UNIVERSITY OF TWENTE.

AI FOR EARTH OBSERVATION APPLICATIONS: OPPORTUNITIES AND CHALLENGES

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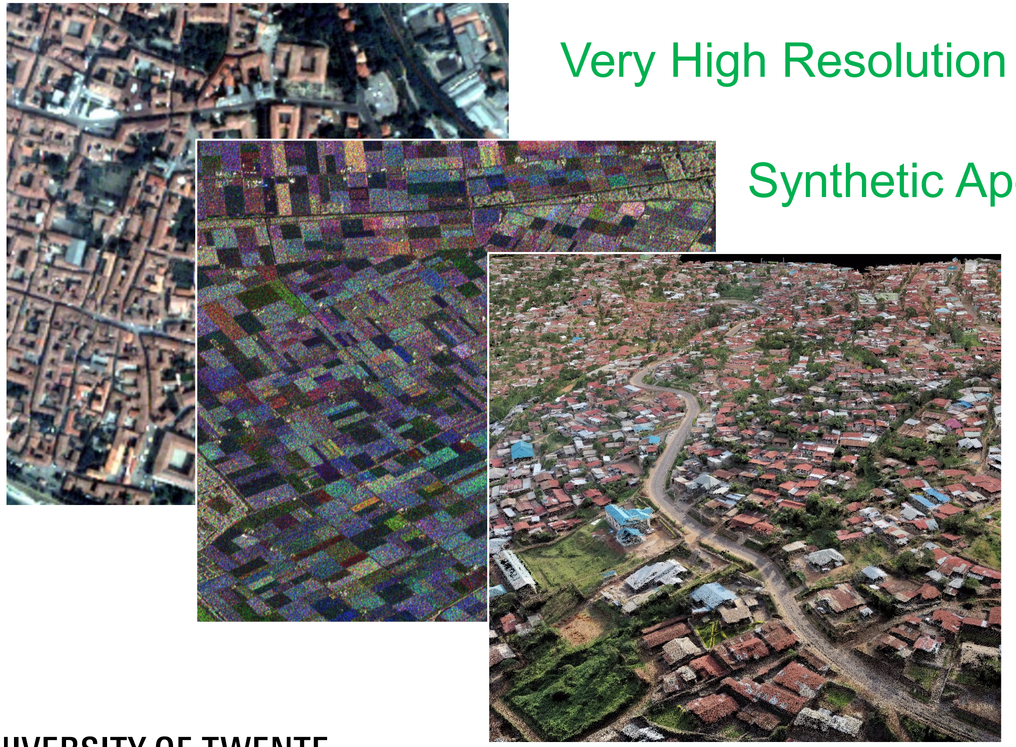
WHY AI FOR EARTH OBSERVATION?

Opportunity: Increasing amount of (big) geo-data

- Large variety of Earth Observation (EO) data
- Data collected by terrestrial sensors and citizens



Very High Resolution (VHR) images

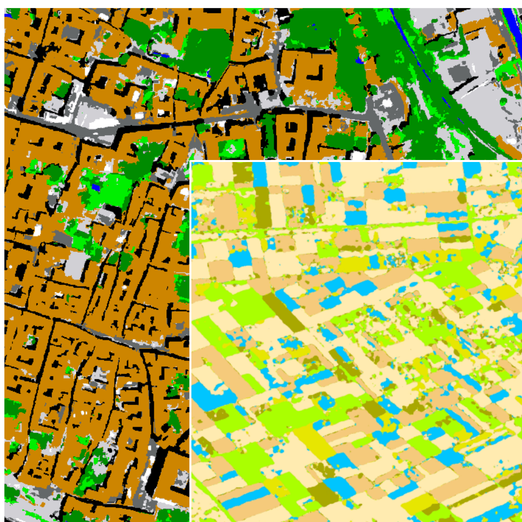
Synthetic Aperture Radar (SAR) images

Unmanned Aerial Vehicles (UAV)

WHY AI FOR EARTH OBSERVATION?

Challenge: Efficiently extract the information content from EO data and address geospatial applications

➡ AI (deep learning) techniques



Land cover maps

Crop type maps

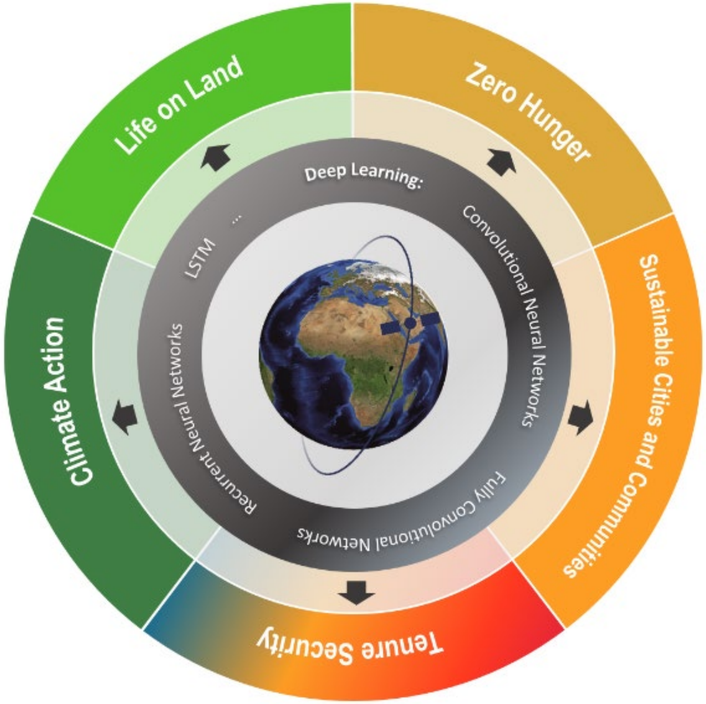
Cadastral or field Boundaries

AI & EO FOR THE SUSTAINABLE DEVELOPMENT GOALS

Numerous geospatial applications:

- Mapping and monitoring the natural and urban environment

- Global environmental and societal challenges, e.g.,
  - Zero hunger (SDG 2)
  - Sustainable cities and communities (SDG 11)
  - Tenure security (SDG 1, 2, 5, 11,15, 16)
  - Climate action (SDG 13)
  - Life on Land (SDG 15)



C. Persello et al., **"Deep Learning and Earth Observation to Support the Sustainable Development Goals,"** IEEE Geoscience and Remote Sensing Magazine, Volume: 10, No. 2, June 2022

MAPPING SMALLHOLDER FARMS

- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Target 2.3. By 2030, double the agricultural productivity and incomes of small-scale food producers

Smallholder farmers in Africa

- >80% of the cropland in Africa is cultivated by smallholder farmers
- Employing about 60% of the labour market
- Large growth of African population
- Incomplete spatial information is available

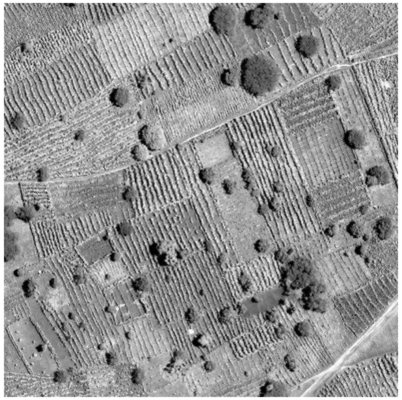
Source: oneacrefund.org

DELINEATION OF SMALLHOLDER FARMS

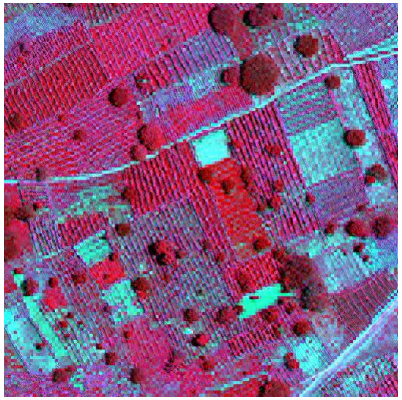
Goal: Delineation of agricultural fields in smallholder farms from VHR satellite images

Challenges

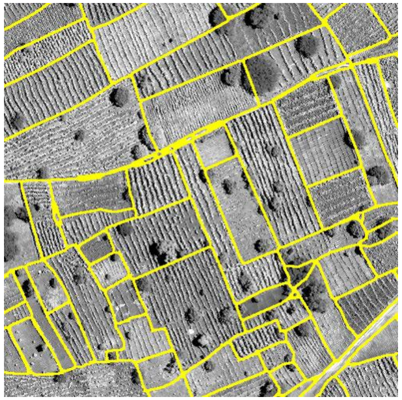
- Small sized and irregularly shaped fields
- Physical edges often indistinct
- Complex textural patterns



PAN

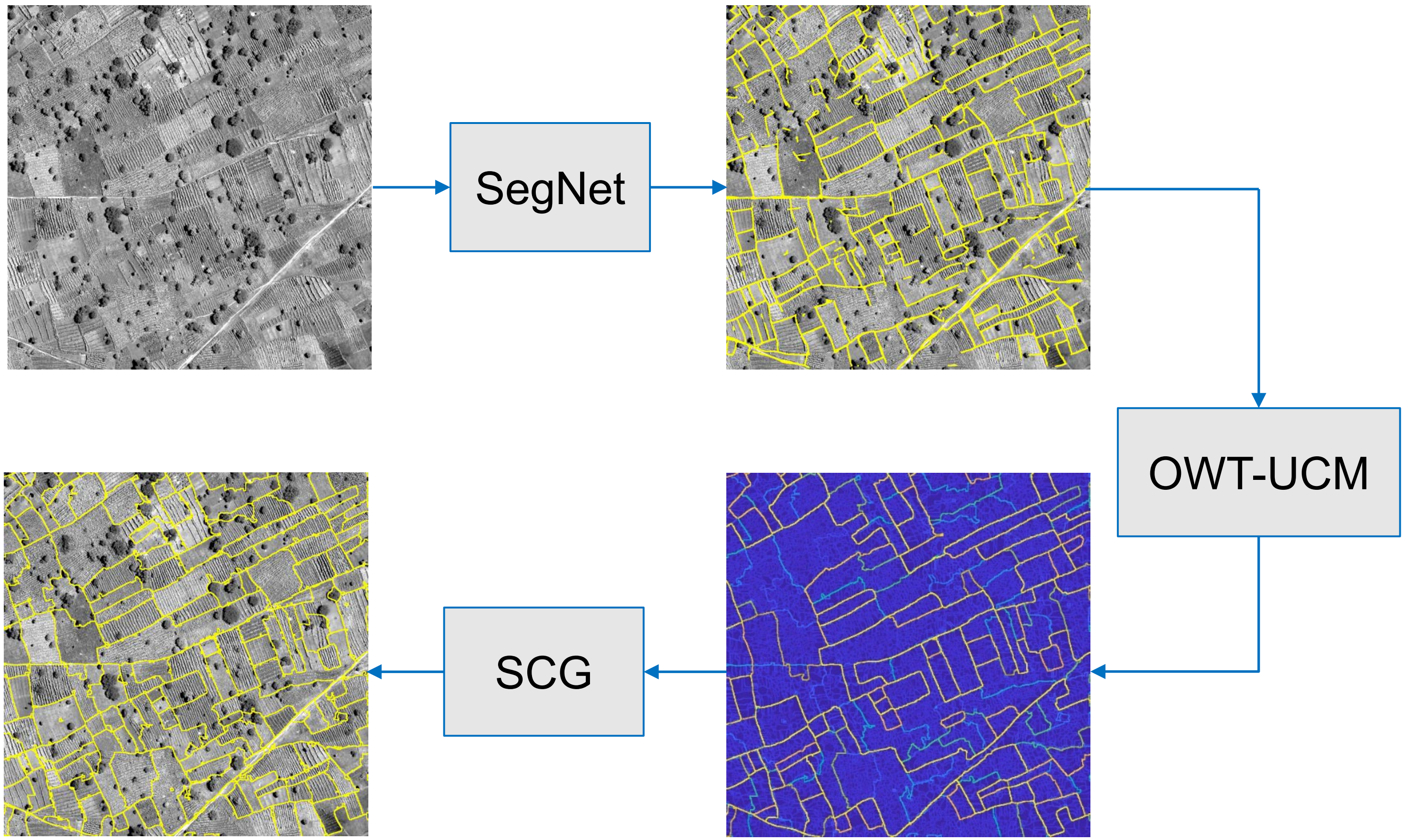


MS



Boundaries

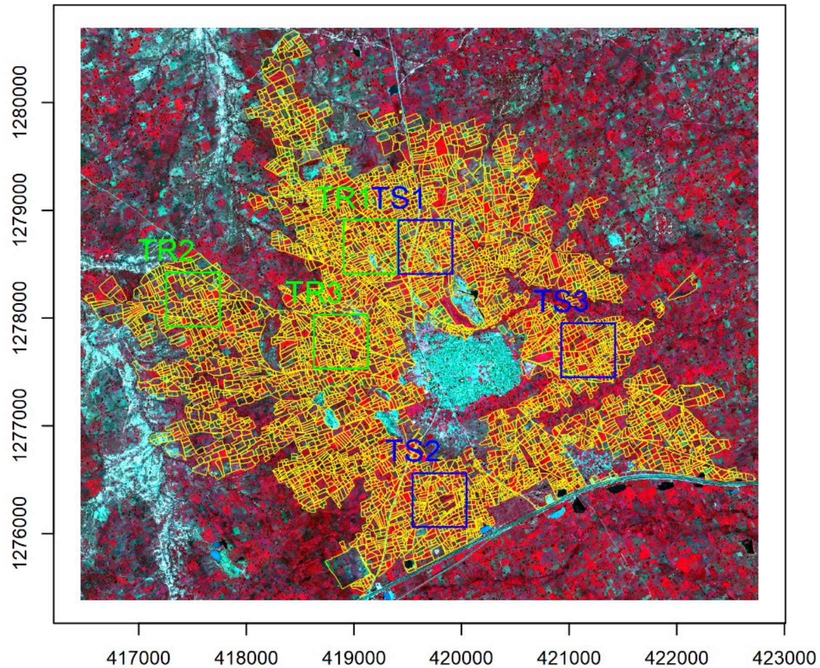
DEEP LEARNING APPROACH TO FIELD DELINEATION

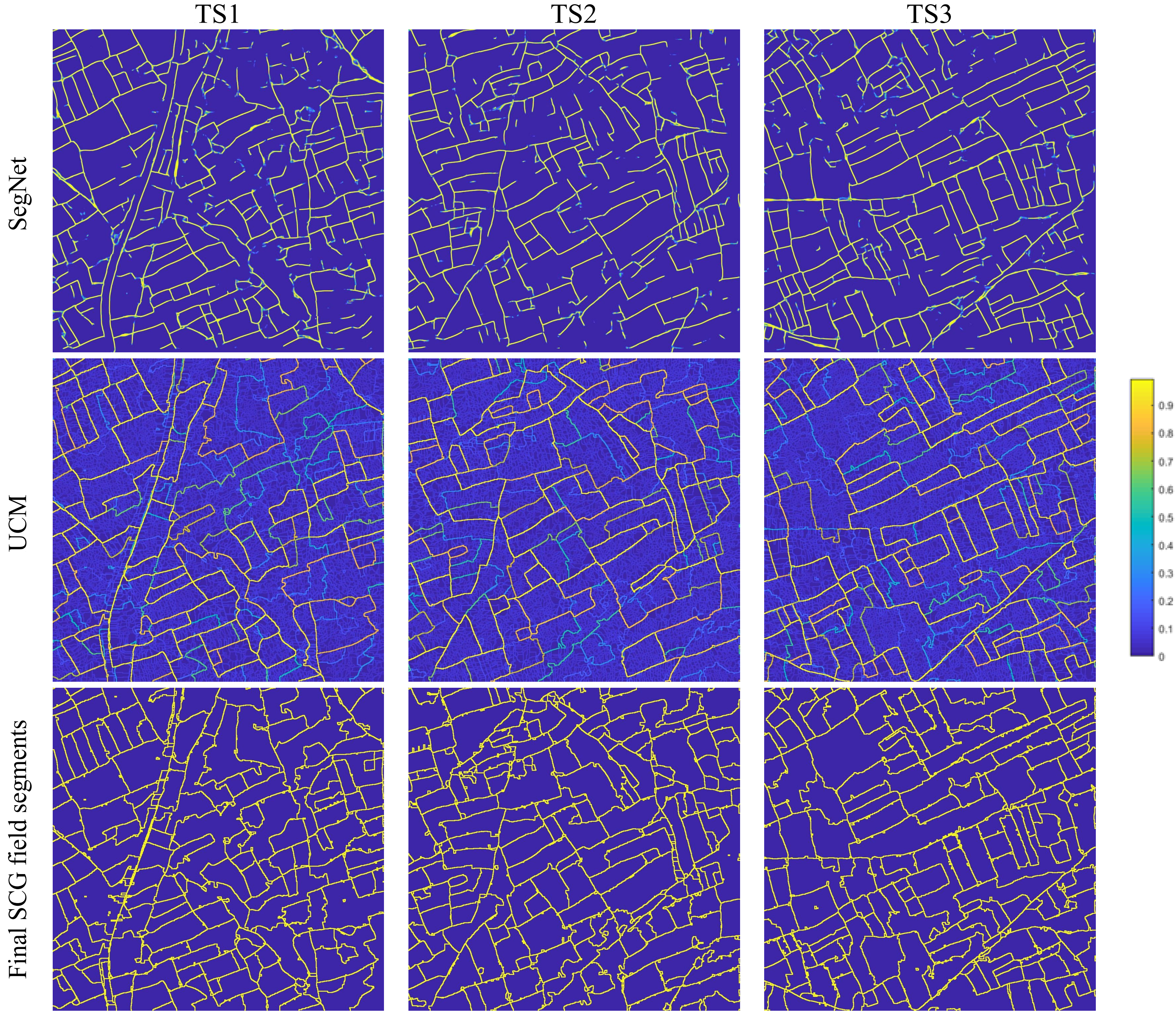


C. Persello, V.A. Tolpekin, J.R. Bergado, R.A. de By, "**Delineation of Agricultural Fields in Smallholder Farms from Satellite Images using Fully Convolutional Networks and Combinatorial Grouping,"** Remote Sensing of the Environment, Vol. 231, 15 September 2019.

KOFA DATA SET

- Rain-fed agricultural production in the Sudano-Sahelian savanna region of northern **Nigeria**, around the city of Kofa.
- Small fields (average 0.22 ha), with only 5% pure crops, and more than 50% having three or more crops at any moment in the crop season.

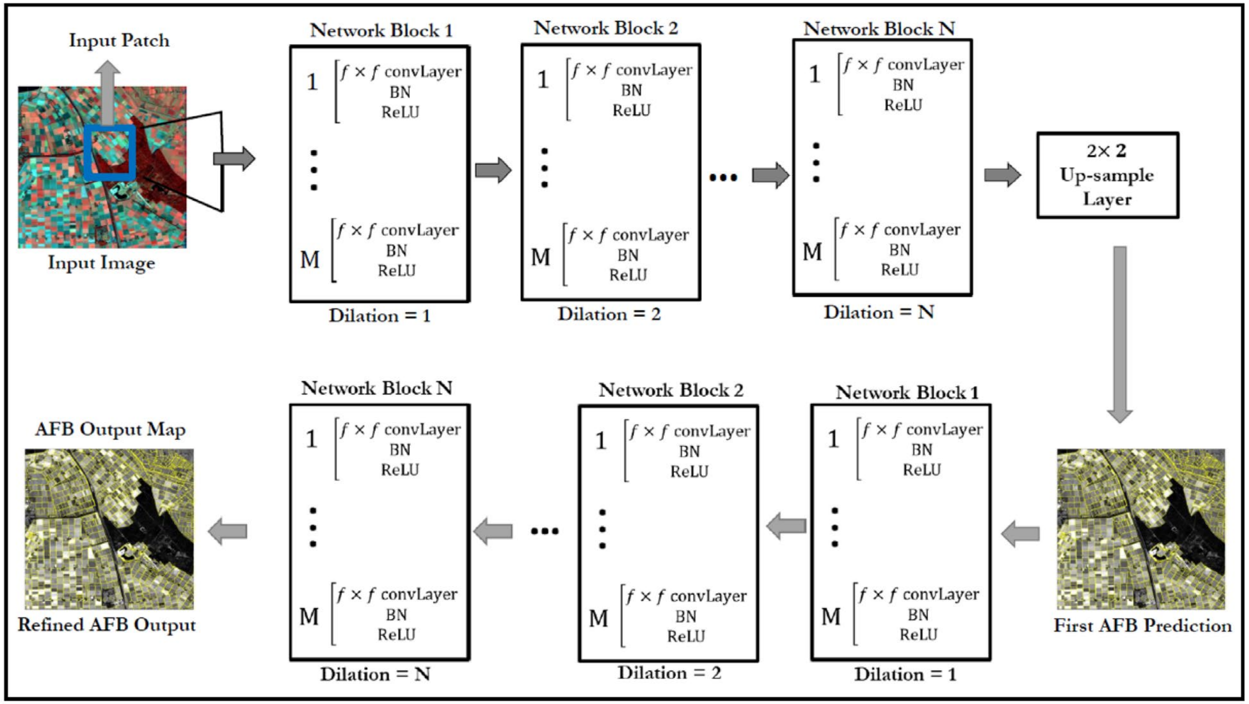




TS1
TS2
TS3
SegNet
UCM
Final SCG field segments
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

AGRICULTURAL BOUNDARIES FROM SENTINEL-2

Super-resolution semantic contour detection



K.M. Masoud, C. Persello, and V.A. Tolpekin, **'Delineation of Agricultural Field Boundaries from Sentinel-2 Images Using a Novel Super-Resolution Contour Detector Based on Fully Convolutional Networks'**, *Remote Sensing*, 12 (1), 2020, p. 59.

URBAN DEPRIVATION

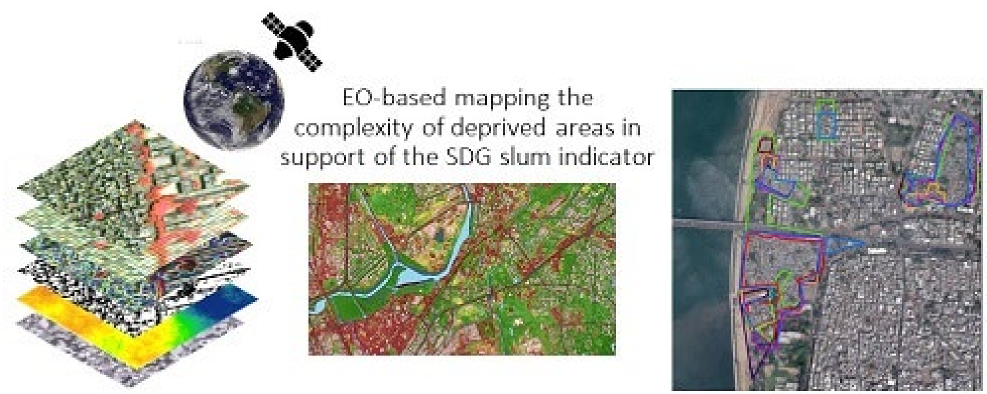
- The rapid urbanization lead often to the proliferation of deprived neighborhoods, also commonly called slums
- These areas are often invisible in official maps and statistics

Mumbai, Source: https://unequalscenes.com

A GLOBAL SOCIETAL CHALLENGE

- Make cities inclusive, safe, resilient and sustainable
- Target 11.1: by 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums

- Indicator 11.1.1: Proportion of urban population living in slums, informal settlements or inadequate housing



Kuffer et al. "**The Scope of Earth-Observation to Improve the Consistency of the SDG Slum Indicator**," *ISPRS Int. J. Geo-Inf.* 2018, *7*(11), 428

MAPPING INFORMAL SETTLEMENTS FROM SPACE

Challenges

- Abstract land-use semantic classes
- Complex spatial-contextual and textural features

Quickbird image of Dar es Salaam, Tanzania.

Standard Methods

- Object-based image analysis
- Grey level co-occurrence matrix measures

Deep Learning

Fully Convolutional Networks (FCN)

FCN WITH DILATED KERNEL

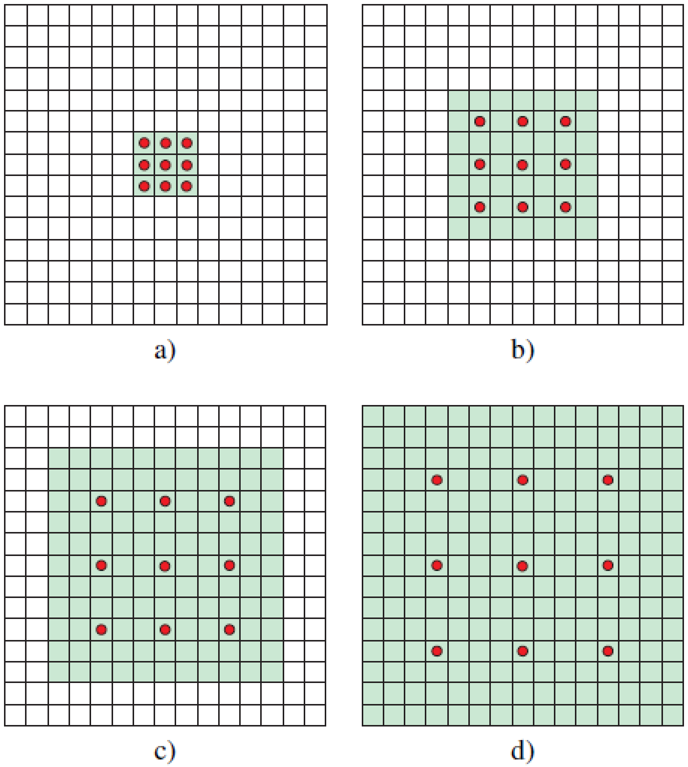
Network Architecture

- Dilated Convolutions
- No down-sampling

Advantages:

- Enlarged the receptive field
- Limited number of learnable parameters
- Simple network design

Dilated Convolutional Kernels



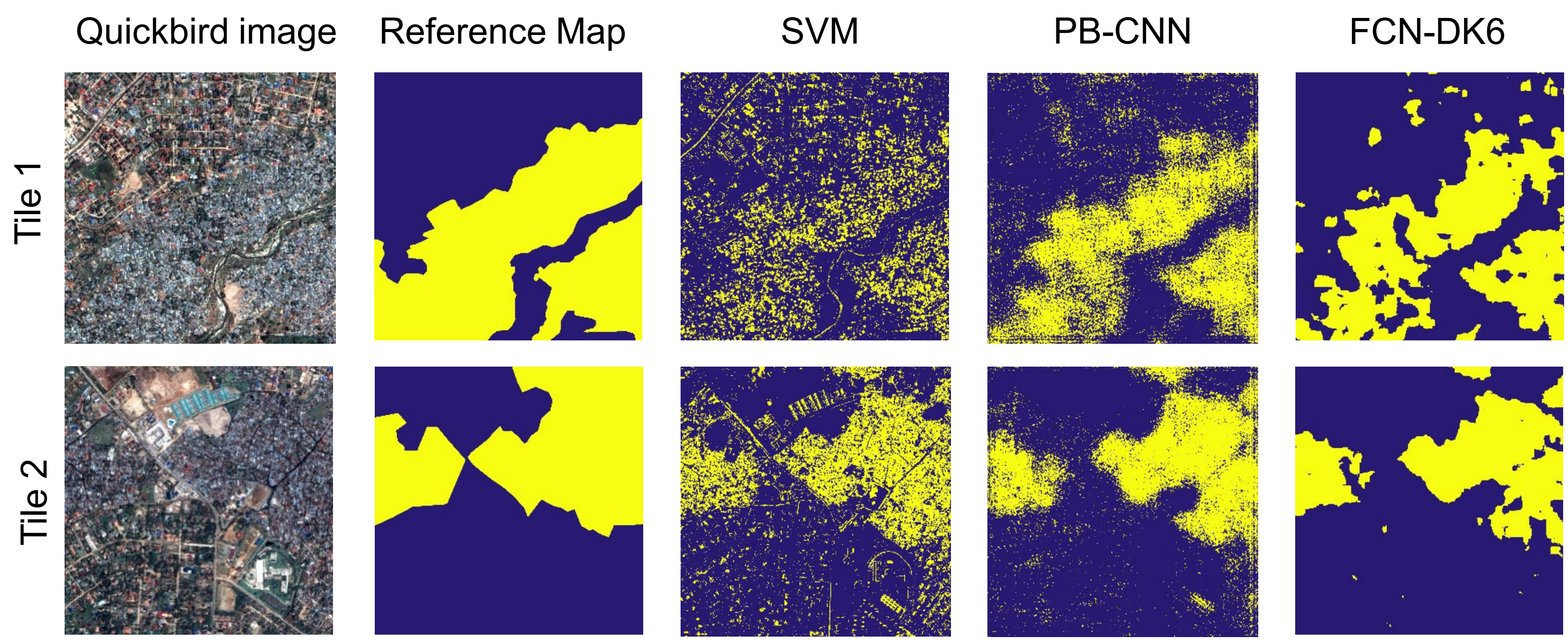
C. Persello and A. Stein, "**Deep Fully Convolutional Networks for the Detection of Informal Settlements in VHR Images,**" *IEEE Geoscience and Remote Sensing Letters*, Vol 14, No. 12, December 2017.

DEEP FULLY CONVOLUTIONAL NETWORK

OA (%)	SVM	PB-CNN	FCN-DK6
Tile 1	59.5	76.87	81.3
Tile 2	77.0	84.39	86.1

Computational cost

- PB-CNN: 110 min
- FCN-DK6: 2.7 s

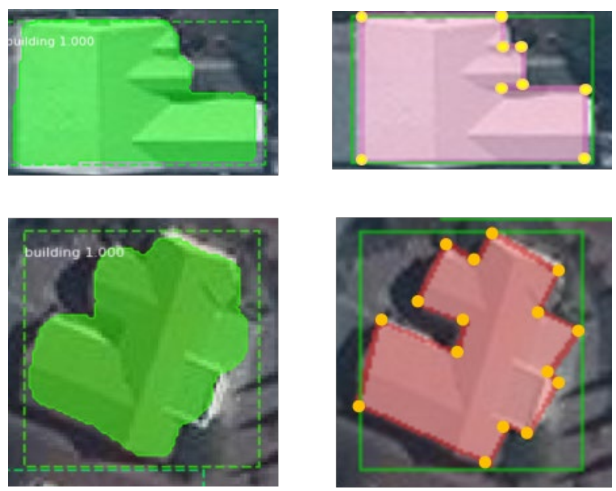


BUILDING OUTLINE EXTRACTION

Opportunity: Automatic building delineation from imagery has many applications such as the production of cadastral and topographic maps

Challenge: Pixel-based segmentation methods often results in irregular edges and over smoothed corners

a) Instance segmentation with raster output (Mask R-CNN).



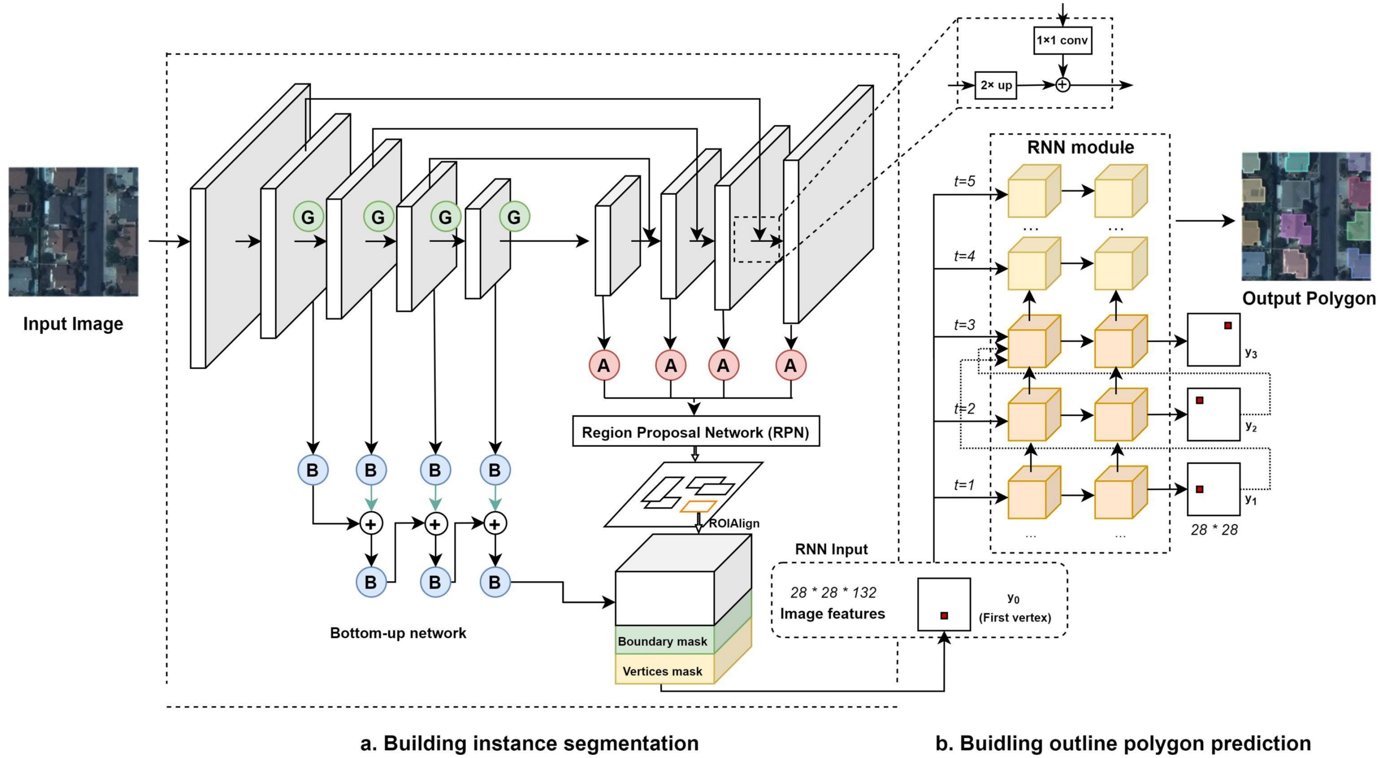
a) b)

b) Regularized object extraction with vector (polygon) output

W. Zhao, C. Persello, A. Stein, “**Building outline delineation: From aerial images to polygons with an improved end-to-end learning framework,”** ISPRS Journal of Photogrammetry and Remote Sensing, Volume 175, 2021.

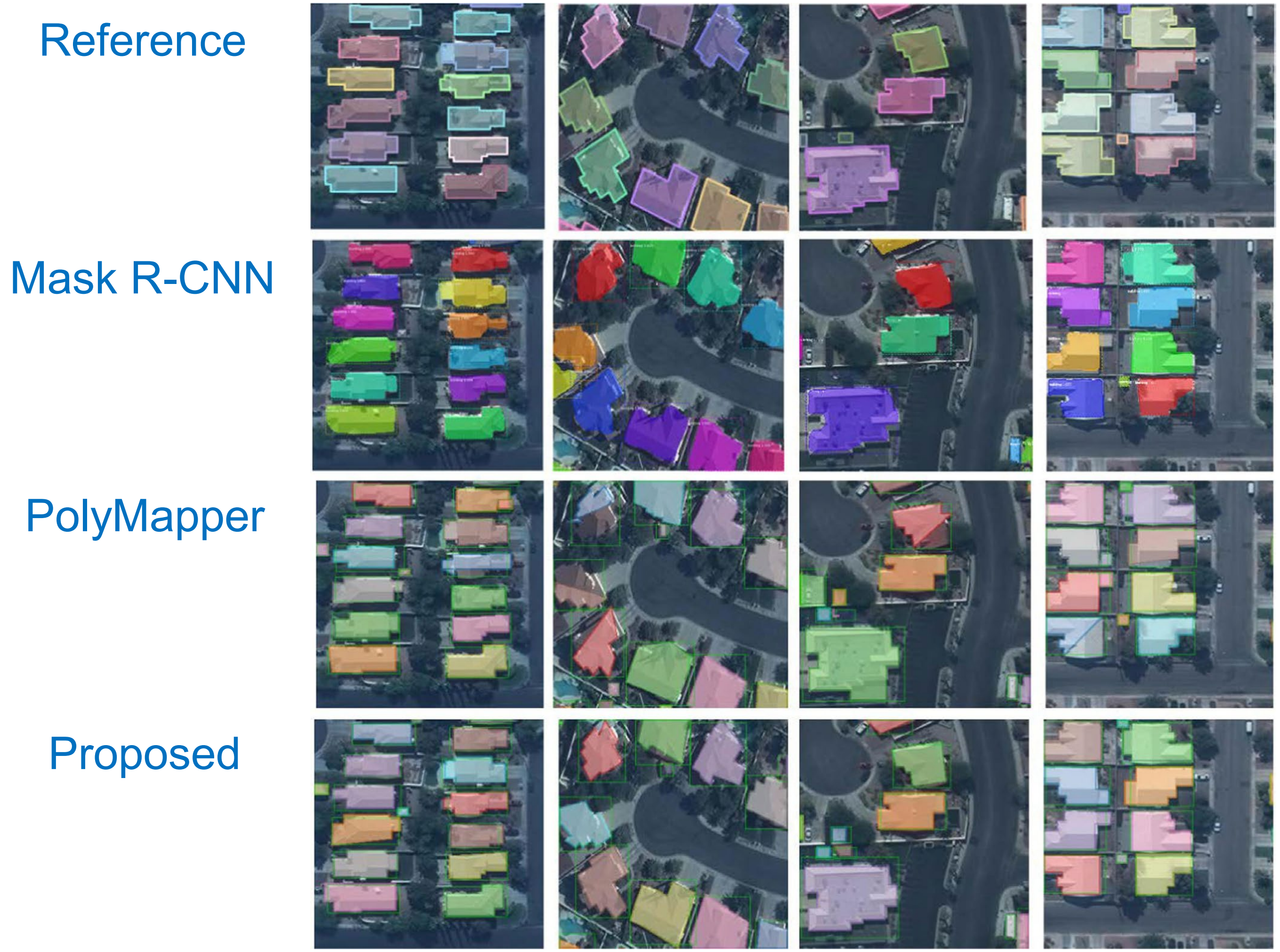
BUILDING INSTANCE SEGMENTATION & VECTORIZATION

Proposed end-to-end CNN + RNN architecture



W. Zhao, C. Persello, A. Stein, "**Building outline delineation: From aerial images to polygons with an improved end-to-end learning framework,**" ISPRS Journal of Photogrammetry and Remote Sensing, Volume 175, 2021.

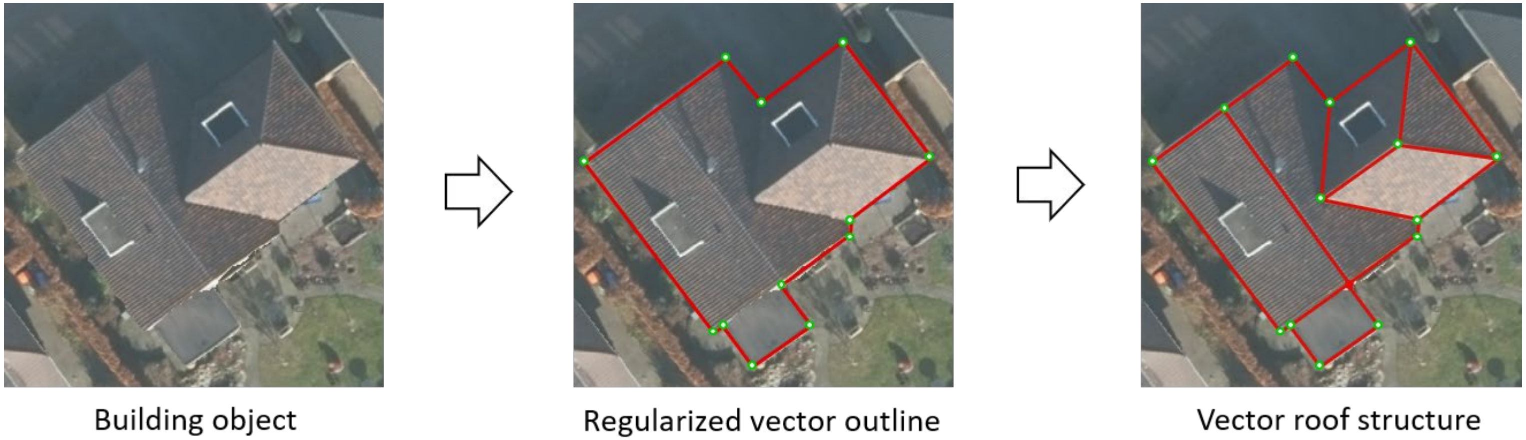
RESULTS



VECTOR MODEL OF THE ROOF STRUCTURE

Planar roof structure extraction

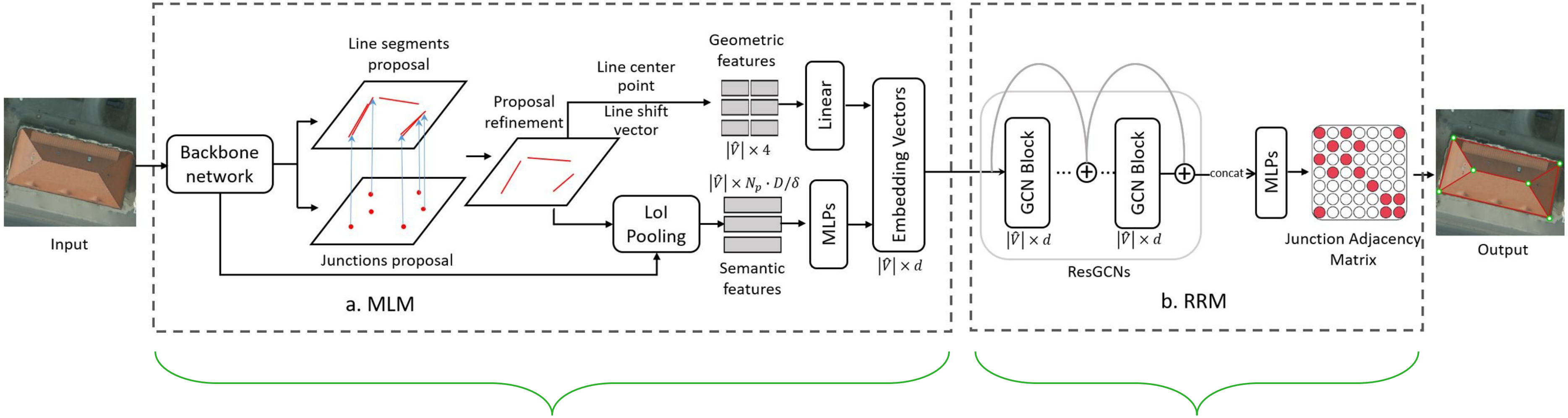
The model learns the graph describing the connections of line segments representing the roof structure



W. Zhao, C. Persello, A. Stein, "**Extracting Planar Roof Structures from Very High Resolution Images Using Graph Neural Networks,"** ISPRS Journal of Photogrammetry and Remote Sensing, *under review*.

GRAPH NEURAL NETWORK

Proposed end-to-end deep learning network



Extraction of vertices and line segments

Extraction of the graph of connected junctions

RESULTS

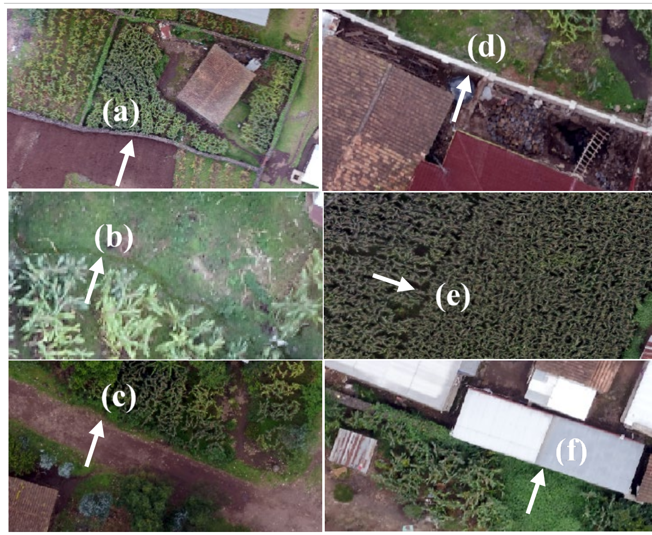
DELIVER TENURE SECURITY FOR ALL

- Secure property rights and efficient registration systems are essential for the modern economy
- A mere 30% of the global population has legally registered rights to their land and homes

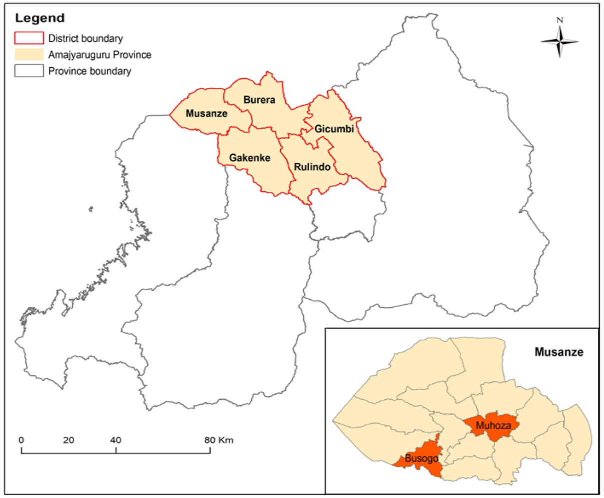
- Insecurity of property rights is often at the root of:
  - poverty and inequality
  - leading to legal conflicts
  - unequal economic systems

EXTRACTION OF VISIBLE CADASTRAL BOUNDARIES

Visible boundaries are demarcated by physical objects, e.g., fences, walls, hedges or roads.



(a) Strip of stone
(b) Water drainage
(c) Road ridges
(d) Fences
(e) Textural pattern transition
(f) Edge of rooftop



Two case study sites in Rwanda are selected, Busogo and Muhoza.

X. Xia, C. Persello, and M. Koeva, 'Deep Fully Convolutional Networks for Cadastral Boundary Detection from UAV Images,' *Remote Sensing, Vol. 11, No. 14, 2019*

CADASTRAL BOUNDARIES FROM UAV IMAGERY

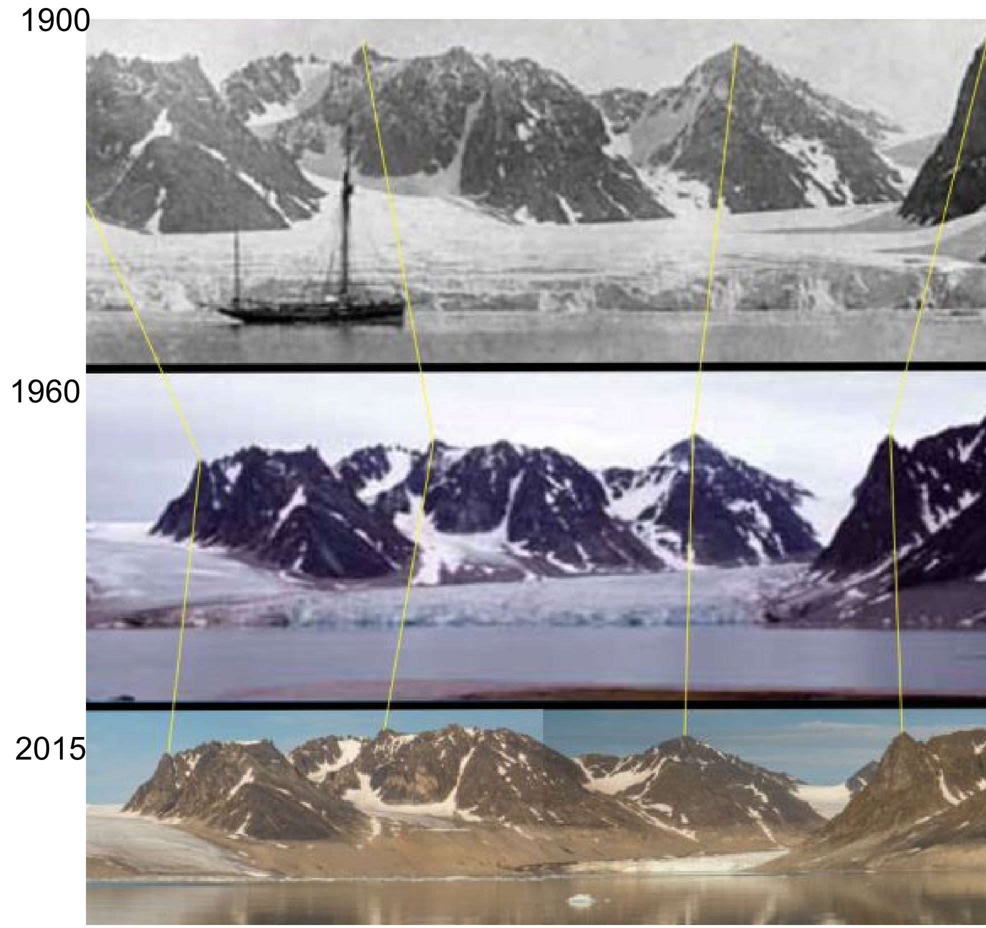
Reference and classification maps obtained by the investigated techniques. The first row shows the maps of TS1 and the second row of TS2. The visible boundary references are the green lines; the invisible are the red lines; and the detected boundaries are the yellow lines.

GLACIER MAPPING

Glaciers

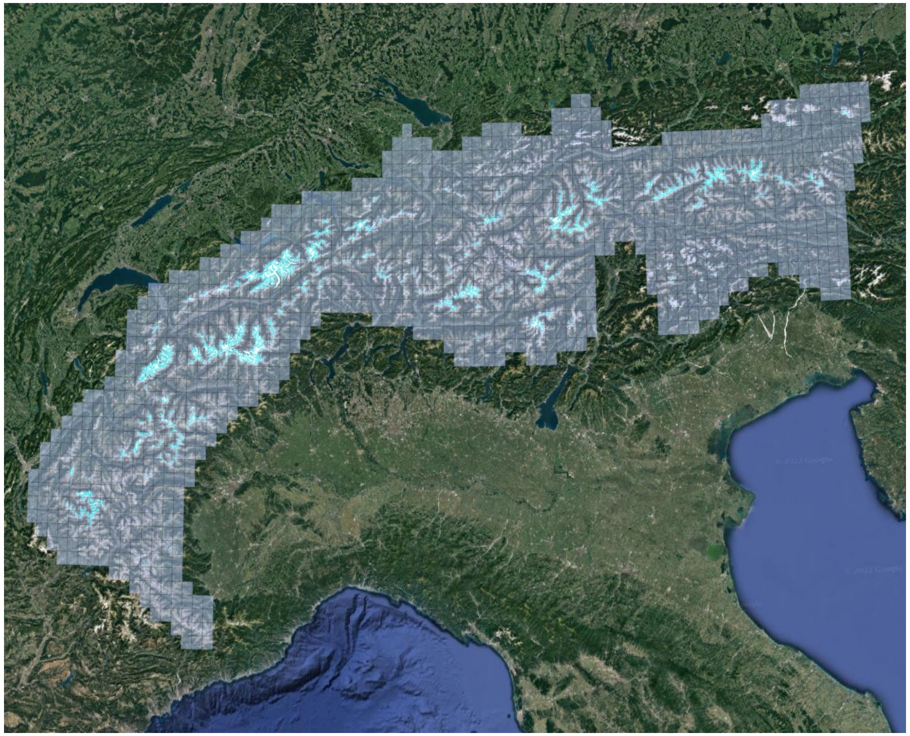
13 CLIMATE ACTION

- Important indicator to monitor climate change
- Major source of freshwater
- Glacier retreat influences:
    - the local hydrology
    - sea level rise
    - ecosystems and their biodiversity



The Waggonwaybreen glacier in Svalbard; Photo: Andreas Weith
source: https://news.climate.columbia.edu/

CASE STUDY: GLACIER MAPPING IN THE ALPS



Input data:

- Sentinel1/2 (optical + SAR)
- DEM
- Reference data: inventory by Paul et al., 2020

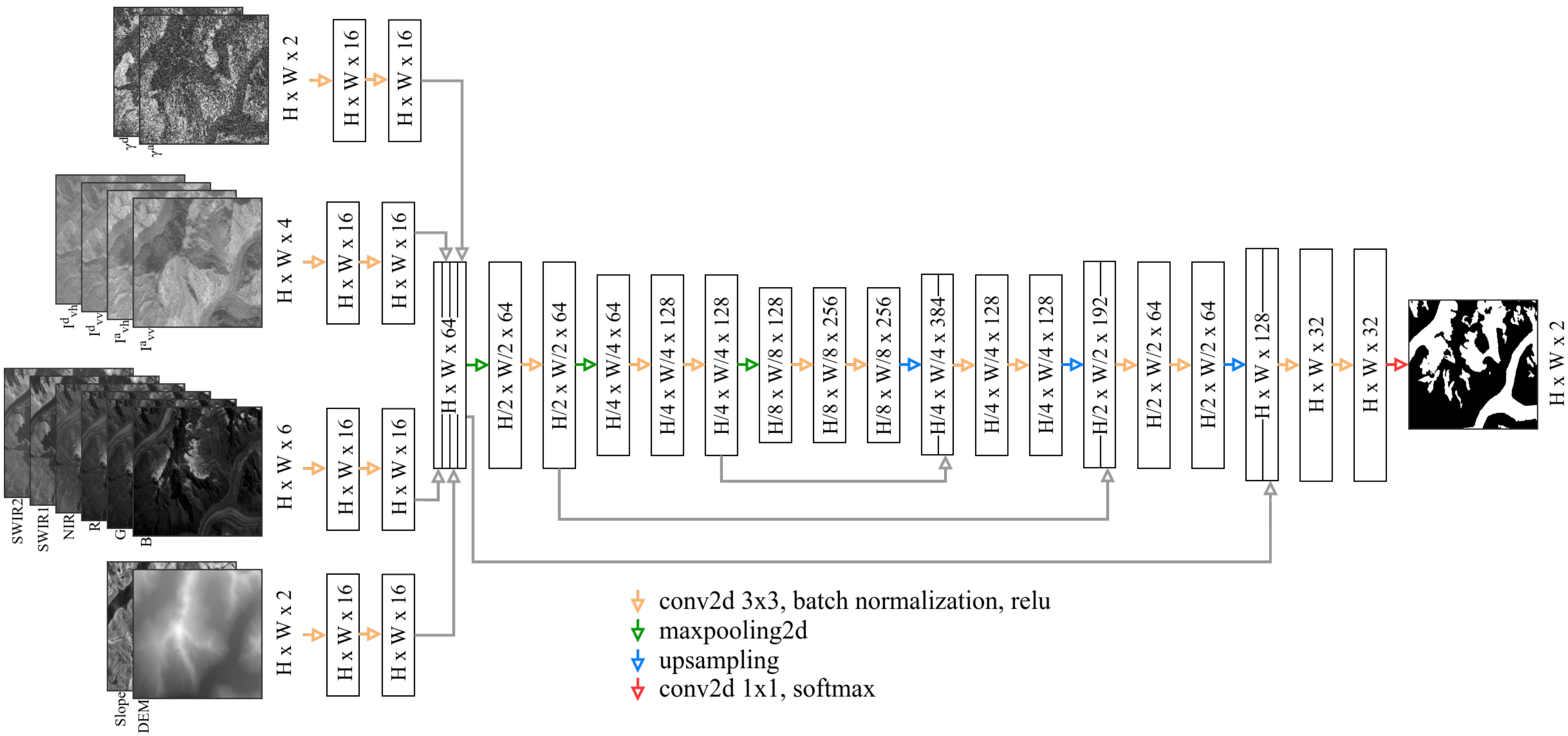
Challenges:

- debris-covered parts

Konstantin A. Maslov, Deep Learning for Large-Scale Glacier Mapping and Surface Mass Balance, Doctoral proposal, 2022.

NETWORK DESIGN

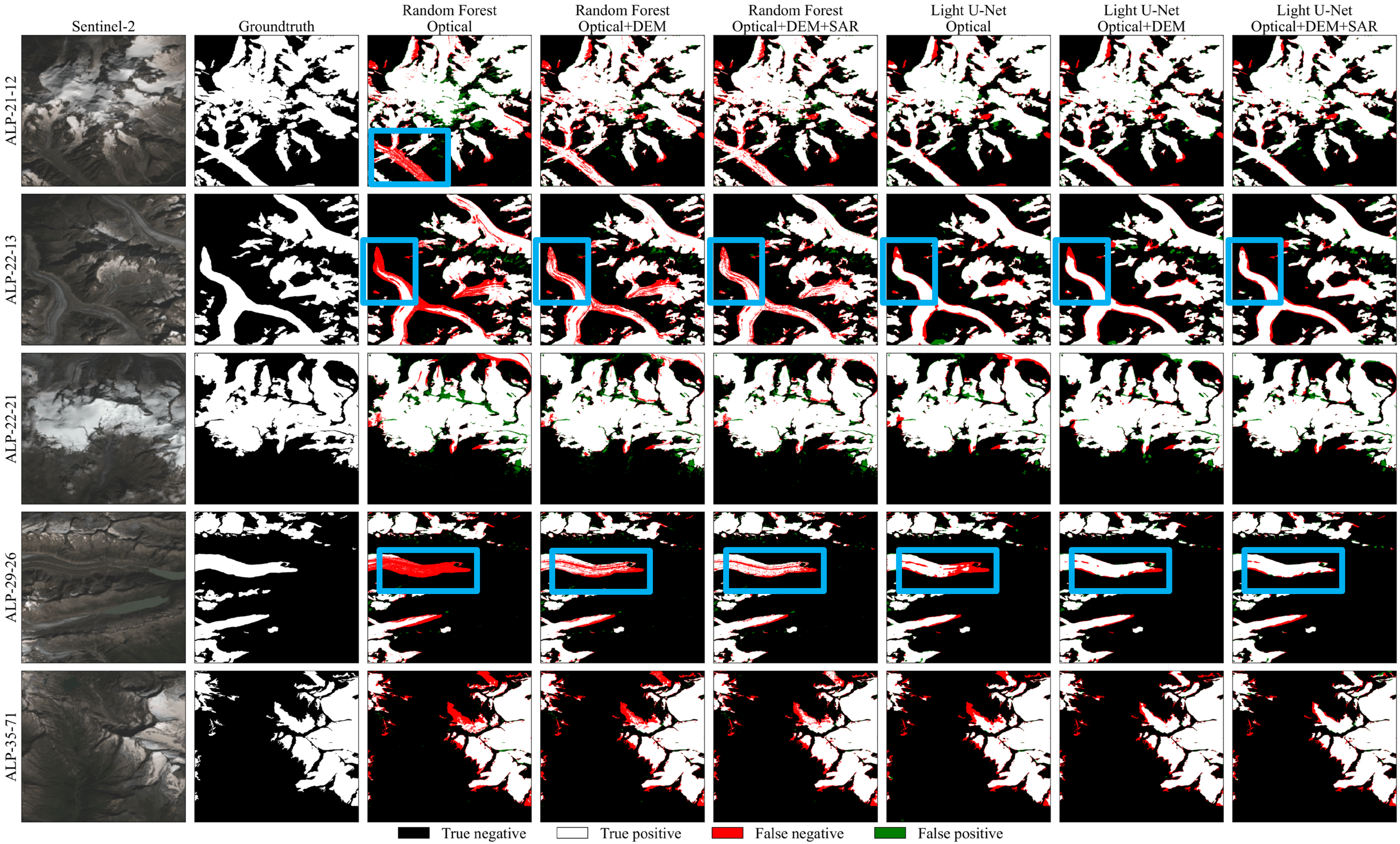
In-network fusion of multi-source data



RESULTS

Data	Precision	Recall	F1-score	IoU
		Random forest		
Optical	0.929	0.828	0.876	0.779
Optical+DEM	0.941	0.857	0.897	0.813
Optical+DEM+SAR	0.944	0.870	0.905	0.827
		U-Net-based method		
Optical	0.946	0.893	0.919	0.850
Optical+DEM	**0.950**	0.906	0.928	0.865
Optical+DEM+SAR	0.948	**0.917**	**0.932**	**0.873**

- U-Net-based methods outperform random forest
- Adding DEM and SAR data increases the performance (especially, for the glacier tongues)


Sentinel-2
Groundtruth
Random Forest Optical
Random Forest Optical+DEM
Random Forest Optical+DEM+SAR
Light U-Net Optical
Light U-Net Optical+DEM
Light U-Net Optical+DEM+SAR
ALP-21-12
ALP-22-13
ALP-22-21
ALP-29-26
ALP-35-71
True negative
True positive
False negative
False positive

TOWARDS GLOBAL MAPPING

MASSIVE (Machine Learning To Infer Surface Mass Balance Of Glaciers Globally By Means Of Snow Cover, In Situ Measurements and Volume Changes From Earth Observation)

The aim is to obtain *global and consistent datasets* of glacier maps with *high spatio-temporal resolution* and *dense mass balance* time series.

Challenges:

- Big data processing → cloud computing (CREODIAS)
- Model transferability in space and time → advanced methods and training strategies

CONCLUSION

Opportunities

- Earth observation and deep learning are useful tools for extracting semantic and geometric information
- They can play an essential role towards the SDGs
- Can provide consistent maps across countries

Many open challenges

- Transforming research results into operation solutions
- Building trustworthy AI models for decision making
- Data quality for decision making
- Improve model generalization ability for global applications

THANK YOU FOR YOUR ATTENTION!