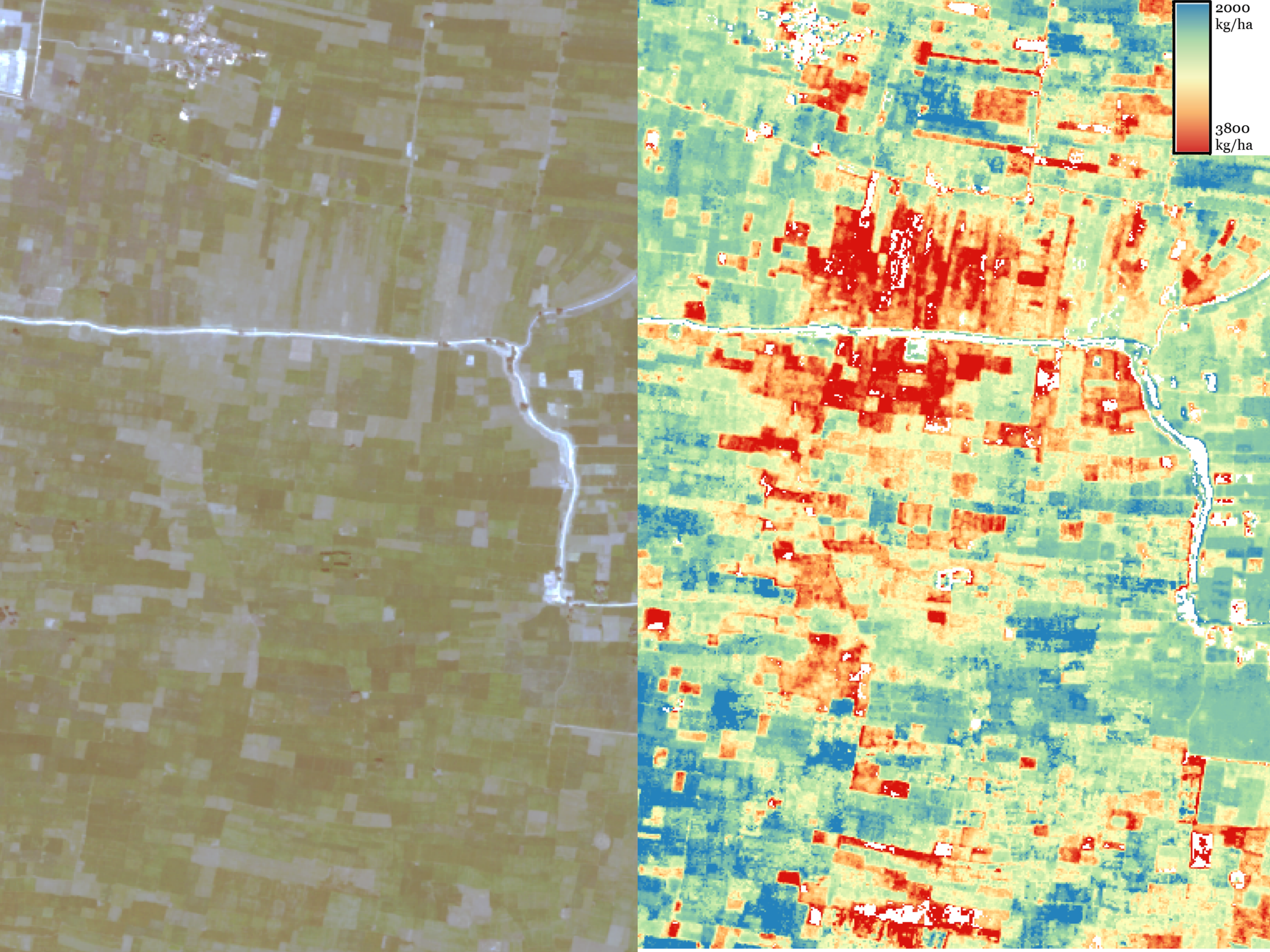
Outline

- Primer on satellite data products & potential pitfalls
- Work on mapping field-level yields of smallholder wheat fields in India

Large scale yield estimation can help enhance food production

- Identify regions that are low yielding with large yield gaps
- Conduct impact evaluation of new interventions, policies, or technologies on the ground to identify potential solutions

Crop cut data are the gold standard for yield estimation, but are difficult and costly to obtain



2000
kg/ha
3800
kg/ha

Micro-satellite data better match the spatial resolution of smallholder farms, but only available for recent years

Training data vary in their ease of collection

Hardest,
Most
expensive

Crop cut data

Self-report data

Crop model simulations

Easiest,
Lowest cost

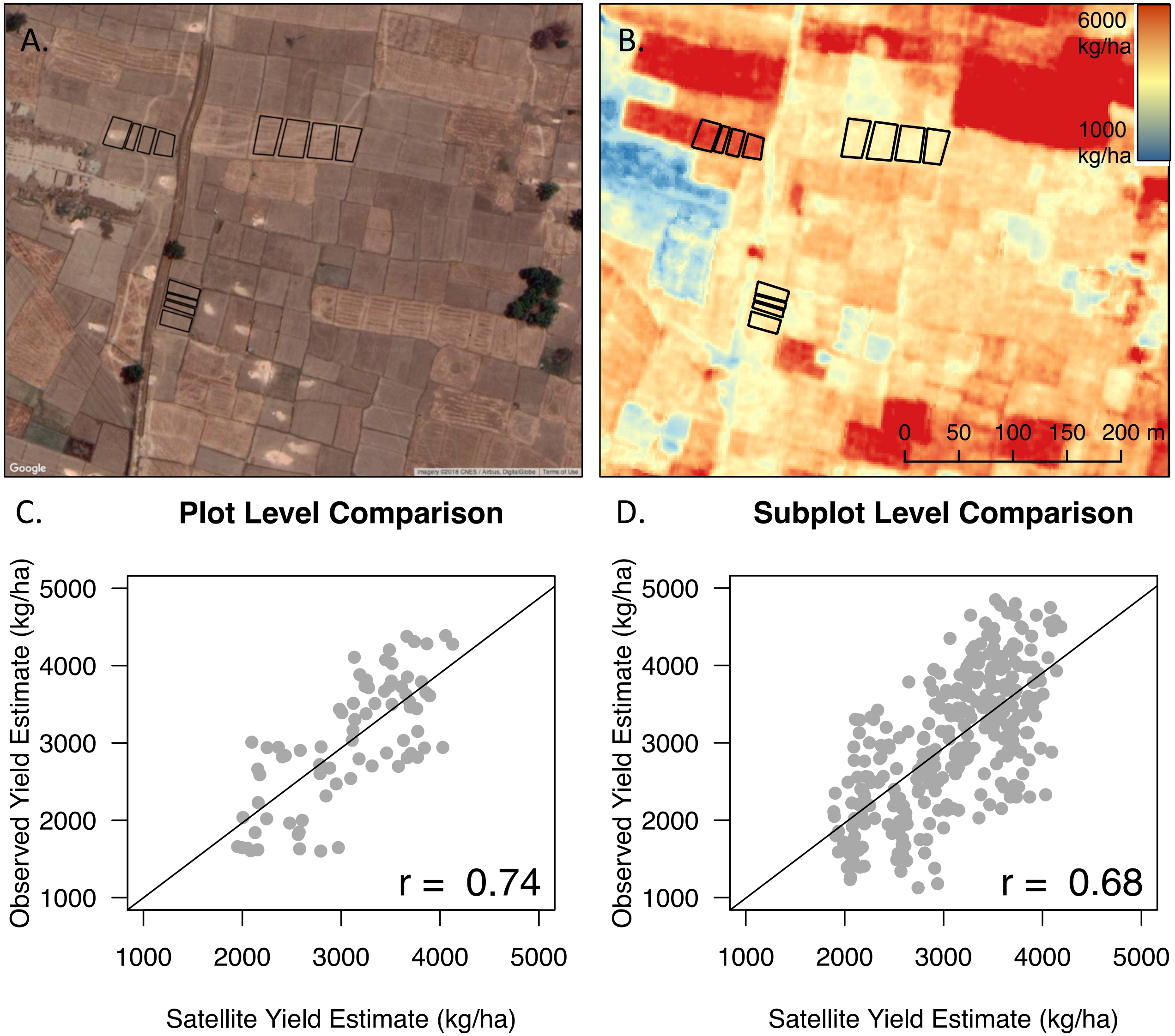
Jain et al. (2016). *Remote Sensing*

Yield Estimation

$$\text{Yield} \sim \beta_1 \text{GCVI}_{t1} + \beta_2 \text{GCVI}_{t2} + \beta_3 \text{GCVI}_{t3} \ldots$$

We then apply these β coefficients to GCVI data across the landscape to estimate yield in all fields

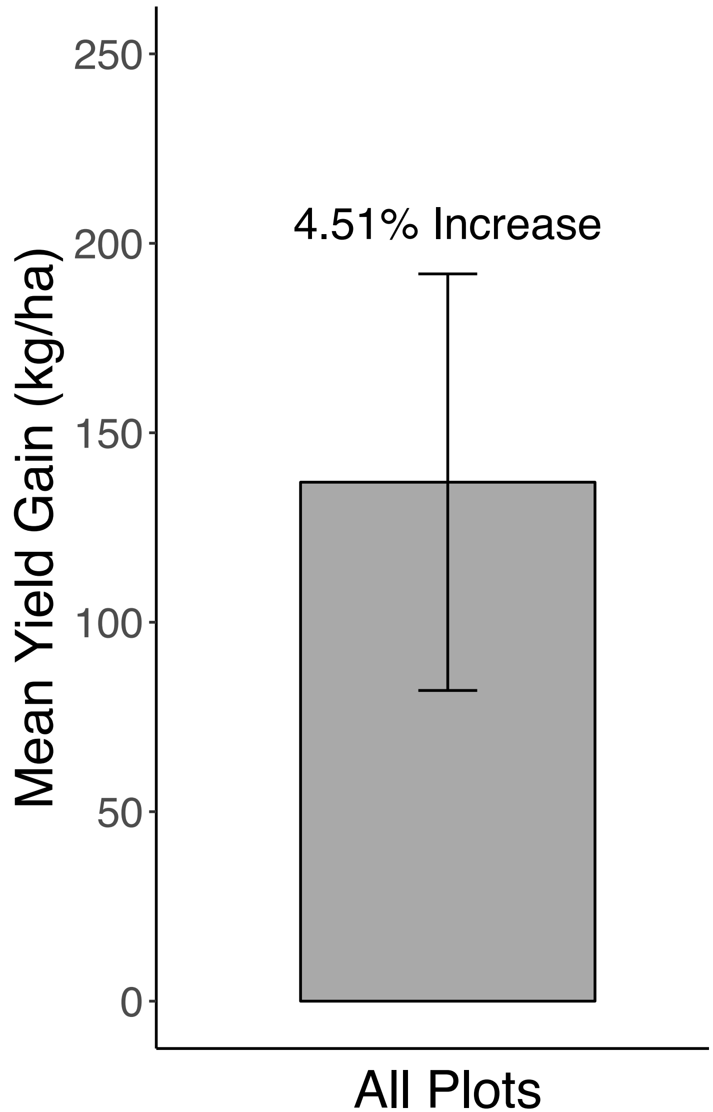
Can map field and sub-field yields accurately



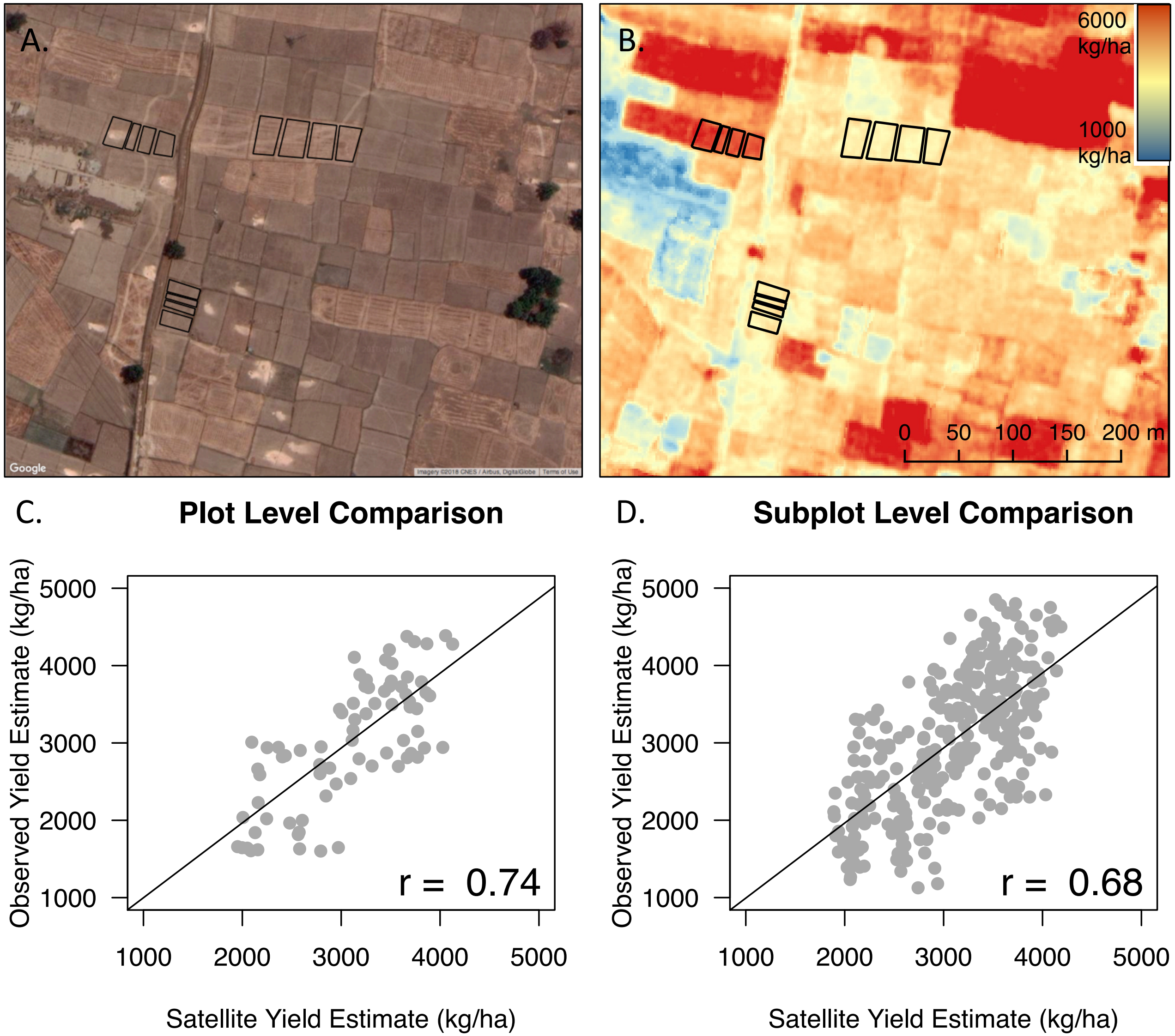
We ran a split-plot experiment where in half of the field farmers used a new fertilizer spreading technology

Jain et al. (in review)
Nature Sustainability

The fertilizer spreader increases yields with no increase in inputs



Satellite data are able to detect yield gains, providing a low cost way to conduct impact evaluation



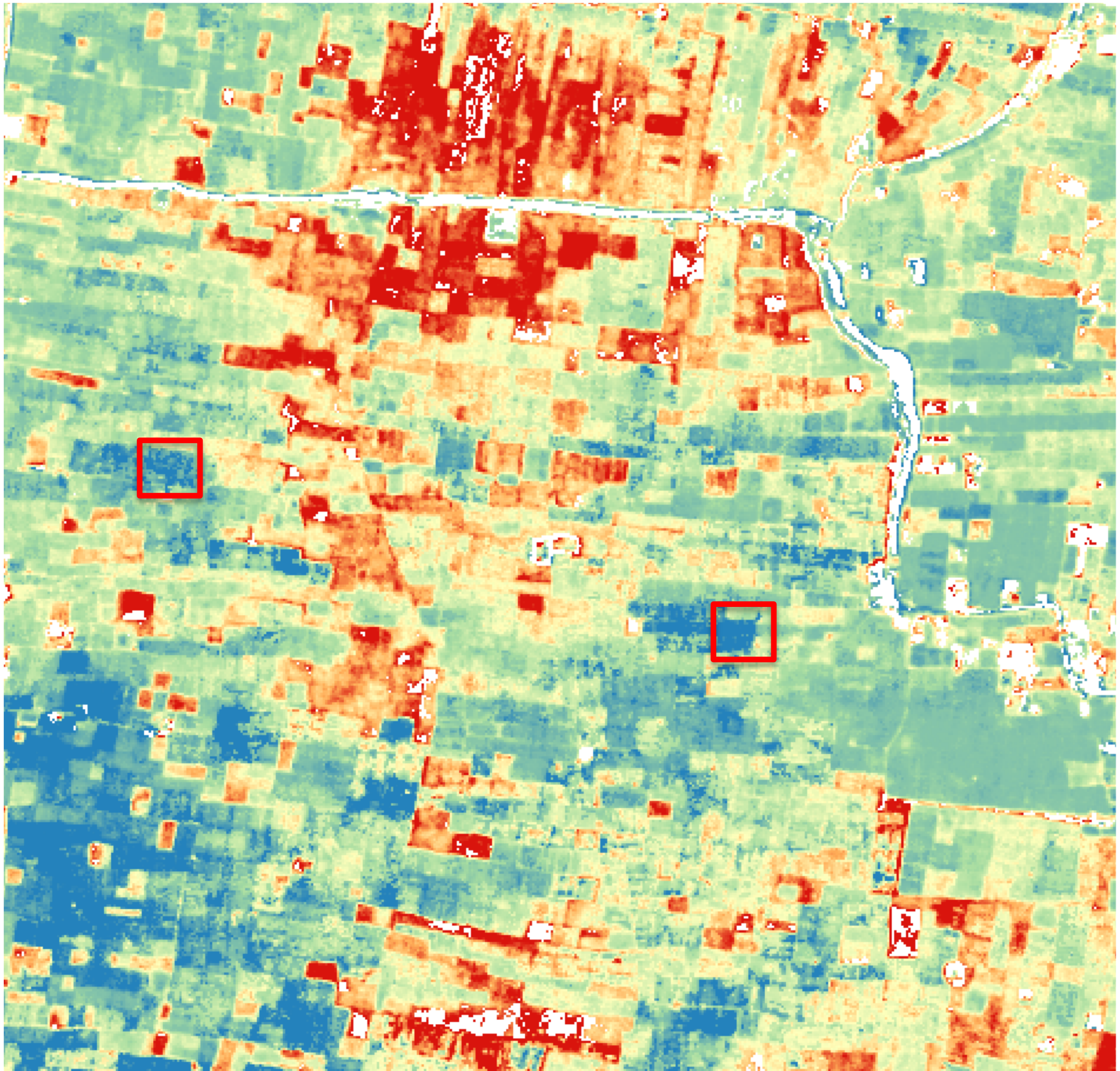
Fields that are lower yielding have larger absolute and relative yield gains

	Difference Between Spreader and Manual (Crop Cut Yield)	
	Yield Abs. Diff. (t/ha)	Yield % Diff. (%)
	(1)	(2)
Mean Baseline Yield (t/ha) (Crop Cut in the Same Year)	-0.121***	-7.151***
	(0.044)	(1.471)
Sowing Date	0.005*	0.182*
	(0.003)	(0.103)
Year	-0.157*	-5.791**
	(0.080)	(2.677)
Constant	0.475**	27.396***
	(0.195)	(6.540)
Mean Baseline Yield	0.112	0.228
Sowing Date	0.031	0.039
R^2	0.215	0.371

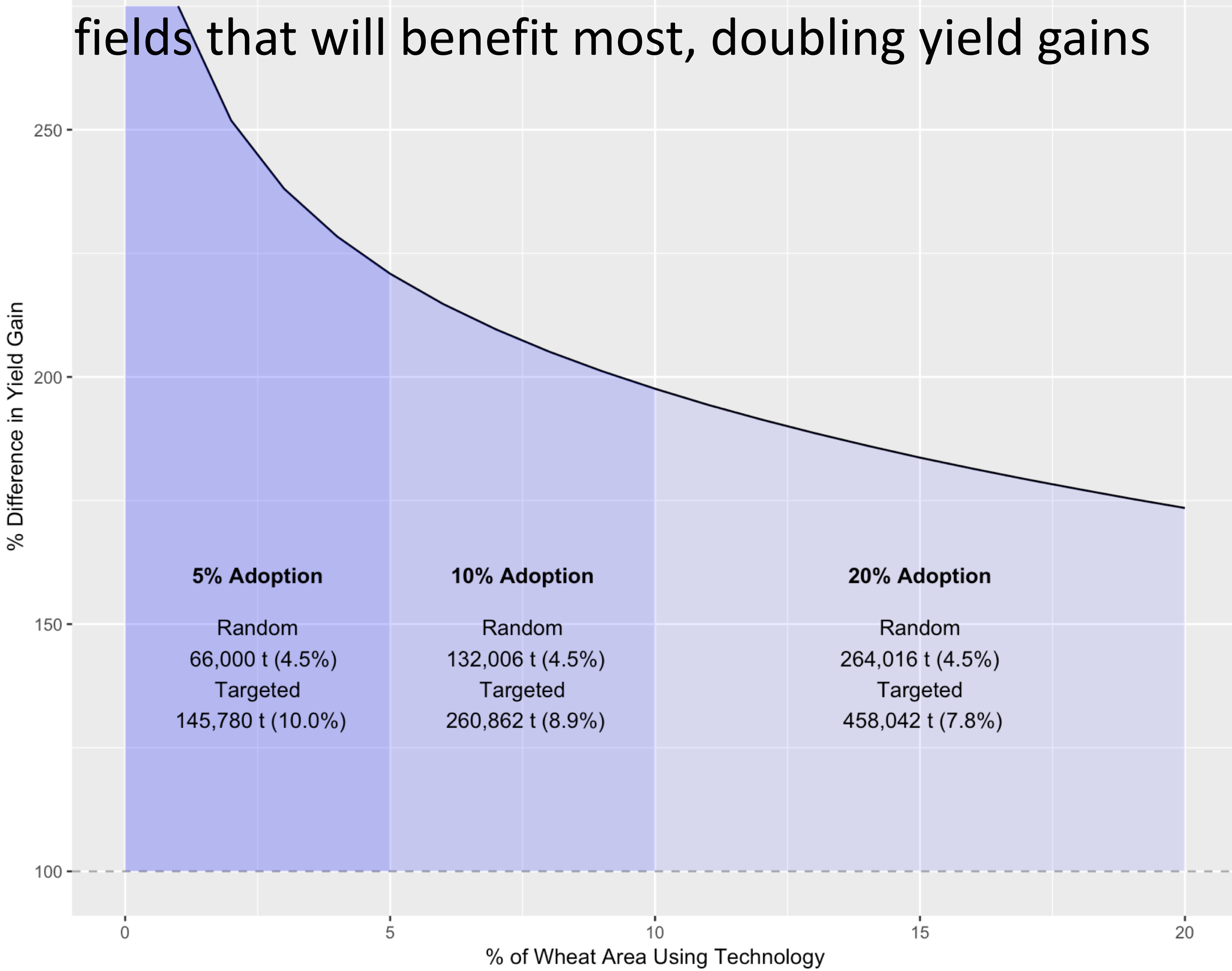
Note: *p<0.1; **p<0.05; ***p<0.01

Jain et al. (in preparation)

What happens to yield gains if I target the lowest yielding fields (that get the largest yield benefits)?



Satellite data can be used to target the technology to the fields that will benefit most, doubling yield gains



Main Findings

- The fertilizer spreader leads to large yields gains with no increases in inputs, and yield gains can be detected using satellite yield estimates

Main Findings

- The fertilizer spreader leads to large yields gains with no increases in inputs, and yield gains can be detected using satellite yield estimates
- We can use satellite data to target lower yielding fields, doubling yield gains with the same intervention effort

Thanks!

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- Coauthors: David Lobell (Stanford), Balwinder Singh, Amit Srivastava, Ram Malik (CIMMYT), Andrew McDonald (Cornell)

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