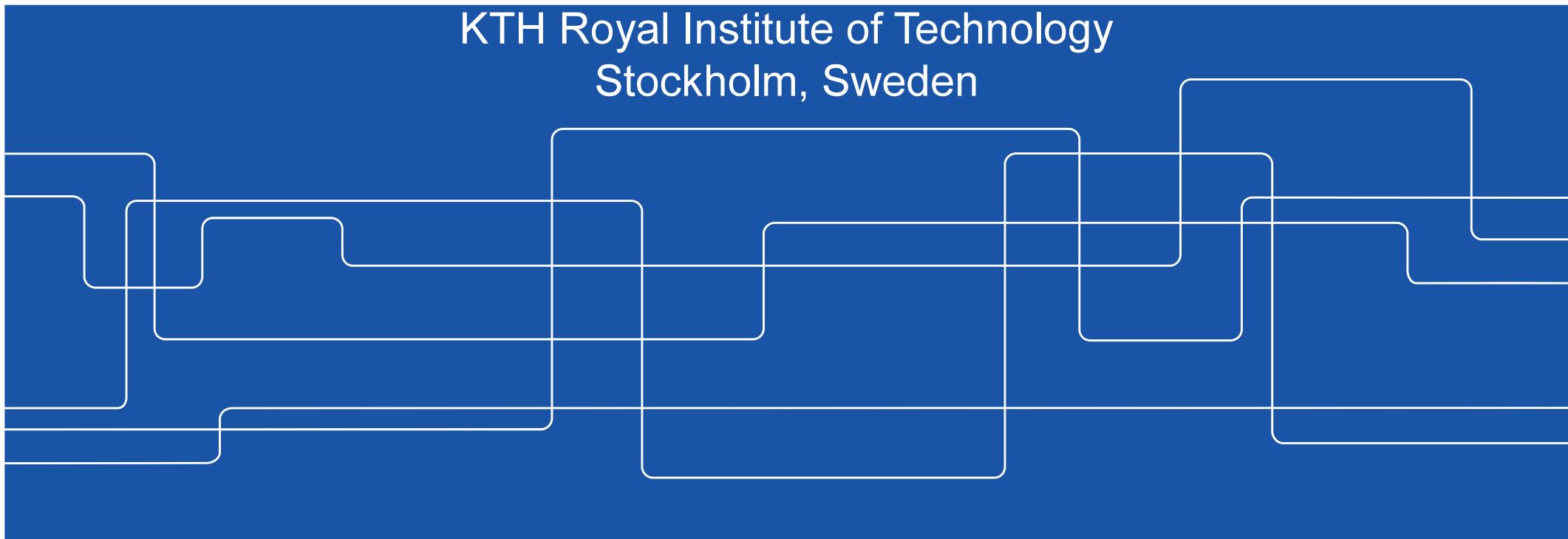




EO4Urban: Multitemporal Sentinel-1A SAR and Sentinel-2A MSI Data for Global Urban Services

Yifang Ban, Professor & Director

Division of Geoinformatics
KTH Royal Institute of Technology
Stockholm, Sweden





ESA DUE Innovator III Program

→ DUE INNOVATORS

A programmatic framework for developing innovative EO products and services, in response to authoritative requirements from end-user organisations.

A set of R&D activities to prepare the ground for a broad involvement of and wide adoption by large user communities.

User laboratories to test innovative EO products and services for and with end-user organisations

Project Incubators where new ideas can be germinated and grown.

breeding places to prepare the ground for a long-term exploitation by large user communities

EO pioneers to shape the future of Earth Observation applications and programs



Global Urbanization Trend



- In 2008, more than 50% of the world live in cities.
- By 2050, the world is expected to add an additional 2.5 billion urban dwellers;
- Nearly 90 percent of the increase is concentrated in Asia and Africa. (United Nations, 2014).
- China, India and Nigeria expected to account for 37% of the projected growth of the world's urban population





Dubai

1973



Shanghai, 1979



A satellite map of Shanghai, China, showing the city's dense urban sprawl along the coast. The map uses a color-coded legend where red represents built-up areas, green represents water bodies, and blue represents land. A prominent red area in the center-left represents the city's core, while a large green area to the right represents the Yangtze River. The map also shows several smaller red spots representing islands or artificial landfills. In the bottom left corner, there is a small black silhouette of a person standing and looking at the map.

Shanghai, 2001



Shanghai, 2010



Environmental Consequences

High concentrations of aerosols, exhaust gases, pollution and dust

- Hazardous to health
- Increased smog, haze, fog, clouds



Source: Suicup via Wikimedia



Source: zmescience.com



Source: The Associated Press

Environmental Consequences

➤ Paved surfaces -> rainfall water -> flooding

- Urbanization results in more impervious surfaces, thus reducing the area where infiltration to ground water can occur. Thus, more storm water runoff occurs.
- 79 people died in July 2012 Beijing flooding



Environmental Consequences

Urban heat island (UHI) and heat waves

- UHI - urban air temperatures higher than surrounding rural areas.
- The average air temperature in a city with 1 million inhabitants is 1-3 degrees warmer.
- Heat waves: In the afternoon, the difference can be 12 degrees warmer, no night time cooling. Death rate raise during heat waves.

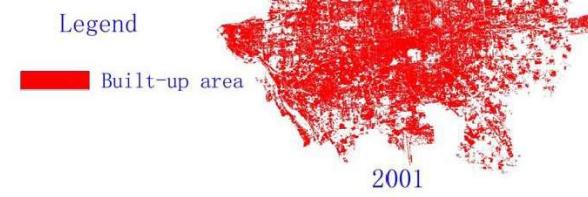
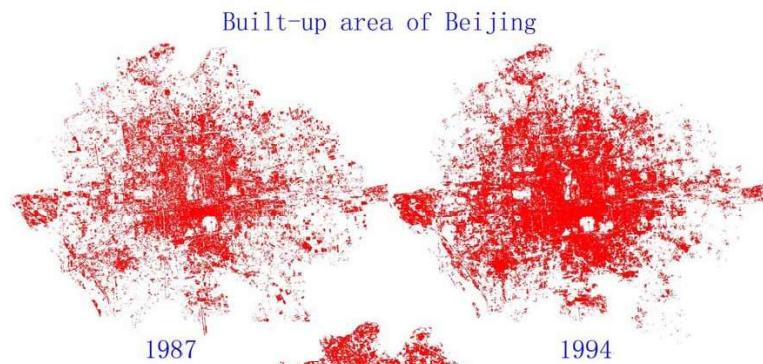
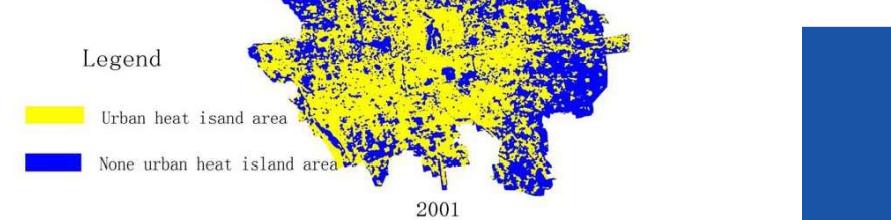
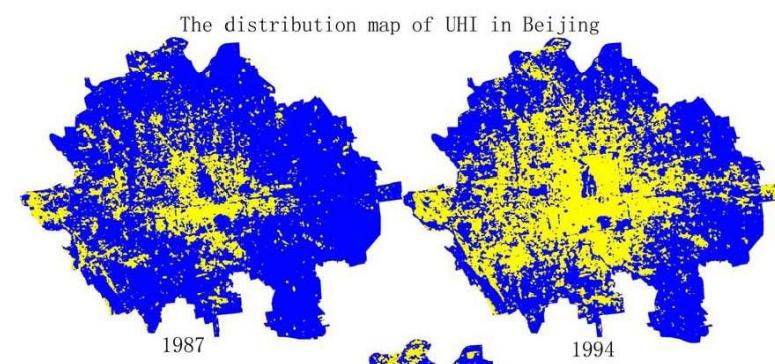


Fig.1 Built-up area of Beijing



2001



UN Urban SGD Targets & Indicators

Target 11.3: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

Indicator 11.3.1 Ratio of land consumption rate to population growth rate – Land use efficiency

Target 11.7, is providing universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

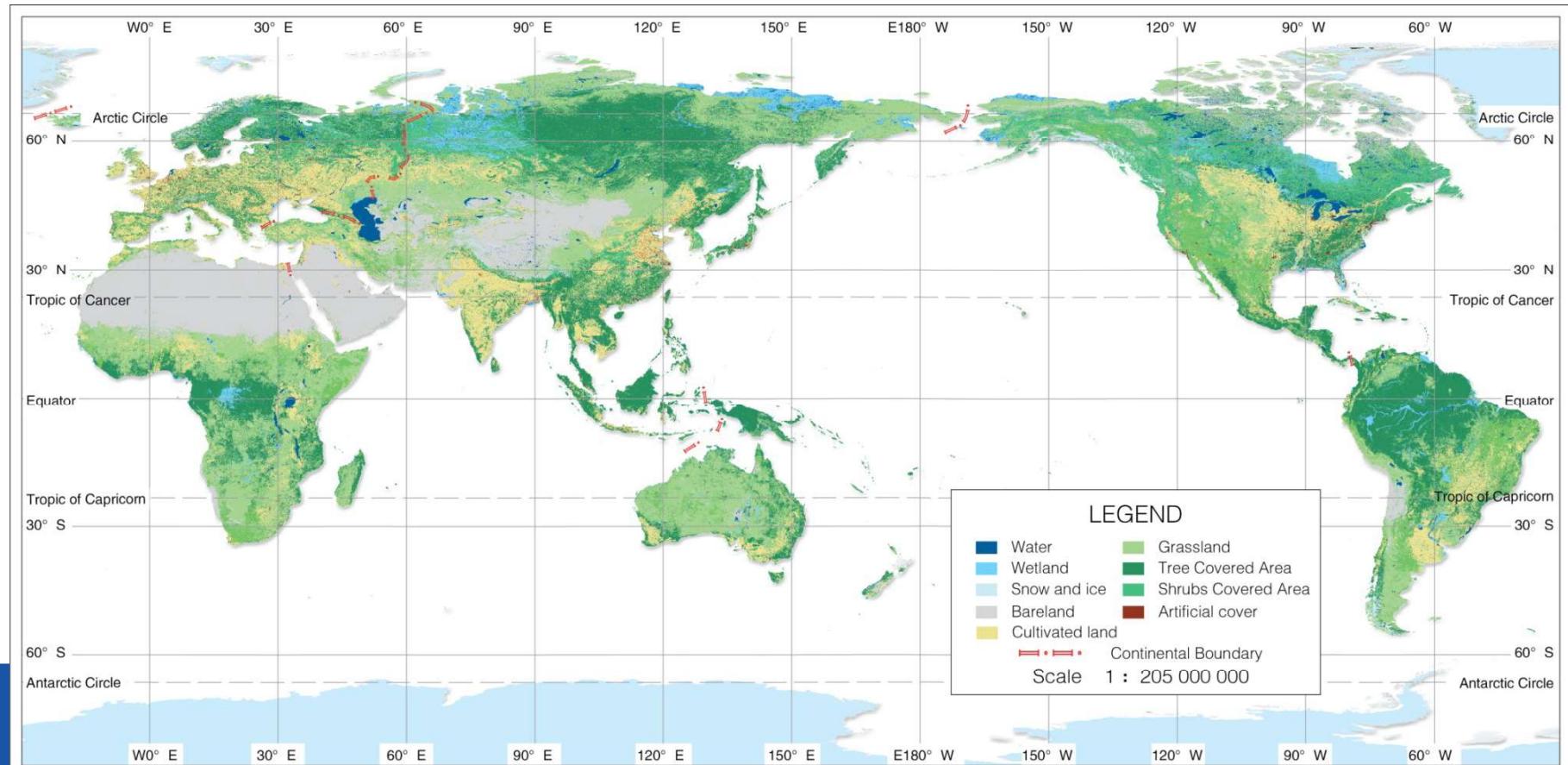
11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities

Target 11.1 – By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Indicator 11.1 – Proportion of urban population living in slums, informal settlements or inadequate housing.

Existing Global Urban Data in GLC Products

- Derived from optical data (TM, MERIS, MODIS, etc.)
- Data gaps: difficulties to acquire images in appropriate seasons
- Information gaps: confusions among various classes such as bare soil and buildup areas, and among vegetation classes



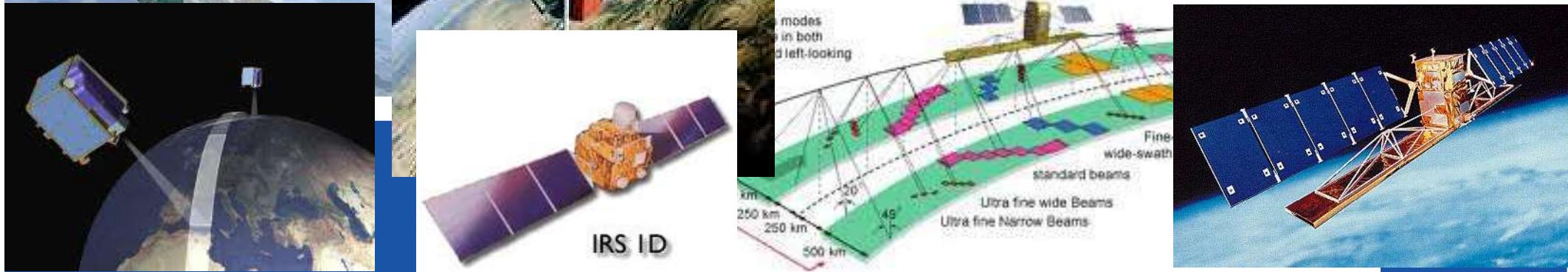
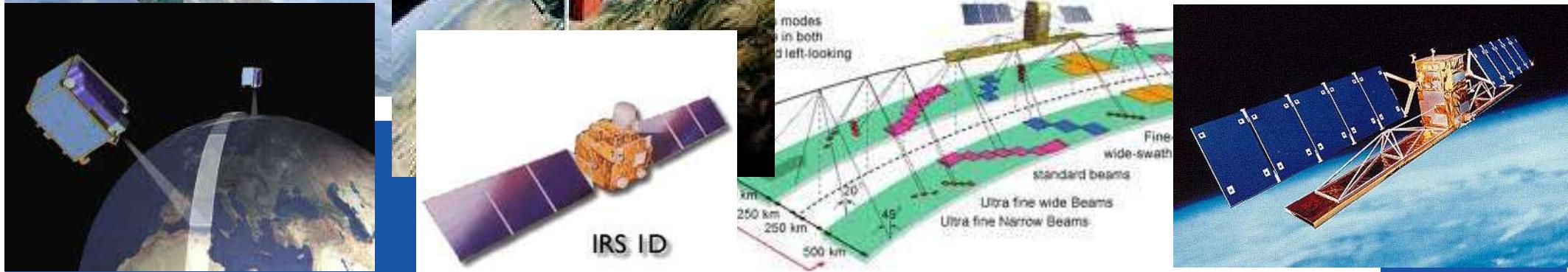
Existing Global Urban Data in GLC Products

1. Comparison of GLC maps with regional LC datasets: Urban

Regional LC datasets	Urban classification	LC-CCI 2005	MODIS 2005	GlobCover 2005
Europe CORINE-LC 06	Correspondence %	51.4	35.5	28.0
	Fully omitted %	19.6	40.3	39.6
USA NLCD-LC 06	Correspondence %	52.4	55.1	19.4
	Fully omitted %	16.1	14.1	22.1
Indonesia IND-MOFOR LU-06	Correspondence %	7.8	22.1	8.4
	Fully omitted %	54.0	42.1	69.4
Brazilian Amazon Terra Class 2008	Correspondence %	37.2	36.1	8.1
	Fully omitted %	31.8	30.0	67.2
Average correspondence %		37.2	37.2	15.9

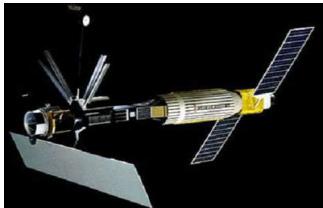
% of total urban area in reference

- The LC-CCI performed better in Europe, USA and Brazilian Amazon, in terms of classifying urban areas. Urban areas in Indonesia were poorly detected.
- In detecting urban areas, the LC-CCI urban detection was worse in Indonesia than other regions.
- General trend of underestimating urban areas.
- On average, the LC-CCI and MODIS have better correspondence, however it needs improvement.

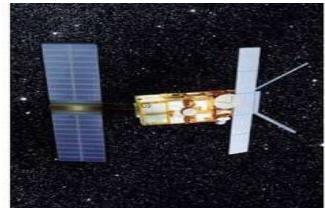




Spaceborne SAR Systems



SEASAT
NASA/JPL (USA)
L-Band, 1978



ERS-1
European Space Agency (ESA)
C-Band, 1991-2000



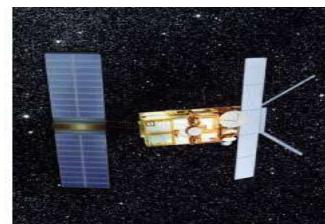
J-ERS-1
Japanese Space Agency (NASDA)
L-Band, 1992-1998



SIR-C/X-SAR
NASA/JPL, L- and C-Band (quad)
DLR / ASI, X-band
April and October 1994



RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995-today



ERS-2
European Space Agency (ESA)
C-Band, 1995-today



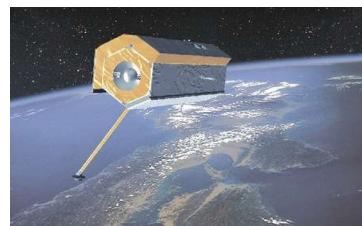
Shuttle Radar Topography Mission (SRTM)
NASA/JPL (C-Band), DLR (X-Band)
February 2000



ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002-today



ALOS / PALSAR
Japanese Space Agency (NASDA)
L-Band (quad), 2004



TerraSAR-X
German Aerospace Center (DLR) / Astrium
X-Band (quad), 2005



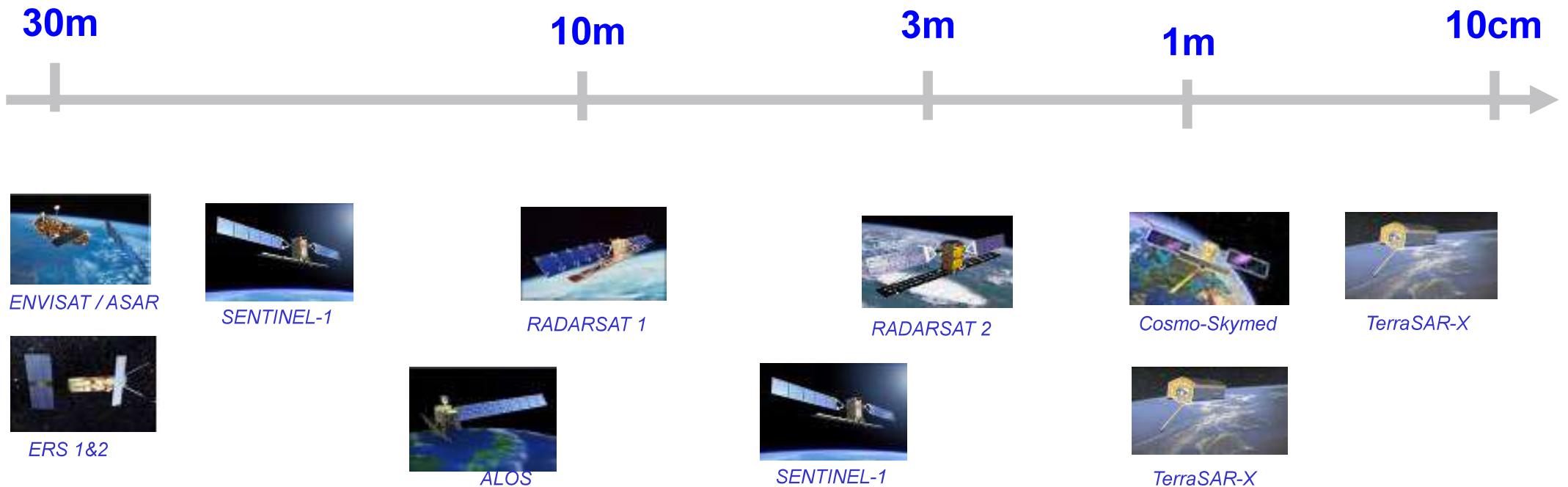
RadarSAT-II
Canadian Space Agency (CSA)
C-Band (quad), 2005



SAR-Lupe
BWB, Germany
X-Band, 2005

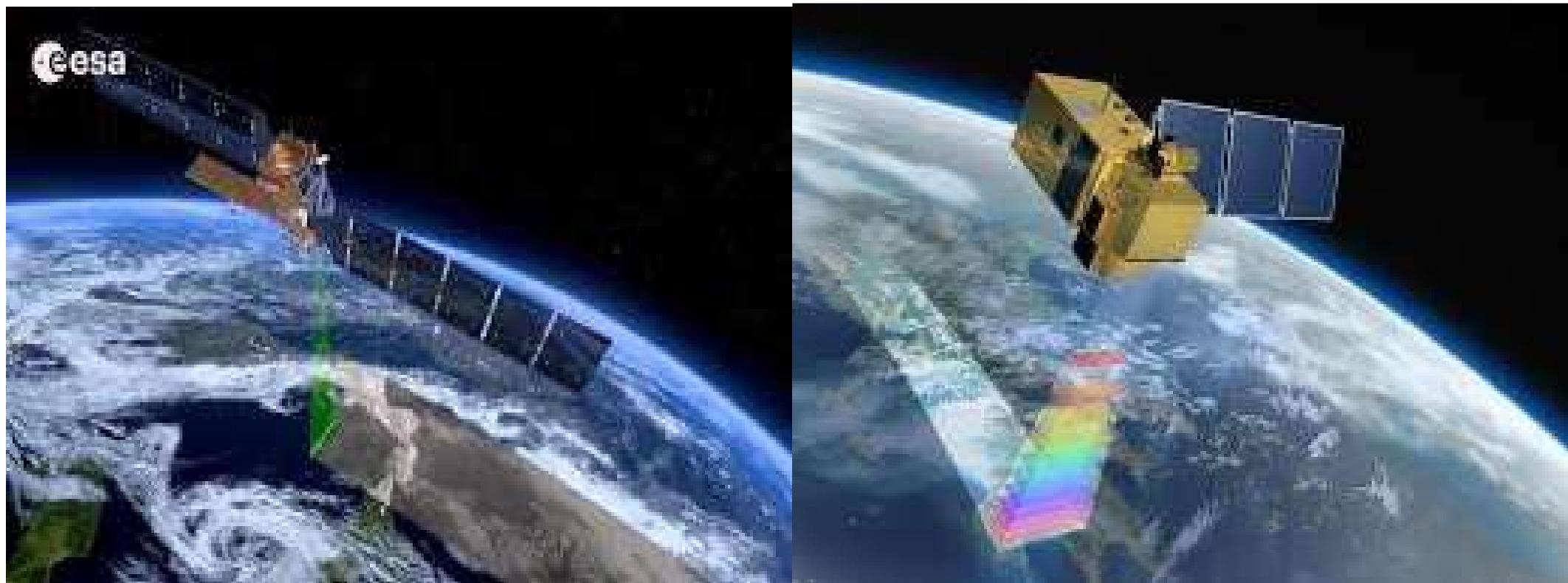


Range / Azimuth Resolution





Sentinel-1A SAR & -2A MSI Data





EO4Urban: Objectives

- The overall objective is to evaluate multi-temporal multi-resolution Sentinel-1A SAR and Sentinel-2A MSI data for developing a pilot global urban services based on user requirements to support smart and sustainable urban development.

Team KTH Royal Institute of Technology, Sweden
University of Pavia, Italy

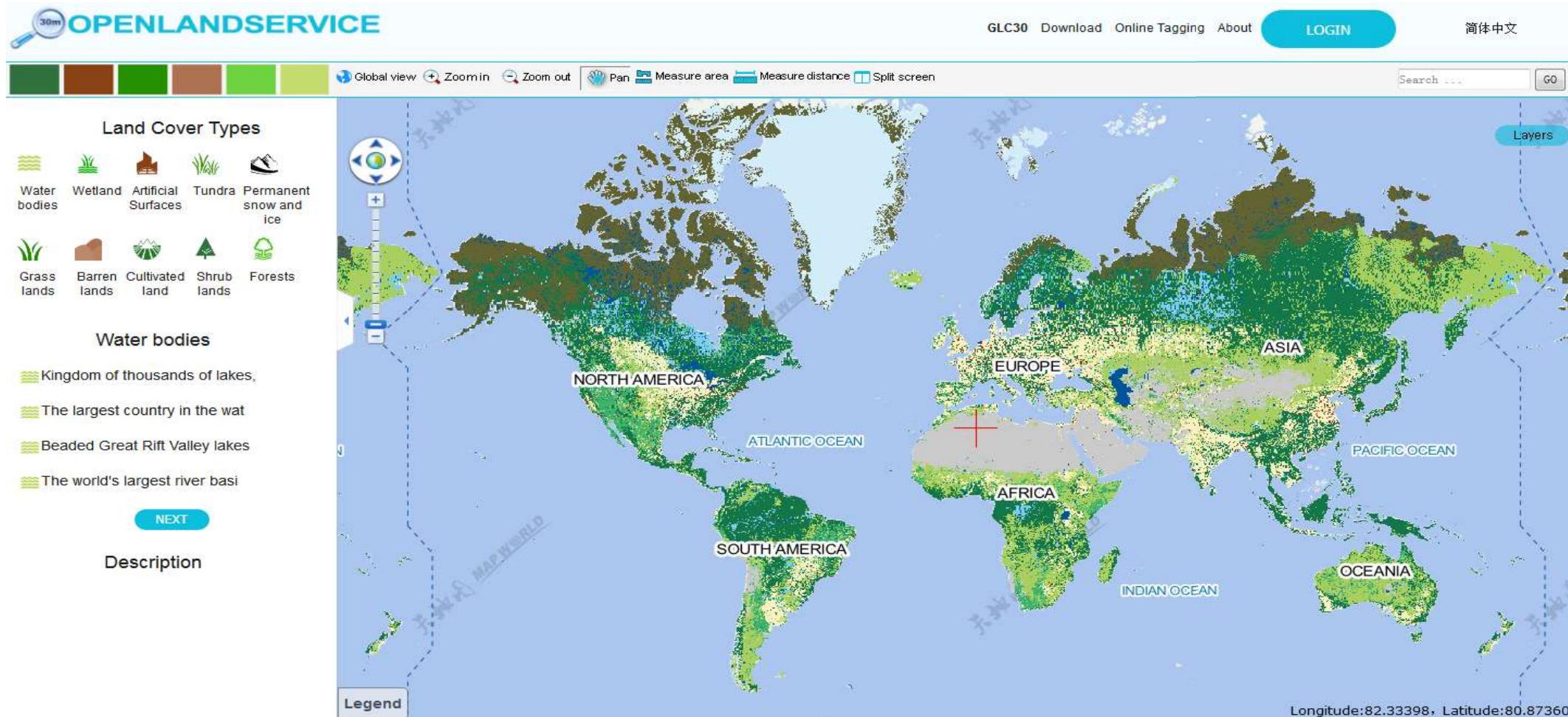
Users Stockholm County Administrative Board, Sweden
National Geomatics Center, China





National Geomatics Center of China

User Needs





User Requirement Baseline

- Global Urban Mapping
 - Urban Extent Maps
- Semi-Global Urban Mapping
 - Urban Land Cover Maps
- City-Level Urban Mapping
 - New Builtup Area Maps
 - Urban Green Structure Maps
 - Urban Green Structure Change Maps

User Requirements: Urban Extent Maps



- 2015 and 2016 Urban extent maps for Stockholm and Beijing
- Minimum Mapping Unit at 30m x 30m.
- Historical urban extent maps from 1995, 2005 and 2010 if possible.



User Requirements: Urban Land Cover Maps

High-Density Builtup Areas: Large buildings and Builtup areas with $\geq 50\%$ buildings

MMU: 30mx30m (3 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Low-Density Builtup Areas: Villas with gardens and builtup areas with $< 50\%$ buildings

MMU: 30mx30m (3 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Roads, Railways and Airport Runways: Highways, local roads, railways, airport runways

MMU: 10mx30m (1 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 60%

Urban Green Structure: Parks, botanical gardens, zoos, playgrounds, sports fields, colony lots, cemeteries and grass areas

MMU: 30mx30m (3 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Golf Courses: golf courses,

MMU: 30mx30m (3 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Agricultural Fields: Vegetated and bare agricultural fields

MMU: 60mx60m (6 pixels x 6 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Forest: includes Conifers, deciduous and mixed forest.

MMU: 60m x 60m (6 pixels x 6 pixels for Sentinel-2A MSI data), acceptable accuracy: 80%

Water: Rivers and Water Bodies

MMU: Rivers: 10m x 30m and Water Bodies: 30m x 30m (1 pixels x 3 pixels or 3 pixels x 3 pixels for Sentinel-2A MSI data), acceptable accuracy: 85%

User Requirements: New Builtup Area Maps



- Maps of new built-up areas:
base map in 2015 and
updated yearly

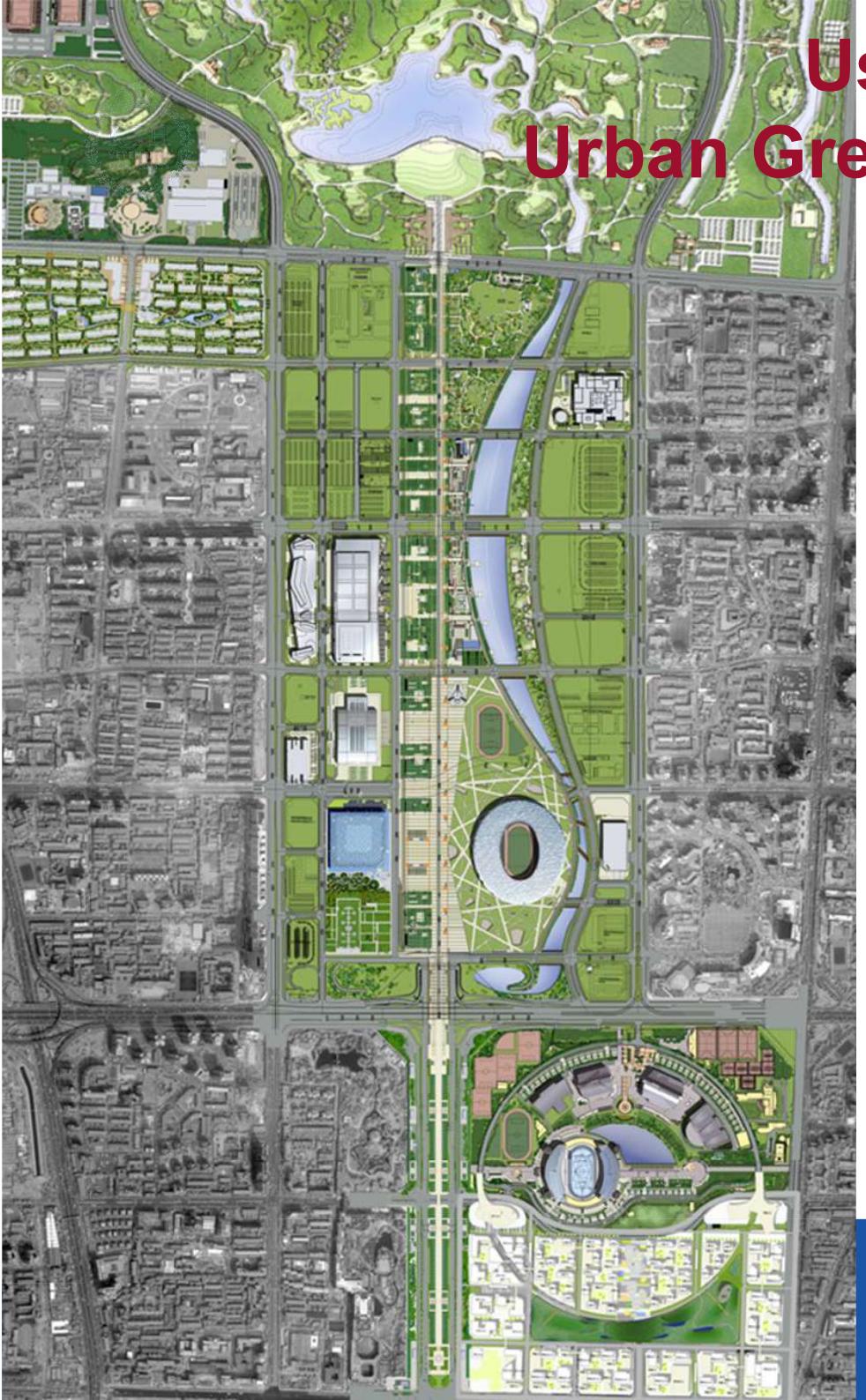
- Minimum Mapping Unit at
30m x 30m.

Green wedges

User Requirements: Urban Green Structure Maps



- Maps of Urban Green Structure in 2015 and updated yearly
- Minimum Mapping Unit at 30m x 30m.



User Requirements: Urban Green Structure Change Maps

- Maps of urban green structure changes in 2015 and updated yearly
- Minimum Mapping Unit at 30m x 30m.



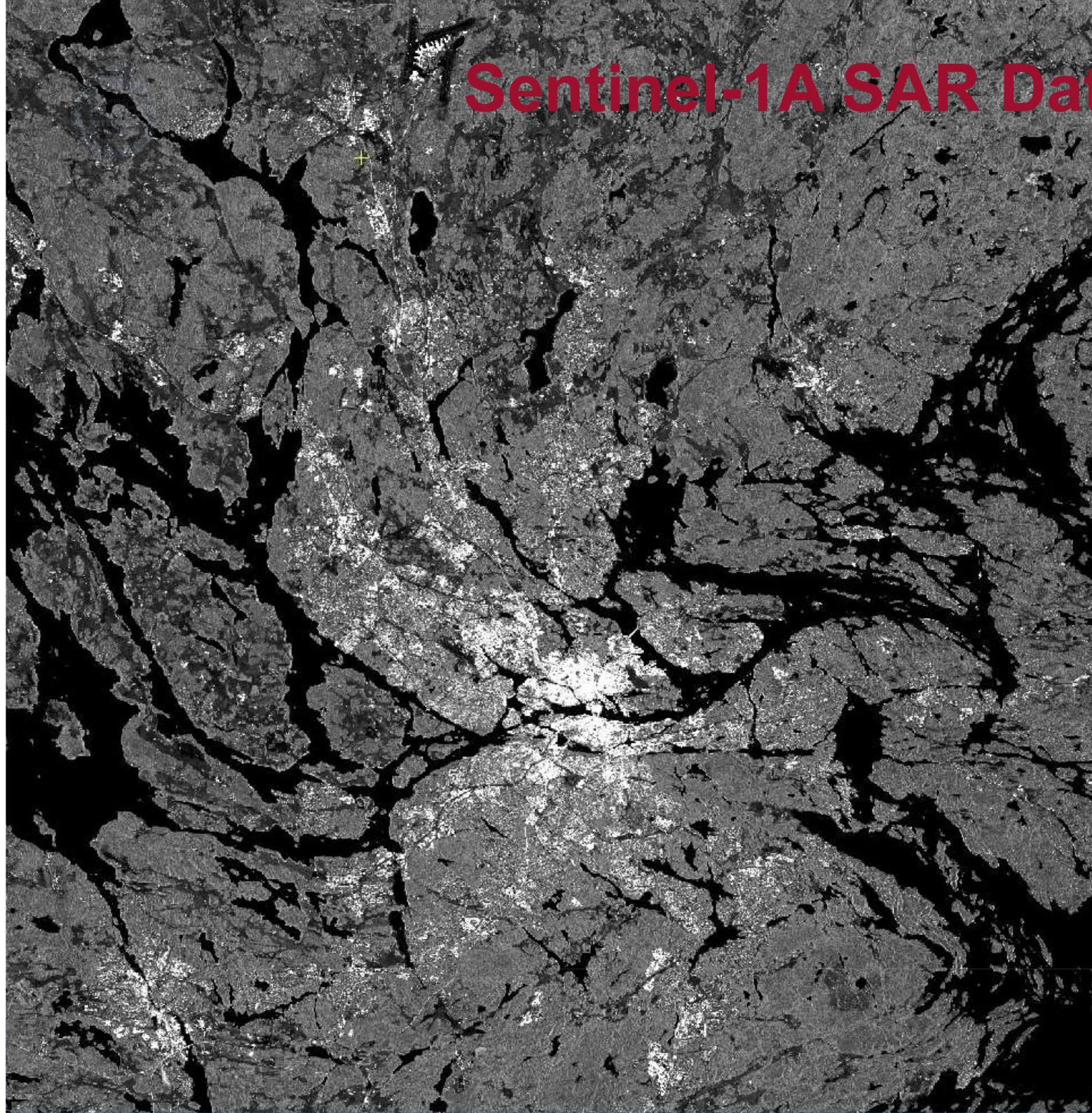
Study Areas



Study Areas

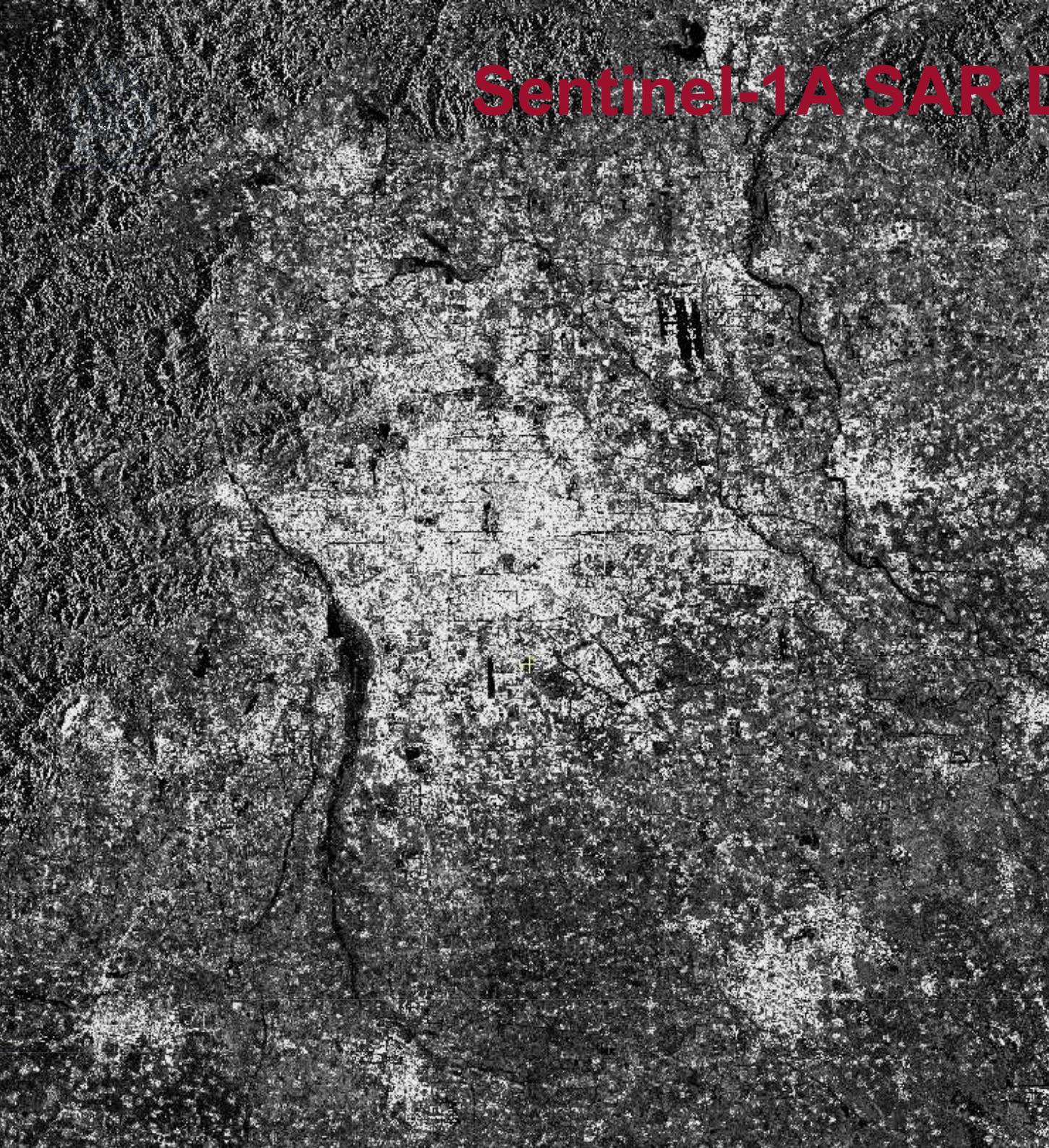


Sentinel-1A SAR Data



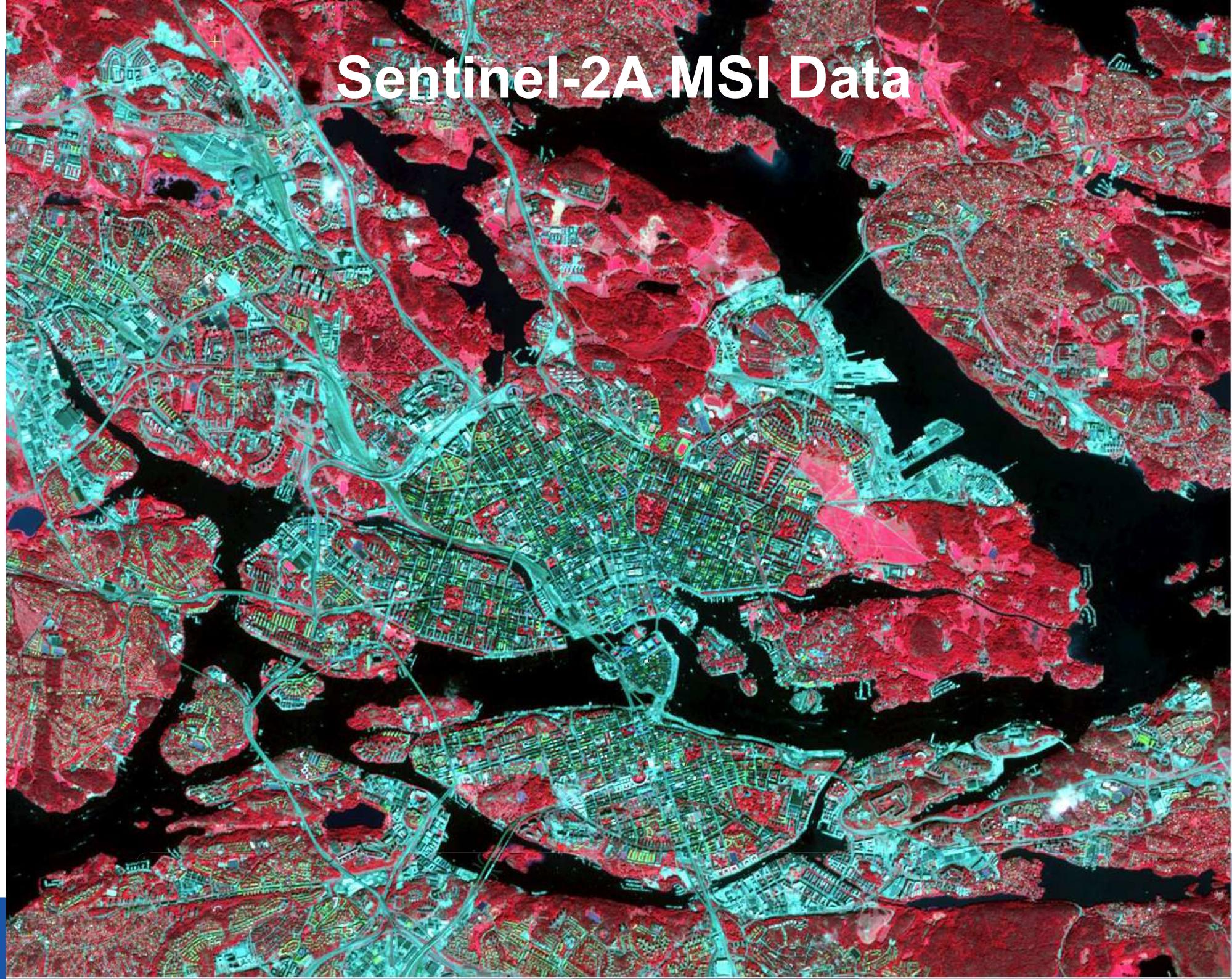
2015/05/16	ASC
2015/06/04	DSC
2015/06/09	ASC
2015/06/28	DSC
2015/07/10	DSC
2015/07/15	ASC
2015/07/22	DSC
2015/08/08	ASC
2015/08/15	DSC
2015/08/20	ASC
2015/09/08	DSC
2015/09/20	DSC
2015/09/25	ASC
2015/10/02	DSC
2015/10/07	ASC
2015/10/19	ASC
2015/10/26	DSC
2015/10/31	ASC

Sentinel-1A SAR Data

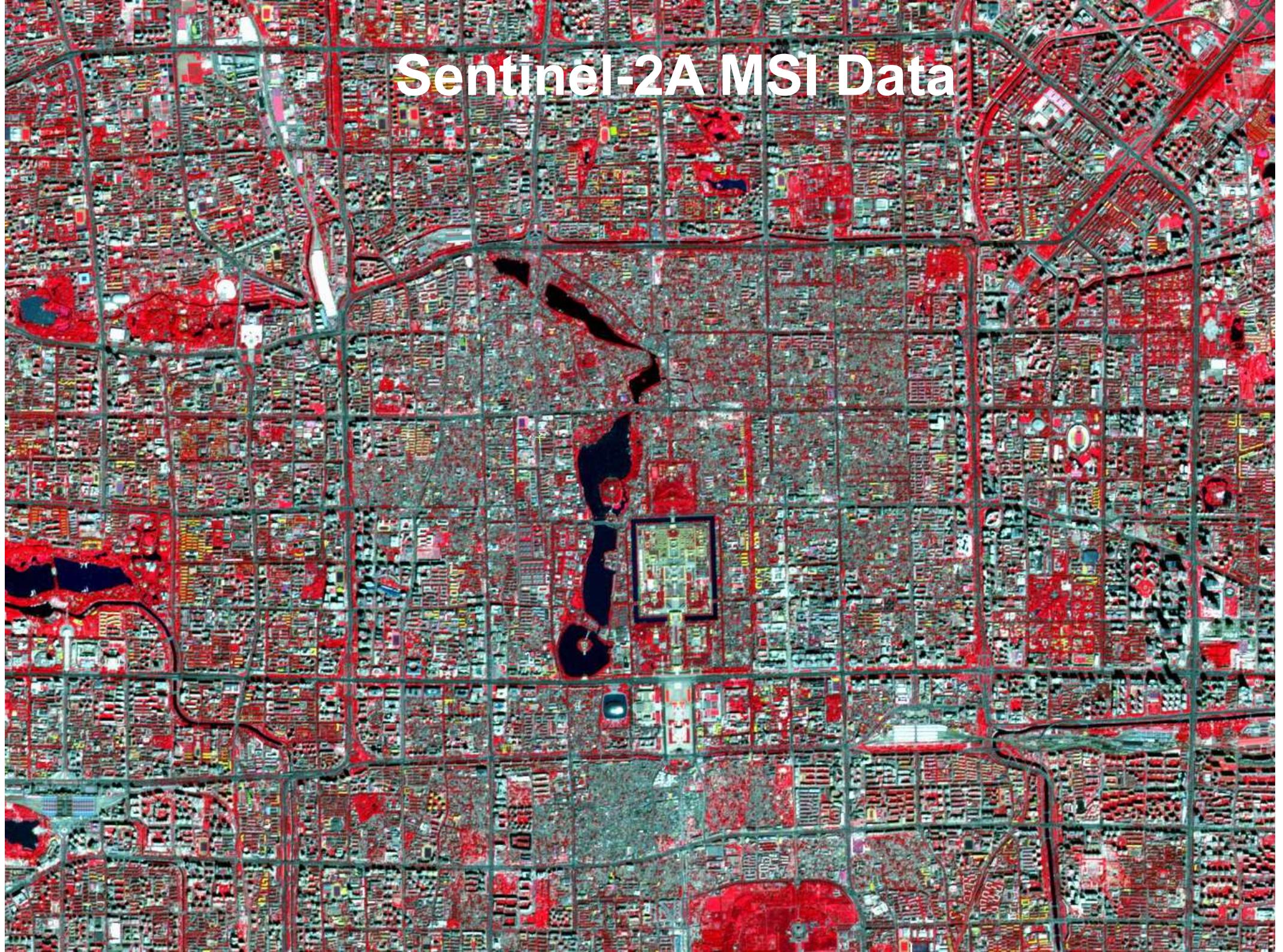


2015/05/24	DSC
2015/06/05	DSC
2015/06/17	DSC
2015/07/23	DSC
2015/07/30	ASC
2015/08/23	ASC
2015/09/09	DSC
2015/09/16	ASC
2015/10/03	DSC
2015/10/10	ASC

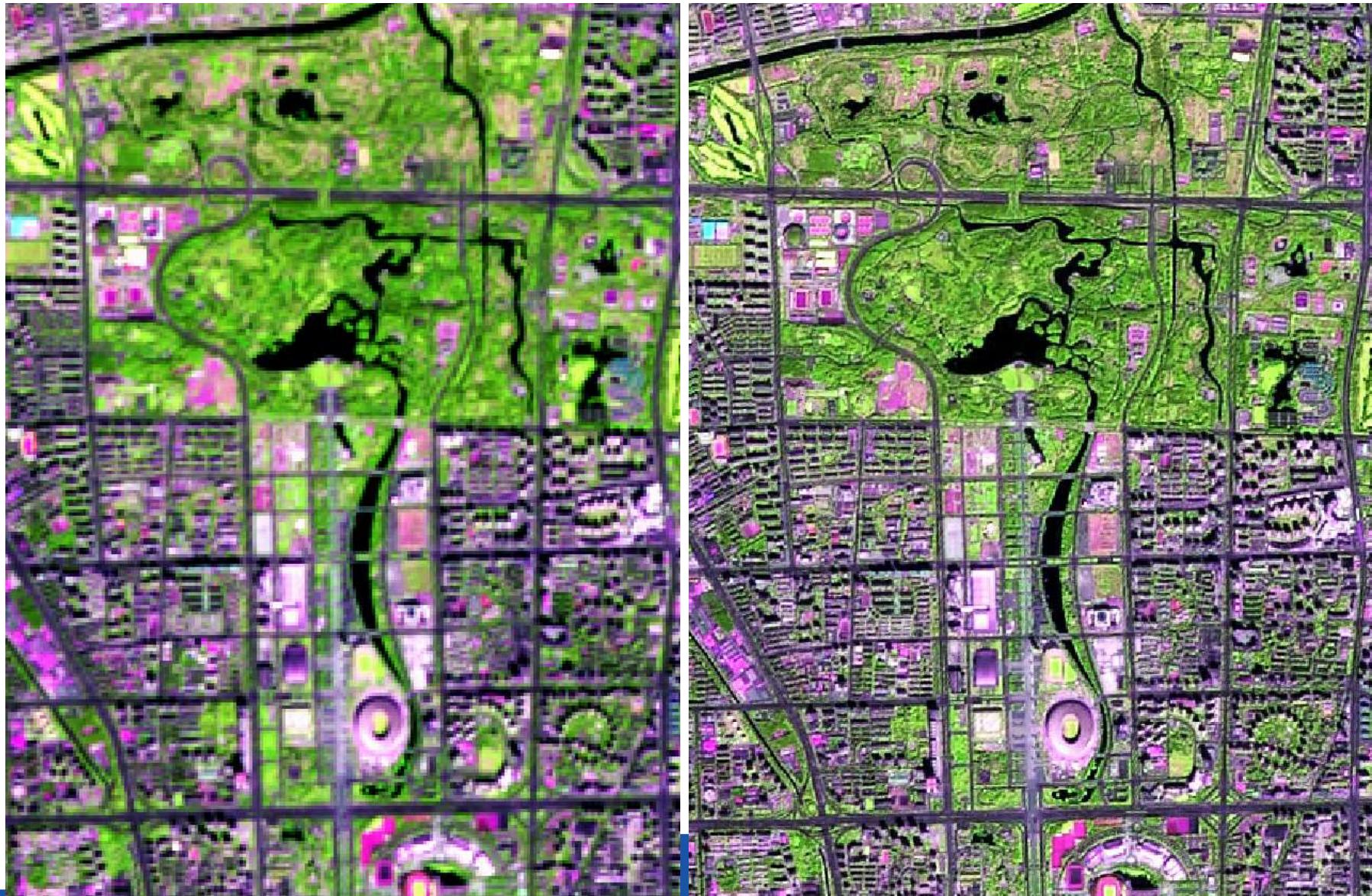
Sentinel-2A MSI Data

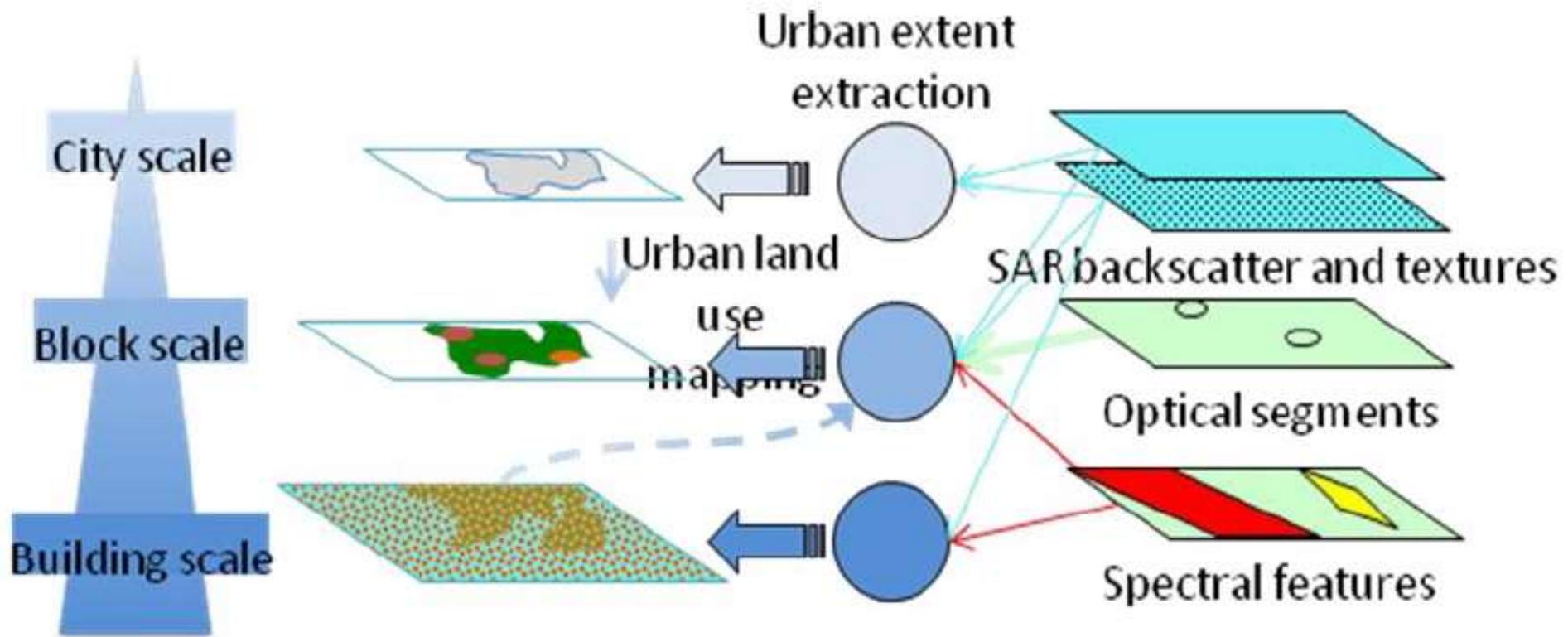


Sentinel-2A MSI Data

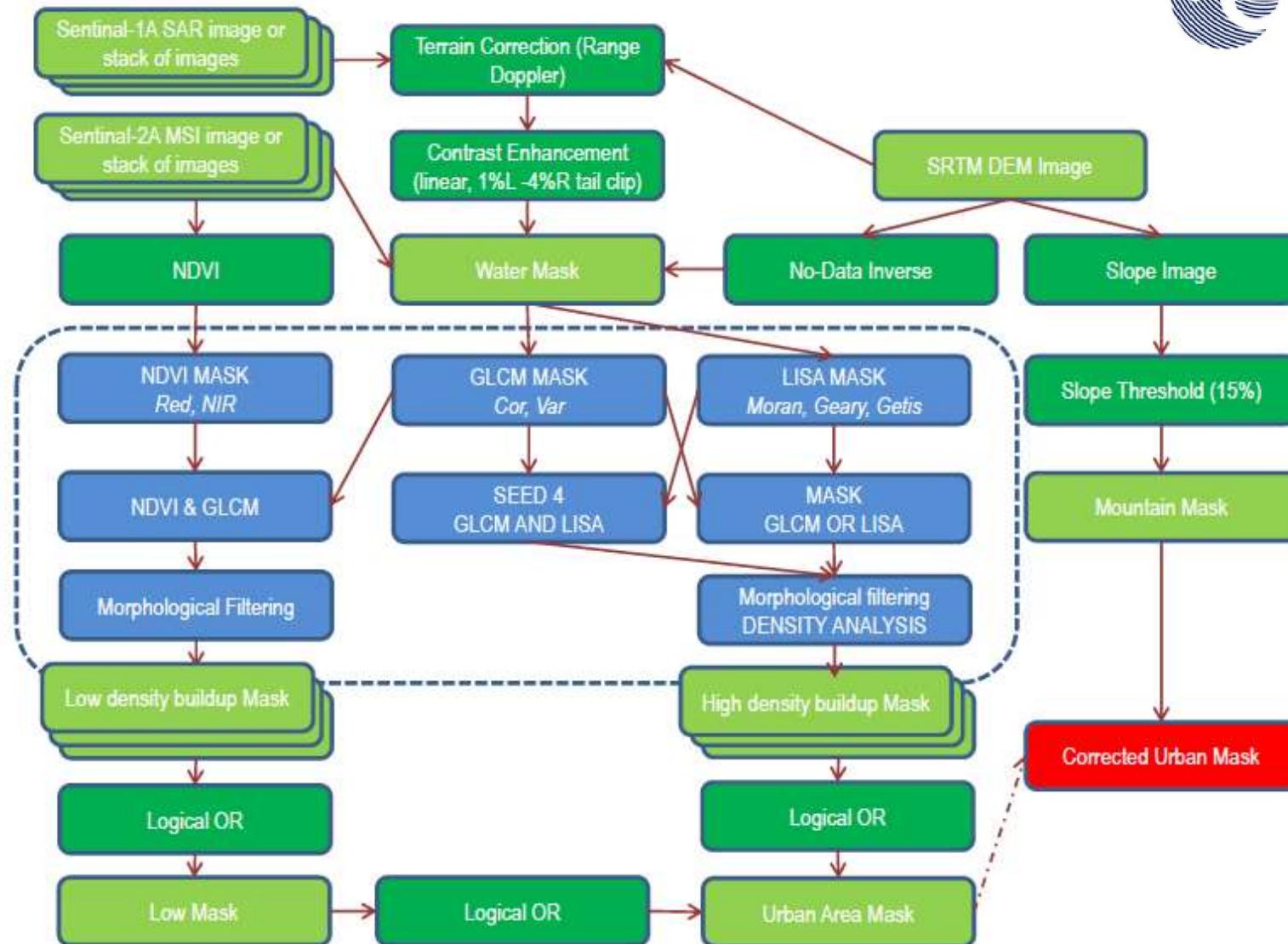


Sentinel-2A: Pan-sharpening

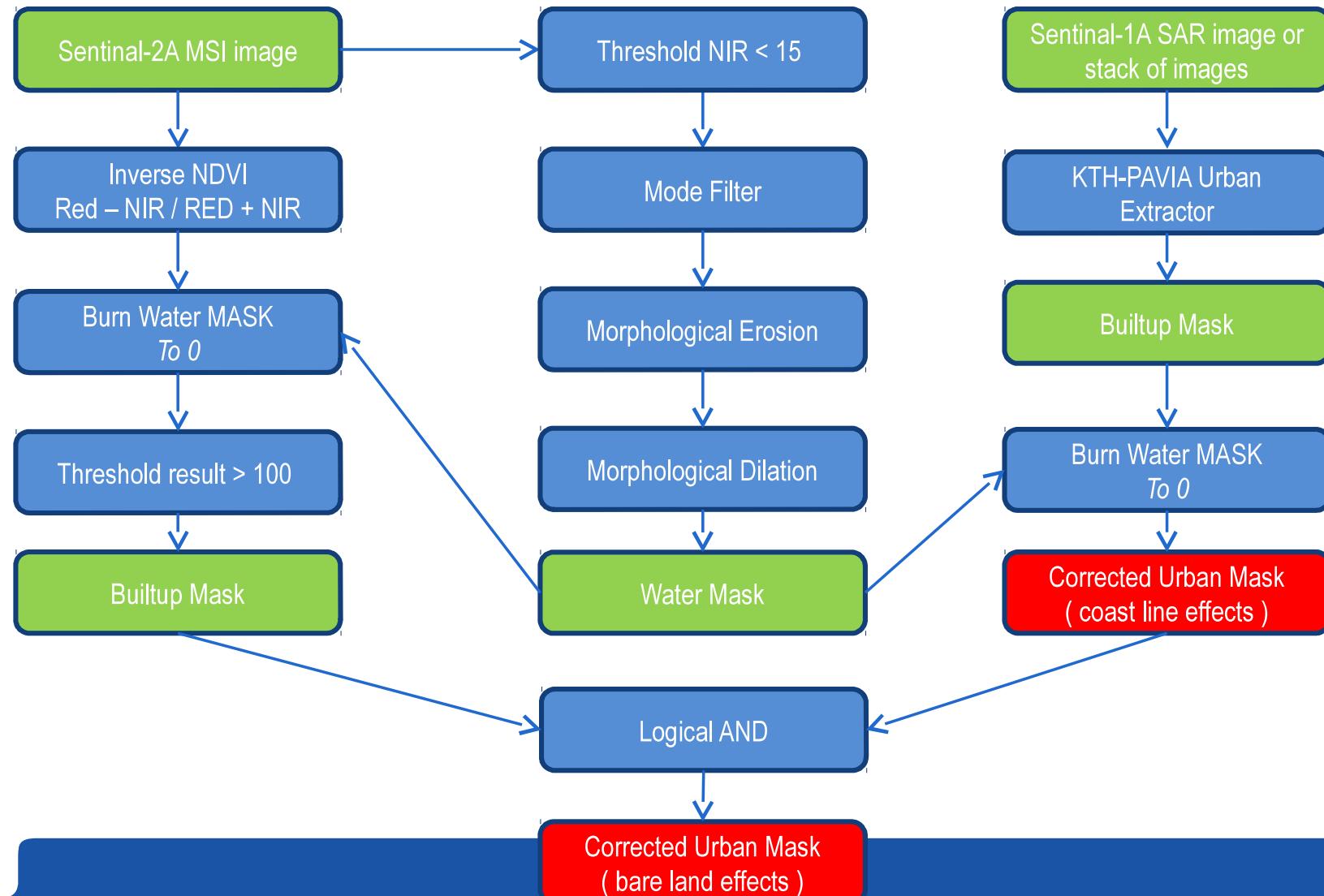




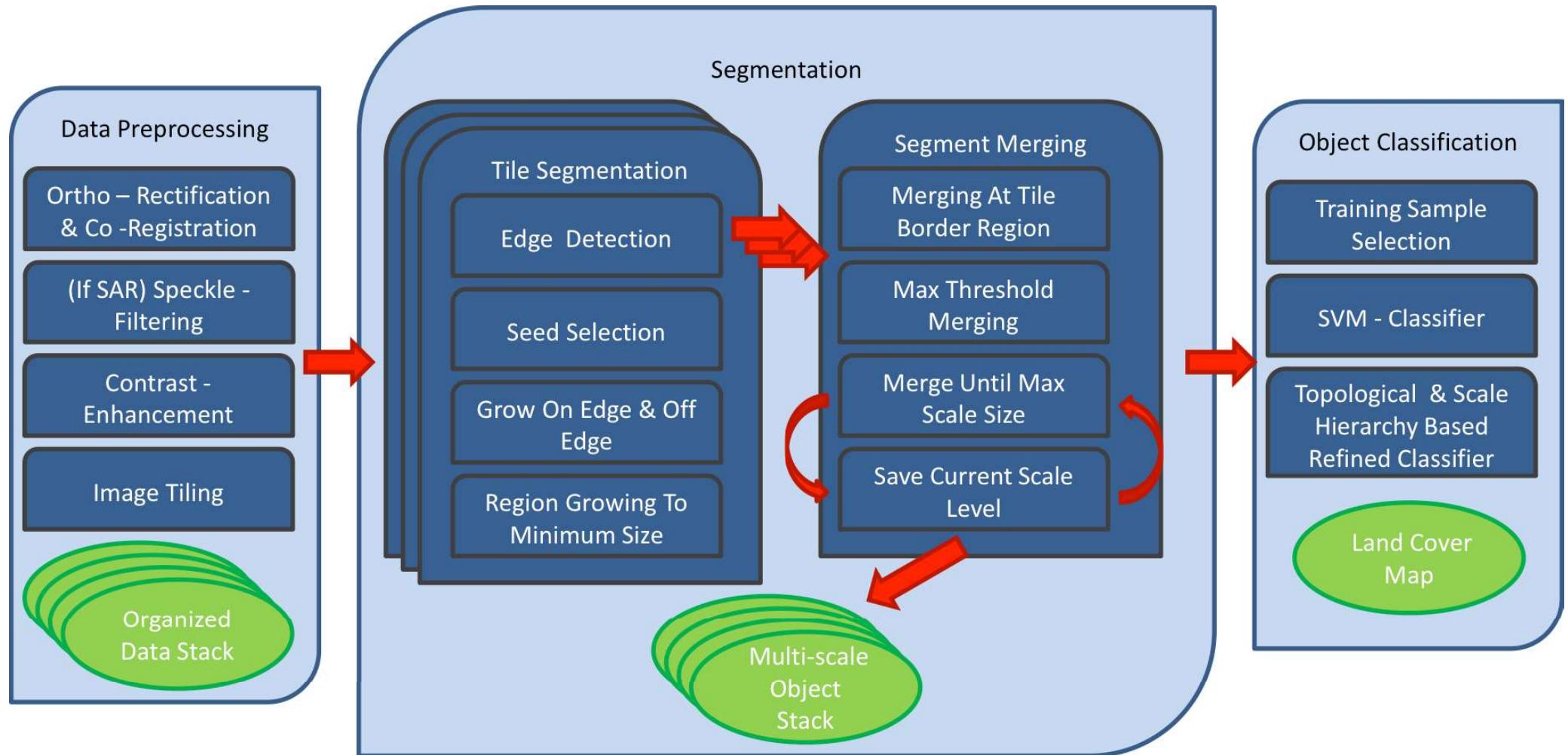
KTH-Pavia Urban Extractor



Urban Extraction with Sentinel-2A & Fusion of Sentinel-1A/2A

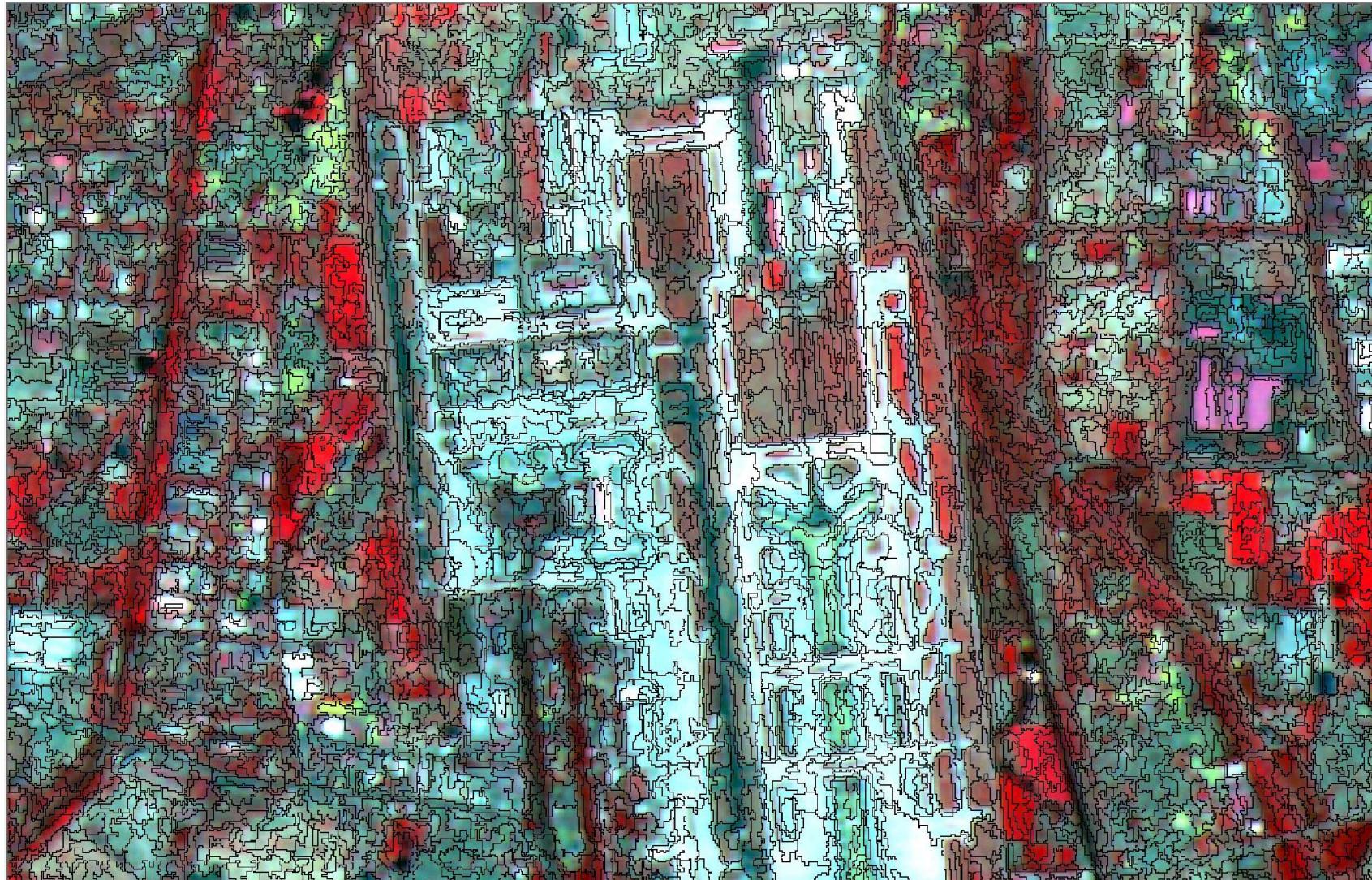


KTH-SEG: Edge-Aware Region Growing & Merging Algorithm



Ban, Y. and A. Jacob, 2013. Object-based Fusion of Multitemporal Multi-angle ENVISAT ASAR and HJ-1 Multispectral Data for Urban Land-Cover Mapping. *IEEE Transaction on GeoScience and Remote Sensing*, Vol. 51, No. 4, pp. 1998-2006.

EO4Urban: KTH-SEG



Ban, Y. and A. Jacob, 2013. Object-based Fusion of Multitemporal Multi-angle ENVISAT ASAR and HJ-1 Multispectral Data for Urban Land-Cover Mapping. *IEEE Transaction on GeoScience and Remote Sensing*, Vol. 51, No. 4, pp. 1998-2006.

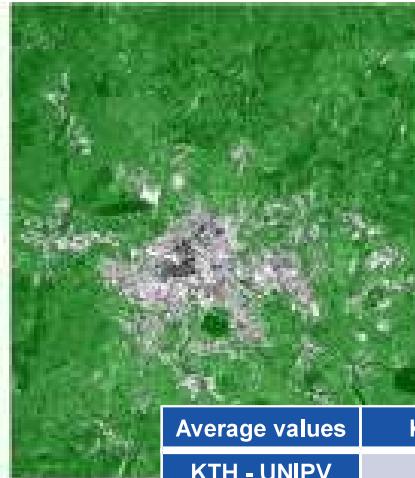


Urban Extraction: ENVISAT ASAR Data

Beijing



Berlin



Jakarta



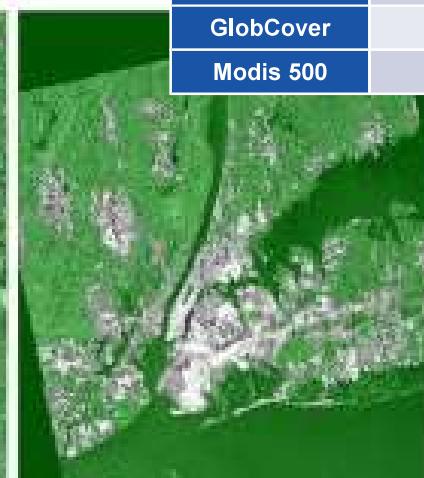
Lagos



Mexico City



Average values	Kappa	Overall Accuracy	Std. Dev.	Comission	Omission
KTH - UNIPV	0,707	85,36%	4%	5,47	23,75
GlobCover	0,471	72,67%	13%	17,10	40,47
Modis 500	0,525	76,31%	11%	20,03	31,12



Mumbai

New York City

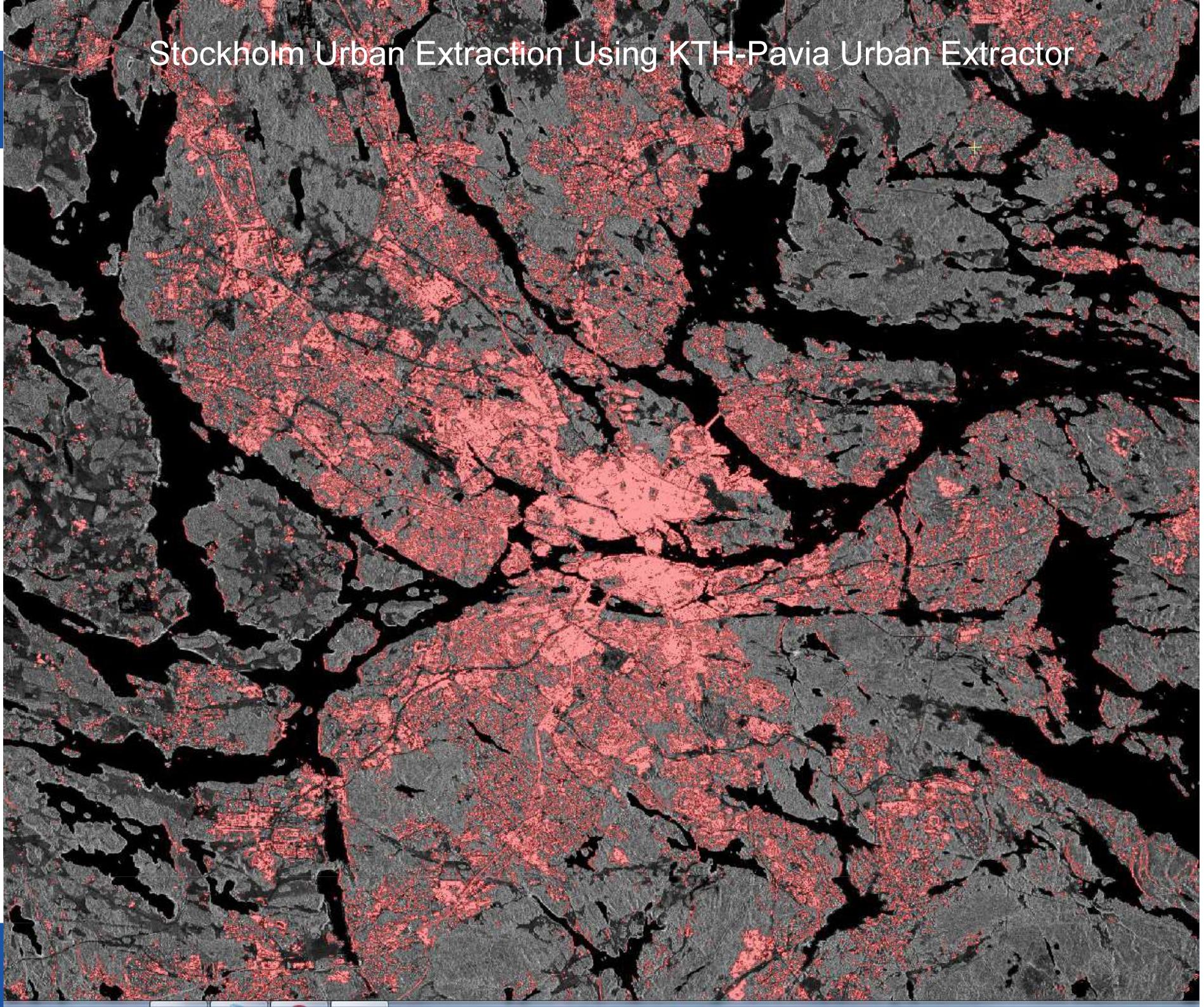
Rio de Janeiro

Stockholm

Sydney



Stockholm Urban Extraction Using KTH-Pavia Urban Extractor



Urban Extent Extraction: SAR





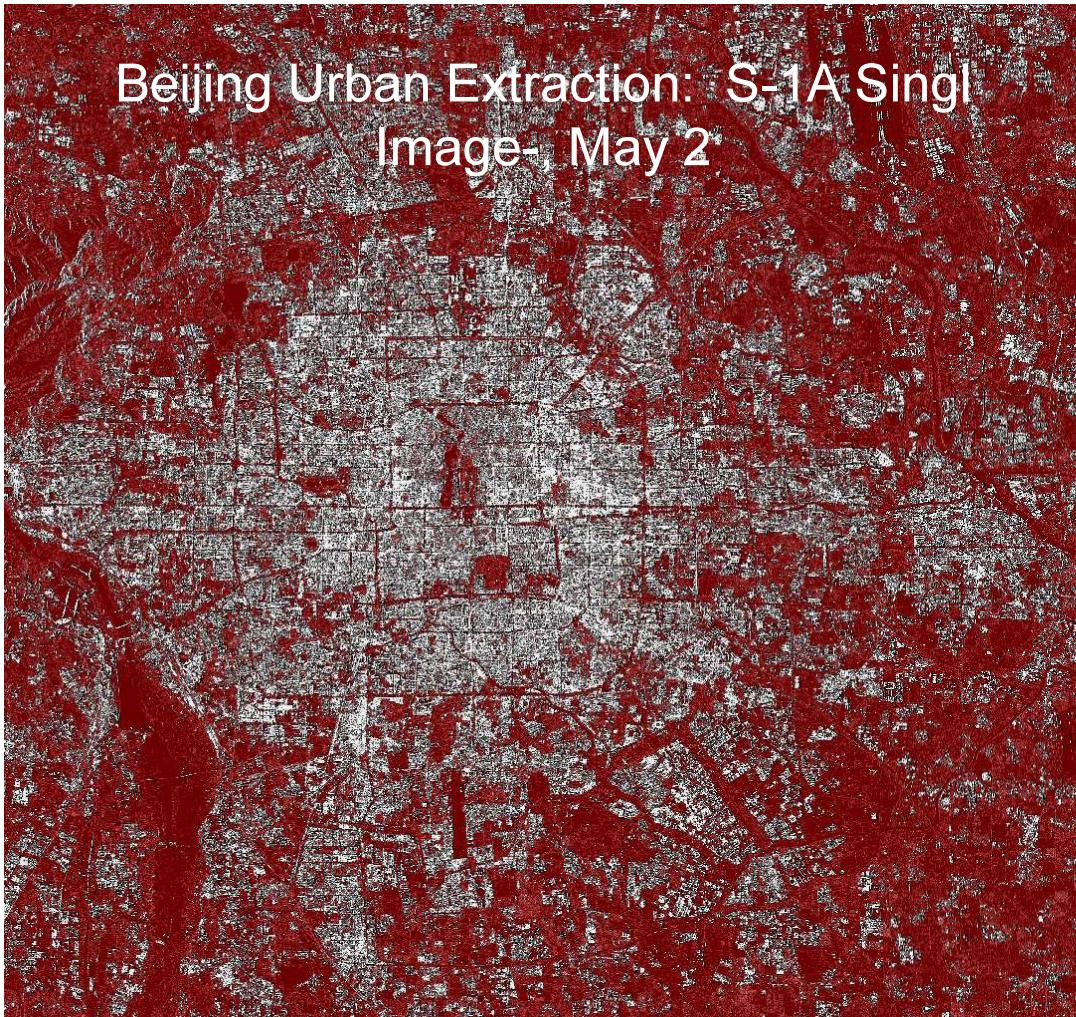


Urban Extent Extraction

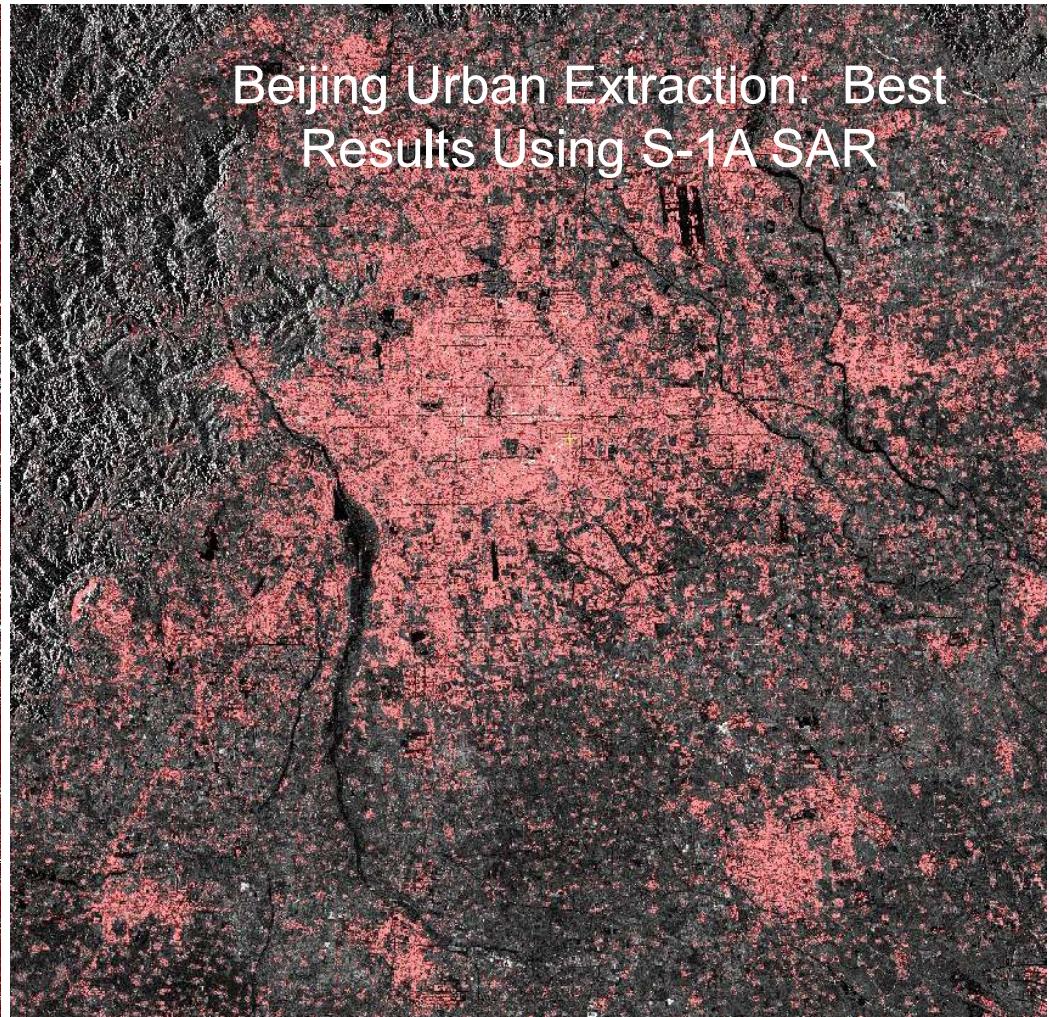
Dataset	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Coefficent	Urban Points in Area %	Non Urban Points in Area %
KTH	89.91	93.41	91.83	0.83	100	100
PAVIA	78.9	92.30	86.24	0.72	100	100
GUF	74.56	98.64	86.84	0.73	100	100
Globland30	94.39	89.97	91.97	0.83	100	100
NYU						
JRC	67.19	96.47	82.46	0.64	100	100

Urban Extraction: Beijing

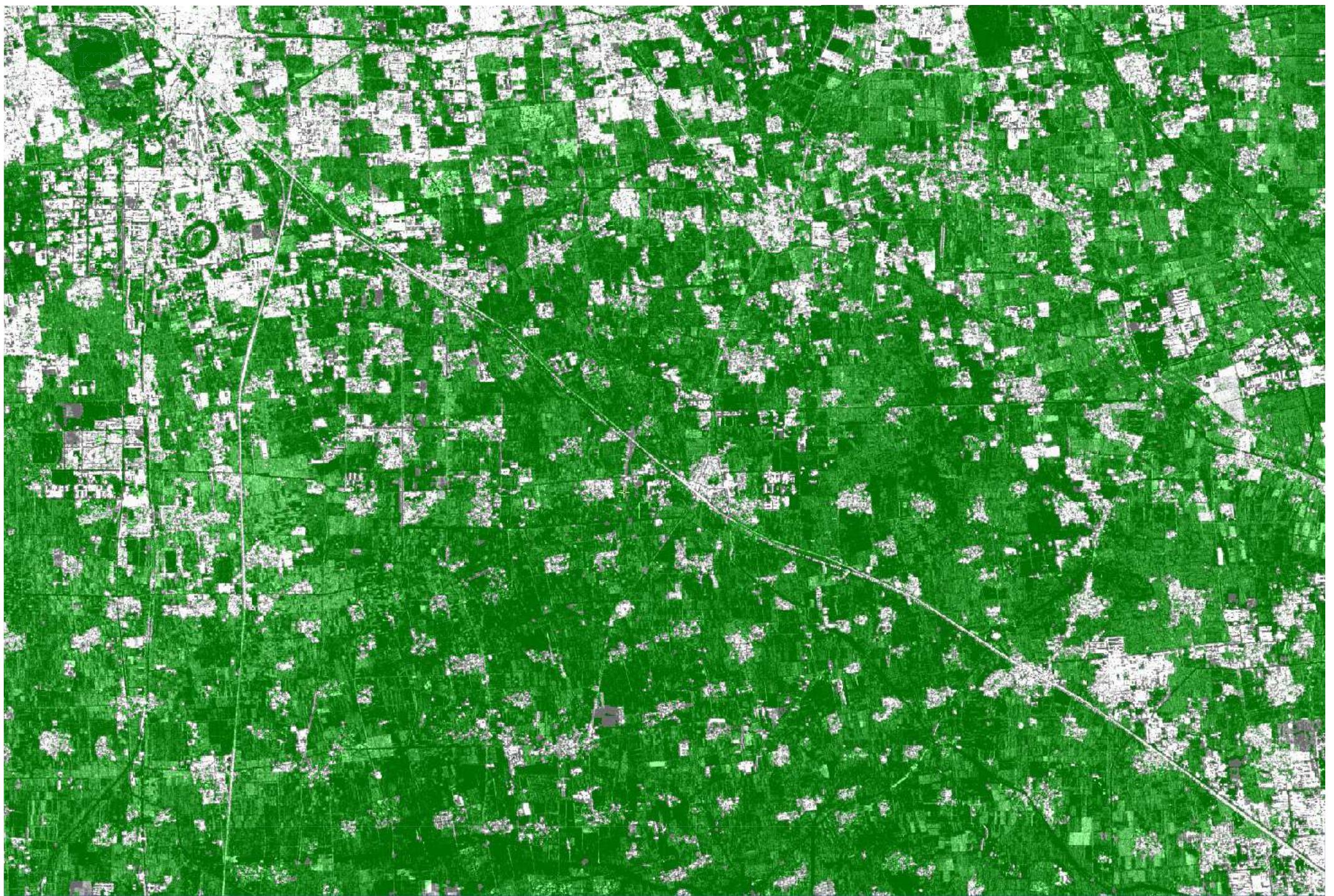
Beijing Urban Extraction: S-1A Single Image-, May 2017

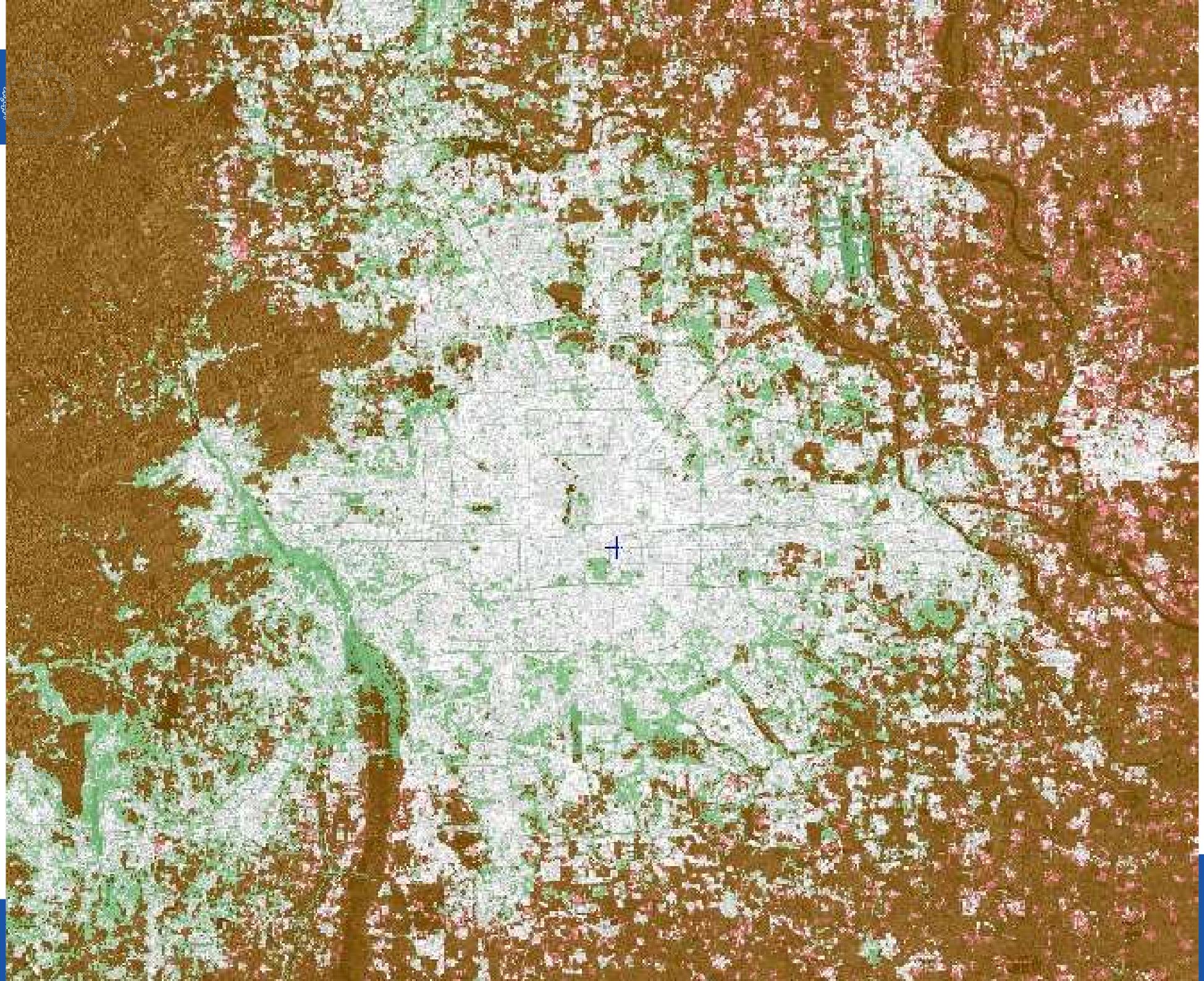


Beijing Urban Extraction: Best Results Using S-1A SAR





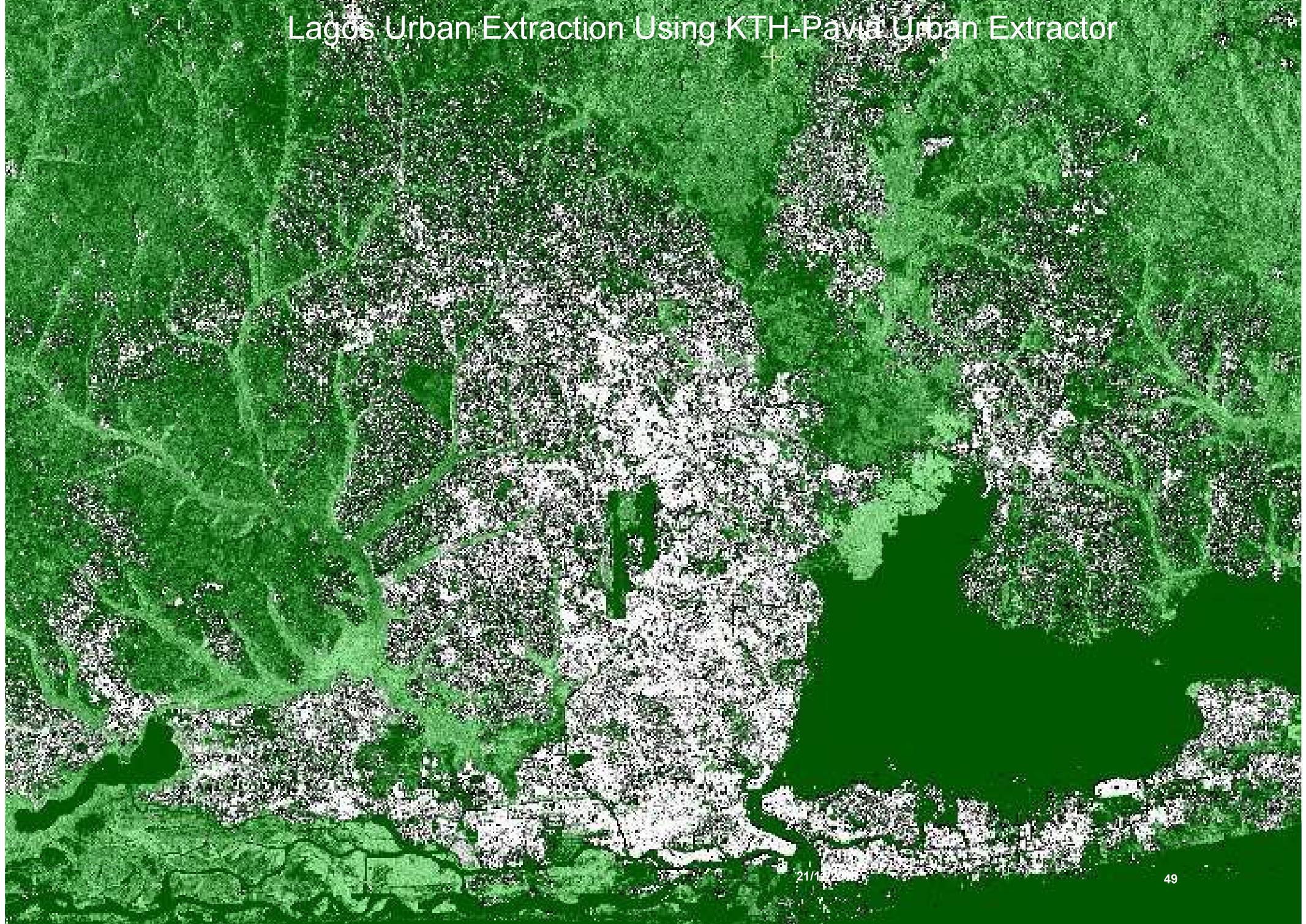


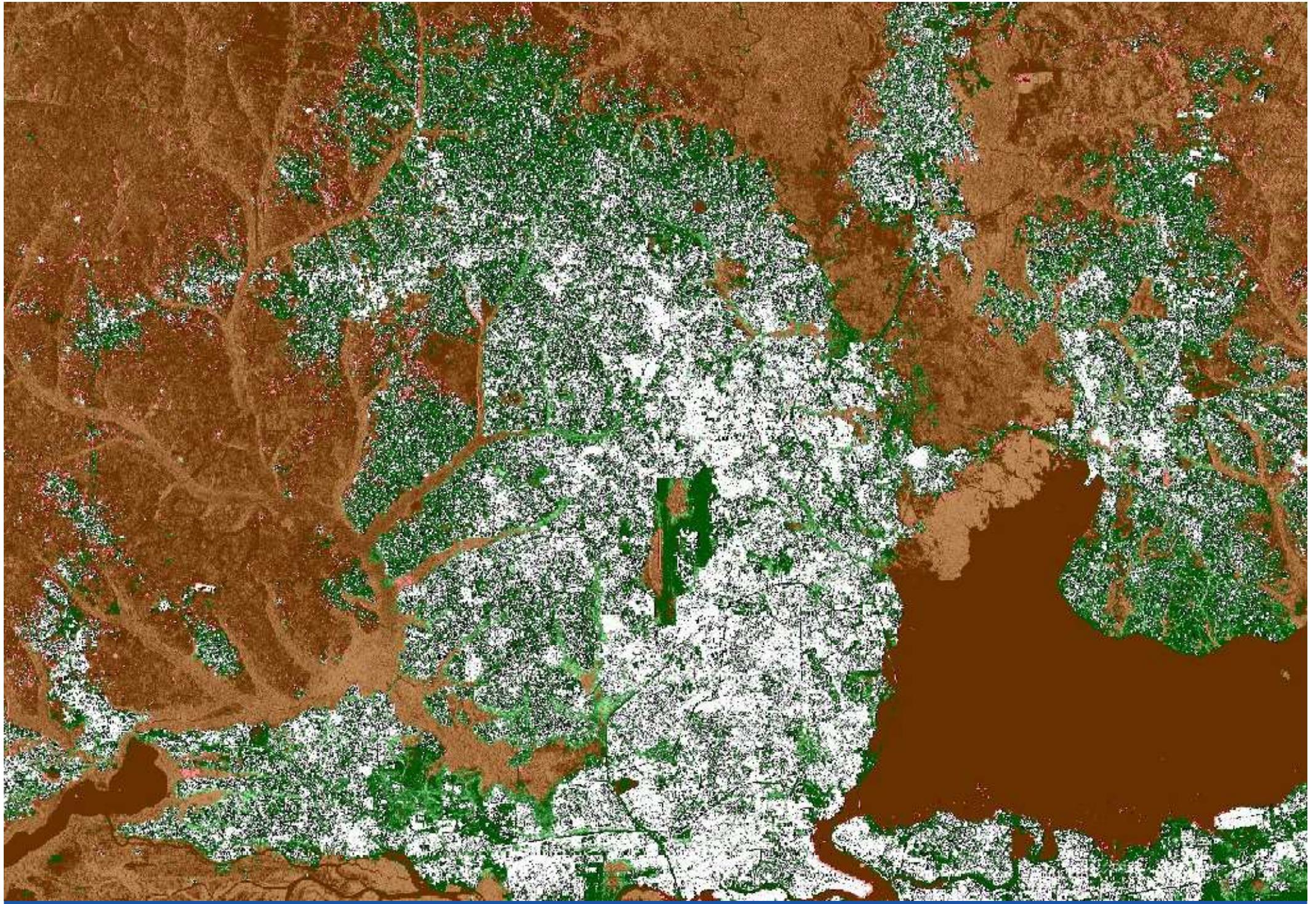


Dataset	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Coefficent	Urban Points in Area %	Non Urban Points in Area %
KTH	95.24	92.26	93.62	0.87	100	100
Pavia	92.22	87.45	89.26	0.79	95.98	88.89
GUF	80.88	98.14	88.77	0.78	95.6	79.82
GlobeLand30	80.74	84.37	82.88	0.66	100	100
NYU	86.19	73.83	77.81	0.56	100	100
JRC GHSL	91.78	79.81	84.26	0.69	100	100

Dataset	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Coefficent
ASC_VV_20150730	84.95	94.79	89.98	0.8000
ASC_VV_20150823	86.74	92.76	89.83	0.7968
ASC_VV_20150916	87.30	93.29	90.36	0.8074
ASC_VV_20151010	89.33	93.67	91.52	0.8304

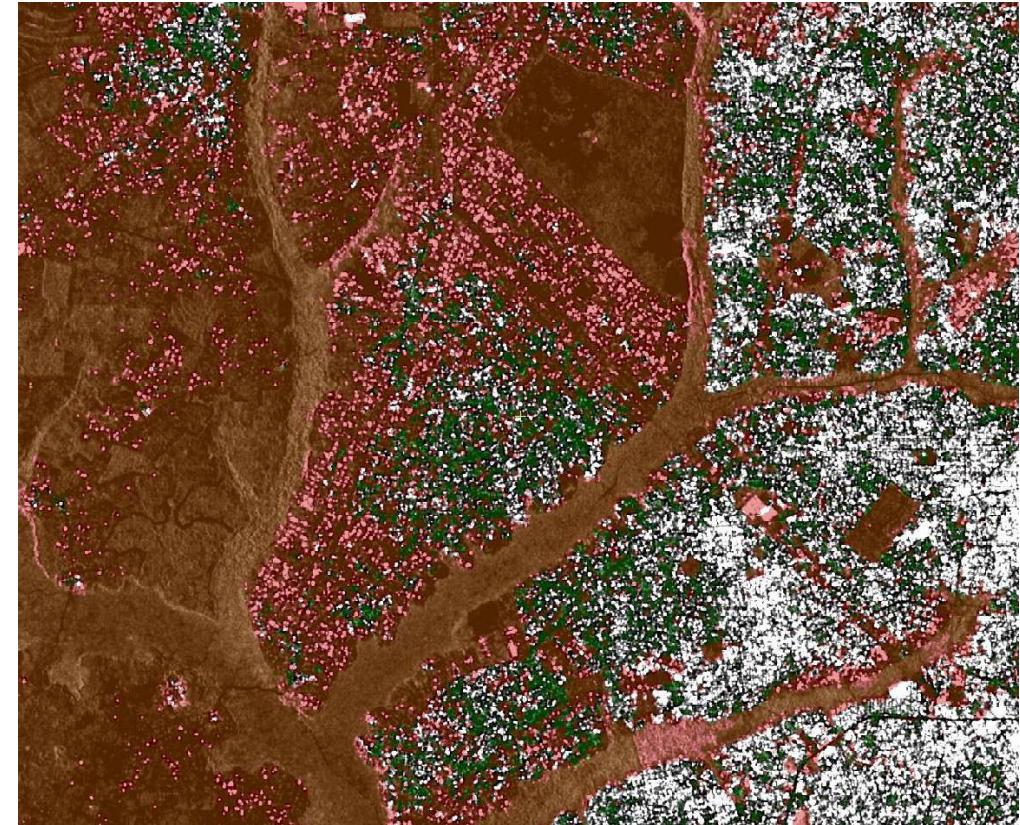
Lagos Urban Extraction Using KTH-Pavia Urban Extractor

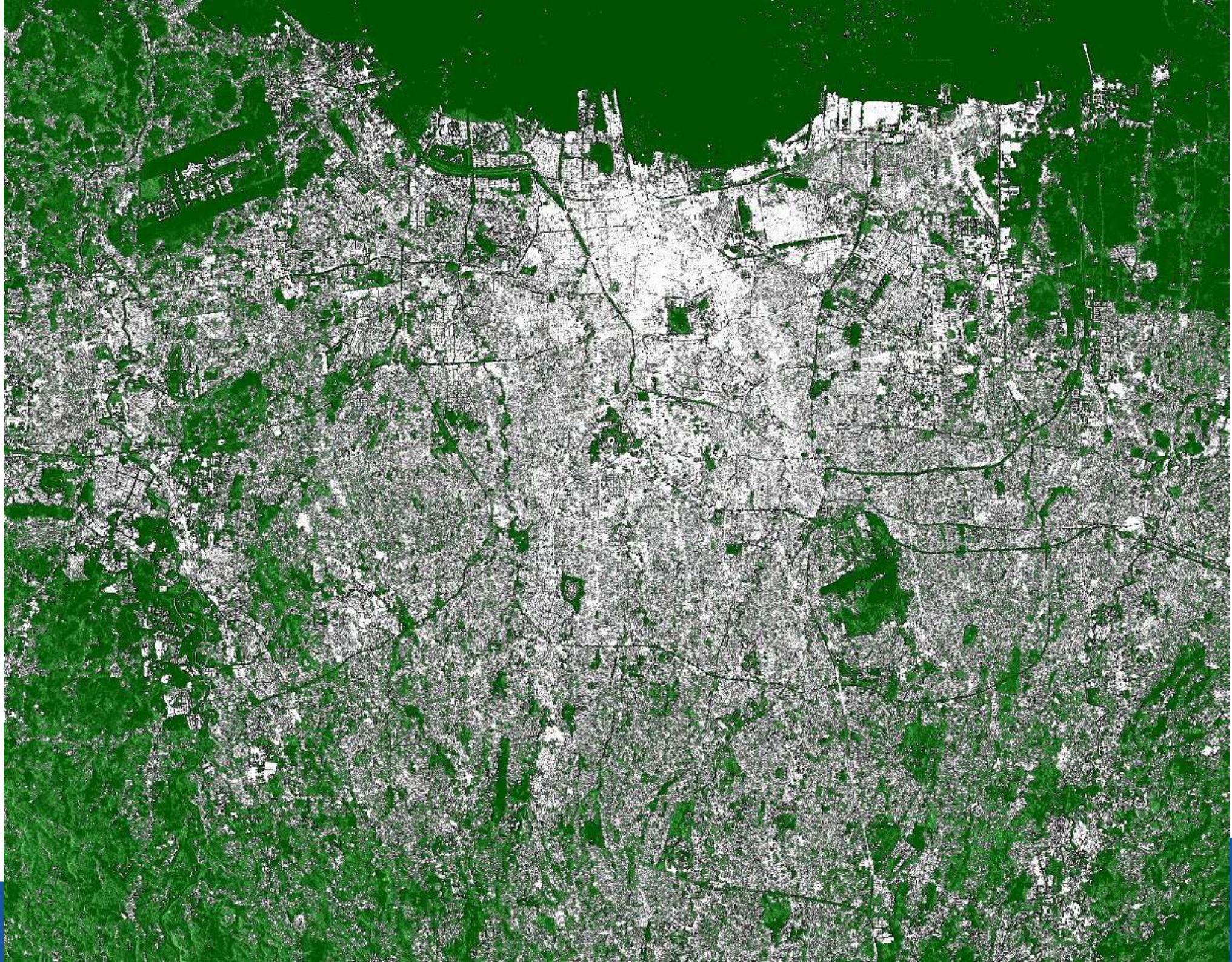






Dataset	Producers Accuracy %	Users Accuracy %	Overall Accuracy %	Kappa Coefficent	Urban Points in Area %	Non Urban Points in Area %
KTH	91.34	93.93	91.51	0.83	100	100
PAVIA	93.12	91.79	91.13	0.82	100	100
GUF	79.07	99.37	87.50	0.75	100	100
Globland30	77.44	97.54	85.70	0.72	100	100
NYU	69.02	93.82	79.3853	0.60	100	100
JRC GHSL	67.19	96.47	82.46	0.64	100	100

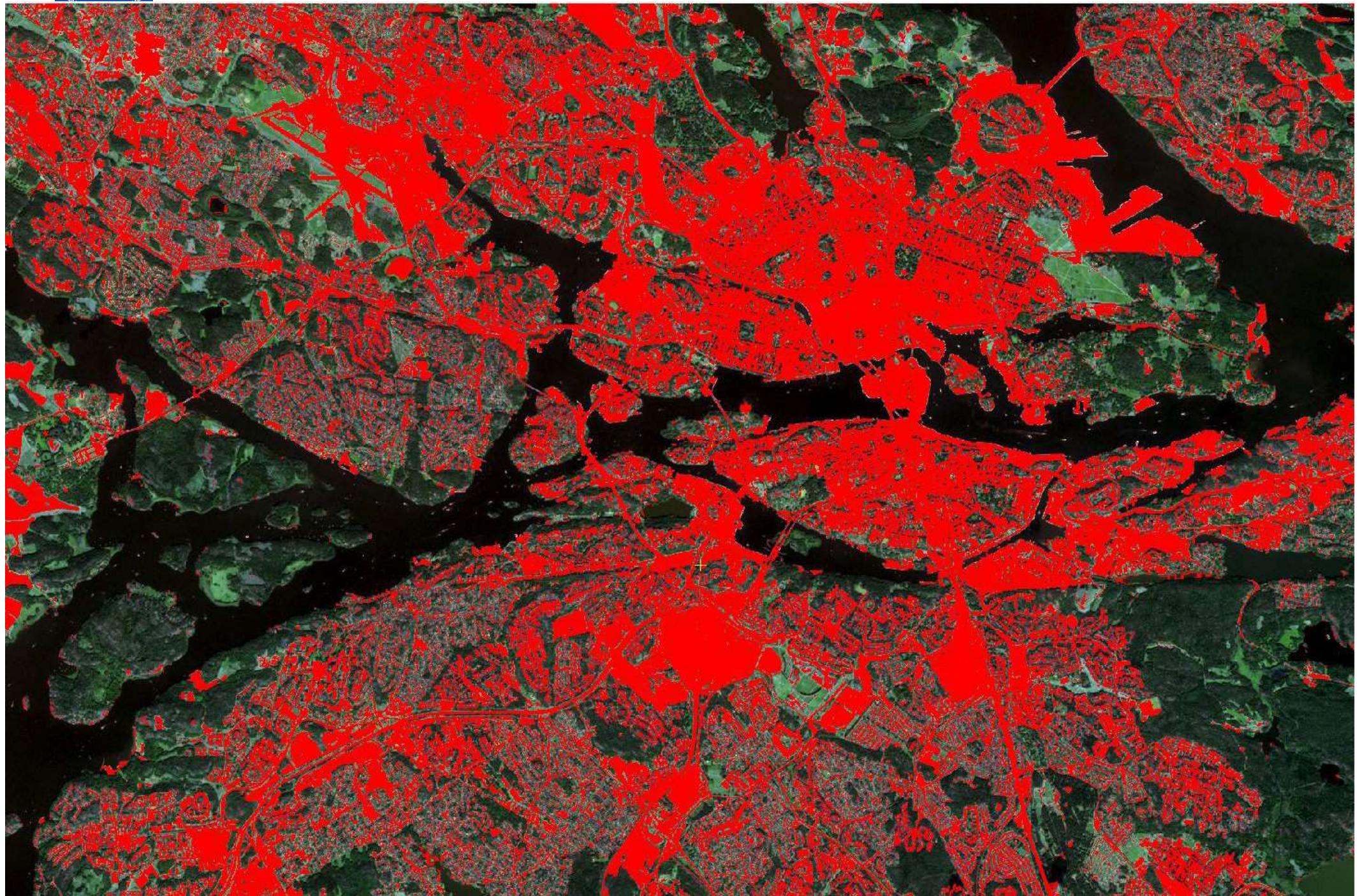




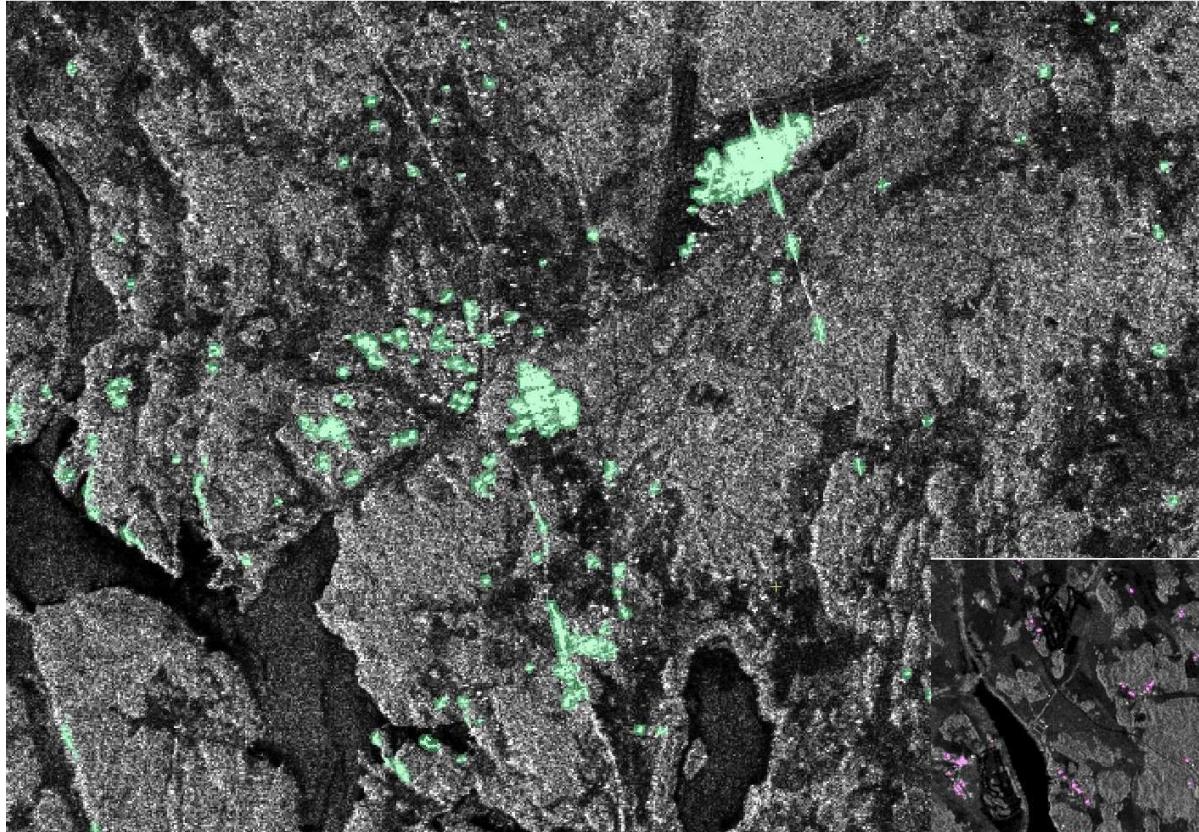




S-2A Results: Stockholm

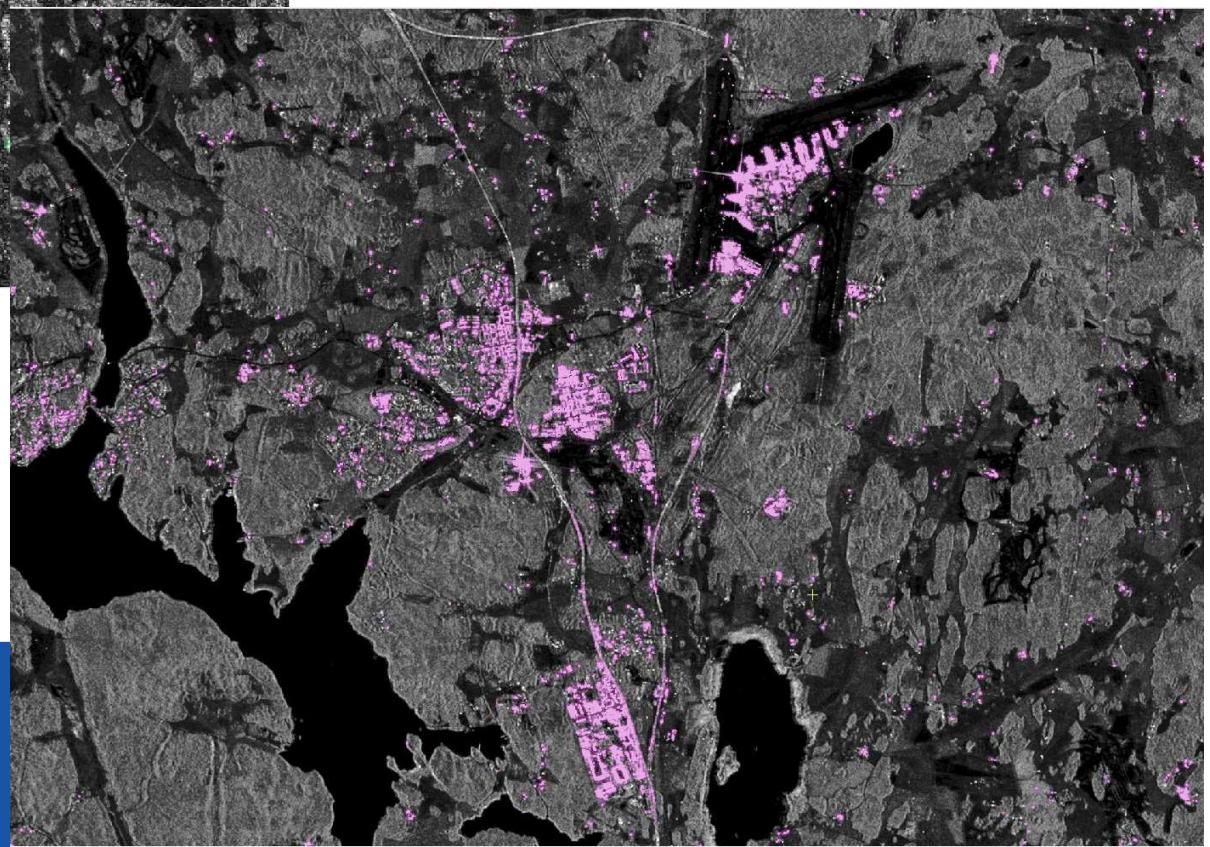


Change Detection



Purple: Builtup Areas in 2015

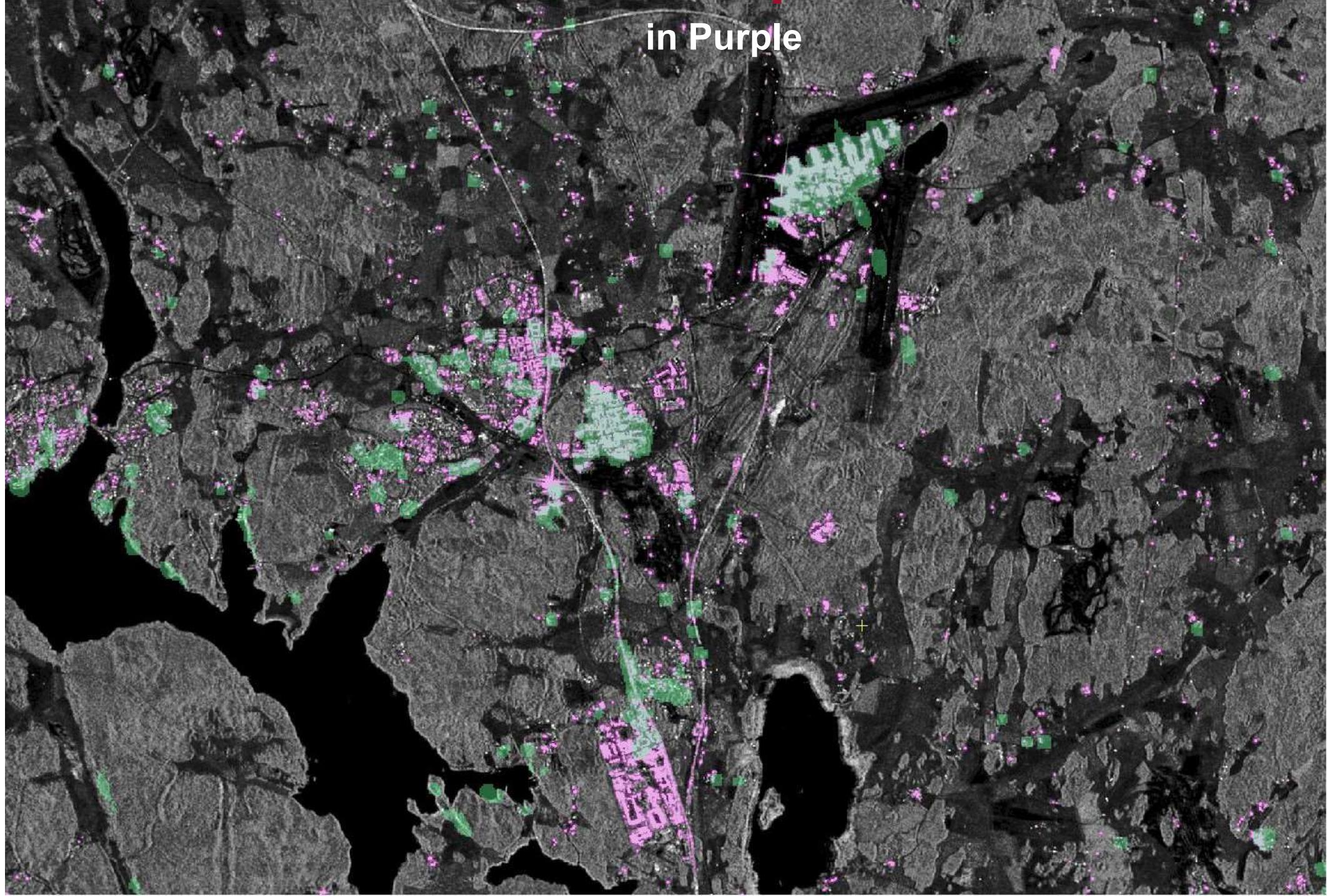
Green: Builtup Areas in 1995



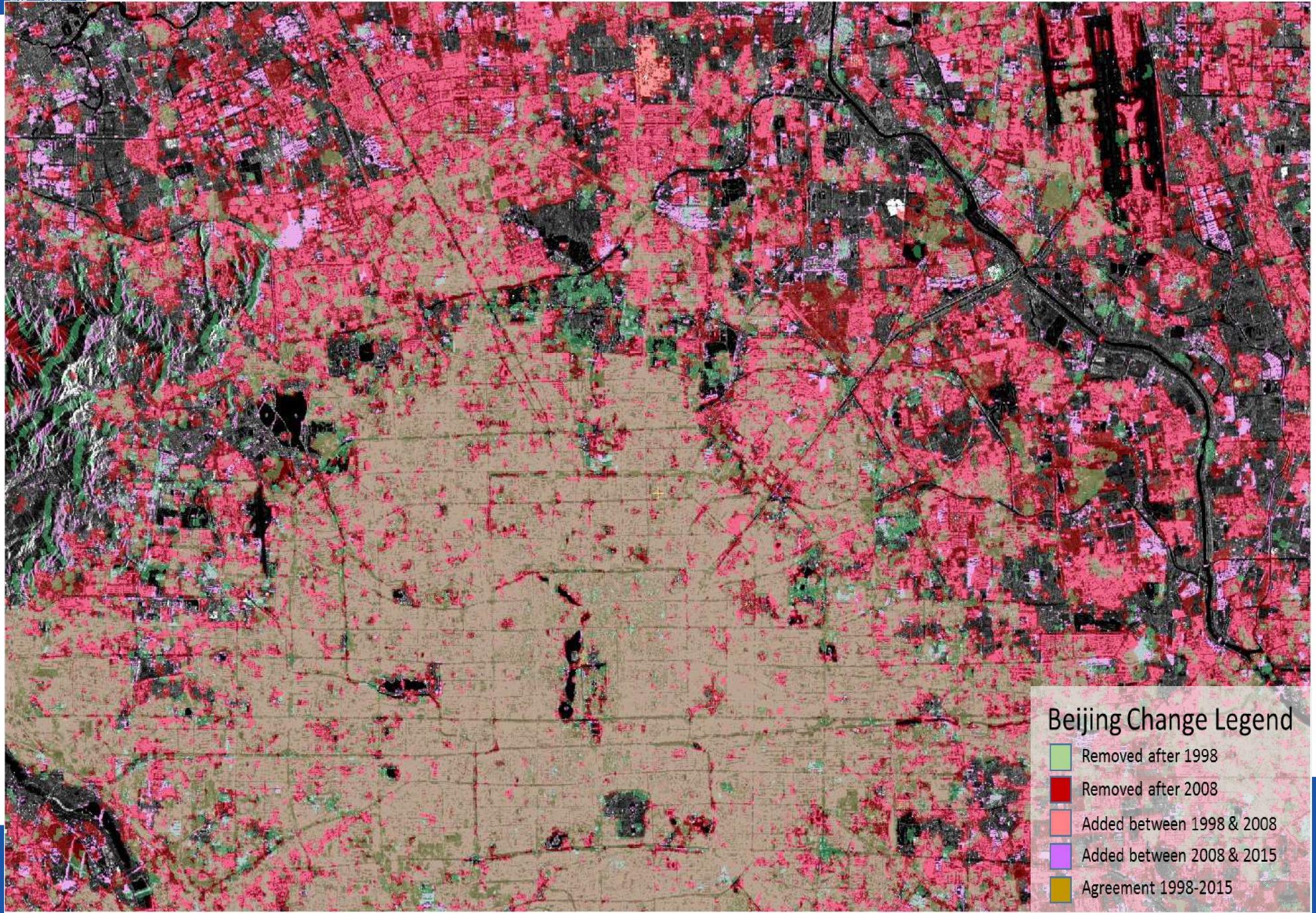


New Builtup Areas

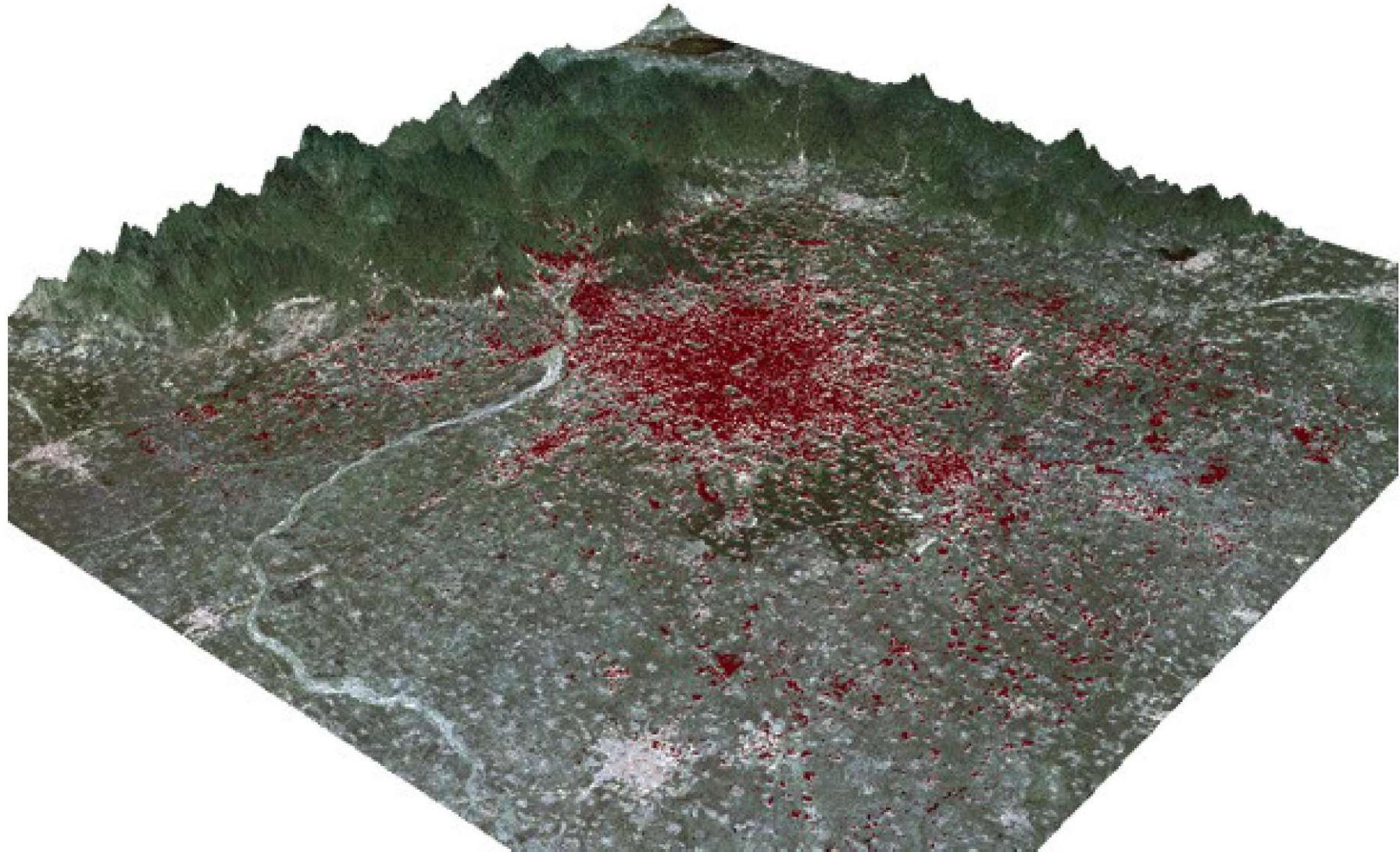
in Purple



Beijing: 1998 → 2008 → 2015



Urban Change Detection

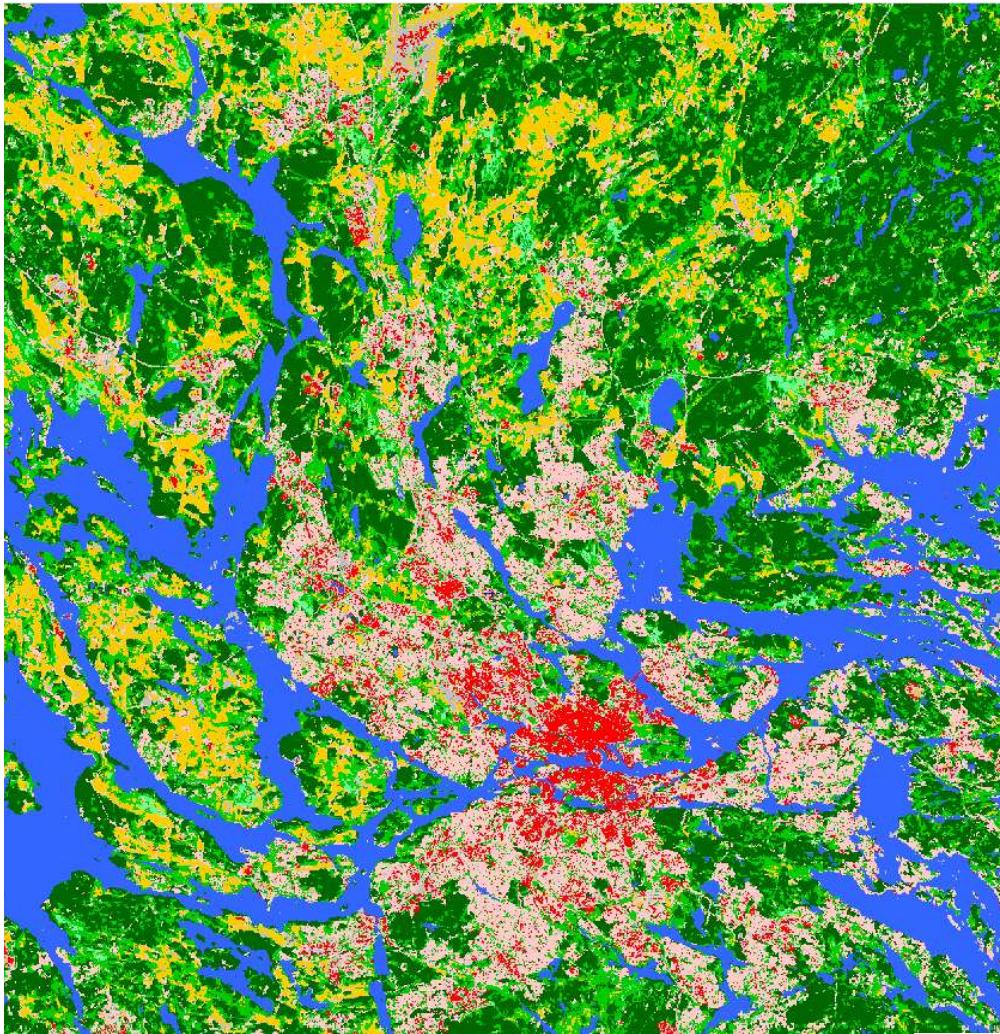


Urban Land Cover: Stockholm



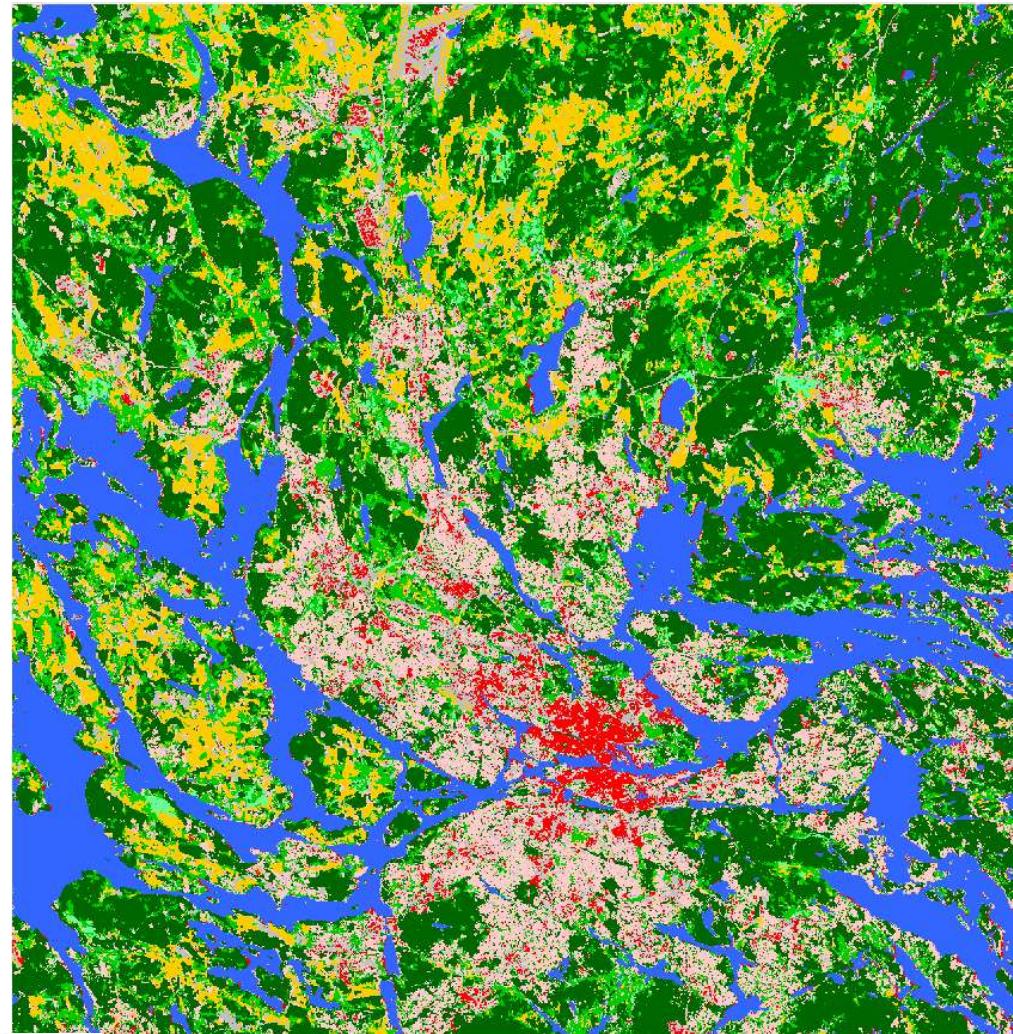
Overall accuracy = 82.75 %
Kappa Coefficient = 0.80

Stockholm: S2 vs. S1 & S2 Fusion



Overall accuracy = 82.75%

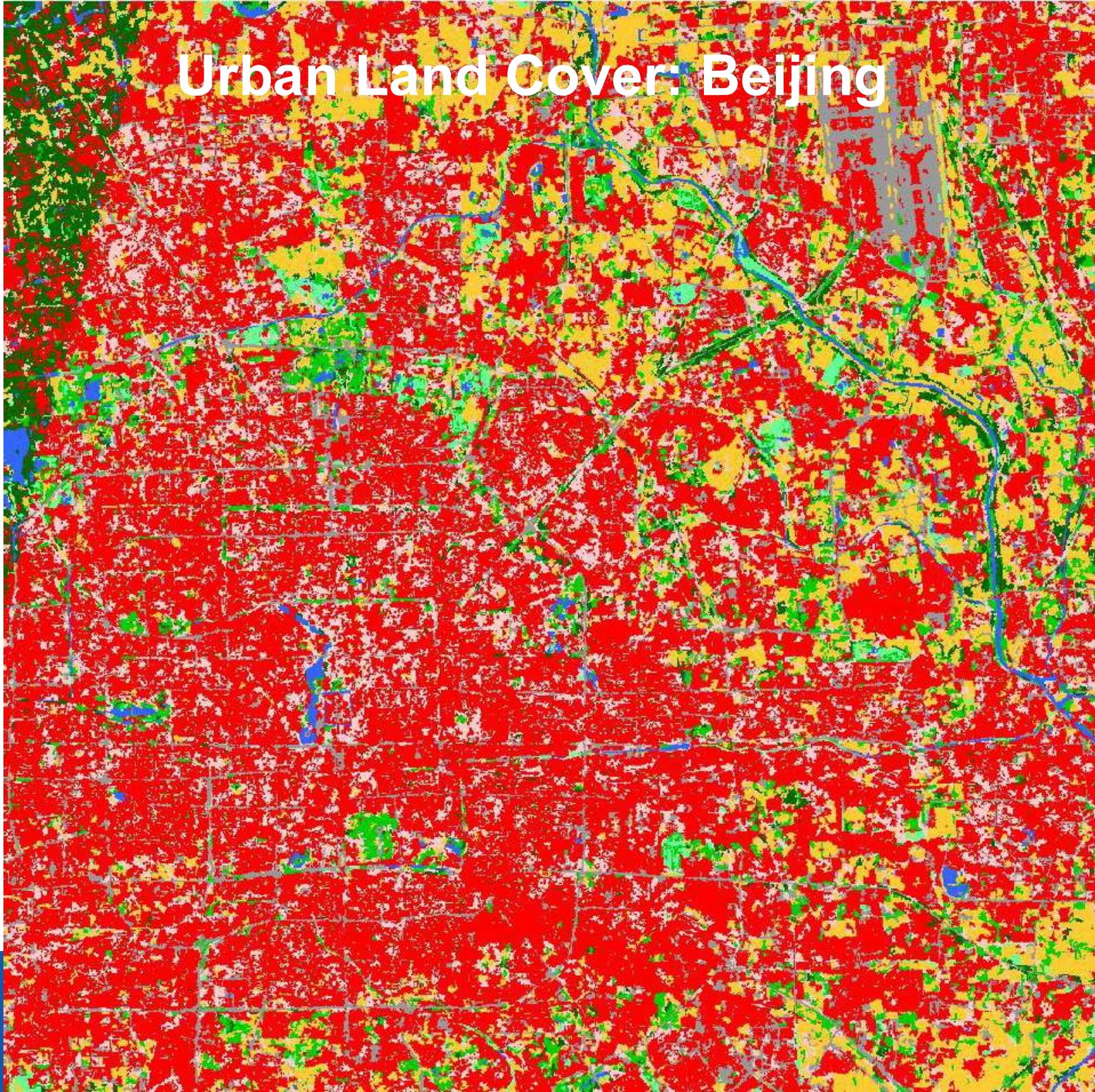
- HD_Builtup
- LD_Builtup
- Roads_Runways
- UGS_Parks
- Golf_Courses
- Agriculture
- Forest
- Water



Kappa Coefficient = 0.80



Urban Land Cover: Beijing





Urban Green Structure





Changes in Urban Green Structure

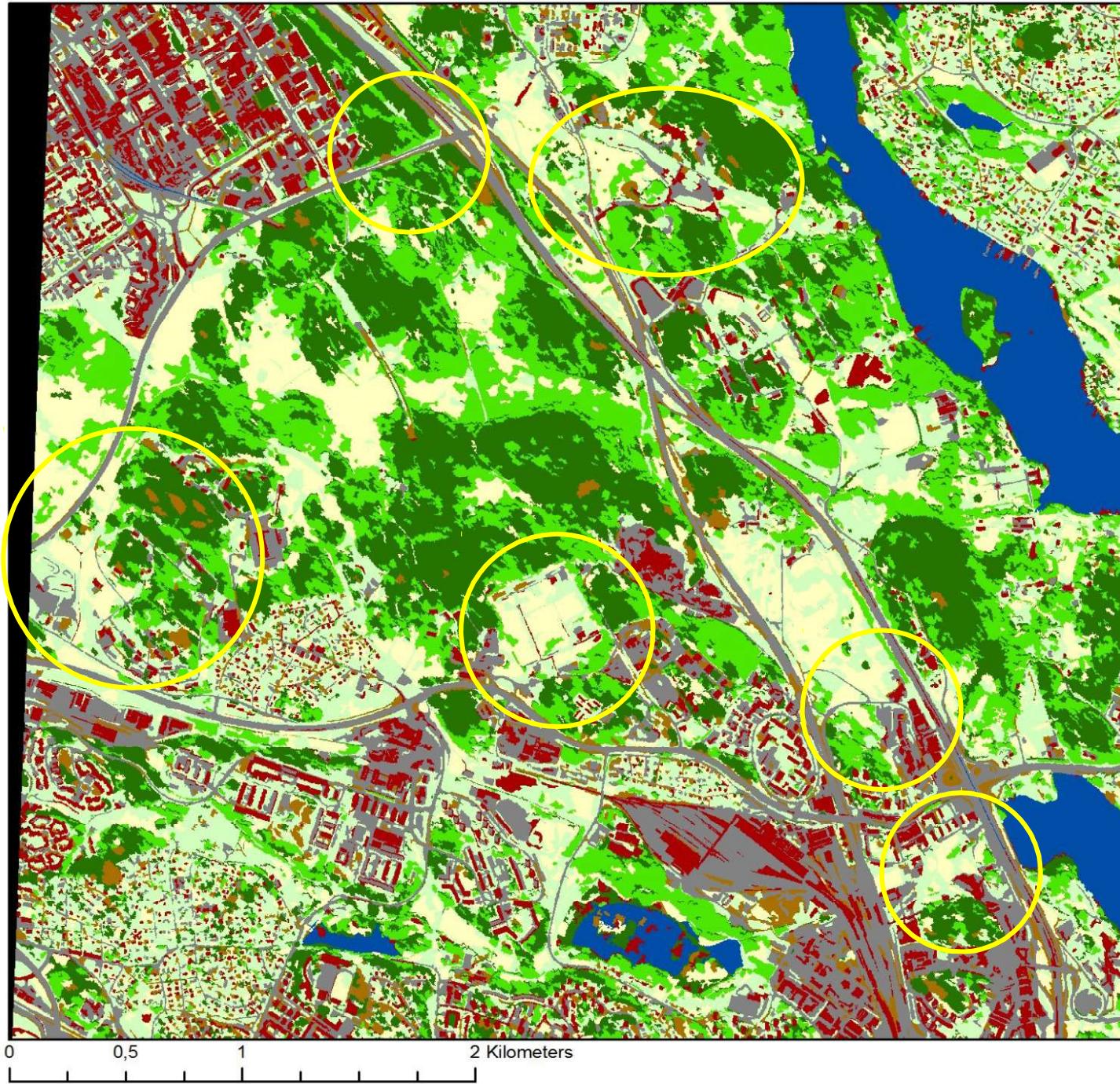
Change in UGS north of Täby, Sweden



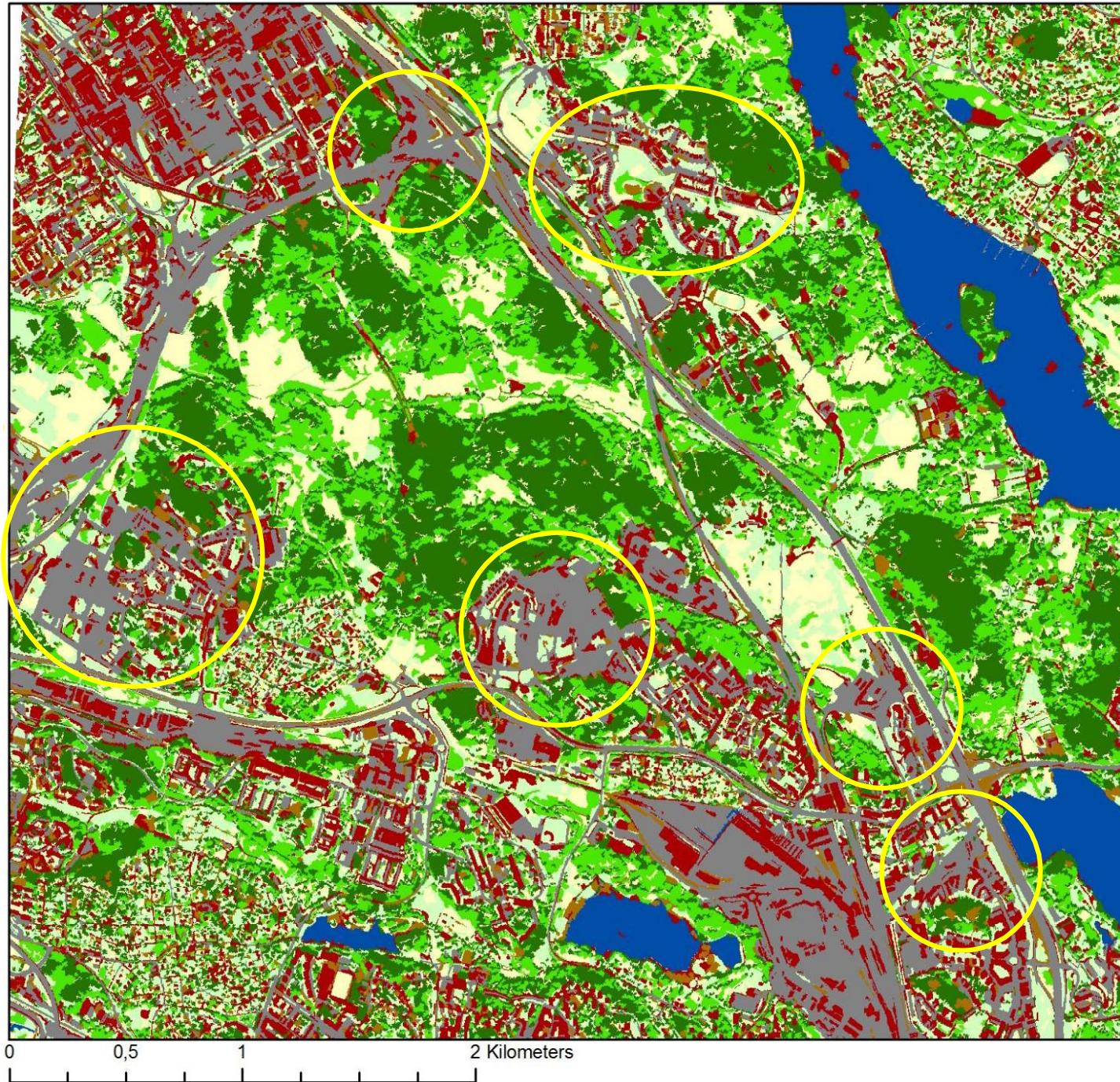
Change in UGS: Rosersberg Industrial Area



2001



2011





Conclusions

- Multitemporal Sentinel-1A SAR data is very promising for urban extent mapping at global scale
 - High-density buildup areas are very well extracted
 - Under-estimation in low-density buildup areas
 - Fusion of S-1A SAR and S-2A MSI data reduced commission errors
- For urban land cover classification at semi-global scale
 - Sentinel-2A MSI data produced very good results with confusions
 - Fusion of S-1A SAR and S-2A MSI data reduced the confusions
- For new buildup area mapping
 - S-1A SAR and historical SAR data produced very good results
- For urban green structure mapping and change detection:

Remote Sensing and Digital Image Processing 20

Yifang Ban *Editor*

Multitemporal Remote Sensing

Methods and Applications

Written by world renowned scientists, this book provides an excellent overview of a wide array of methods and techniques for the processing and analysis of multitemporal remotely sensed images. These methods and techniques include change detection, multitemporal data fusion, coarse-resolution time series processing, and interferometric SAR multitemporal processing, among others. A broad range of multitemporal datasets are used in their methodology demonstrations and application examples, including multispectral, hyperspectral, SAR and passive microwave data.

This book features a variety of application examples covering both land and aquatic environments. Land applications include urban, agriculture, habitat disturbance, vegetation dynamics, soil moisture, land surface albedo, land surface temperature, glacier and disaster recovery. Aquatic applications include monitoring water quality, water surface areas and water fluctuation in wetland areas, spatial distribution patterns and temporal fluctuation trends of global land surface water, as well as evaluation of water quality in several coastal and marine environments.

This book will help scientists, practitioners, students gain a greater understanding of how multitemporal remote sensing could be effectively used to monitor our changing planet at local, regional, and global scales.

Earth Sciences
ISSN 1567-3200

ISBN 978-3-319-47035-1



springer.com

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