ForestNet: Classifying Drivers of Deforestation in Indonesia using Deep Learning on Satellite Imagery

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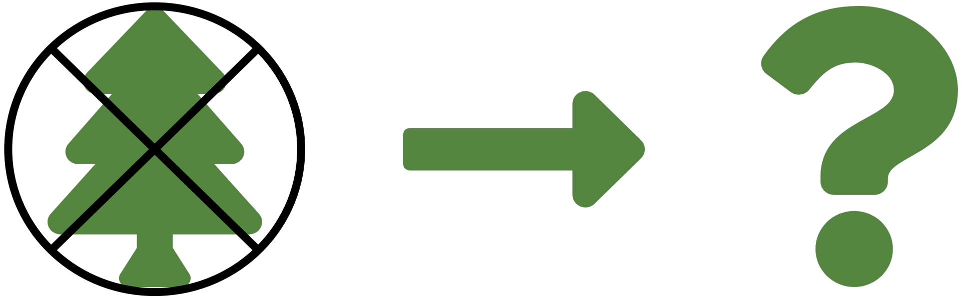
Deforestation

- Preserving forests is critical.[1,2]
- Tropical deforestation:
  - 10% of annual GHG emissions[3]
  - Potential for climate tipping points[4]
- **Indonesia** is among the largest GHG emitters worldwide[5]

[1]Global consequences of land use. *Science 2005.*
[2]Solutions for a cultivated planet. *Nature 2011.*
[3]IPCC special report on climate change. *2019.*
[4]Climate tipping points—too risky to bet against. *Nature 2019.*
[5]A review of land-based greenhouse gas flux estimates in Indonesia. *Environmental Research Letters 2018.*

Forest Loss Direct Drivers



- What causes tropical forest loss?
  - *Direct drivers:* land-use which replaces forest
- Why is determining forest loss drivers useful?
  - To help **companies** fulfill their zero-deforestation commitments[6]
  - To help **decision makers** design and implement targeted policy[7]

[6]Supply change: Tracking corporate commitments to deforestation-free supply chains. *Forest Trends 2017.*

[7]A policy-driven framework for conserving the best of earth's remaining moist tropical forests. *Nature Ecology & Evolution 2020.*

Driver Attribution

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	Scalability	Accuracy
Manual Inspection[8]		

[8]What causes deforestation in Indonesia? *Environmental Research Letters 2019*.

Driver Attribution

	Scalability	Accuracy
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Deep Learning		

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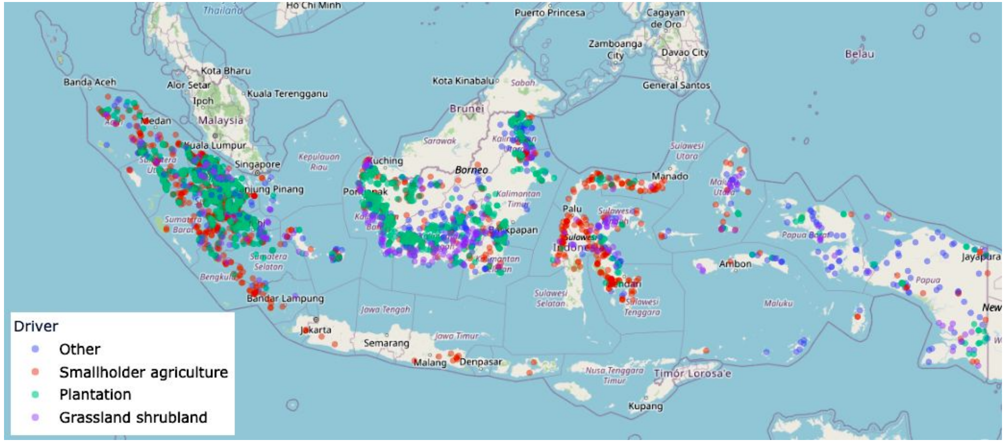
Data

Forest Loss Events and Driver Annotations



Driver Class, N	Training	Validation	Test
Plantation	686	219	265
Smallholder Agriculture	556	138	207
Grassland/shrubland	143	47	85
Other	231	70	112
Overall	1,616	474	669

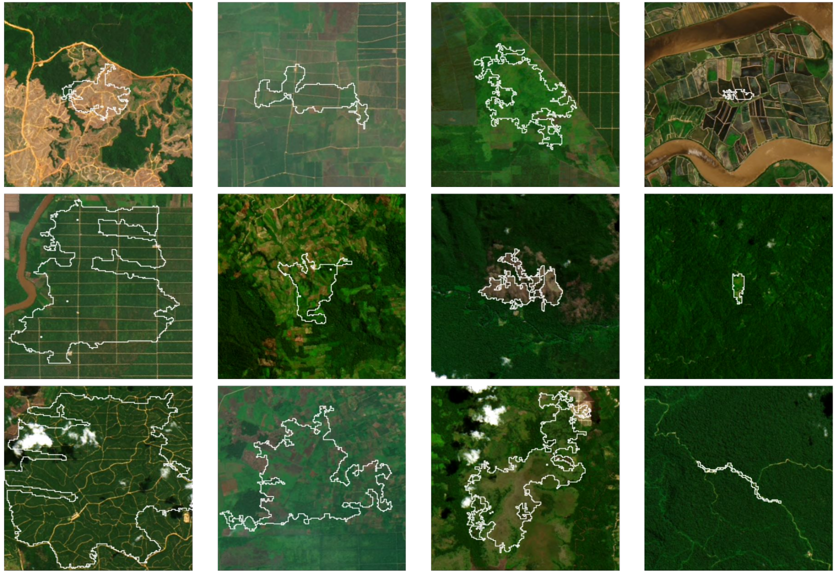
- Curated in Kemen et al.[8]
- Global Forest Change for forest loss regions from 2001 to 2016[11]
- Expert-annotated events using high res imagery in Google Earth

[8]What causes deforestation in Indonesia? *Environmental Research Letters 2019*.

[11]High-resolution global maps of 21st-century forest cover change. *Science 2013*.

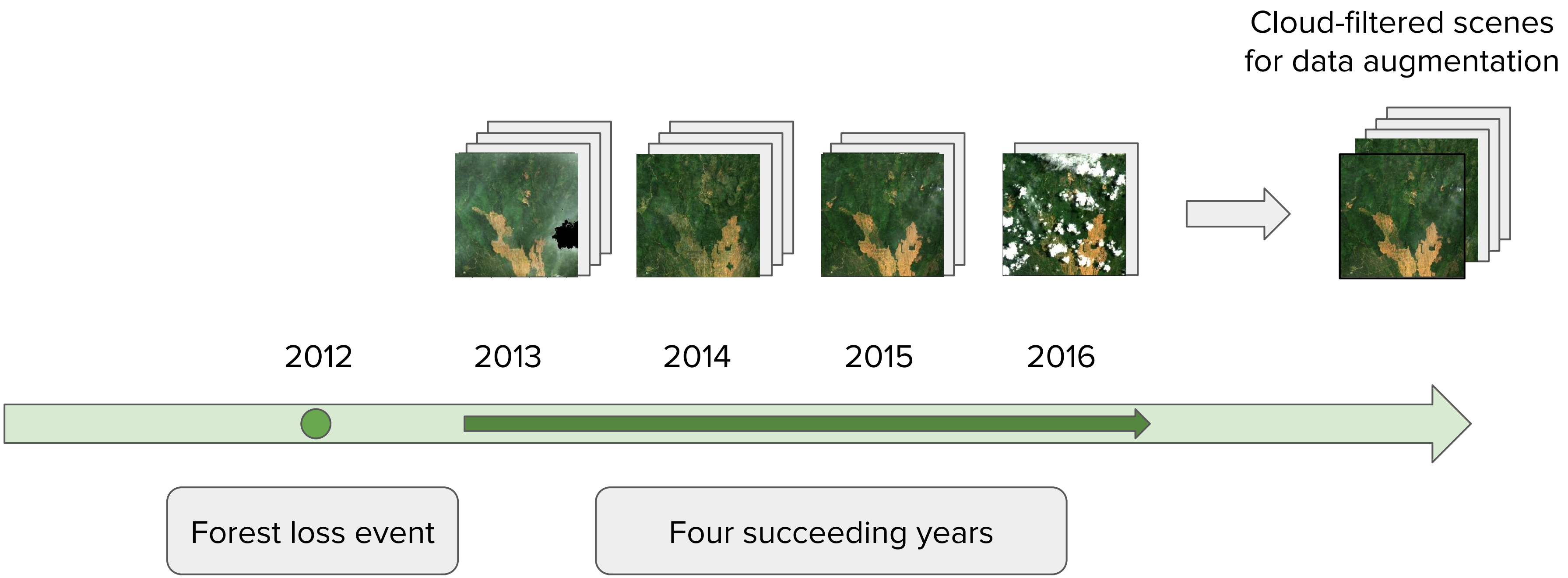
Satellite Imagery

- Landsat 8
  - Publicly available
  - 15m spatial resolution
  - Visible (RGB) + infrared bands
- Cloud-minimized using custom procedure leveraging cloud and cirrus bands



Plantation   Smallholder Agriculture   Grassland/ Shrubland   Other

Scene Data Augmentation (SDA)



Models

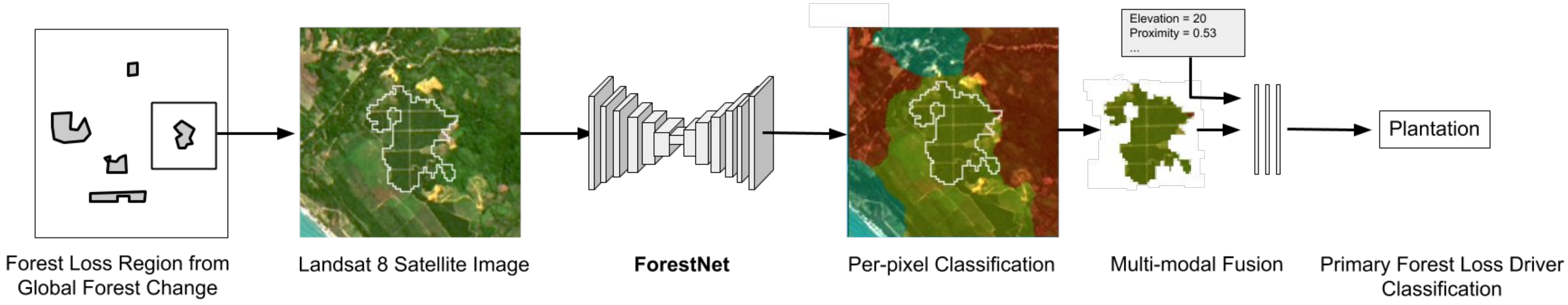
Baseline Models and Auxiliary Predictors

- Random Forest models
- Input variety of predictors
- Inputs and outputs data w.r.t forest loss region

Predictor Group	Predictor (units)	Spatial Resolution	Temporal Resolution	Source
Topographic	Elevation (m) Slope (0.01°) Aspect (0.01°)	30m	N/A	USGS (SRTM)
Climatic	Surface-Level Albedo (0.01%) Clear-Sky Longwave Flux (W/m^2) Clear-Sky Solar Flux (W/m^2) Direct Evaporation from Bare Soil (W/m^2) Longwave Radiation Flux (W/m^2) Ground Heat Net Flux (W/m^2) Latent Heat Net Flux (W/m^2) Specific Humidity (10^{-4} kg/kg) Potential Evaporation Rate (W/m^2) Ground-Level Precipitation (0.1 mm) Sensible Heat Net Flux (W/m^2) Volumetric Soil Moisture Content (0.01%) Air Pressure at Surface Level (10 Pa) Wind Components 10m above Ground (0.01 m/s) Water Runoff at Surface Level (0.01 kg/m^2)	56km	1 day	NCEP (CFSv2)
Soil	Presence of Peat	N/A	N/A	GFW (MoA)
Accessibility	Euclidean Distance to Road (km)	N/A	N/A	Open Street Map
Proximity	Euclidean Distance to City (km)	N/A	N/A	Open Street Map
Imaging	Landsat 8 Visible Landsat 8 IR Landsat 8 NDVI	15m 30m 30m	16 days	USGS (Landsat 8)

ForestNet

- **Semantic segmentation**
- Three key technical developments:
    1. Scene Data Augmentation (SDA)
    2. Multi-modal fusion
    3. Pre-trained (PT)



Results

Results

Model	Predictors	Val		Test	
		Acc	F1	Acc	F1
RF	Visible	0.60	0.52	0.52	0.44
RF	Visible + Aux	0.71	0.67	0.69	0.64
CNN	Visible	0.79	0.76	0.76	0.72
CNN + SDA	Visible	0.83	0.79	0.77	0.72
CNN + SDA + PT	Visible	0.84	0.81	0.79	0.74
CNN + SDA + PT	Visible + Aux	**0.85**	**0.82**	**0.80**	**0.76**

Best CNN: FPN + EfficientNet-B2 Backbone

Limitations and Future Work

1. <u>Inputs a single satellite image</u> during prediction
    a. Different drivers demonstrate different evolution of landscape over time
2. <u>Can’t differentiate</u> species of plantations and types of smallholder agriculture development

Future work should explore use of **multiple high resolution images** to improve prediction accuracy and granularity.

Conclusion

- ForestNet accurately identifies the direct driver of forest loss in satellite imagery
- Potential to generate accurate maps of forest loss drivers over all of Indonesia
- This new data could aid companies and policymakers to **reduce deforestation and mitigate climate change**

Thank you!