

# Global Development Assistance

Accelerating Impact

Earth Observation Based Solutions to Leverage  
Development Assistance for Urban Sustainability

**GAF AG | DLR | GISAT**

World Bank Land Conference

15 May 2024

\* acknowledging inputs from the broader ESA GDA team<sup>1</sup>



### Agriculture

KO Sep'22



### Water Resources



### Clean Energy



### Marine Environment & Blue Economy

KO Jun'22



### Fragility, Conflict & Security

KO Jan'22



### Climate Resilience

KO Dec'21



### Urban Sustainability

KO Feb'22



### Disaster Resilience

KO Sep'21



# GDA

Global Development Assistance

# GDA AID

Agile EO Information Development



# GDA Urban Sustainability: Who We Are



## GDA-Urban Consortium



# Three IFIs | Eight Supported IFI Projects



	World Bank Group				Asian Development Bank		African Development Bank
<b>EO Information Development</b>	Urban Asset Exposure Assessmnt	Wetland Monitoring and Restoration System	SlumMonitor	Sust. Development Scenarios + NBS Potential	EO-informed Green Transformatio	EO-informed Transport Modelling	Support to National Urban Data Platform
<b>Supported IFI Project</b>	Nigeria WACA Multi-Sector Resilience Plan	Second Rwanda Urban Development Project	Cote d'Ivoire Urban Resl. and SWM Project + WAEMU Affordable Housing Finance Project	Jordan Sustainable Cities ASA	Liveable Cities KSTA + DREAMS 2	Updating the Revised Dhaka Strategic Transport Plan	Kenya Integrated Urban Data Platform
<b>Use Case</b>	Nature-Based Solutions 	Nature-Based Solutions 	Slum Monitoring 	Socio-Economic + Liveability 	Liveability 	Transport 	Housing & Revenue 
<b>Lead Partners</b>	TRE-Altamira GAF, DLR	TRE-Altamira GAF, DLR	GISAT DLR	GISAT AIT, DLR	GAF DLR	GAF AIT, DLR	GAF DLR
<b>City</b>	Warri	Kigali	Abidjan	Amman-Zarqa	Sargodha	Dhaka	Nairobi





Partners:



AUSTRIAN INSTITUTE OF TECHNOLOGY



Use Cases



**Urban Asset Exposure**  
WB | Nigeria



**Slum Monitoring**  
WB | Cote d'Ivoire



**Urban Wetland Monitoring**  
WB | Rwanda



**Urban Heat Islands**  
ADB | Pakistan



**(Agent-Based) Modelling of Growth + Transport**  
WB/ADB | Jordan/Bangladesh



**Support to Establishment of Urban Data Platform**  
AfDB | Kenya

EO Data

Non-EO Data



LULC/Imperviousness



Open Green Areas



Population/Informal Settlements



Buildings/Infrastructure



Urban Heat Islands



Ground Motion/Flooding



Census Data



Administrative



Municipal Dashboards



Attractors/Pols



Sensor Data



Economic Projections

...

Types of Innovations

Use of New EO datasets

Enhanced Production (automation, Deep Learning etc.)

Intuitive User Analytics

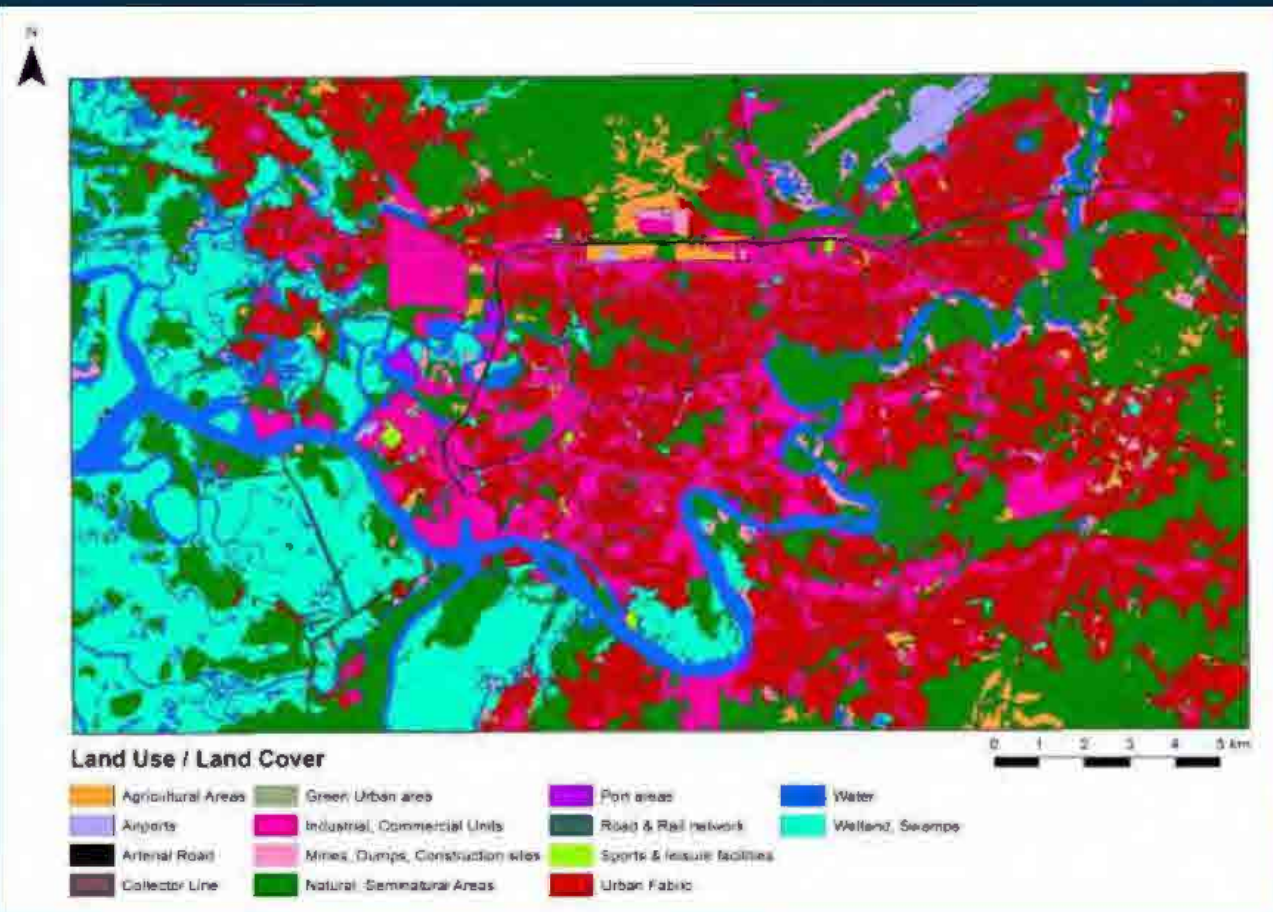
Backcasting -> Now-casting-> Forecasting

Multi-purpose products



# GDA Urban Results | Land Use/Land Cover

(incl. updated transport network)



**WHAT** Highly detailed class nomenclature (Urban Atlas Level 4), overall thematic accuracy >85%



**HOW** Based on *Very High Resolution* imagery, (here 0.5m) + ML + ancillary data



**WHAT FOR** Base product for many derived products and spatial analyses



**TRADE-OFF** Land use -> Higher costs for VHR data acquisition, processing and often also referencing ancillary data

Land Use/Land Cover for Warri 2022





**WHAT** Automated in-house generation of 2D building footprints and road infrastructure based on VHR satellite data



**WHERE** All of Nigeria (>900,000 km<sup>2</sup>), two sets of specifications for rural (e.g. 2D only) and urban areas (e.g. 2D and 3D)



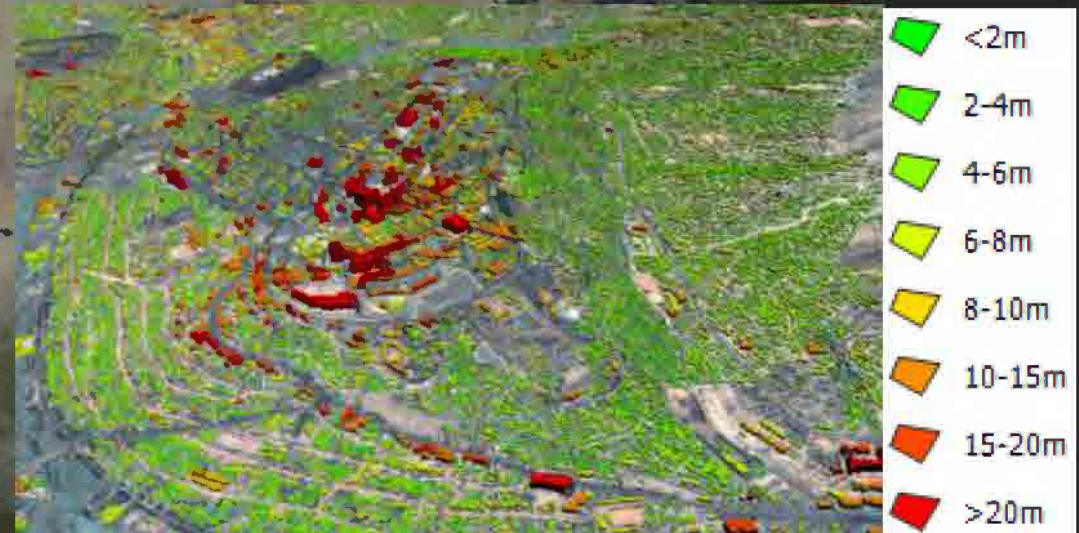
**WHAT FOR** Fundamental data for cadastral records, property taxation, urban planning, DRM



**HEIGHTS** Building heights derived from 0.5m Digital Elevation Model (lower cost, though less accurate, 2m/5m DEMs also available)

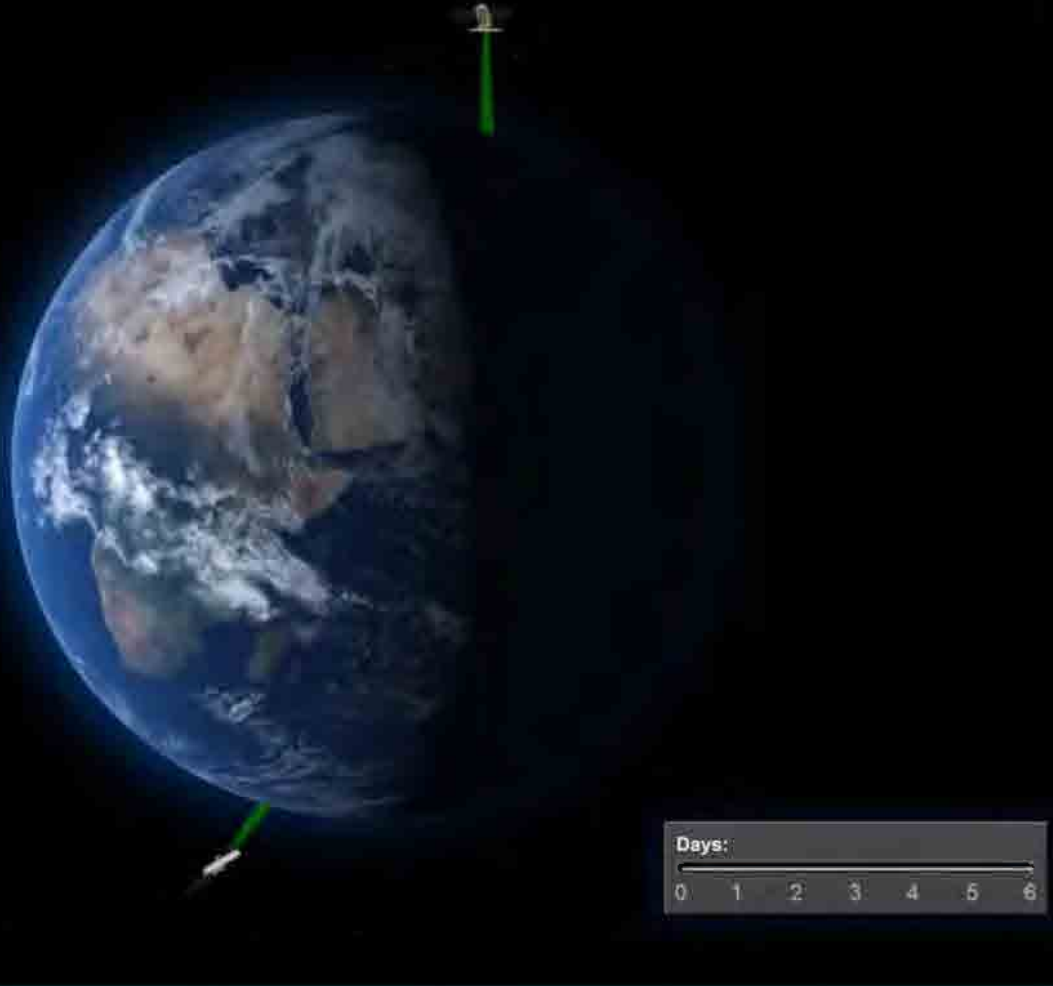


2D building footprints Lagos, Nigeria © GAF AG (2021), © Maxar Technologies (2021)

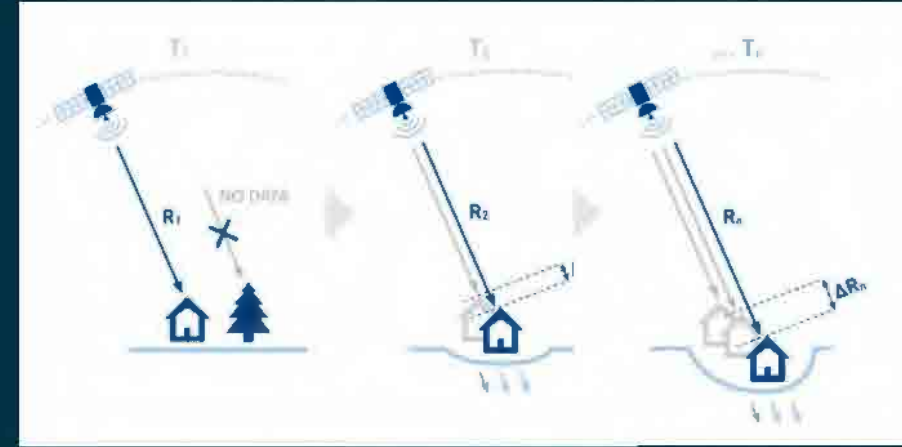


3D building models for Kigali, Rwanda: © 2019, GAF AG, © CNES (2015) Distribution AIRBUS DS.

# SAR Satellites: Ground Motion Measurements



Sentinel-1 mission



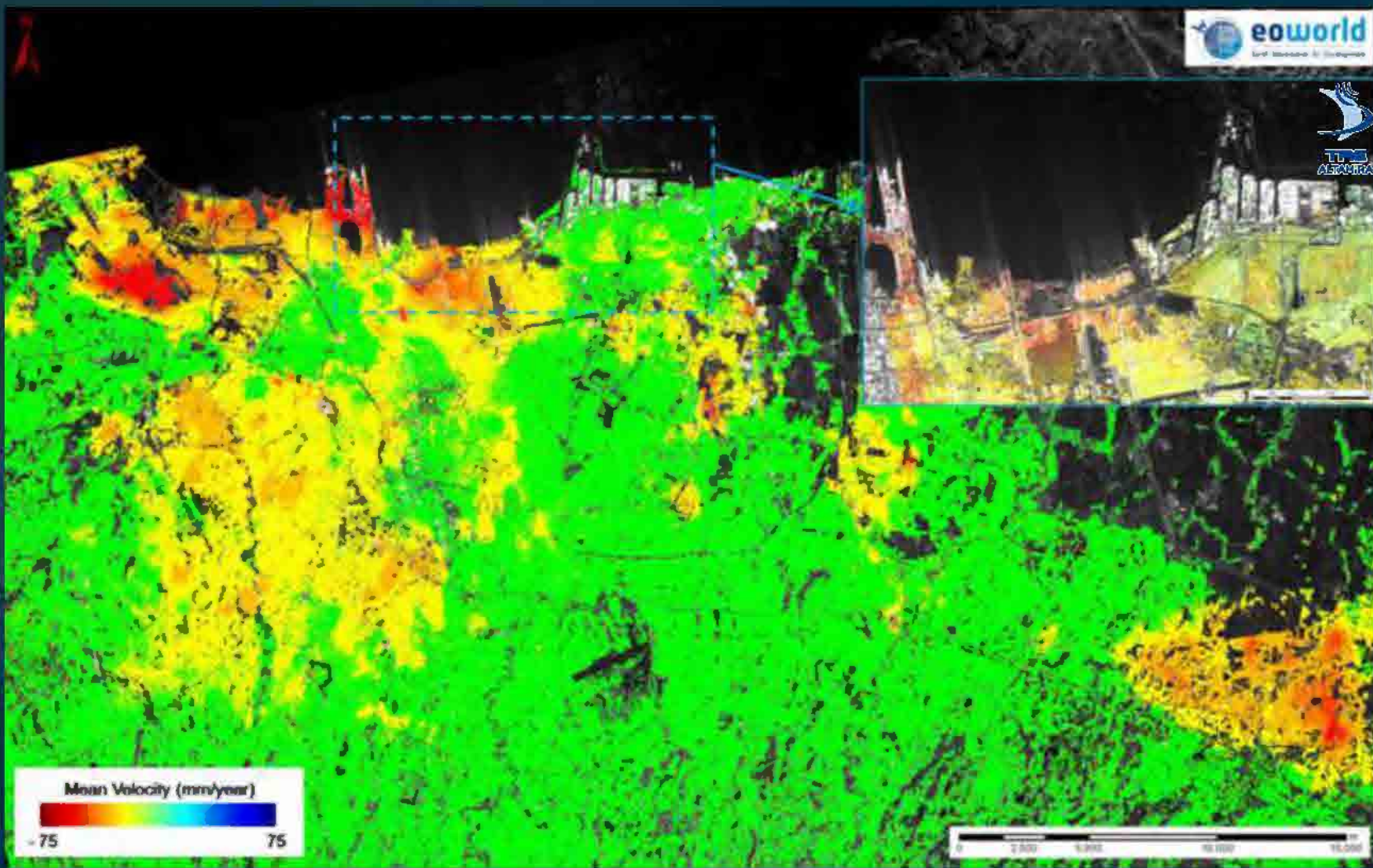
- The distance from the satellite to the reflector on the ground is measured in the first pass.
- A different distance between the first and second passes indicates a surface displacement.
- For a millimeter precision in the measurements, it is necessary to process a minimum of 20 images.





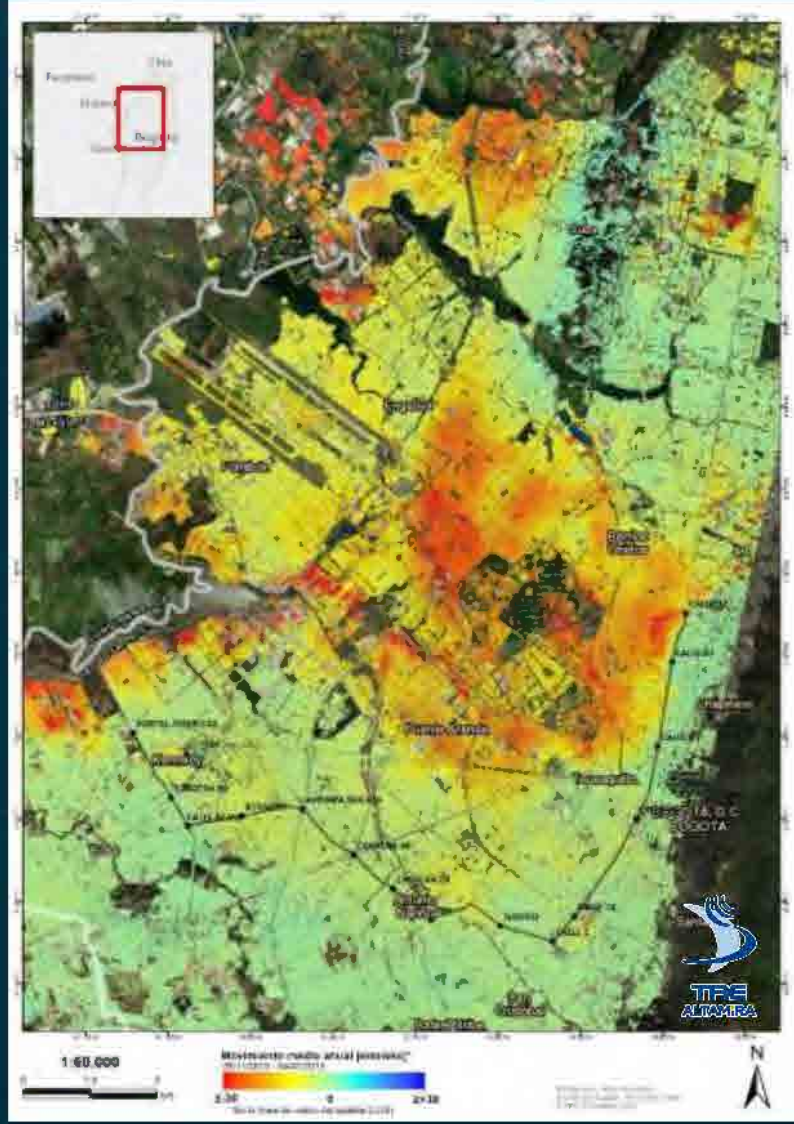
# Ground Displacement TREA Standard Service

Urban Deformation Mapping and Analysis



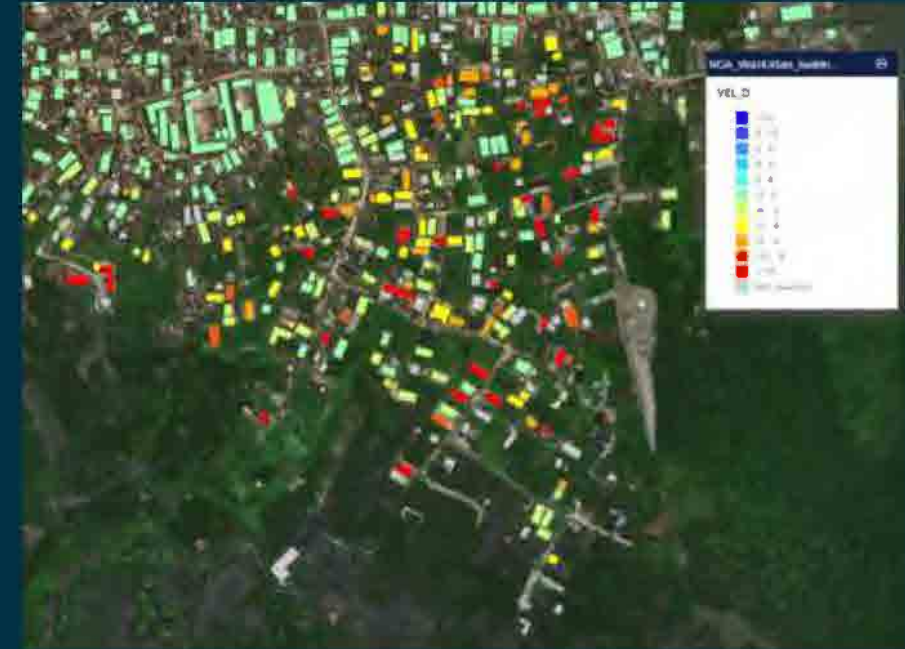
▲ Analysis of land subsidence in Jakarta

▶ Analysis of land subsidence in Bogota



# Ground Displacement TREA Advanced Service

## Aggregation and Priority Maps



▲ Building footprints layer

▲ TSX DESC Ground displacement map

▲ Priority maps based on ground displacement



# Water body mapping and Flood Service

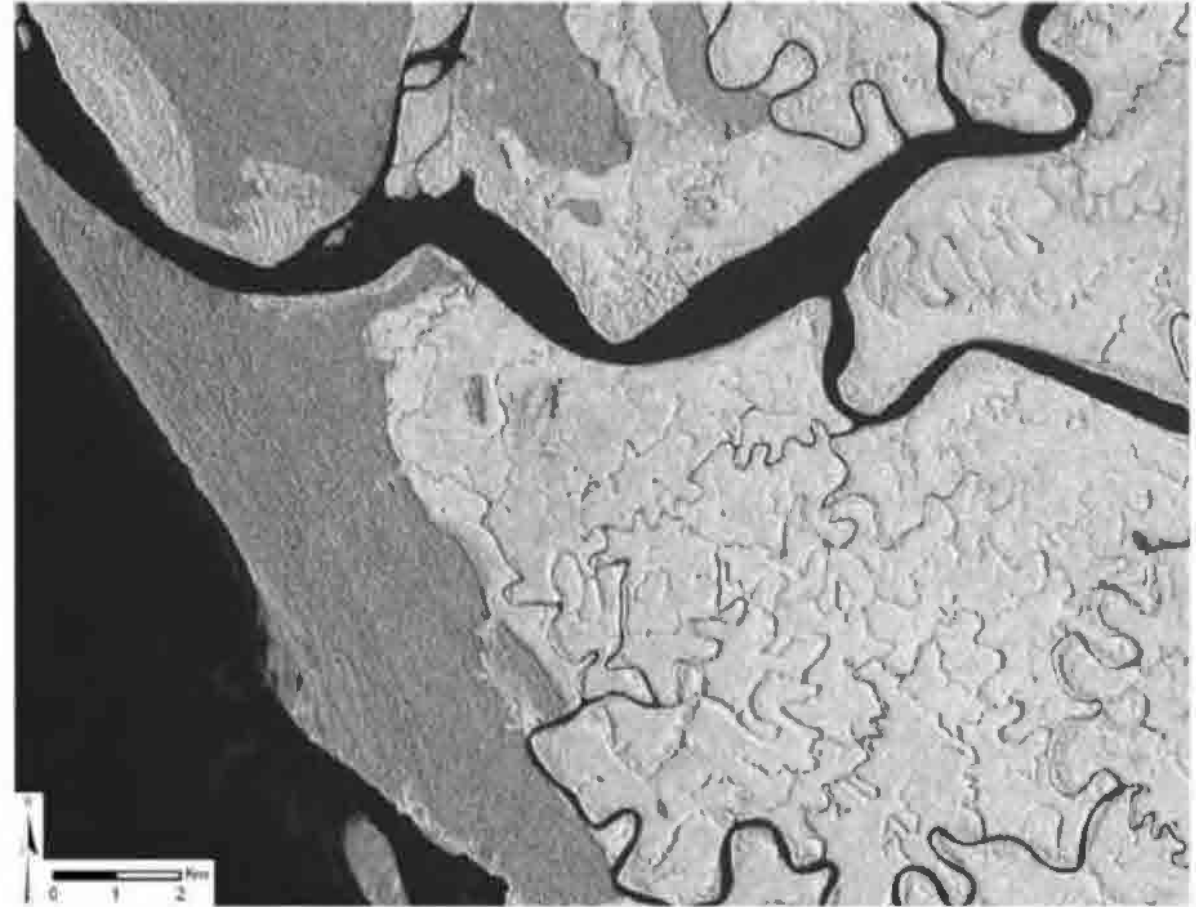
Optical Imagery vs SAR Imagery



Landsat optical image



CSK radar image

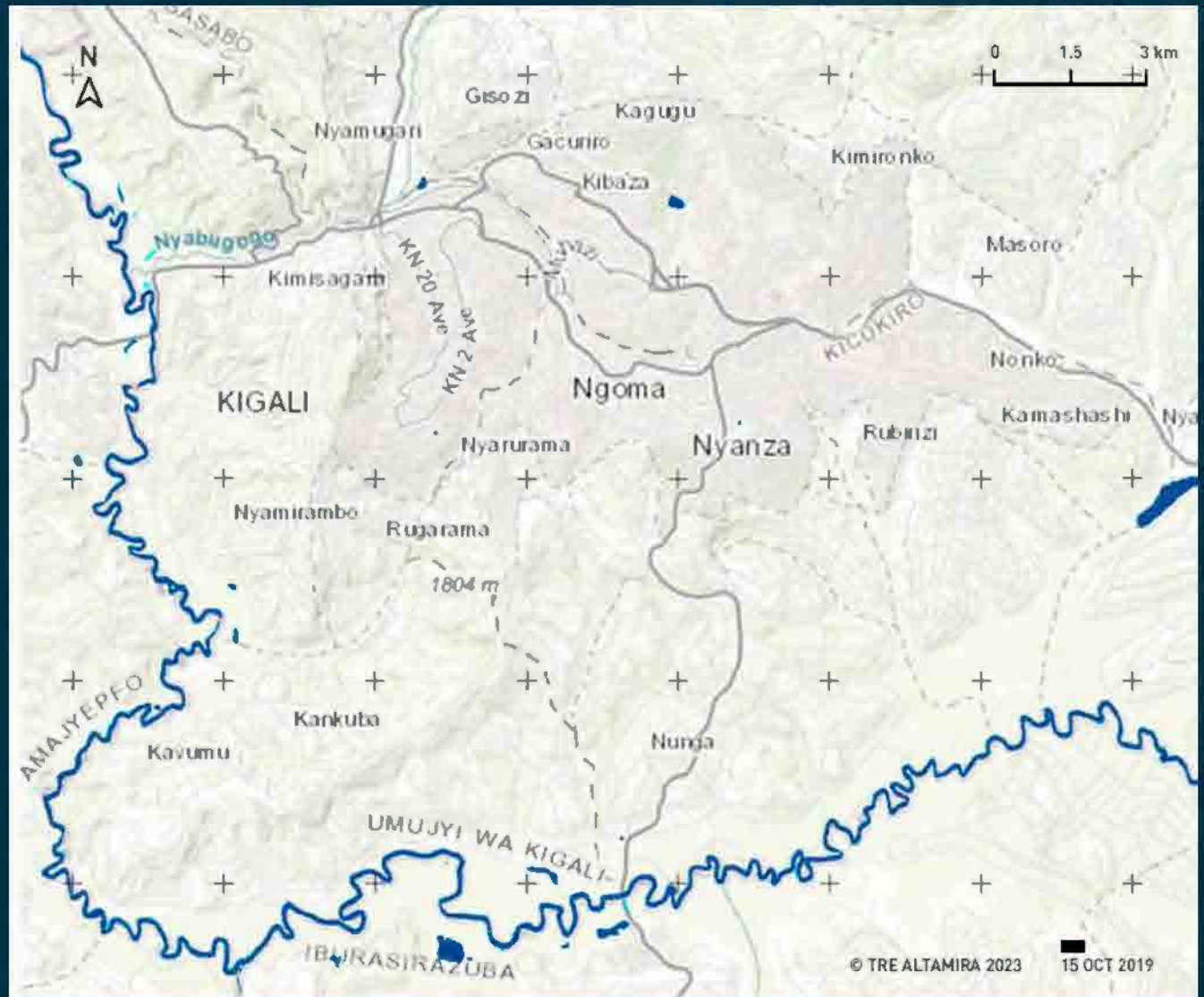


# GDA-Urban Results | Rwanda, Kigali Flood map time-lapse



To delineate a potential flood, a **reference water extent or permanent water layer** is needed, which can be an ancillary layer input or can be extracted from a statistical analysis from a global dataset. In this case, it has been decided to set up a certain percentage of cover of water during the whole data stack.

Example of Flood maps over a period of flooding affecting Kigali, Rwanda.

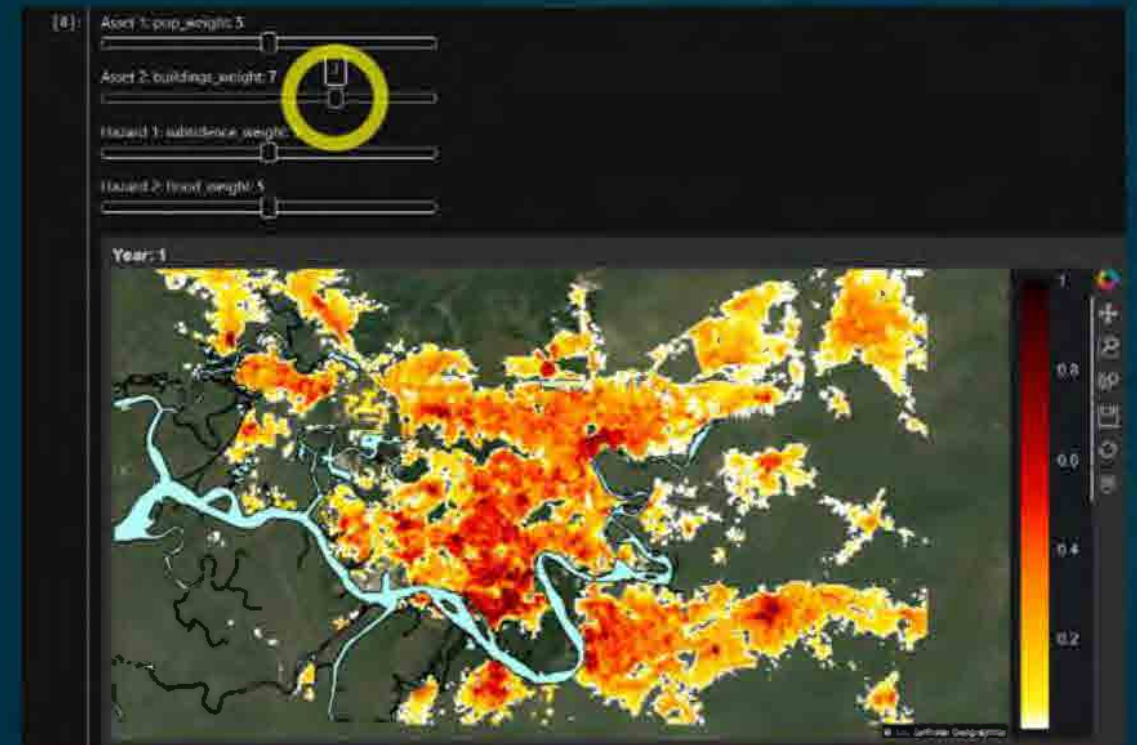


## A demonstration GUI of an interactive weights matrix in Jupyter Notebook

- Open-source Python libraries (xarray, Panel, GeoViews, Bokeh, ...)



Number of buildings per grid cell = weight of 0 → remaining assets layer--population density--the sole contributor to the assets side of the equation, original census boundary being clearly visible



Number of buildings per grid cell = weight of 7 → assets side of the equation now incorporates combined impact of two asset layers, “hotspots” more widely and varyingly distributed across the city.

Find out more | [gda.esa.int/thematic-area/urban-sustainability](https://gda.esa.int/thematic-area/urban-sustainability)



## Brochure

<https://gda.esa.int/wp-content/uploads/2022/11/ESA-GDA-Urban-Brochure.pdf>



## e-Flyer

[https://gda.esa.int/wp-content/uploads/2023/03/GDA\\_E\\_flyer\\_urban.pdf](https://gda.esa.int/wp-content/uploads/2023/03/GDA_E_flyer_urban.pdf)

## Video 1 | General Intro

[https://www.youtube.com/watch?v=vgR\\_D9CdIKms](https://www.youtube.com/watch?v=vgR_D9CdIKms)



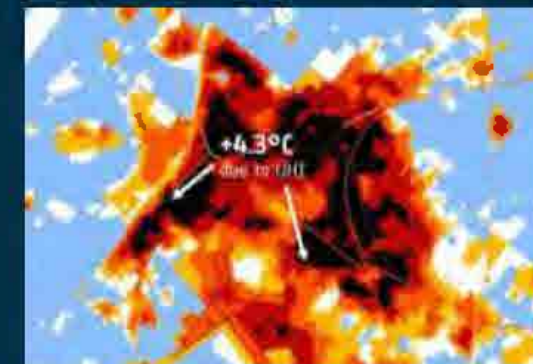
## Video 2 | Use Cases

[https://www.youtube.com/watch?v=CjCWXYOU\\_jU](https://www.youtube.com/watch?v=CjCWXYOU_jU)

## Stories



Putting Transport Modelling on the Fast Lane with satellite Earth observation in Dhaka, Bangladesh



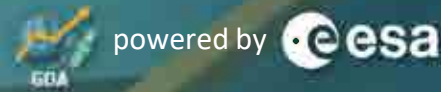
Addressing Urban Heat Islands in Sargodha, Pakistan



# Global Development Assistance

## Urban Sustainability

Accelerating Impact



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Implemented by:

Lead:



Partners:



AUSTRIAN INSTITUTE  
OF TECHNOLOGY



Caribou<sup>15</sup>  
Space  
for Development



# Global Development Assistance

Accelerating Impact

Remote Sensing and Computational Modeling for  
Identifying Nature-Based Solutions Potential in Resource-Scarce Environments  
A Case Study in Amman

Tomas Soukup (tomas.soukup@gisat.cz)

**GISAT | AIT | DLR**

WB Land Conference

14 May 2024

\* acknowledging inputs from the broader ESA GDA team





## GISAT

- spatial information services company from Prague, Czech Republic
- 30 years pioneering Earth Observation mainstreaming
- urban, risk assessment and emergency response support, agriculture and environment
- main experts involved: Tomas Soukup, Jan Kolomaznik, Lucie Stara

In the scope of GDA Urban activities teaming with:

**Austrian Institute of Technology (AIT)** contributing with modelling services

- main experts involved Klaus Steinnocher, Ernst Gebetsroither

**German Space Agency (DLR)** contributing with WSF and WSF tracker services

- main expert involved Mattia Marconcini

## Amman, the capital city of Jordan

Source: 4th Life Photography



- Amman has an ambitious vision to improve the quality of life in the city, addressing climate change with the support of an array of international partners
- At the same time, Amman has experienced significant and rapid urban growth, largely exacerbated by the waves of incoming refugees from the Iraq war in 2003 and the Syrian crisis in 2011. Such unexpected, rapid urbanization, accompanied by weak governance, made it difficult for the city to plan and manage urban growth (Ainsour, 2016; GAM, 2017). It led to a high increase in public debt (83 percent), youth unemployment rate (30 percent), and demand for water (40 percent).
- While addressing urgent planning needs, the essential spatial data remains largely incomplete
- Leveraging Earth Observation presents a significant opportunity to gather and refine the necessary baseline data for comprehensive planning.

- GDA AID Urban Sustainability has worked hand in hand with the WB's Middle East and North Africa (MENA) Urban and Resilience Team under the Jordan Sustainable Cities Review Advisory Services and Analytics (ASA) (P177803):
  - (i) **monitoring rapid urban development** incl. modelling of scenarios to support strategic planning
  - (ii) **understanding of Amman's green areas infrastructure**, needs for urban greening and potential for Nature-Based Solutions (NBS) - to combat scarcity of green areas and prioritizing their expansion

WB team: Jon Kher Kaw, Hogeun Park

Amman team: Rima Odeh (Executive Director of Planning) and GAM colleagues



EO based spatial analytics **enlightening aspects important** for urban planning & sustainable development (with focus on land assets)



**Efficient and flexible scaling** - from city-wide inventory even beyond city administrative boundaries to detailed assessment of district or neighborhoods



Providing information on **past, present and future** (in combination with modelling)



Beside amounts, **spatial distribution and spatio-temporal patterns** and consumption/formation flows



**Ready for spatial relations** with other data on population, other city assets, planning regulation etc...

# GDA Services | Products and Services delivered



AOI	Product	Partner	Resolution
GAM+	Settlement Extent and Change 1985-2021	DLR	30 m
GAM+	Imperviousness Level Status and Change 1985-2021	DLR	30 m
GAM+	Settlement Change Tracker 2016-2023	DLR	10m
GAM	LCLU 2010/2020	GISAT	30 m
GAM	Urban Green Areas 2020 (incl. analytics)	GISAT	0.5 m
GAM	Modelled development scenarios 2035 (incl. analytics)	AIT	30 m

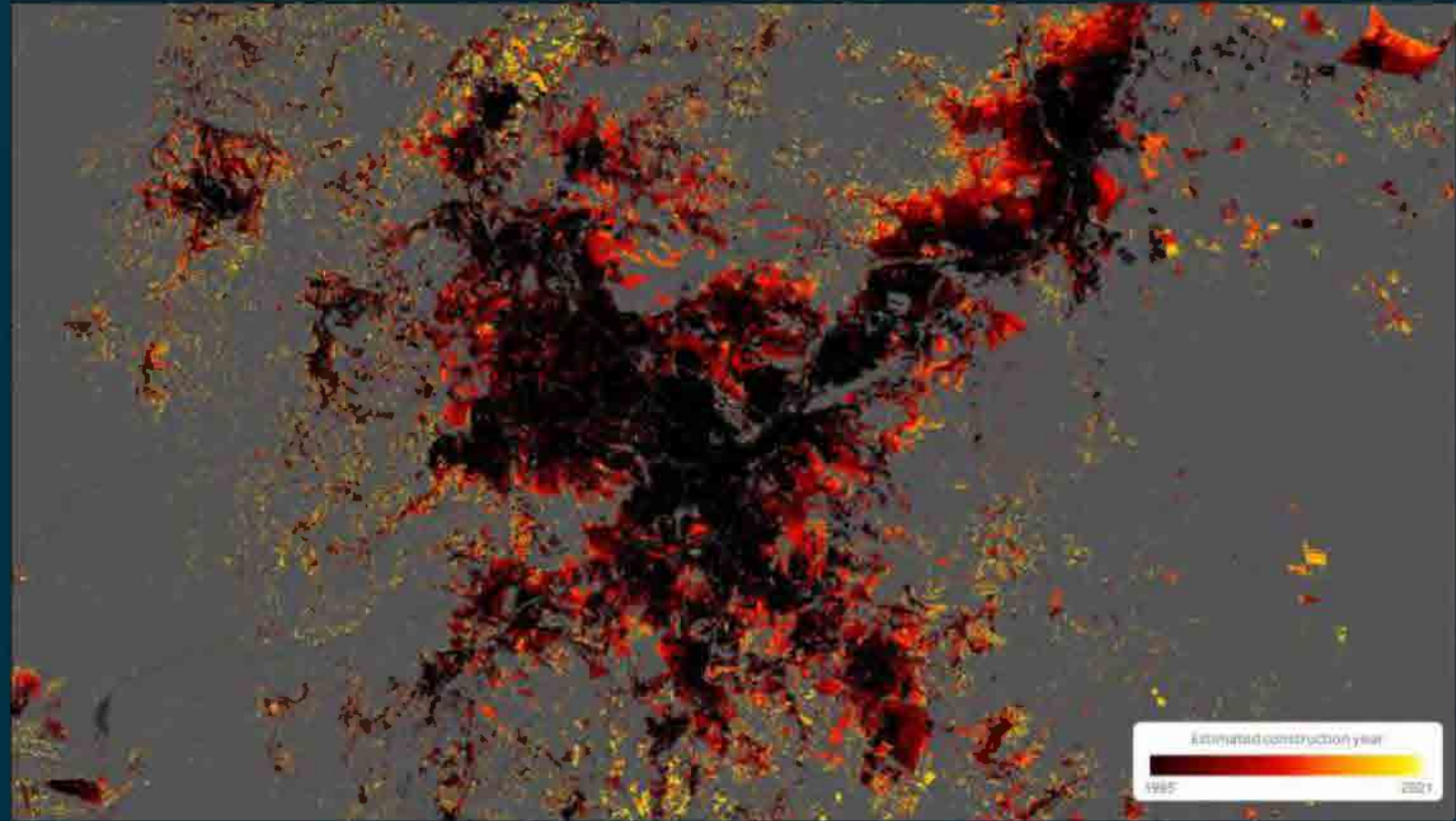


# Long-term City Context – Urban Expansion and Densification

# GDA Services | Settlement Extent and Change



- Product provides **information on long-term city expansion** in spatial-temporal context, its dynamic and main development axes in time.
- Amman's spatial growth is fragmented through leapfrogging and extension, adding to congestion, strain on services, costs, and GHG emissions
- Amman city predominantly grew towards North-East and South over the past decades, while recently a higher dynamics can be seen in the suburban areas, especially in the North-Western and Southern sides.



Source: DLR 2023

**RESOLUTION: 30M, TIMESERIES: YEARLY 1985-2021**



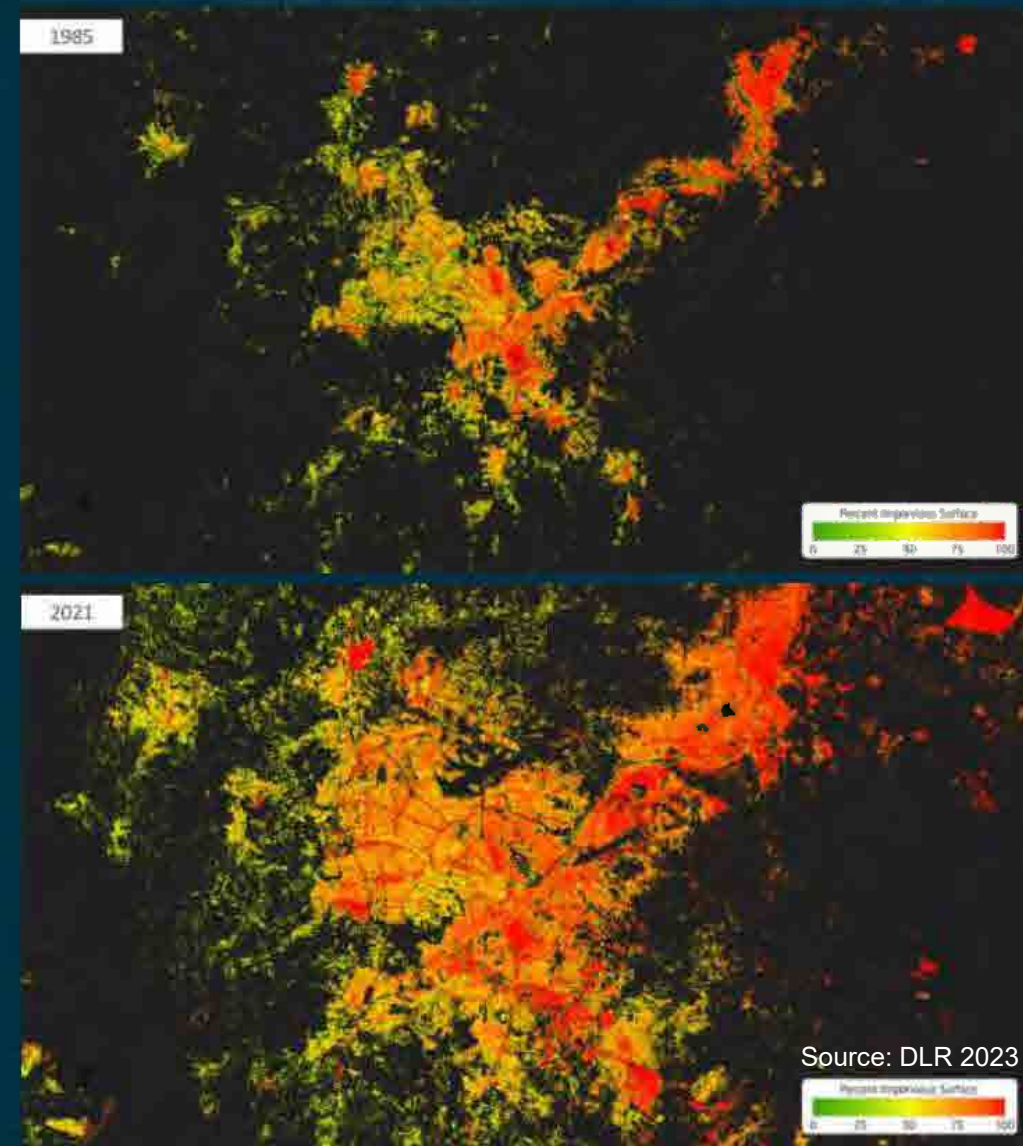


# GDA Services | Imperviousness Level Status and Change



- Product provides **information on long-term city densification** of the city spatial-temporal context, its dynamic and main development axes in time.
- Important broader context both for urban development modelling and NBS potential discussion.
- In 1985 vs. 2021 comparison, it can be seen how the North-Eastern and Southern sides of the Amman city experienced a remarkable densification, which was not as pronounced in the Western side.
- Valuable to combine with local (Master Plan) information (target density) or see policy calendar impact
- Imperviousness Level Status and Change is also important for **heat modelling** or **run-off modelling** in the context of flash floods in Amman.

**RESOLUTION: 30M, TIMESERIES: YEARLY 1985-2021**



# GDA Services | Settlement Change Tracker



- Product provides information on **long-term settlement expansion** in spatial-temporal context, its dynamic and hotspots in time.
- Provided on **fine scale with flexible granularity** up to 1month.
- Product is useful for **hotspot identification of land grabbing or construction progress monitoring**.



**RESOLUTION: 10M, TIMESERIES: 6M from July 2016 - July 2023**

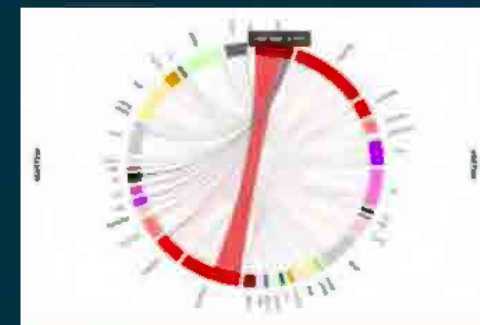
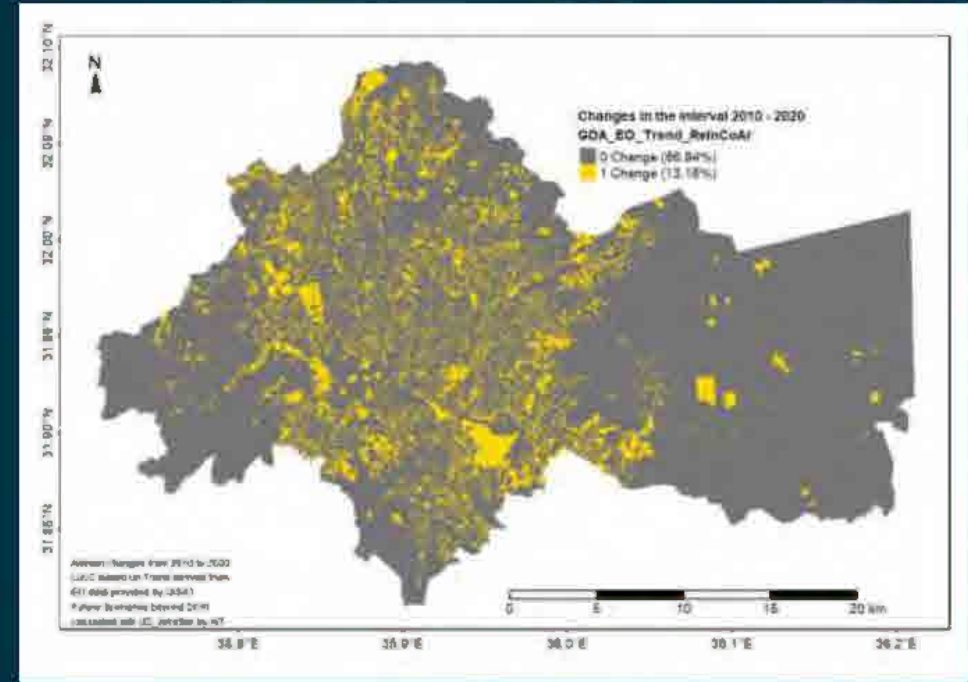
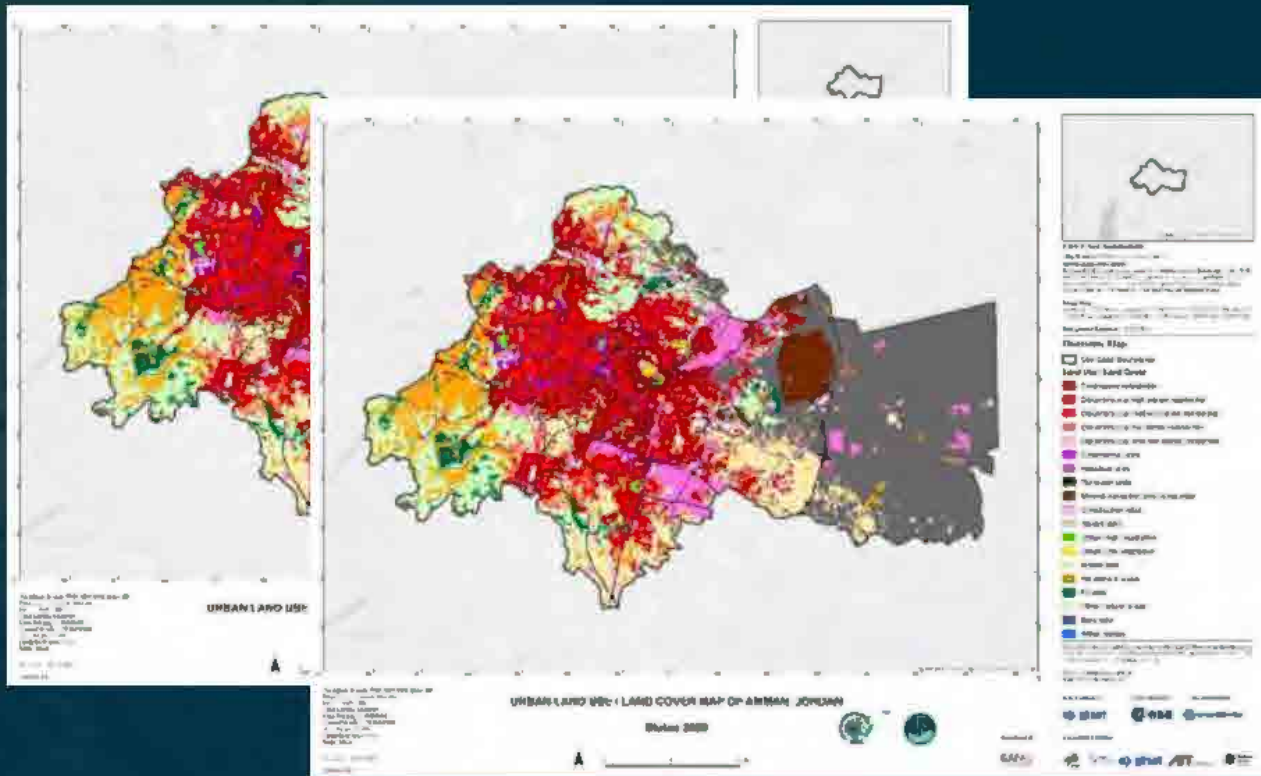
Source: DLR 2023



# City land use land cover structure – Past, present and future

## Land Cover/Land Use data for 2010 and 2020

- The products serve as primary information layers for the modelling exercise (resolution and classes definition)



**RESOLUTION: 30M, 19 THEMATIC CLASSES, TIMESERIES: 2010 - 2020**

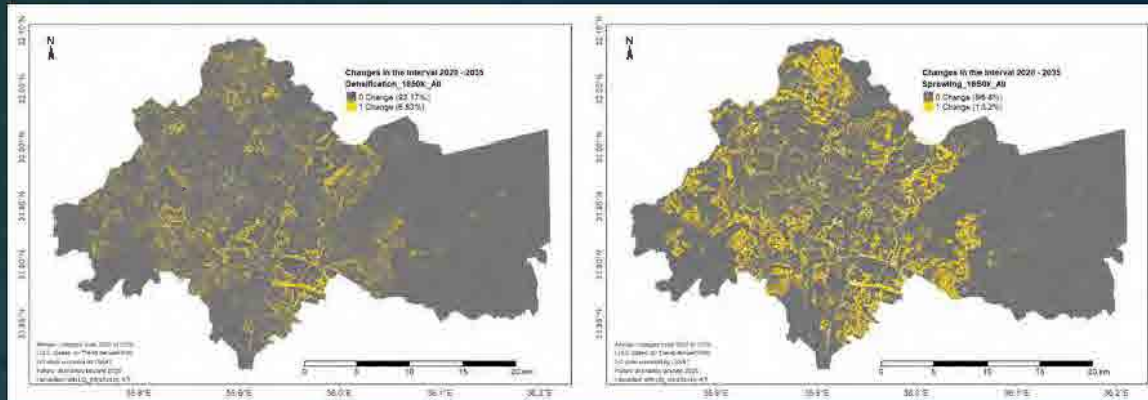
Source: GISAT & AIT 2023



Modelling results examples (available as dataset & interactive analytics in Jupyter Notebooks)

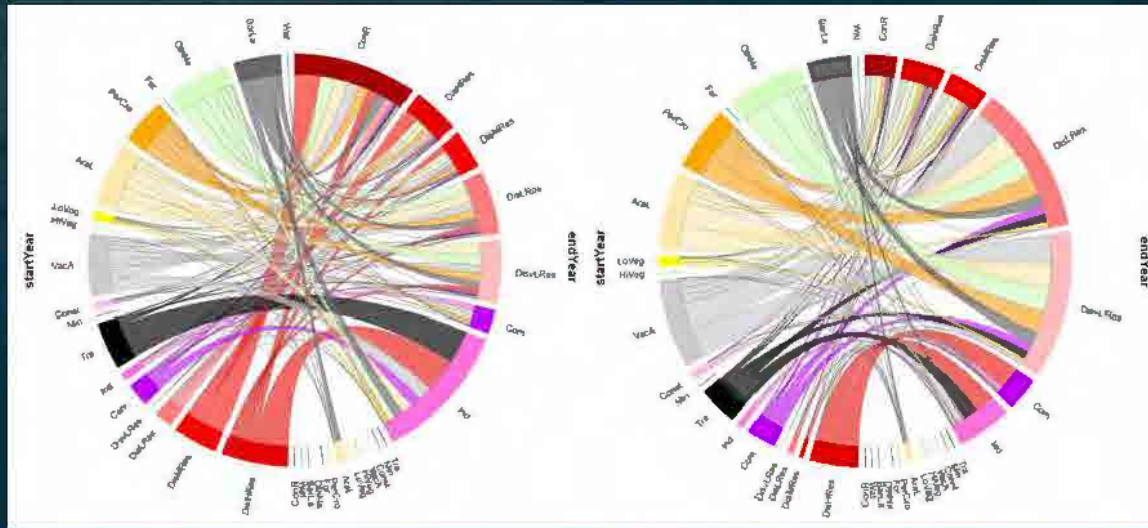
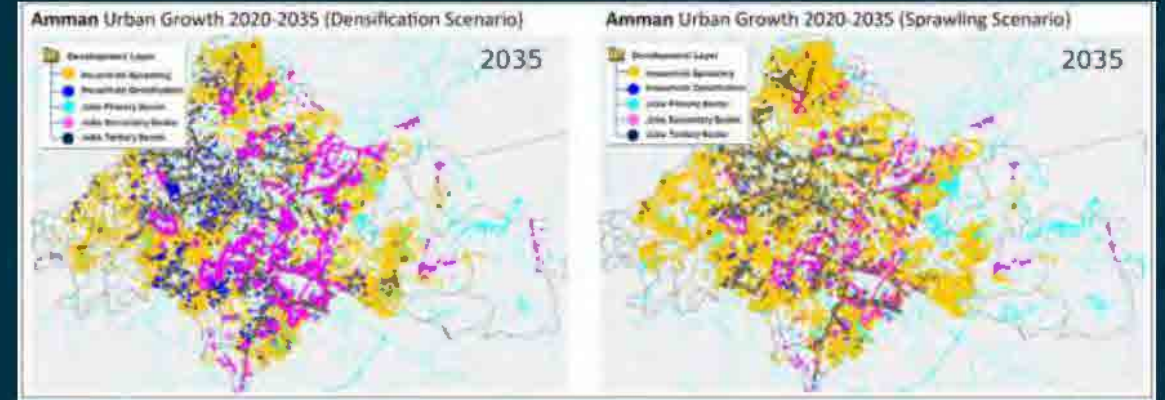
(a) densification scenario

(b) urban sprawl scenario



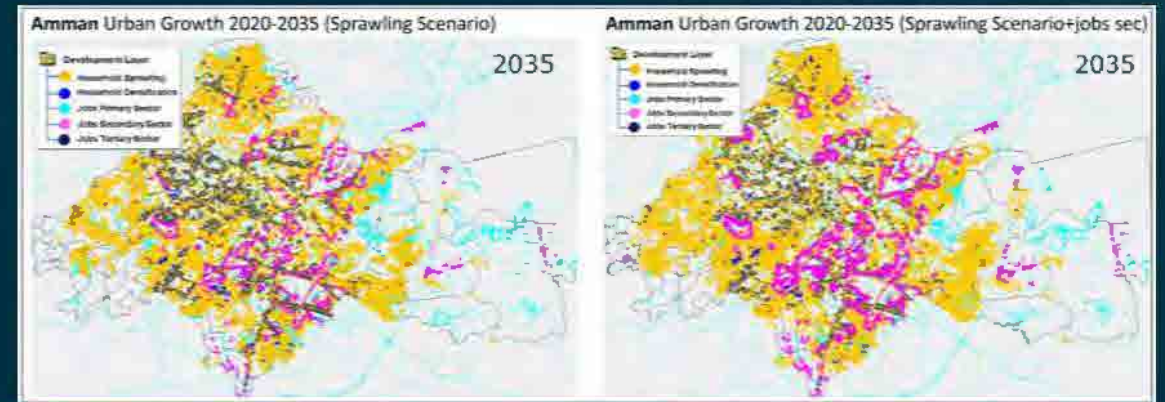
(a) densification scenario

(b) urban sprawl scenario



(b) urban sprawl scenario

(c) urban sprawl scenario with sec sector increased

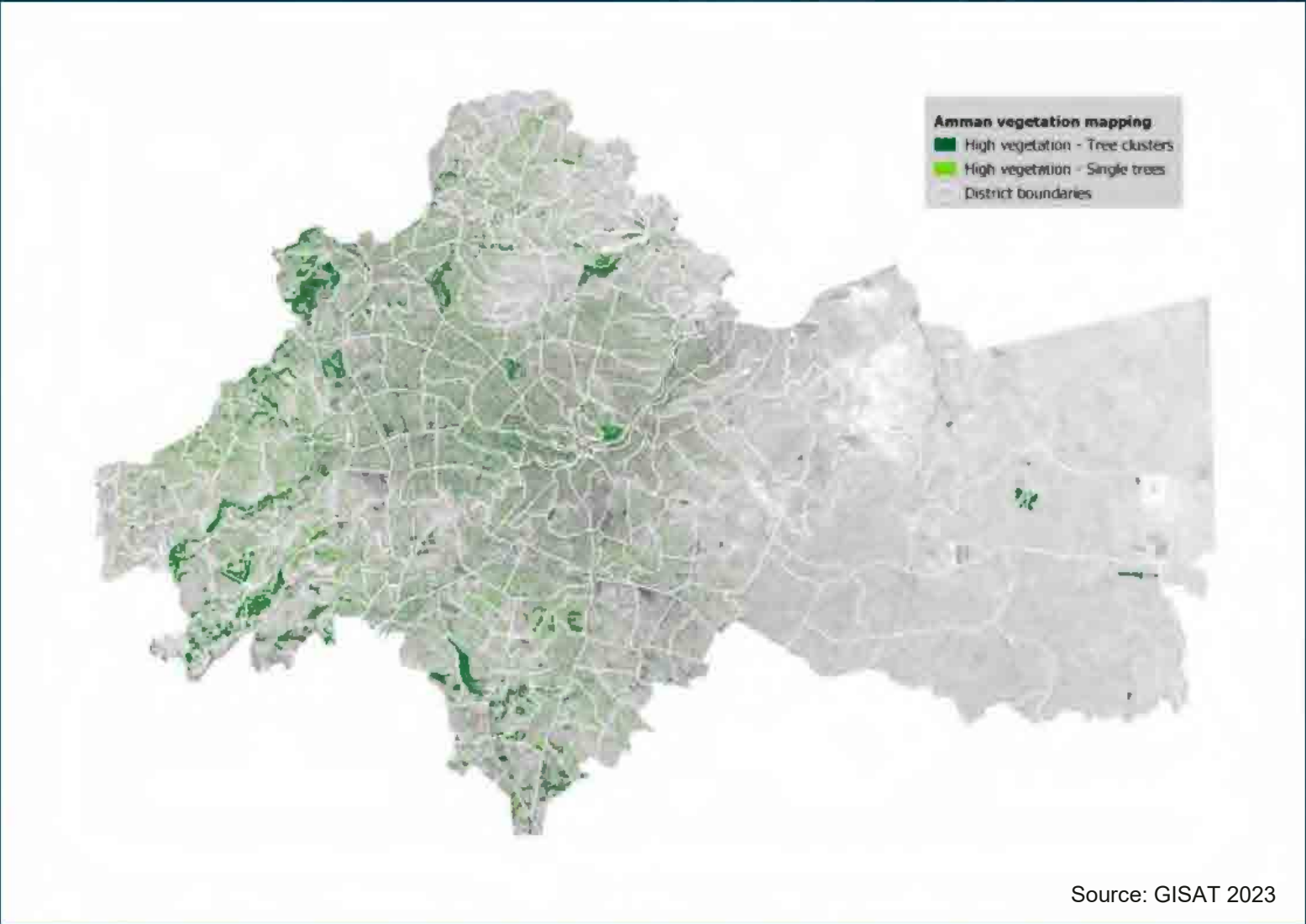
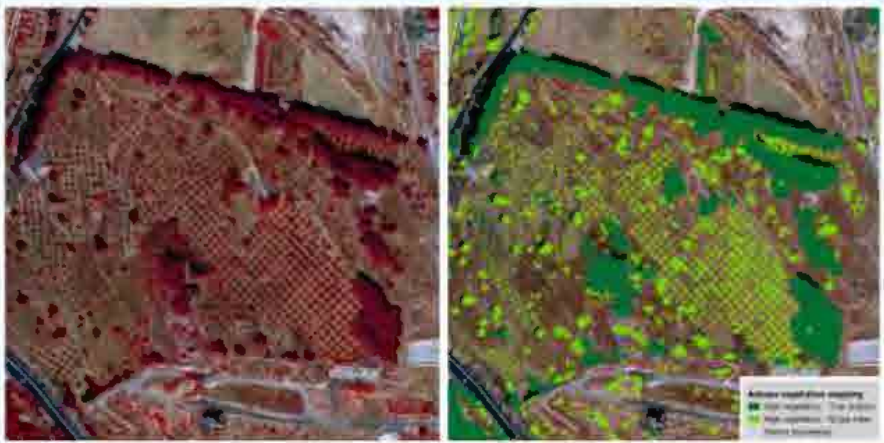


# Focus on city-wide green assets – potential for NBS

# GDA Services | Urban Green Areas Inventory



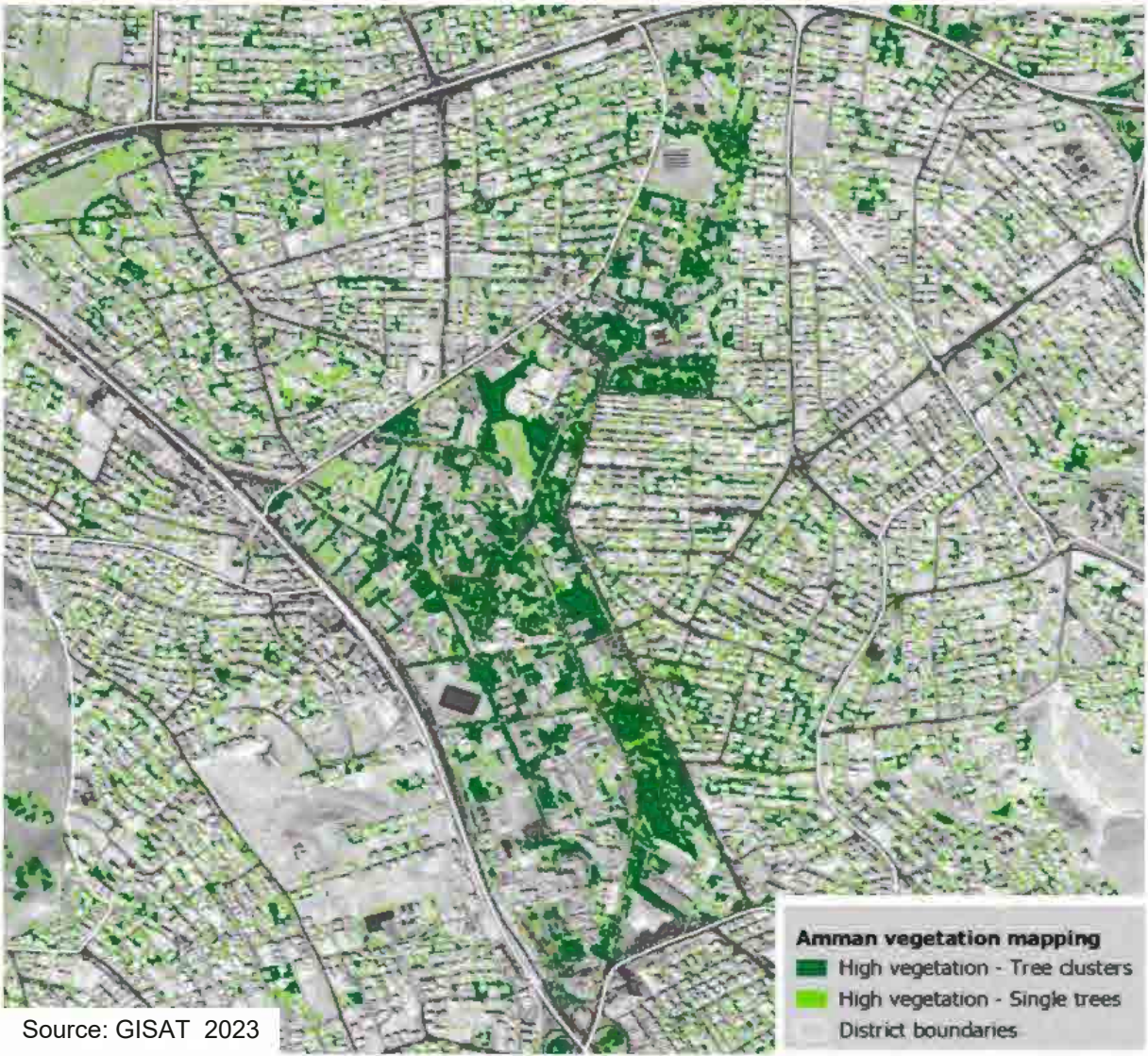
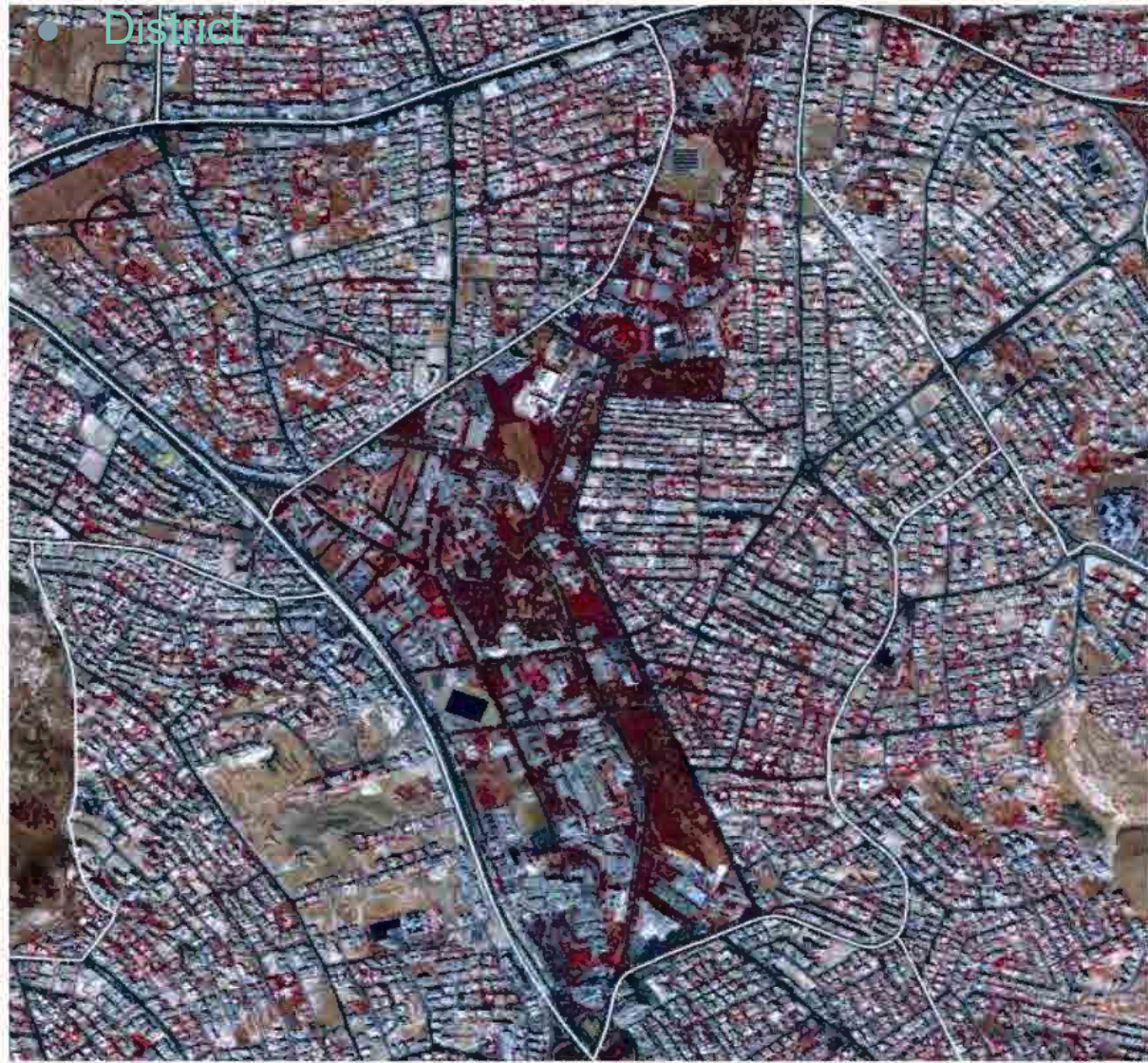
- Tree Clusters
- Single trees



Source: GISAT 2023



# GDA Services | Urban Green Areas Inventory



Source: GISAT 2023

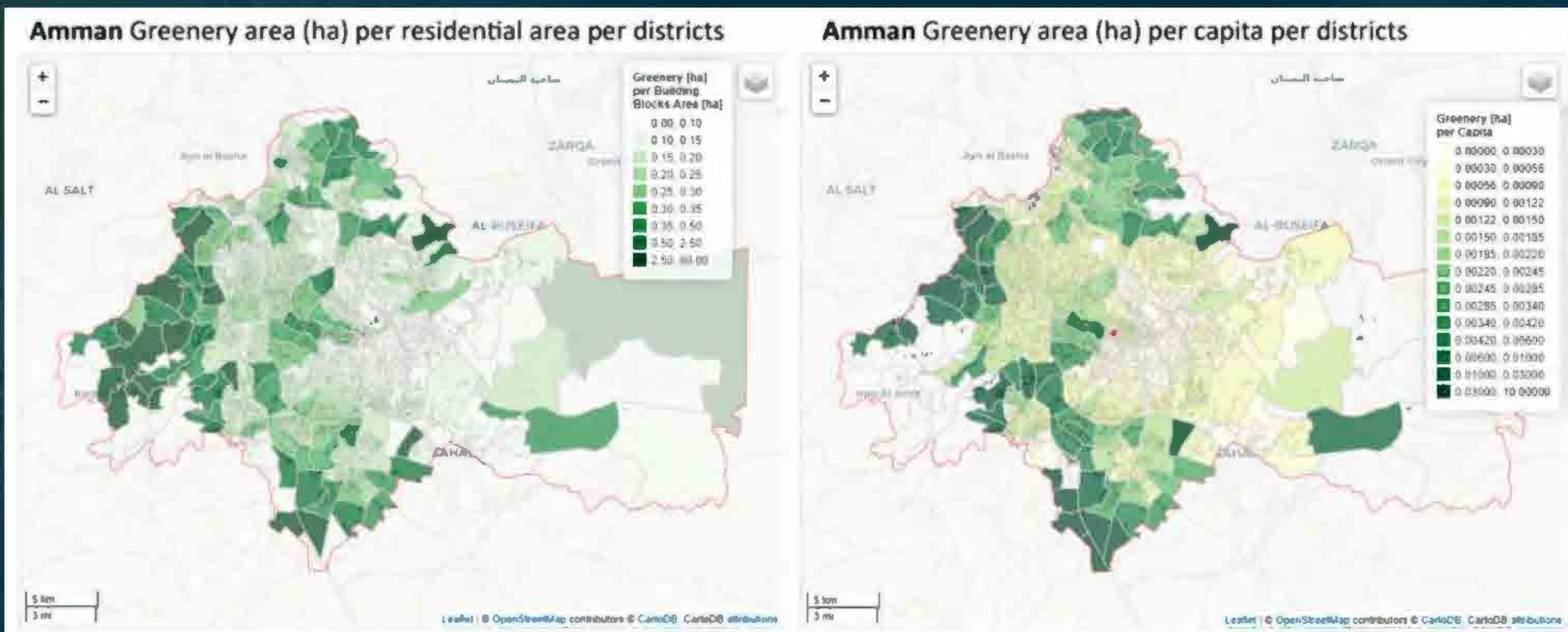


City-wide detailed inventory of green infrastructure (VHR images) based analytics on

- availability
- accessibility
- inclusivity

where GA data are combined with other data available on land use (residential building blocks) and population for present and forecasted (modelled) future

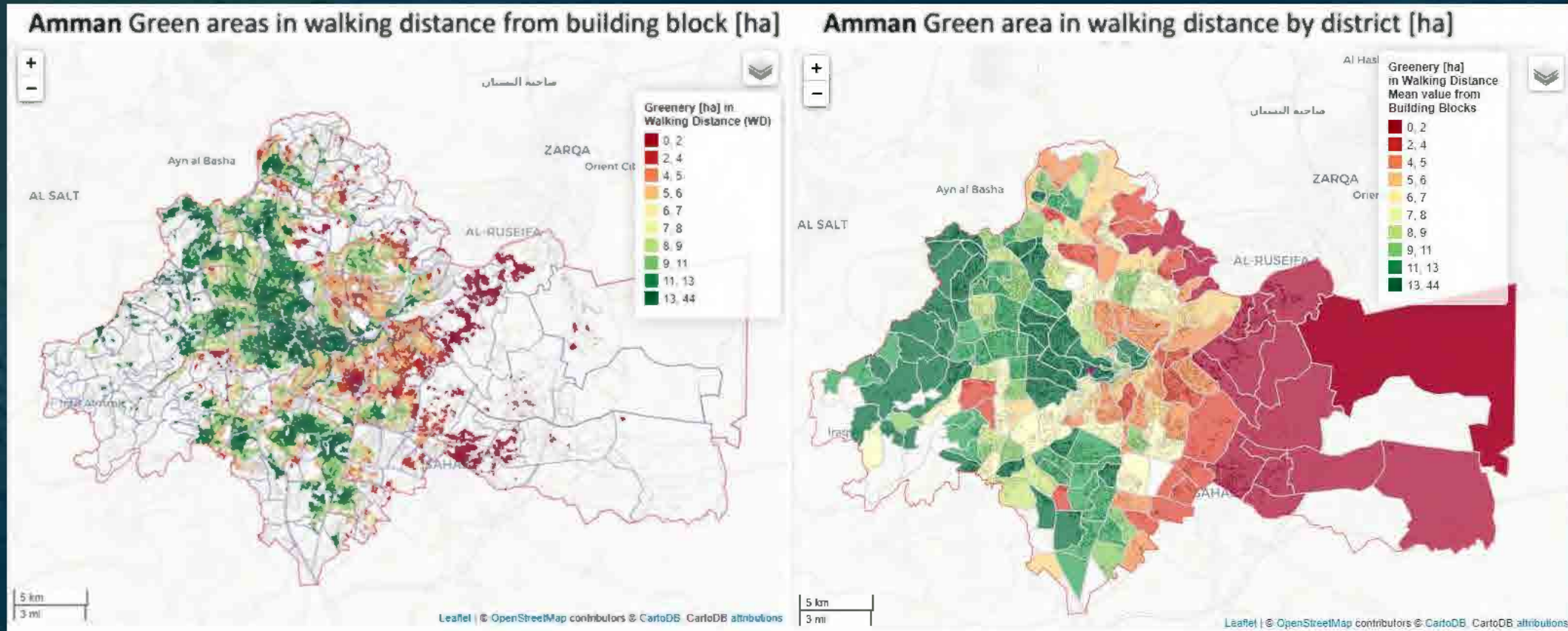
- Availability



Source: GISAT 2023

Unequal distribution – huge differences in availability between west and east part of Amman

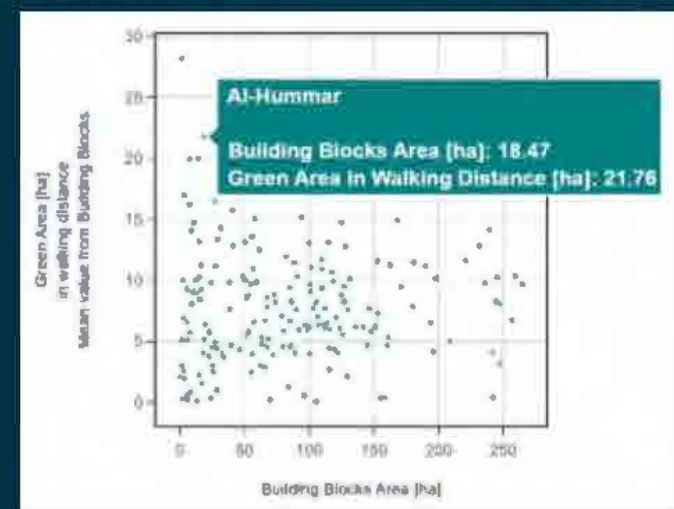
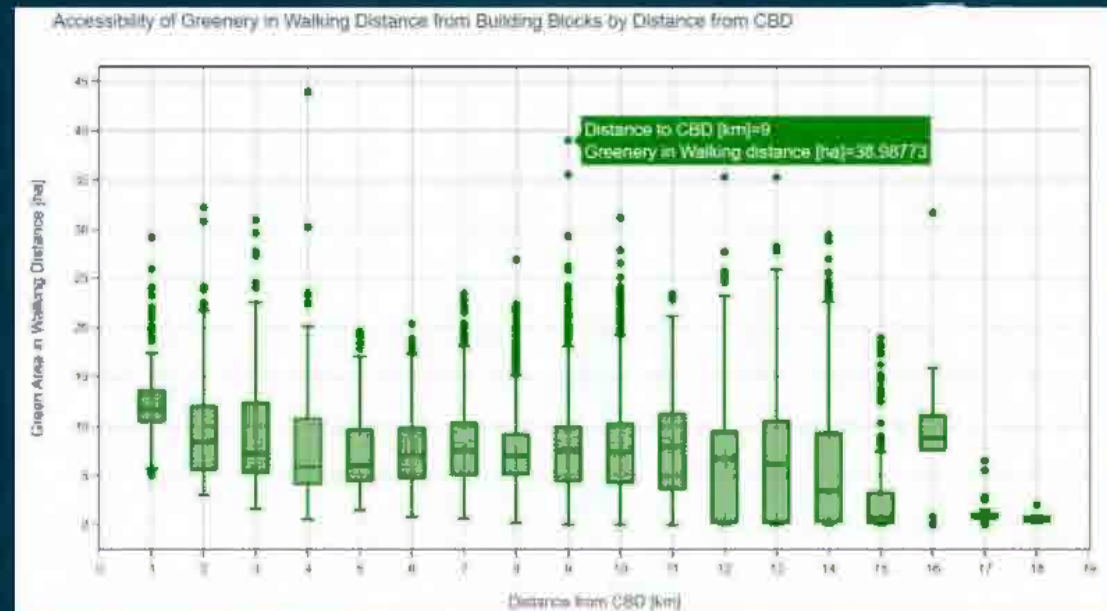
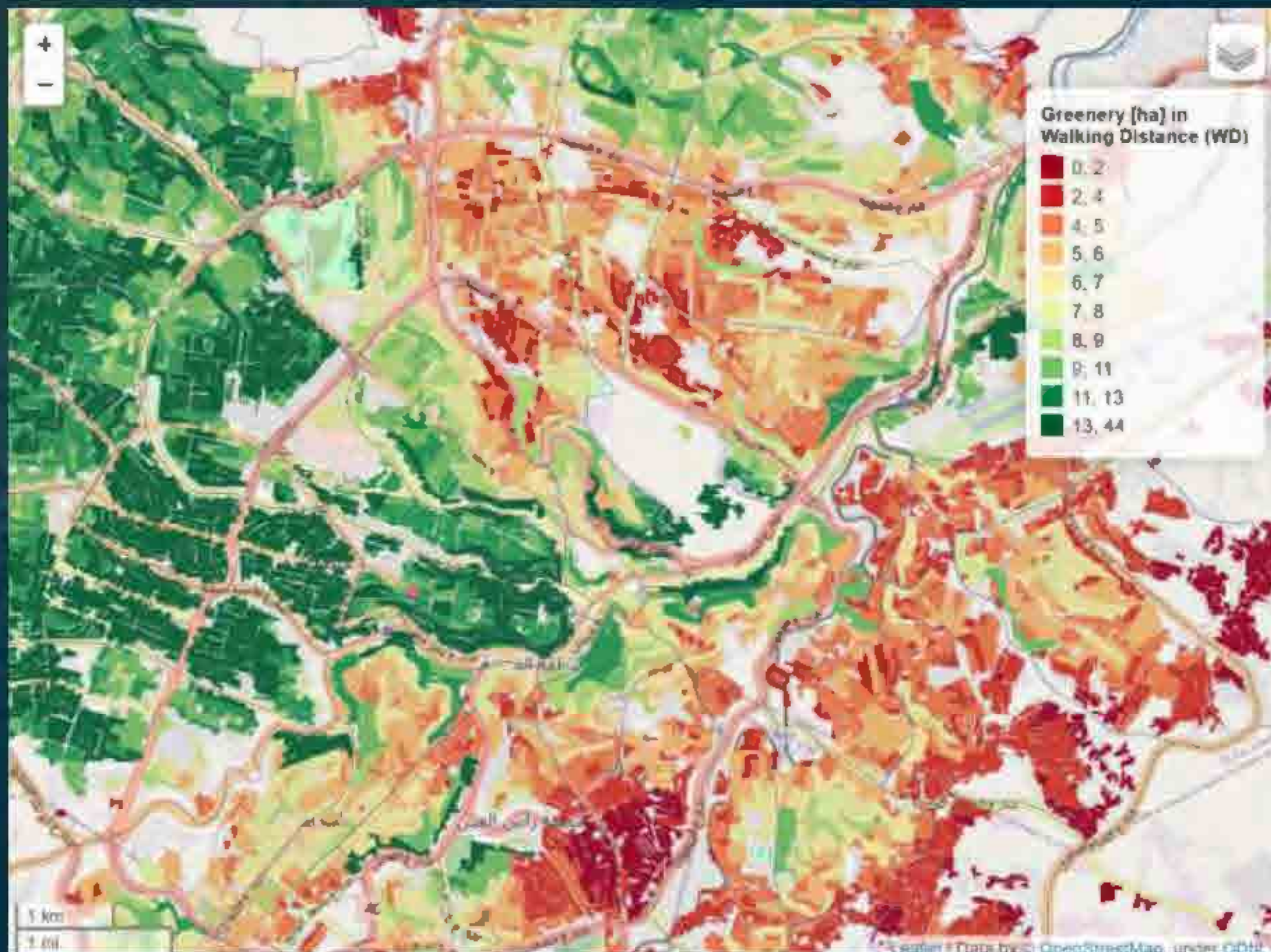
- Accessibility



Uneven accessibility – Sharp gradient between east and west “belt” south of the city centre

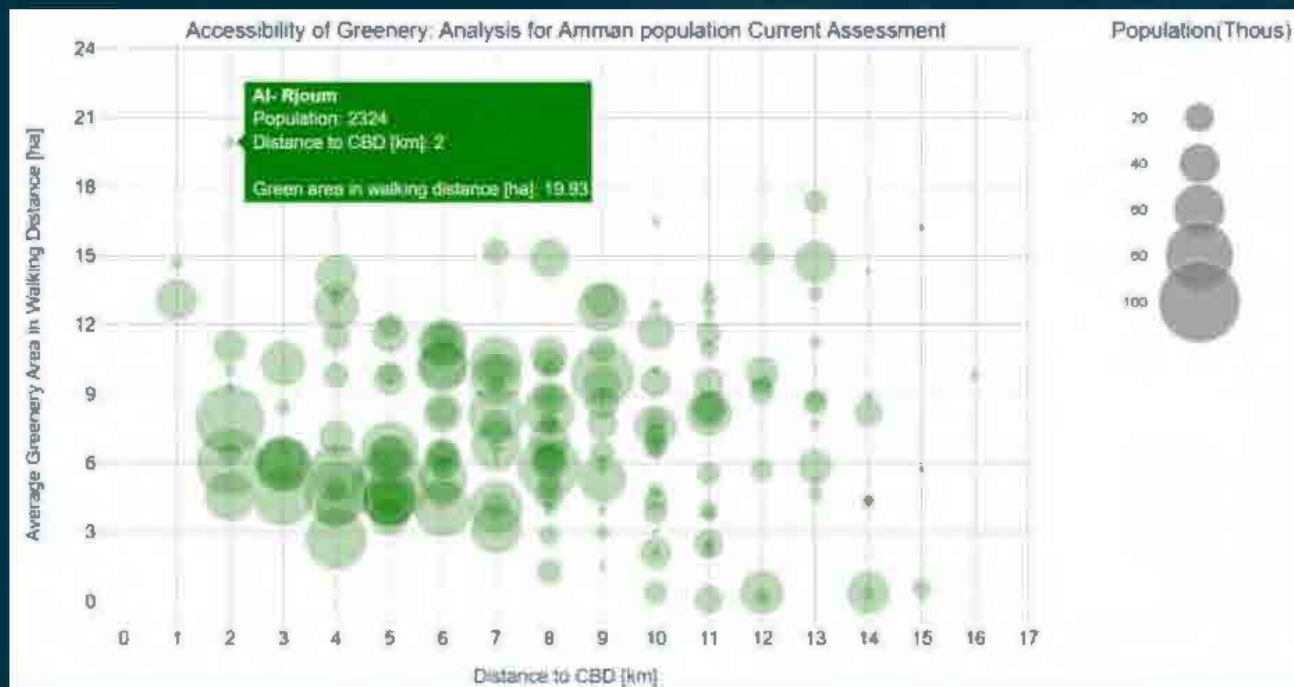
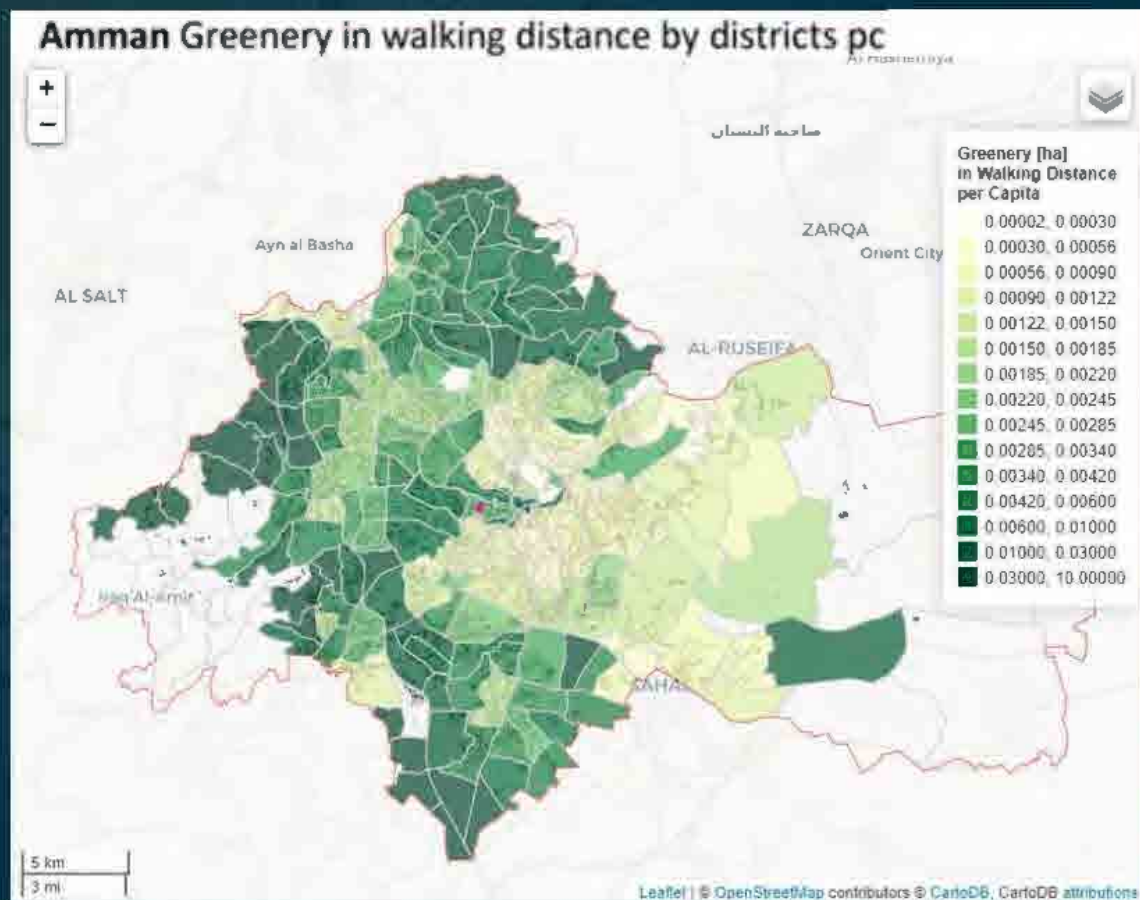
- Accessibility

Walking distance = 400 m



Source: GISAT 2023

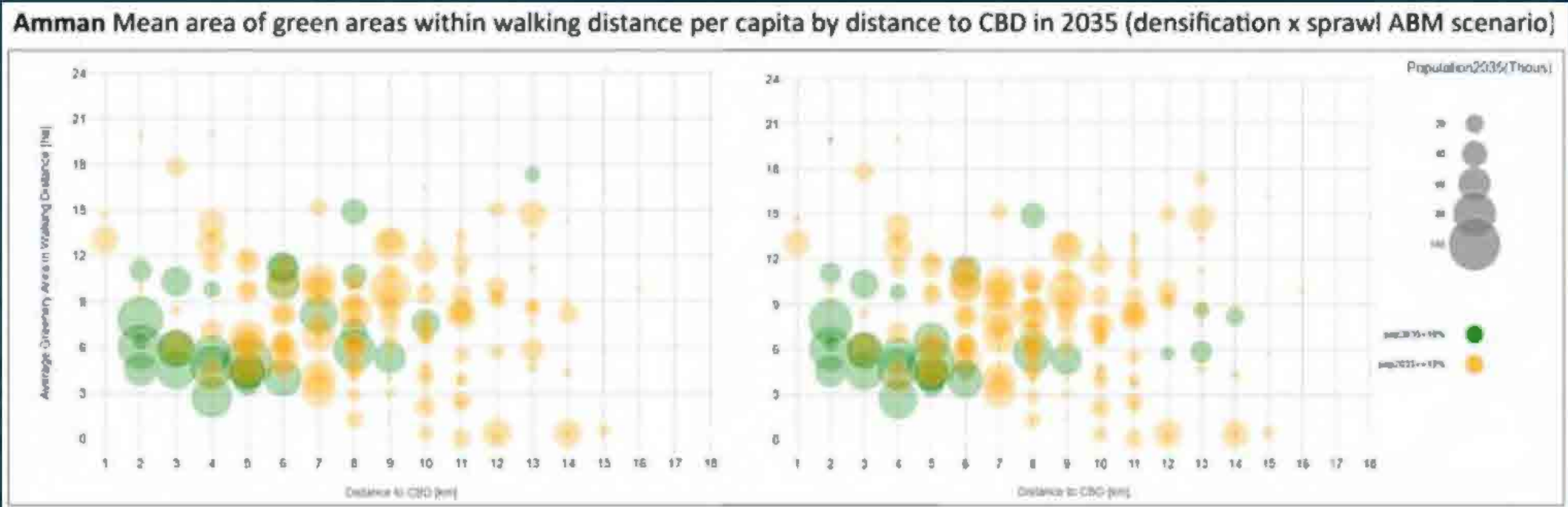
- Inclusivity



Source: GISAT 2023

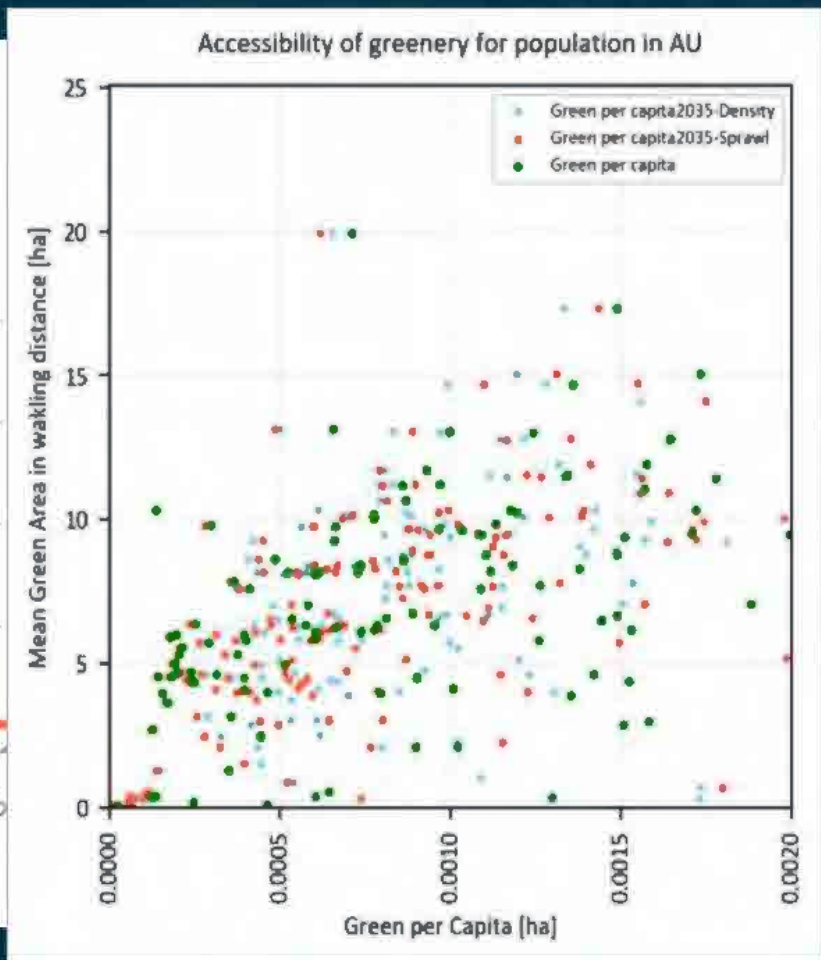
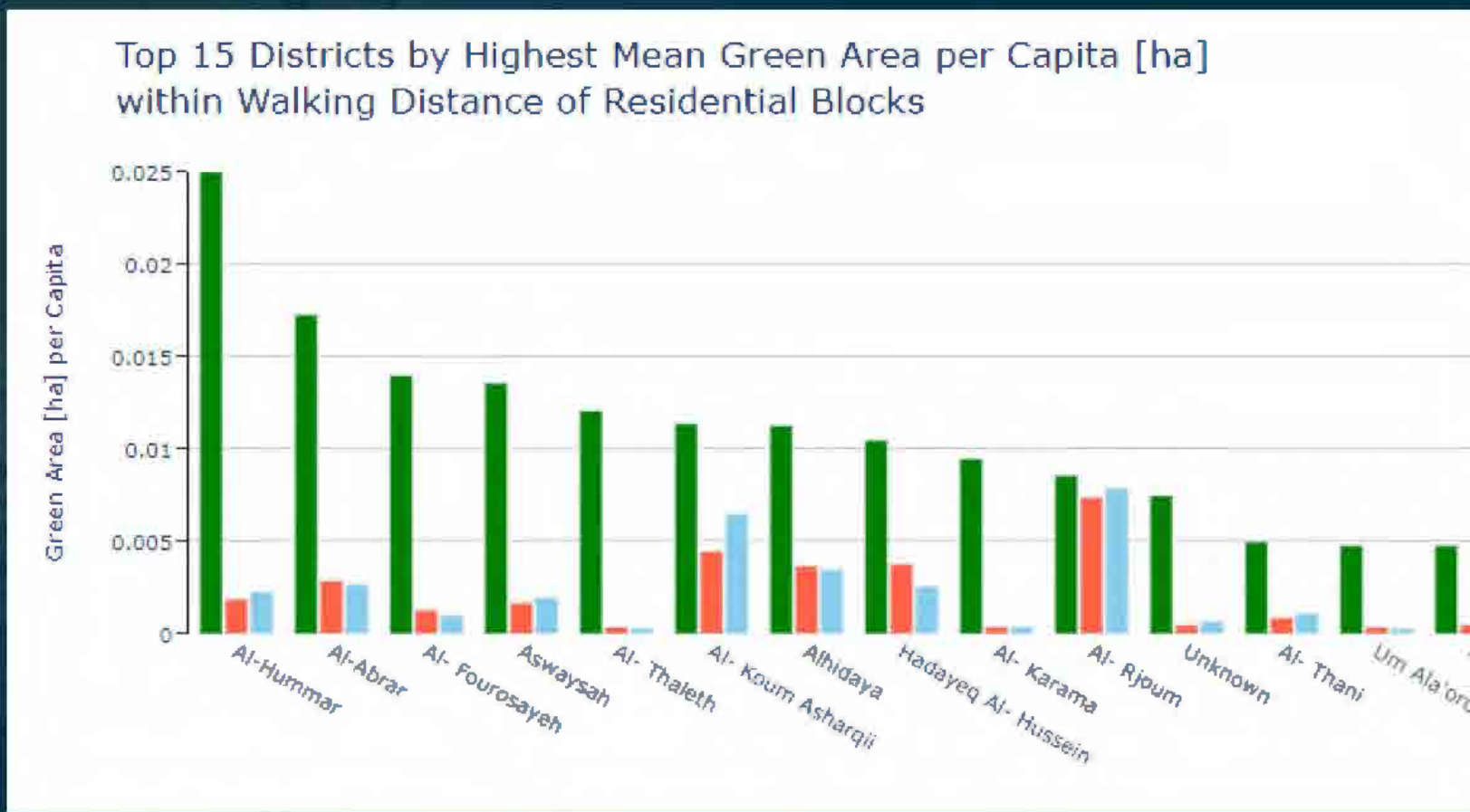
No equitable access to green spaces - many populous districts even near the centre have low inclusivity

- Availability, Accessibility and Inclusivity in modelled future (if status quo of GA)



In yellow districts decreasing access to green areas → higher demand for new green areas

- Availability, Accessibility and Inclusivity in modelled future (if status quo)



Rapid decrease in top districts in access to green areas → higher demand for new green areas



Some key priorities with potential benefits from EO support:

- improvement of spatial planning, **operationalisation** of land management
- deepening of **evidence-based policymaking with digital and geospatial tools**
- building robust and sustainable **spatial data infrastructure**
- **prioritization of greening activities** for NBS (heat, flood)
- **vacant land** reform
- leverage public assets and land based financing - **land and property tax** revenue improvement
- improved **transparency** and involvement of community stakeholders, public funding and private investors

- ESA GDA Urban use case(s) demonstrate **technical readiness and operational capacity** to support similar development support activities
- **Local team uptake and alignment** with local activities is **still work in progress**,
- To be strengthened:
  - user engagement (incl. technical readiness for uptake)
  - financial instruments to support EO as integral part of digital transformation of city administrations
  - support of general organization shift towards a culture of innovation and evidence-based decision
- Need for a systematic capacity building support and training activities as well as streamlining of financial support for organisational changes and innovation adoption.

What are the missing pieces to make it fly?



For further information please contact: [tomas.soukup@gisat.cz](mailto:tomas.soukup@gisat.cz)

# Earth Observation Based Solutions to Leverage Development Assistance for Urban Planning

Use of novel EO based approach to characterise urban heat islands and better plan urban green infrastructure

F. Enssle, C. Fourie, C. Sannier and S. Gomez



## Background on the Urban Heat Island work

- Global Development Assistance (GDA) Urban initiative
- The Asian Development Bank (ADB) expressed interest in, firstly, a status assessment covering the current location and extent of green areas in Sargodha, as well as the Urban Heat Islands.
- Support to the Punjab Livable Cities Project or Developing Resilient Environments and Municipal Services (DREAMS) project of which Phase 2 was to target to green transformation.
- A Knowledge Support Technical Assistance (KSTA) was concurrently supporting Sargodha, one **of the cities also targeted under the investment project: The “Integrated and Innovative Solutions for More Liveable Cities” (PN 53212-001) was preparing “quick, pragmatic” action plans with a broad focus on Nature-Based Solutions (NBS).**
- The focus in Pakistan is on green transformation.

# Urban Heat Island (UHI) and Surface Urban Heat Island Intensity (SUHI)

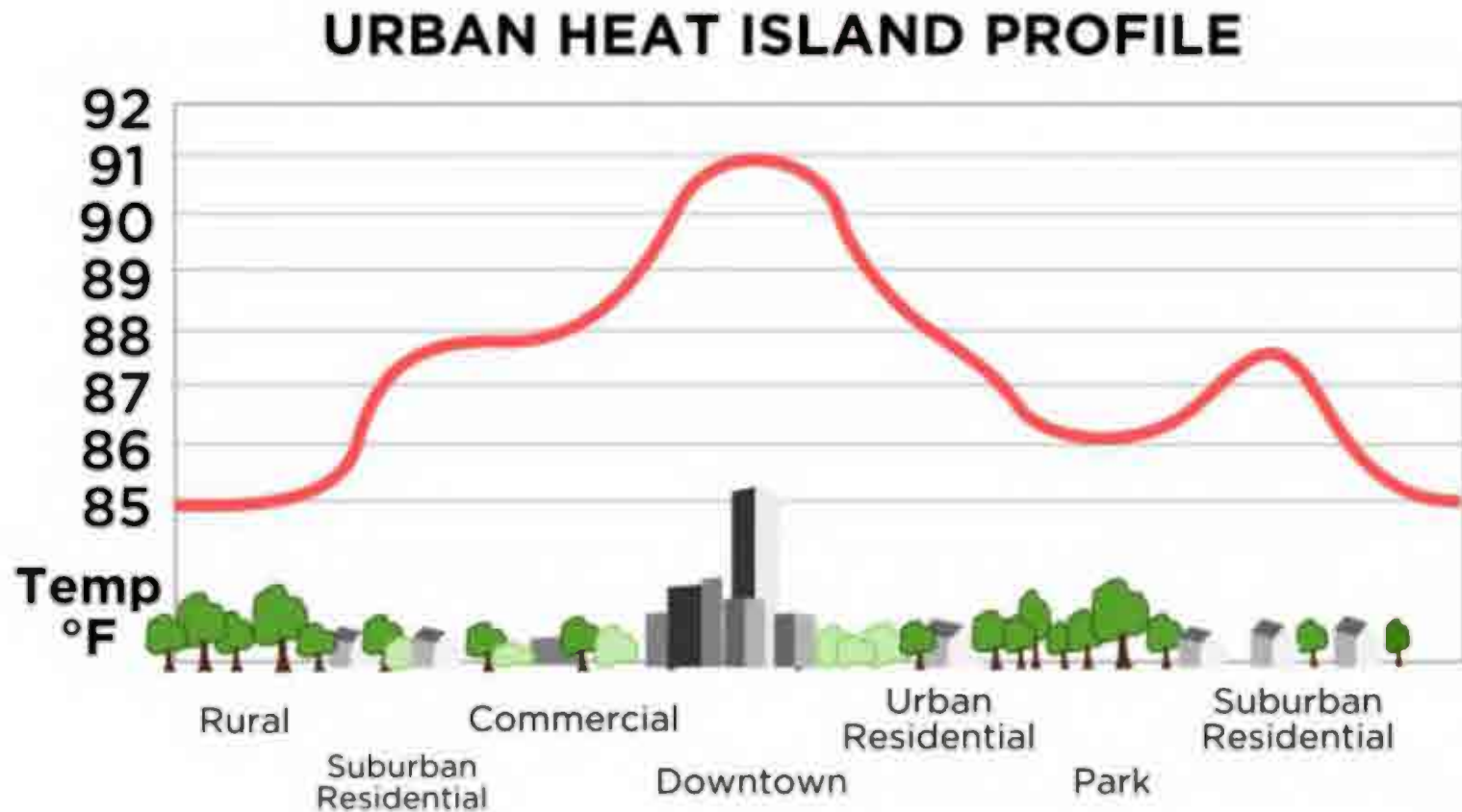


Image Source: [https://upload.wikimedia.org/wikipedia/commons/thumb/8/81/Urban\\_heat\\_island.svg/687px-Urban\\_heat\\_island.svg.png?20081123165512](https://upload.wikimedia.org/wikipedia/commons/thumb/8/81/Urban_heat_island.svg/687px-Urban_heat_island.svg.png?20081123165512)

## Impact of heat

- Human health and wellbeing
- Photosynthetic activity of plants and respiration.
- Solar panels, loss of efficiency with rising temperatures by a coefficient of **-0,3% - 0.5% / °C**

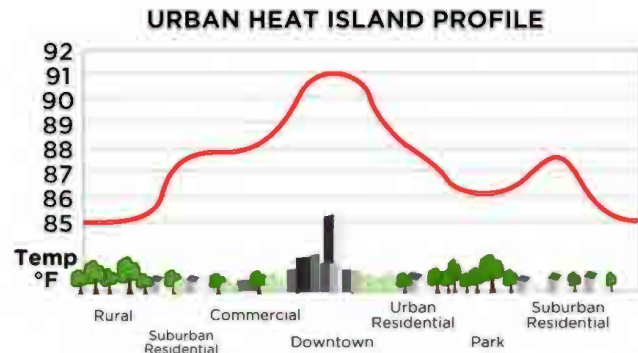
# Urban Heat

- Urban Heat Island (UHI):
  - a metropolitan area where temperatures are significantly higher than in its rural surroundings
- Urban Heat Island Intensity (UHII):
  - the *relative* difference in temperature between urban and surrounding rural regions
- Surface urban heat island intensity (SUHII)
  - quantifies this difference in relation to land surface temperature (LST), rather than air temperature
  - allows for the uniform modelling of UHII using remote sensing technology since LST is primarily affected by land cover only while perceived ambient air temperature is affected by land cover, air advection, and anthropogenic emissions.

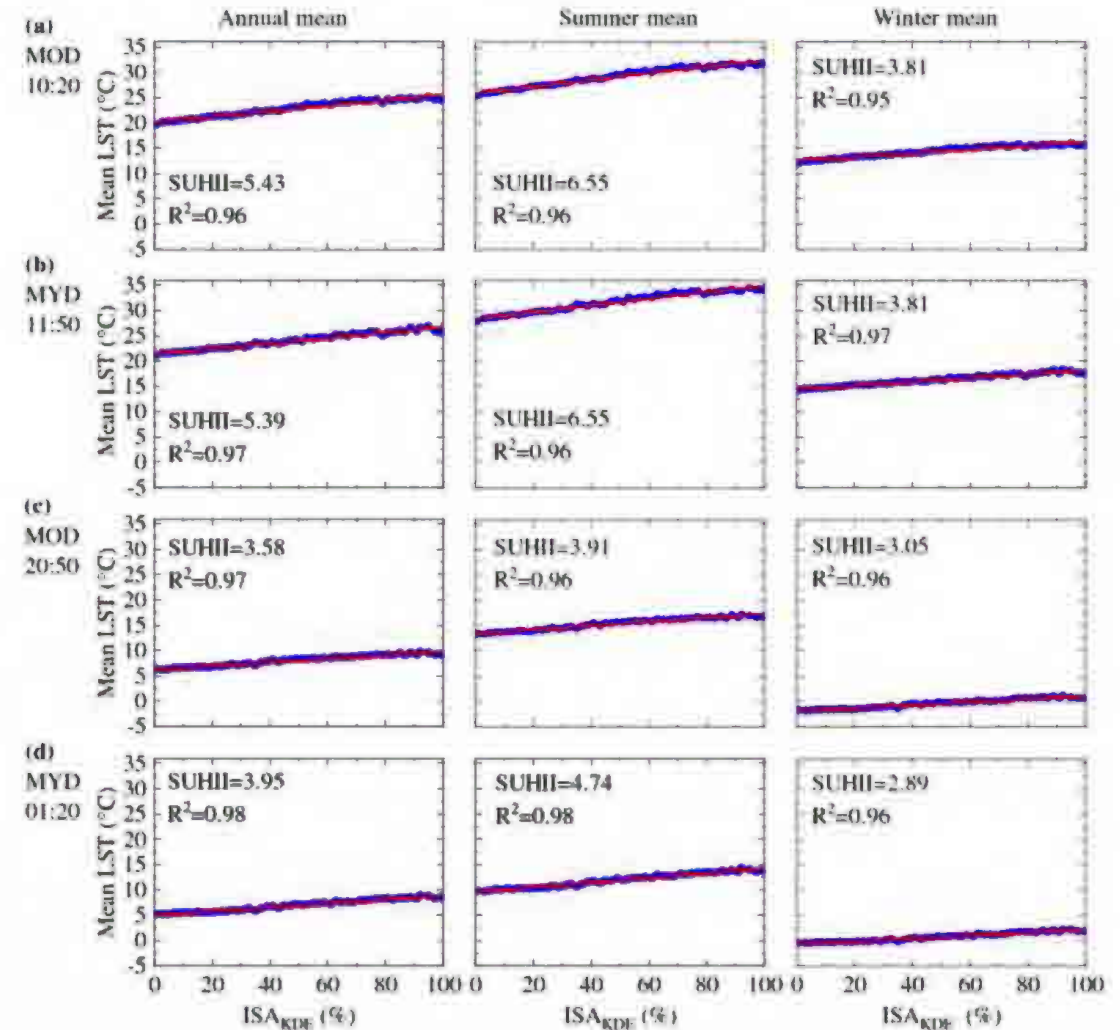
# The correlation of imperviousness and Heat Islands

Use of satellite data

- to determine degree of soil sealing
- Measurement of surface temperature



Method and Figures see: Huidong Li, Yuyu Zhou, Xiaoma Li, Lin Meng, Xun Wang, Sha Wu, Sahar Sodoudi (2018). A new method to quantify surface urban heat island intensity, Science of The Total Environment, Volume 624, ISSN 0048-9697 <https://doi.org/10.1016/j.scitotenv.2017.11.360>.





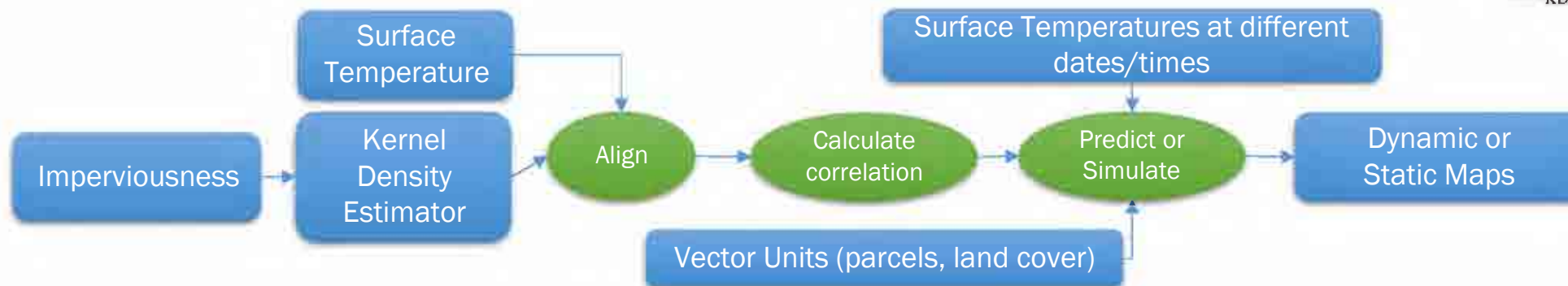
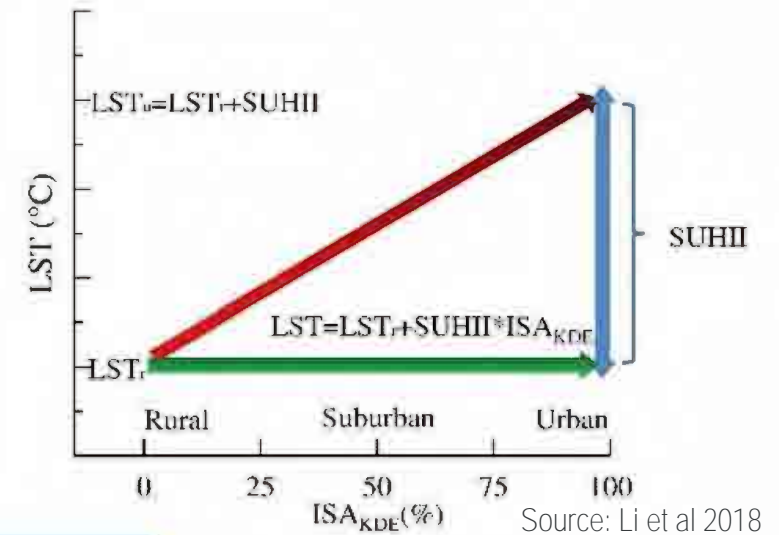
# Calculation SUHII, Sargodha

## Background

- Linear correlation of Impervious Surface Area (ISA) and Land Surface Temperature (LST)

## Processing

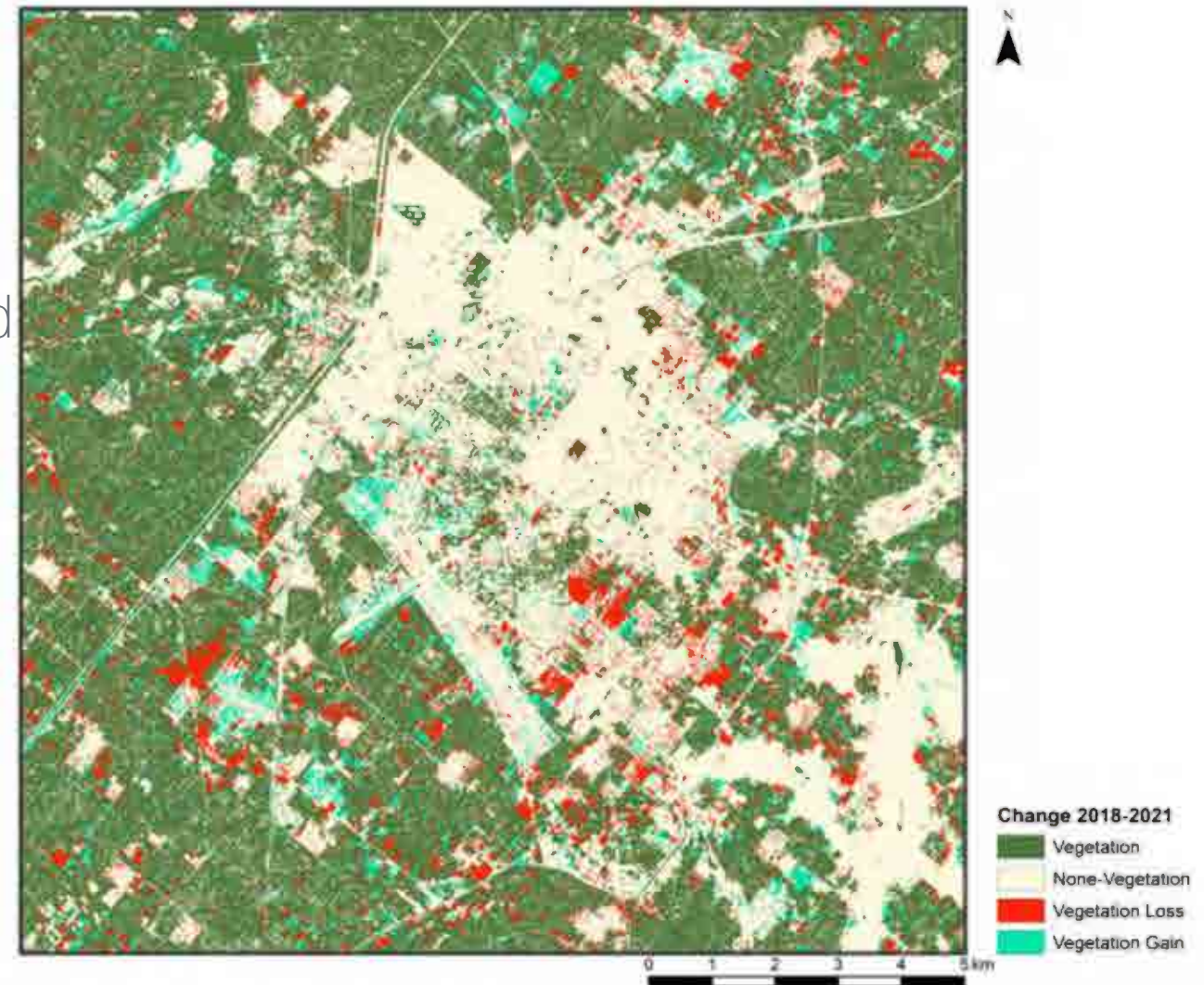
- LST derived from satellite thermal band
- Imperviousness, World Settlement Footprint (WSF)
- Kernel Density Estimation (KDE) normalised WSF
- Derive function
- Zonal statistics on city districts, wards or land parcels



# Green Area mapping and SUHII for Sargodha, Pakistan

Copernicus Sentinel-2 data for green area assessment

- Copernicus
- Data and services free of charge
- Multiple satellites operating and more planned
- Sentinel-2 provides data up to 10m
- 5 day repeat cycle
- Openly accessible
- Green Areas have multiple purposes, important for the SDGs, especially Goal 11: Sustainable cities and communities, Target 11.7 'provide access to safe and inclusive green and public spaces'.



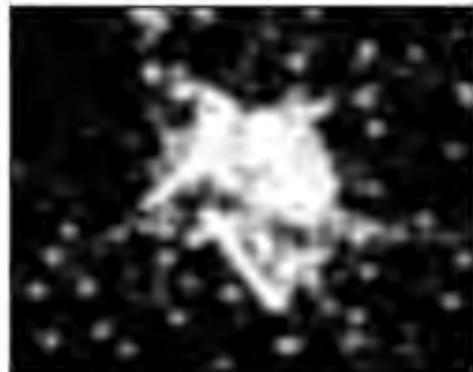
# Calculation of SUHII for Sarghoda, Pakistan

Information on imperviousness

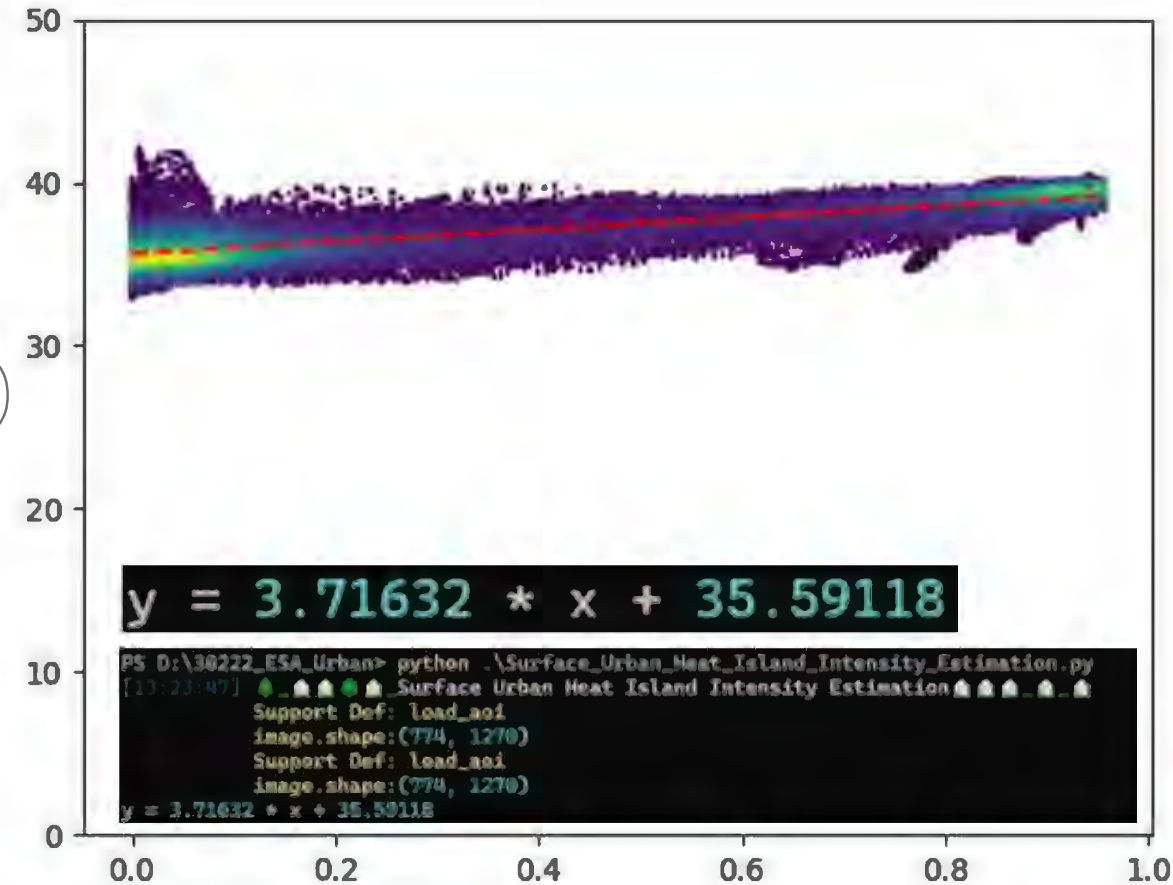
→ World Settlement Footprint (WSF) Imperviousness

Land Surface Temperature

→ Satellite Sensors with thermal bands (e.g. Landsat)



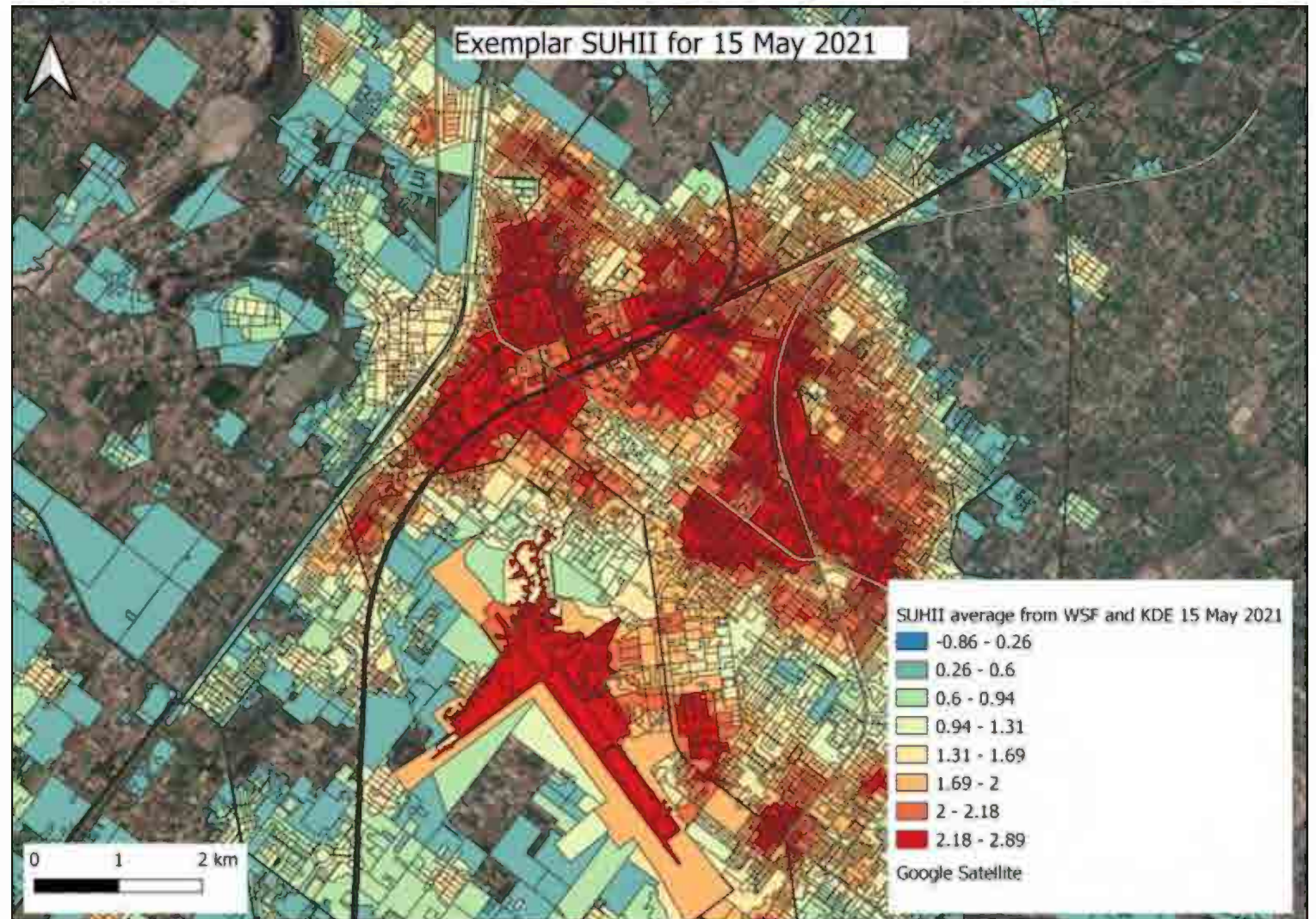
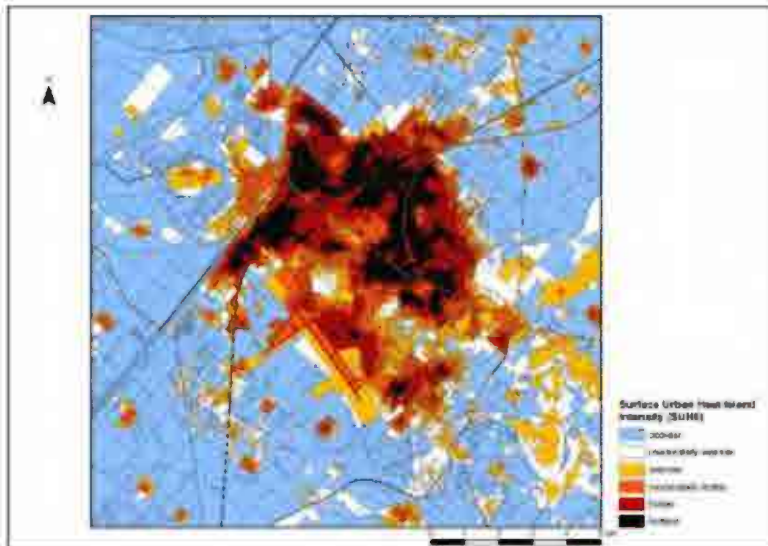
MAX SUHII in this instance 3.7 Degrees Celsius



# Example of SUHII, Sargodha

Capture Time  
for all scenes:  
10:42 AM  
(gmt +5 hours)

20210208\_054253.LST20210208\_05425  
3.LST20210208\_054253.LST20210208\_0  
54253.LST.tif



# Temporal Stack

A temporal stack of LST data was processed. 14 LST imagery were obtained for the year 2021, where very little cloud cover were present. Various preprocessing to clean/harmonize the data.

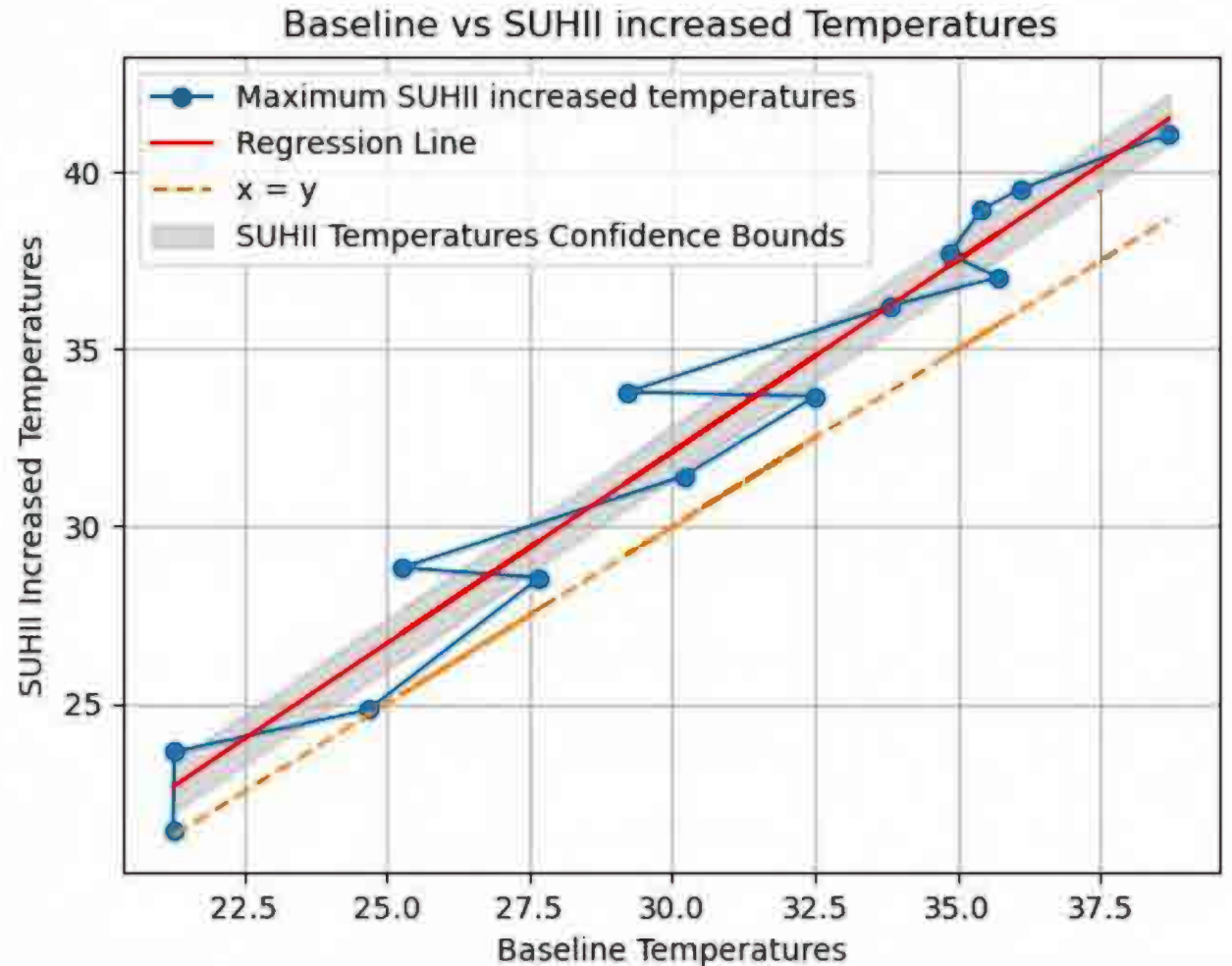


- 2 February
- 24 February
- 28 March
- 15 May
- 16 June
- 18 July
- 8 August
- 19 August
- 9 September
- 6 October
- 22 October
- 7 November
- 23 November
- 9 December

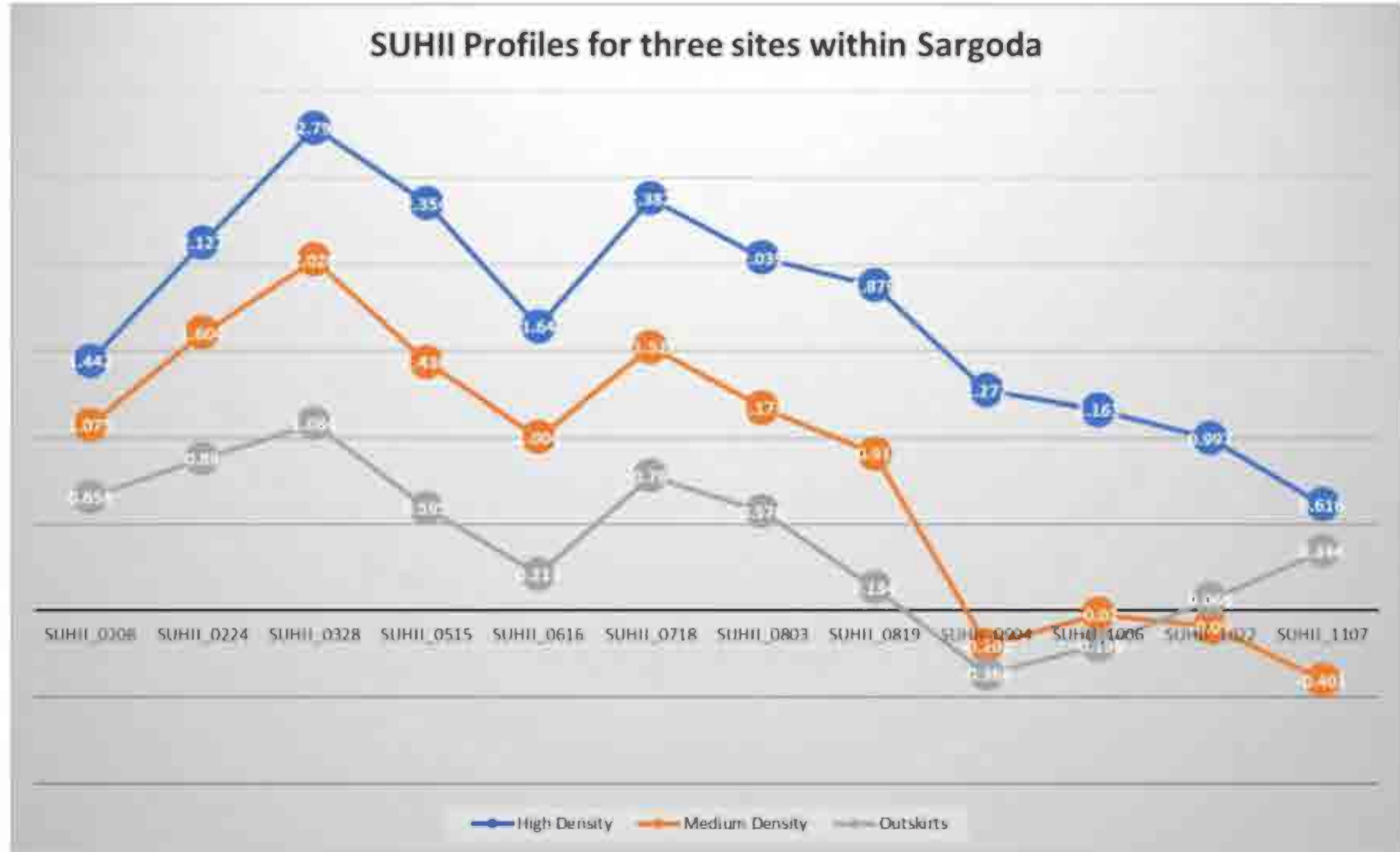
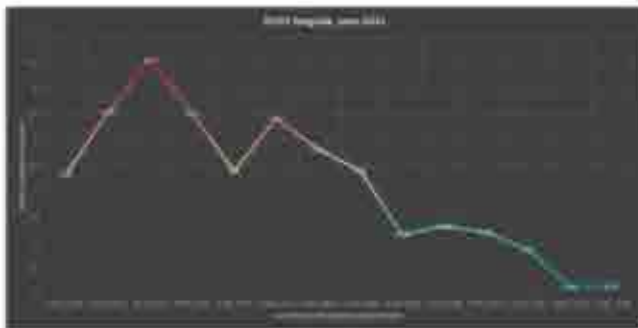
# Temperature increase not linear

Temperature Extrapolation allows for basic forecasts.

Note that calibration with continued daytime temperatures would be needed. One remote sensing capture time at 10:42 is not enough to accurately simulate the maximum SUHII increased temperatures.



# SUHII Profiles, Dense Urban, Medium Density and Outskirts



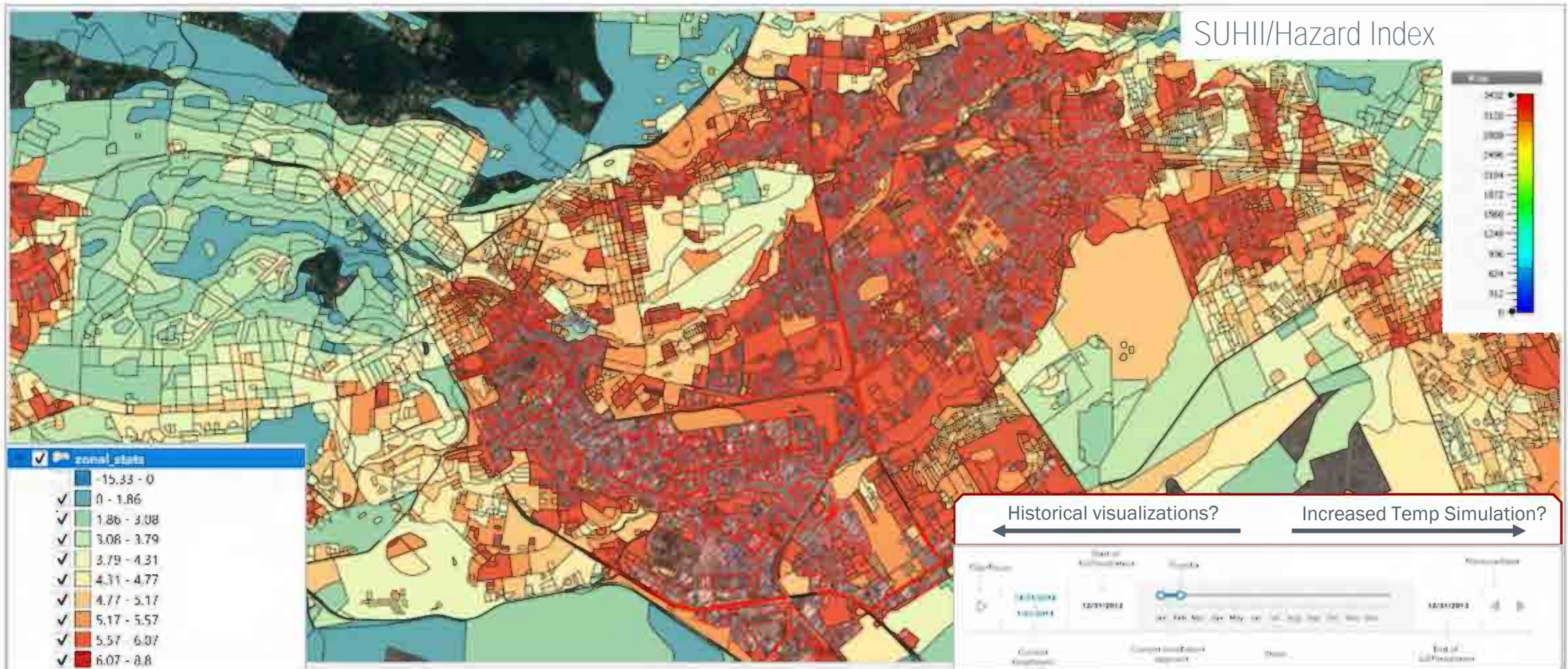
# Satellite sensors with thermal sensitivity

- Moderate Resolution Imaging Spectroradiometer (MODIS), 1km
- Visible Infrared Imaging Radiometer Suite (VIIRS), 375m resolution
- Landsat Thermal Infrared Sensor (TIRS) 100m
- New sensors by
  - Ororatech, resolution down to 80m, focusing on continuous fire monitoring
  - Constellr, up to 30 m native spatial resolution (down sampling up to 10 m) and daily revisit time. Day and night-time measurements, focusing on agricultural monitoring



# Upcoming

Enhance spatial detail and provision of an interactive interface



# GDA Urban – Cosmopolis, by Caribou

A virtual environment to learn about satellite Earth Observation for urban sustainability



- Users explore a city and learn about urban sustainability challenges
- By asking any question, and receiving customised responses, from city residents and Doctor Isla Campbell - a satellite Earth Observation expert
- This allows users to ask specific question based on their own roles and challenges
- This has been designed to simplify scientific complexity, by using immersive & dynamic communications
- <https://share.arcware.cloud/v1/share-d4d28545-8ef2-4d87-9cc1-01eefbe384da>

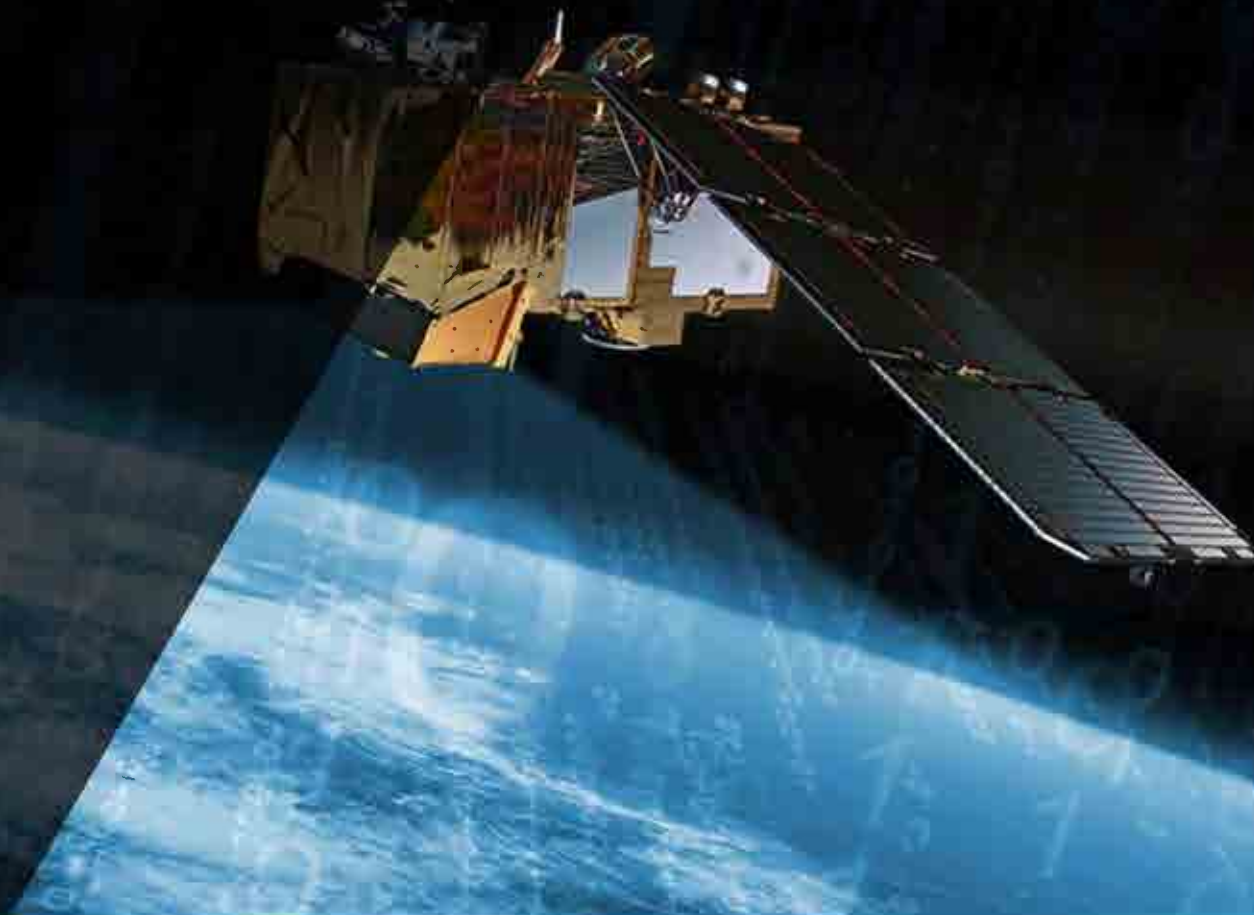
Thank you for your attention

Contact Details

[www.gaf.de](http://www.gaf.de)

[fabian.enssle@gaf.de](mailto:fabian.enssle@gaf.de)

[gda-urban@gaf.de](mailto:gda-urban@gaf.de)





GAF AG – Arnulfstr. 199 – 80634 Munich – Germany

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 [@GAF\\_Munich](https://twitter.com/GAF_Munich)

# The **World Settlement Footprint** products and applications

**M. Marconcini**

German Aerospace Center – DLR



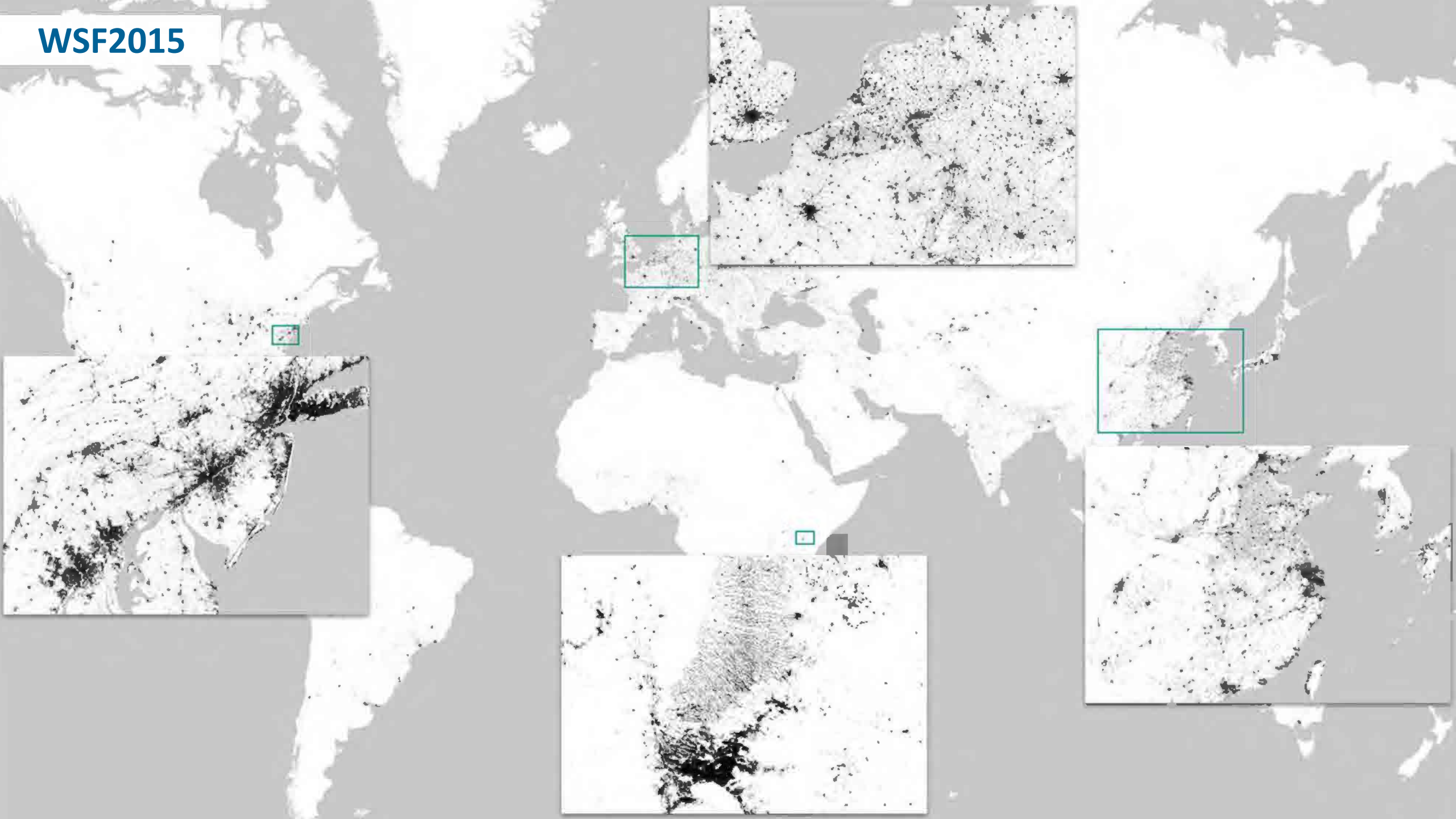
Knowledge for Tomorrow

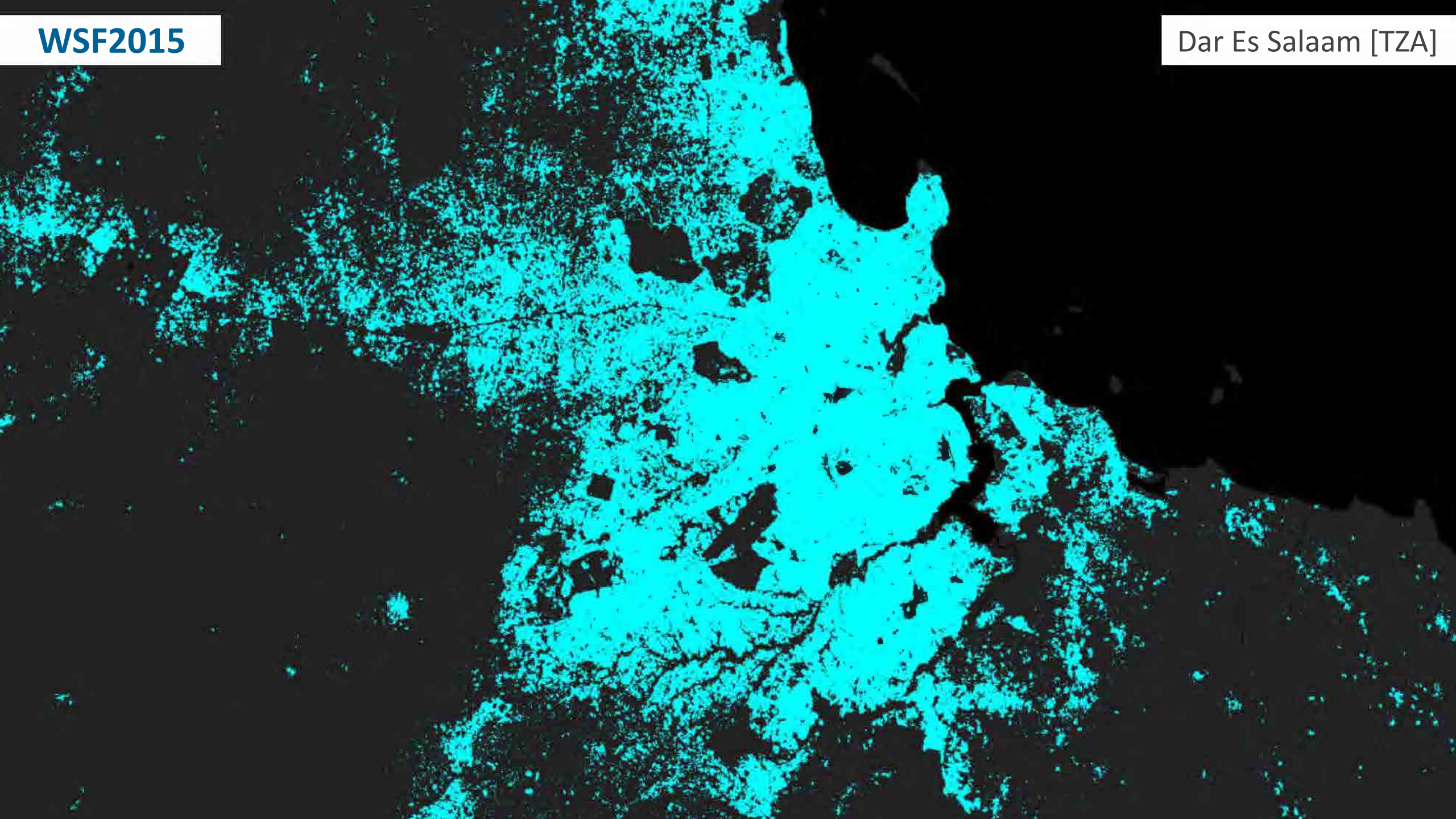


# The World Settlement Footprint suite

→ Developed at the German Aerospace Center (DLR) in collaboration with ESA, the World Bank and the Google Earth Engine team, the **World Settlement Footprint (WSF) suite** is a collection of novel **open-and-free high-resolution global** datasets aimed at advancing the understanding of urbanization at the planetary scale with unprecedented detail and accuracy.

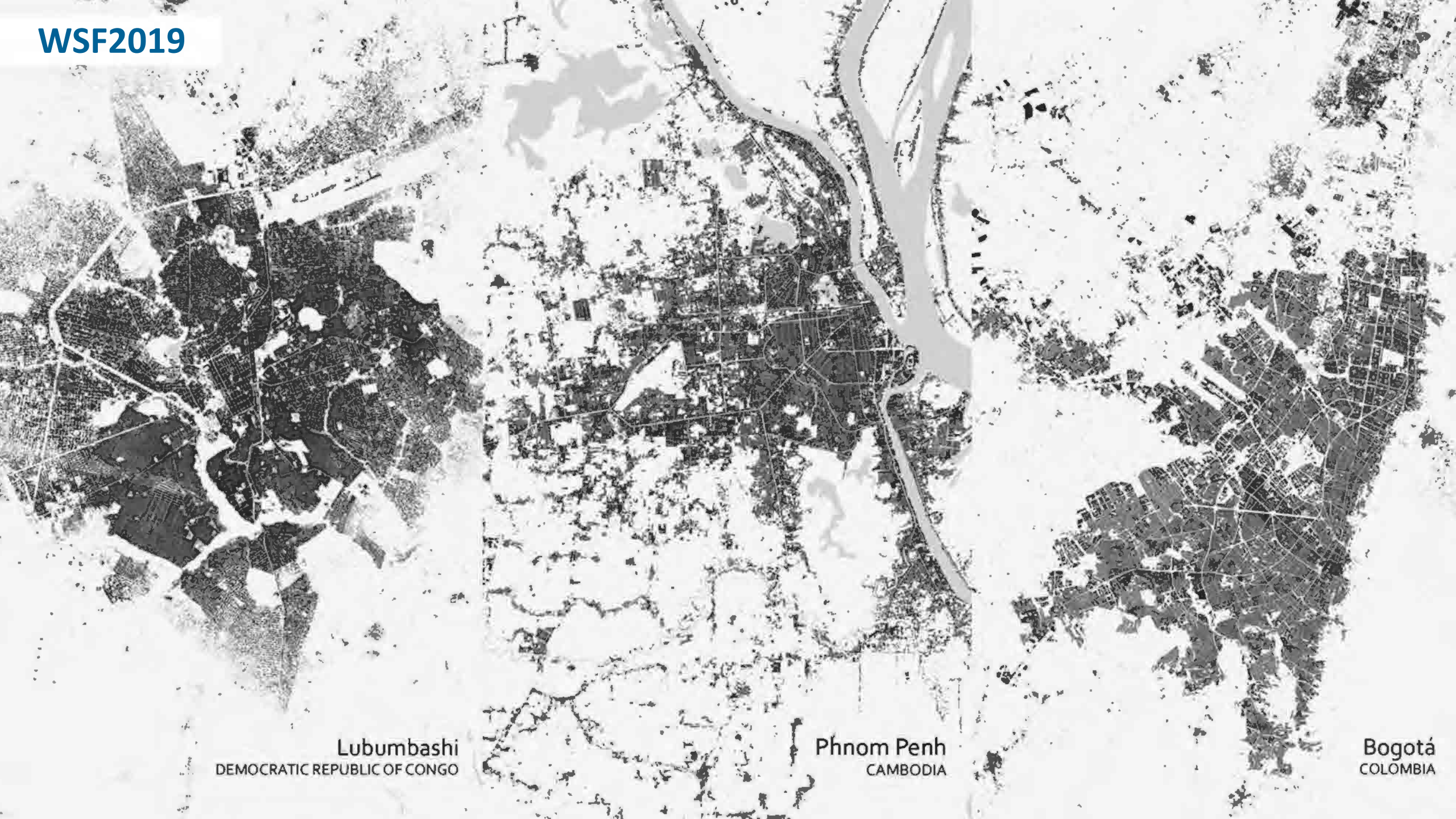
WSF2015











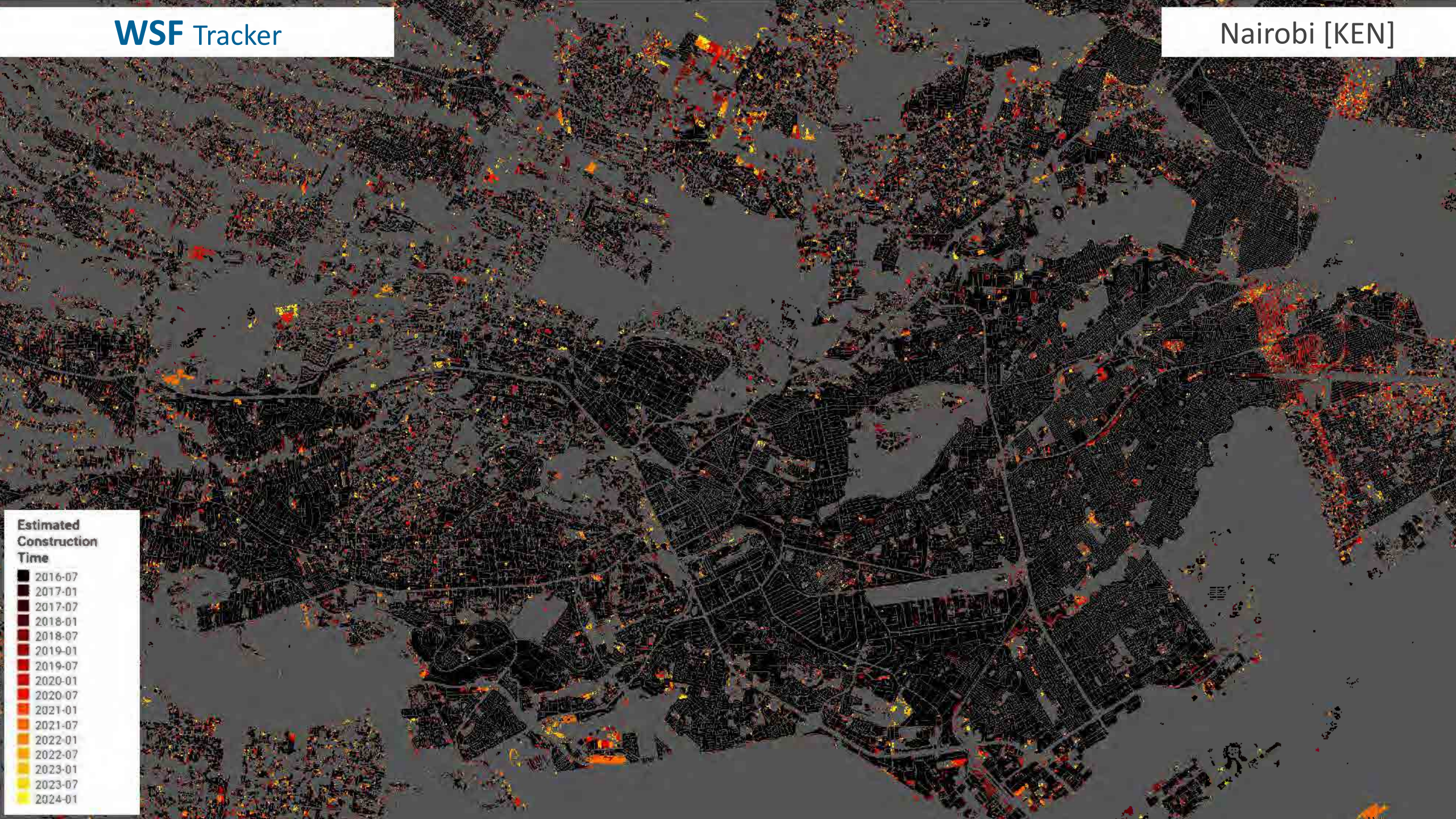
Lubumbashi  
DEMOCRATIC REPUBLIC OF CONGO

Phnom Penh  
CAMBODIA

Bogotá  
COLOMBIA

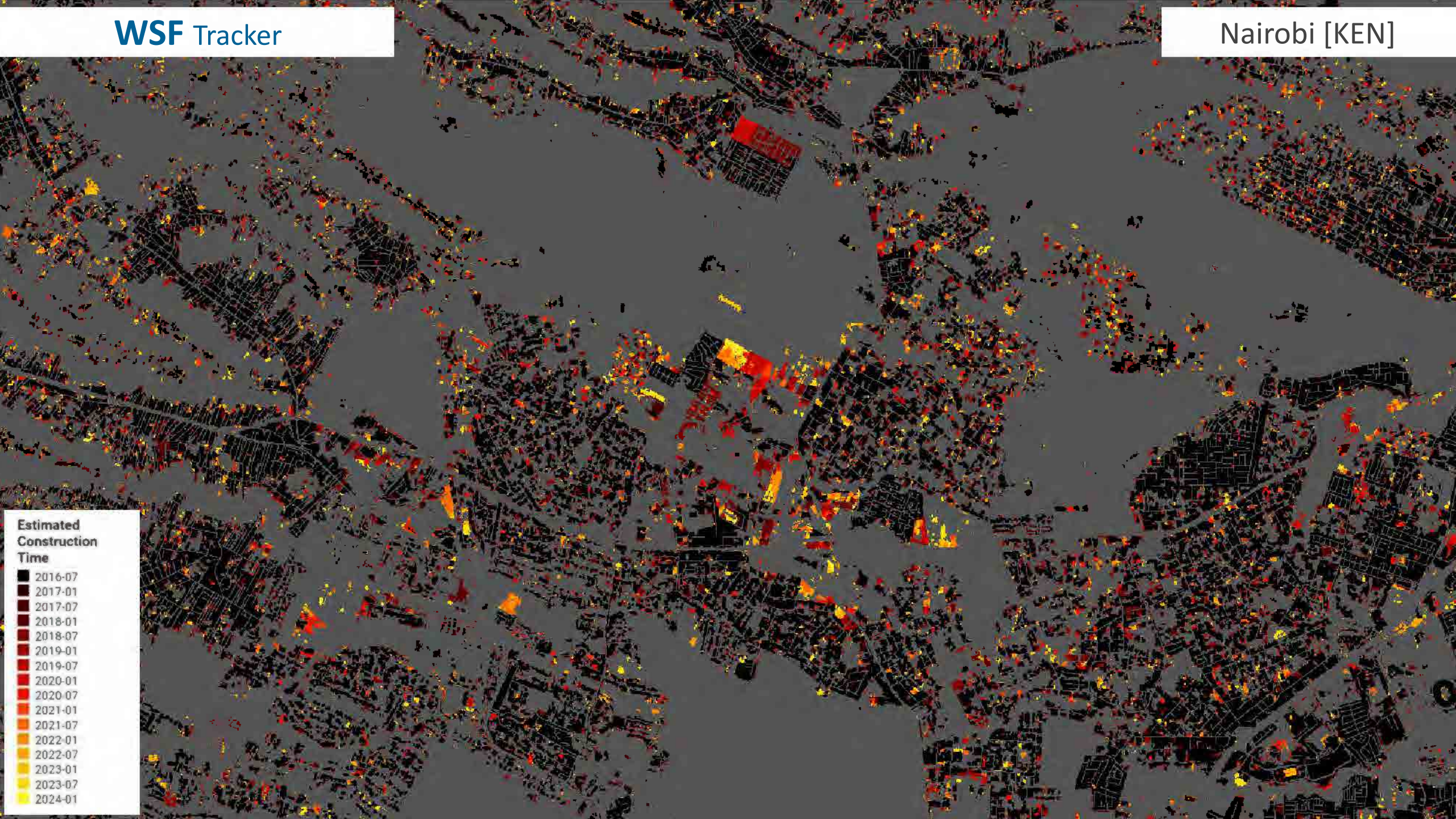
**Estimated  
Construction  
Time**

- 2015-01
- 2016-01
- 2017-01
- 2018-01
- 2019-01
- 2020-01
- 2021-01
- 2022-01
- 2023-01
- 2024-01
- 2025-01
- 2026-01
- 2027-01
- 2028-01
- 2029-01
- 2030-01
- 2031-01
- 2032-01
- 2033-01
- 2034-01
- 2035-01
- 2036-01
- 2037-01
- 2038-01
- 2039-01
- 2040-01
- 2041-01
- 2042-01
- 2043-01
- 2044-01
- 2045-01
- 2046-01
- 2047-01
- 2048-01
- 2049-01
- 2050-01



Estimated Construction Time

- 2016-07
- 2017-01
- 2017-07
- 2018-01
- 2018-07
- 2019-01
- 2019-07
- 2020-01
- 2020-07
- 2021-01
- 2021-07
- 2022-01
- 2022-07
- 2023-01
- 2023-07
- 2024-01

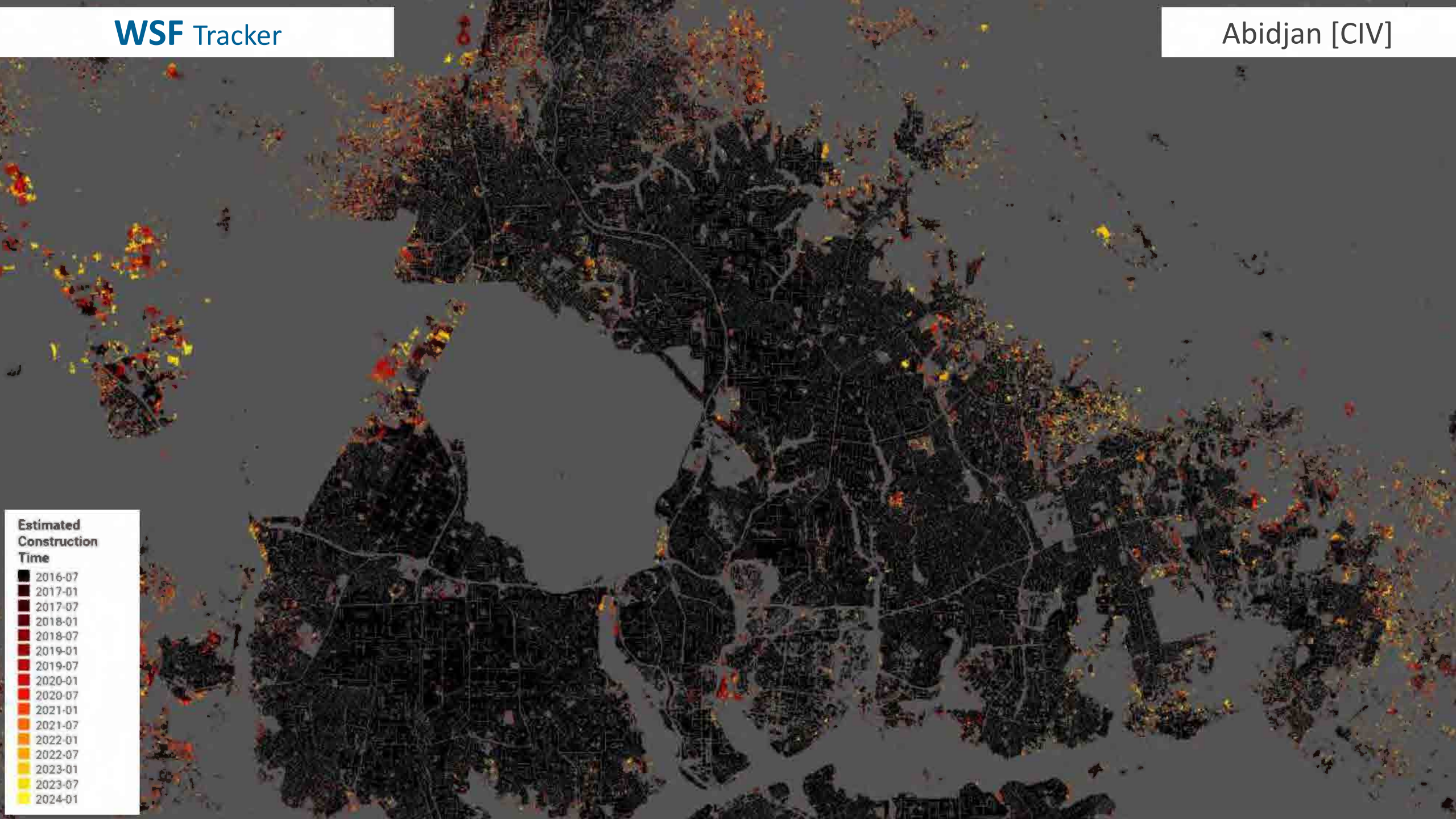


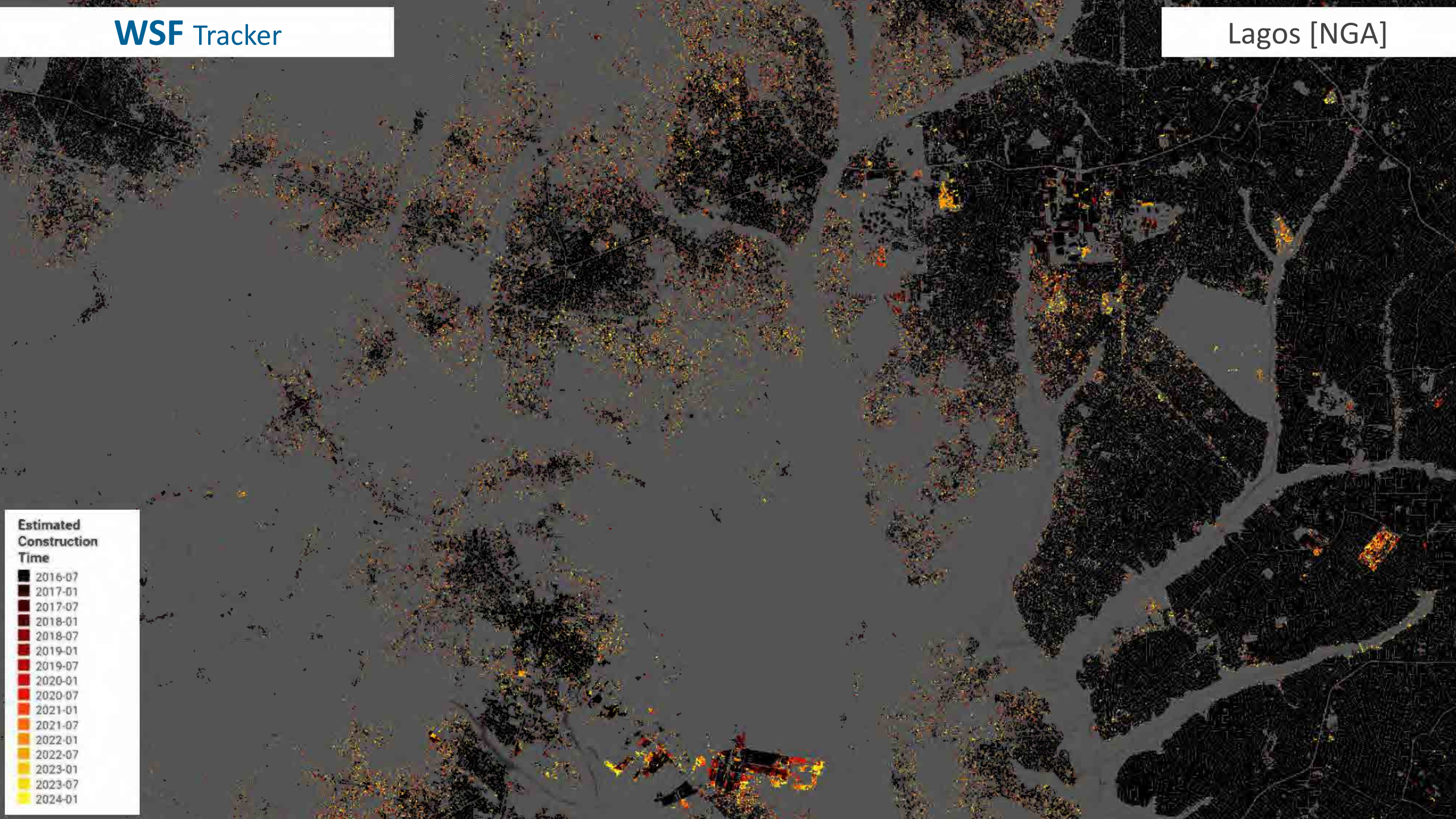
**Estimated Construction Time**

- 2016-07
- 2017-01
- 2017-07
- 2018-01
- 2018-07
- 2019-01
- 2019-07
- 2020-01
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- 2021-01
- 2021-07
- 2022-01
- 2022-07
- 2023-01
- 2023-07
- 2024-01

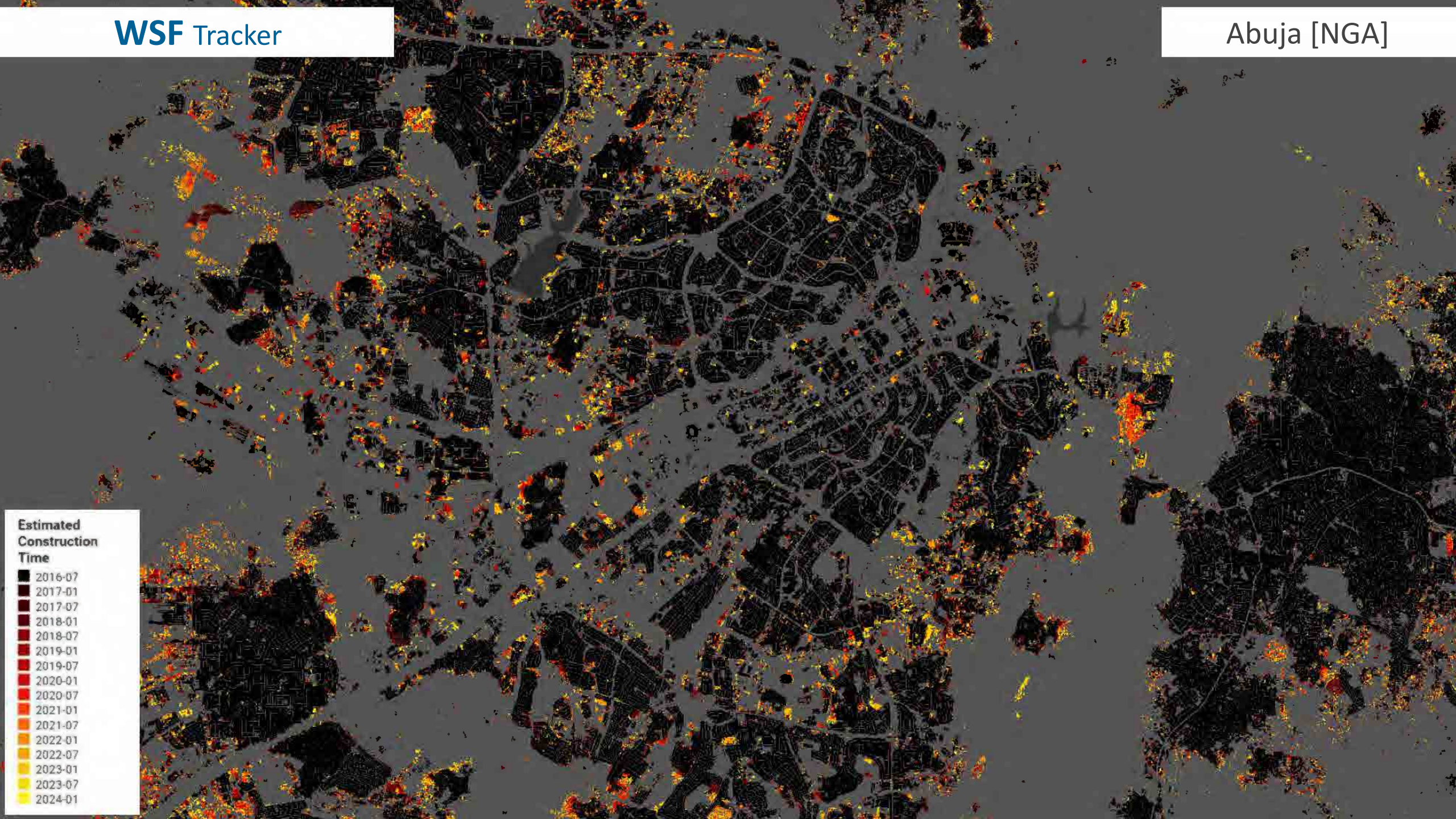
**Estimated  
Construction  
Time**

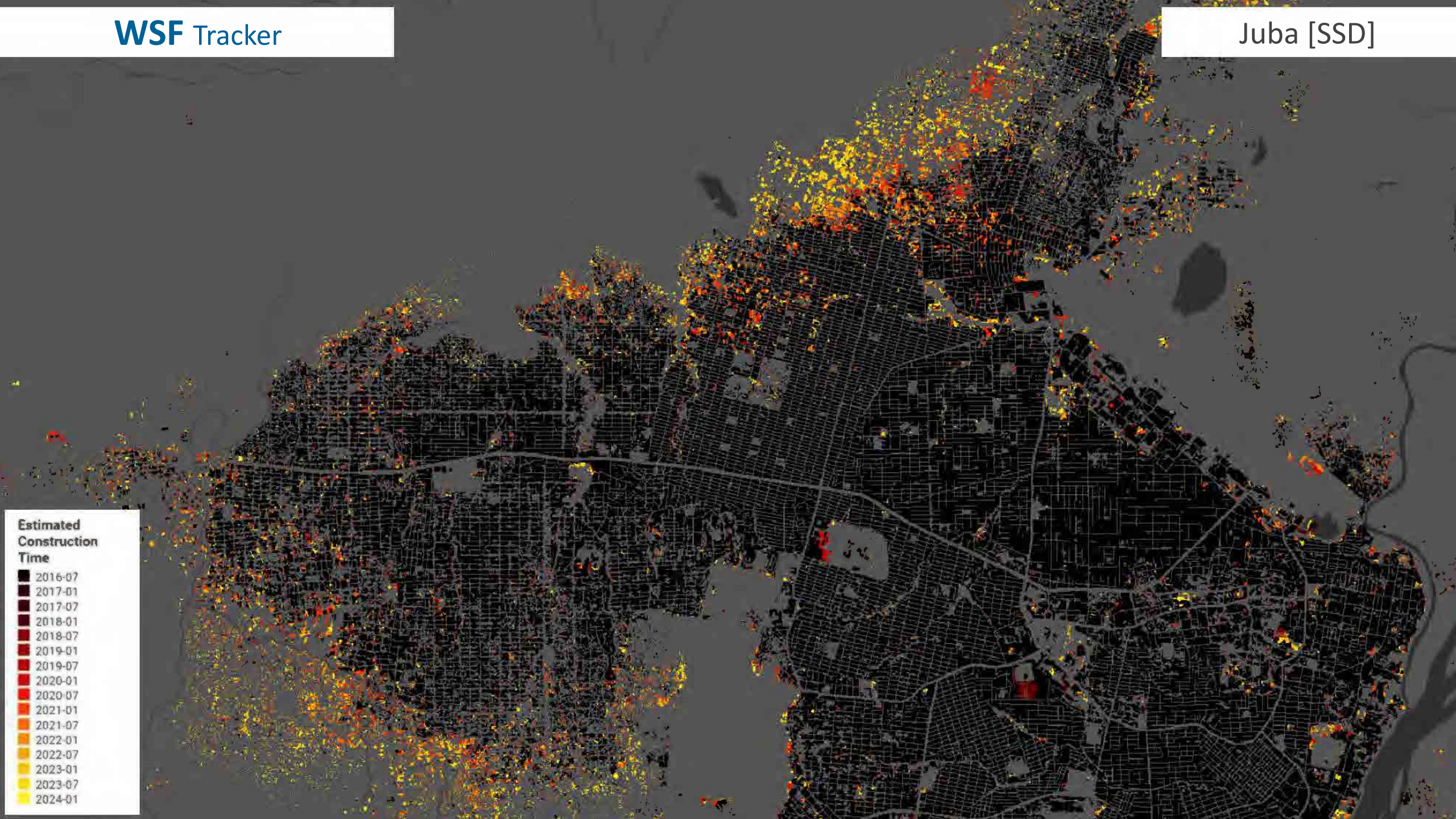
- 2015-01
- 2017-01
- 2018-01
- 2019-01
- 2019-07
- 2019-01
- 2019-07
- 2020-01
- 2020-07
- 2021-01
- 2021-07
- 2022-01
- 2022-07
- 2023-01
- 2023-07
- 2024-01





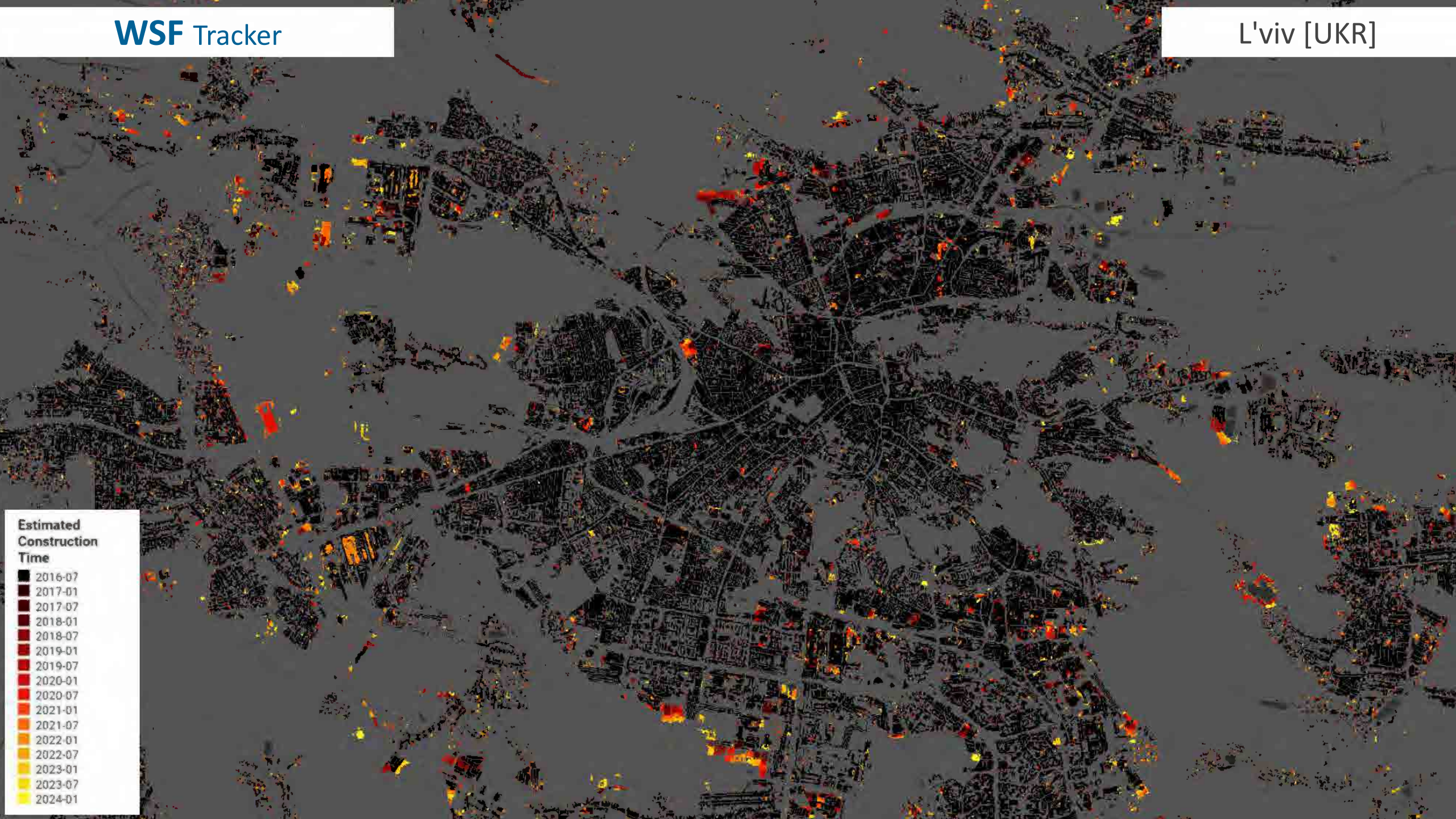




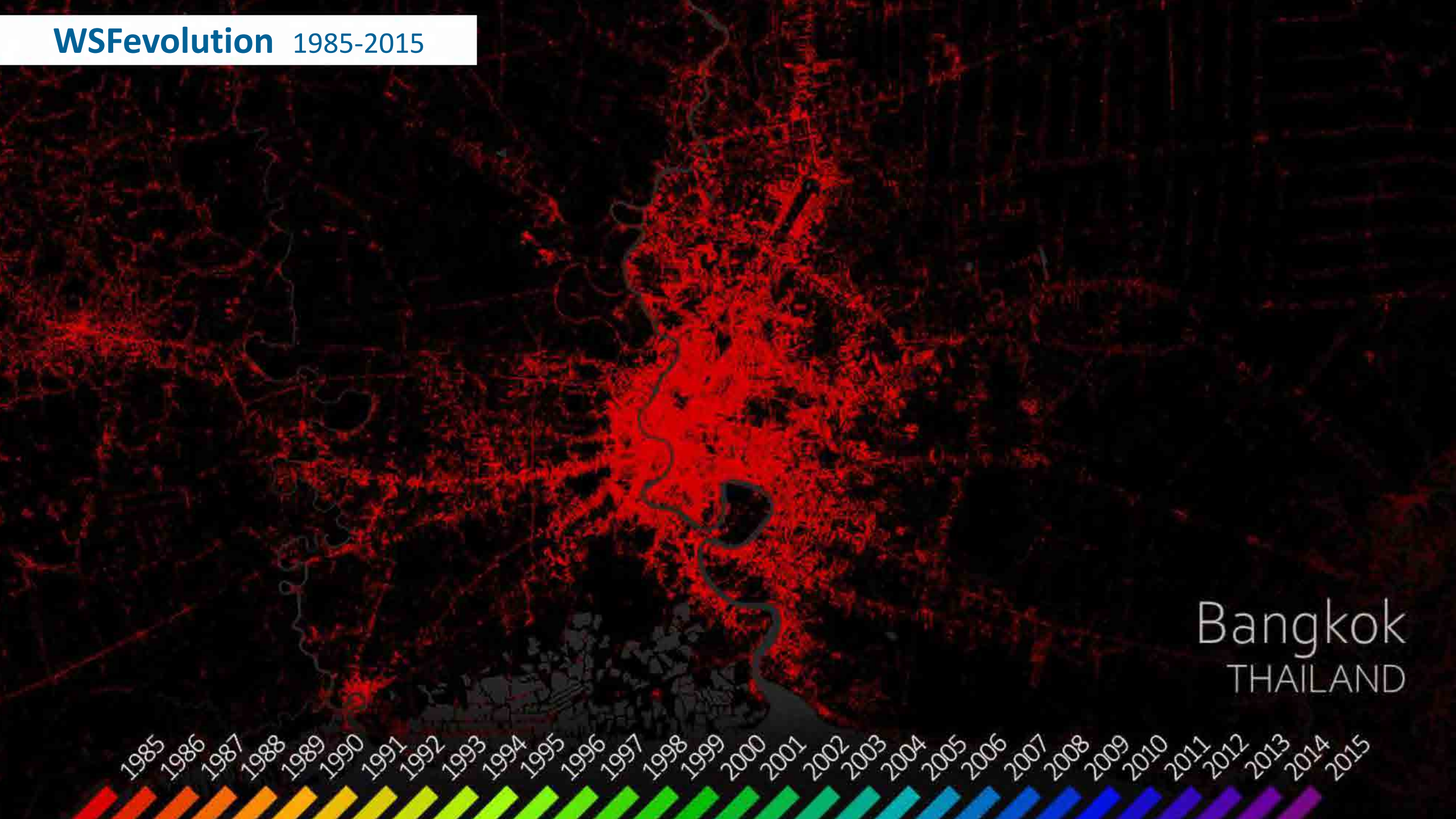


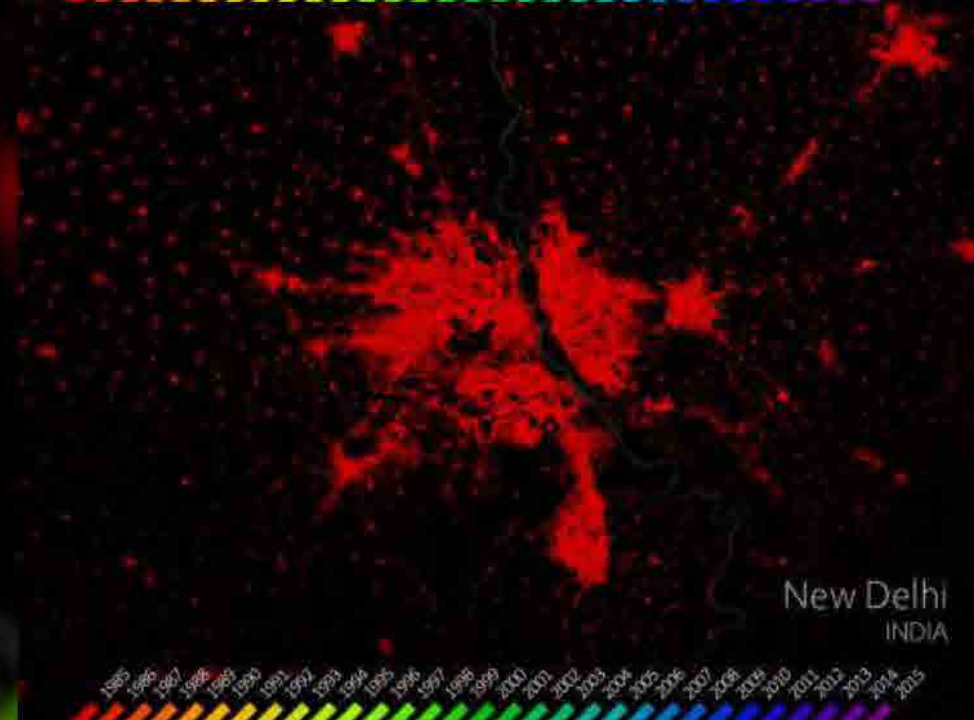
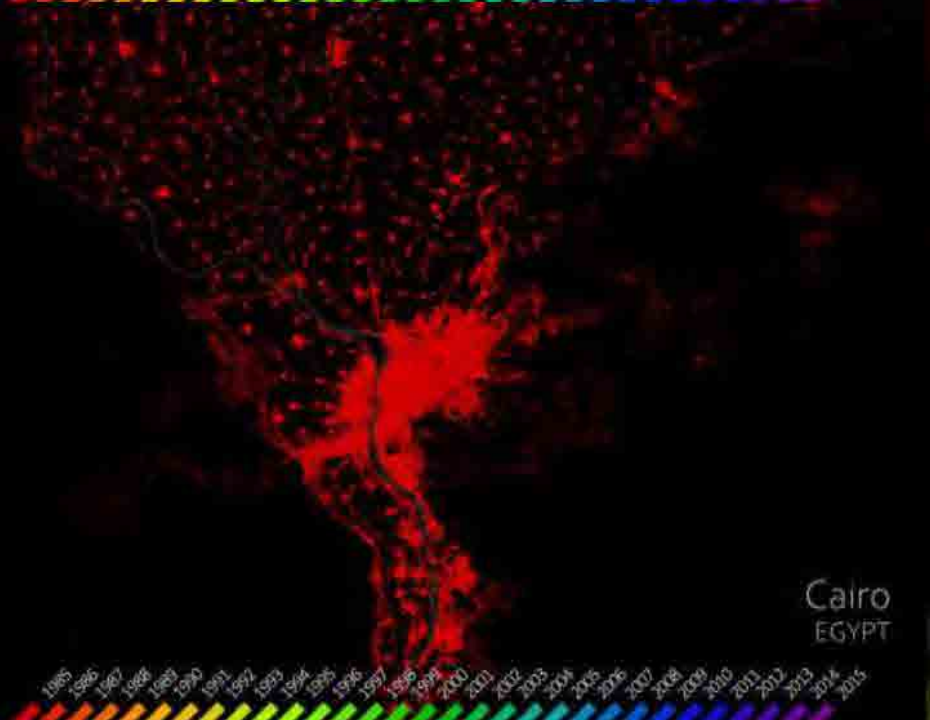
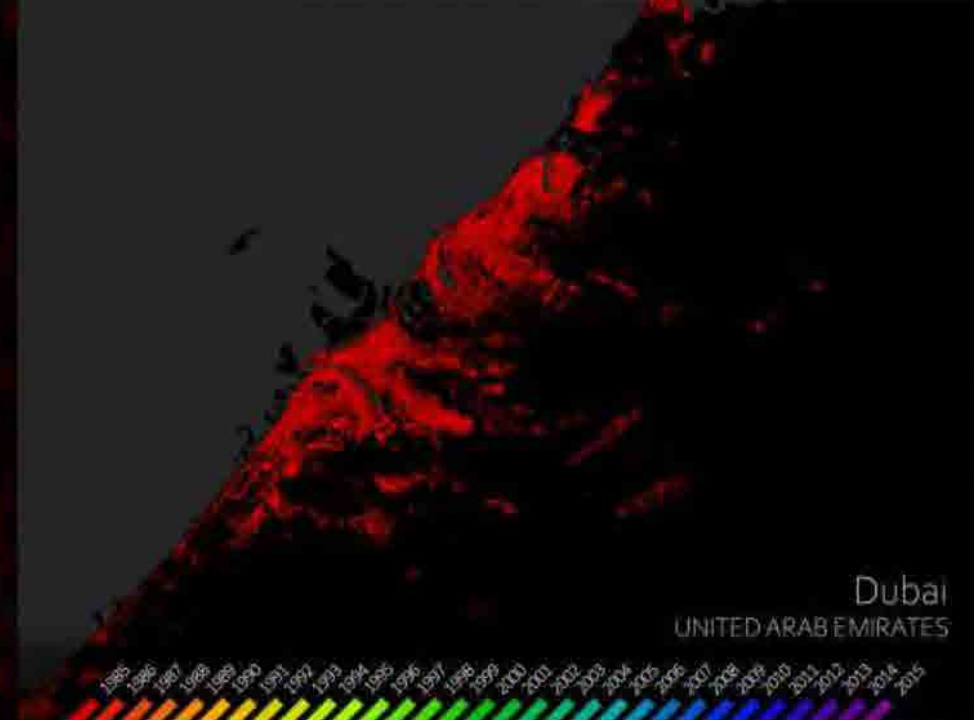
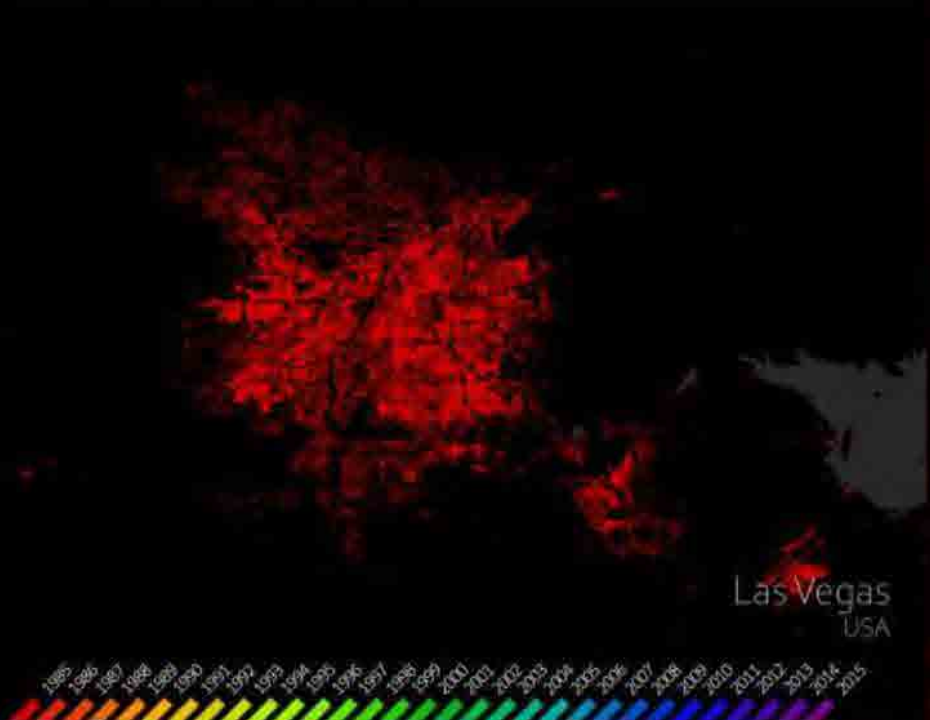
**Estimated  
Construction  
Time**

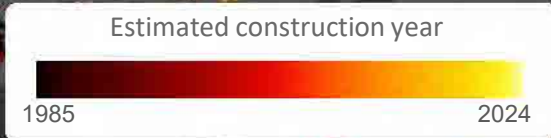
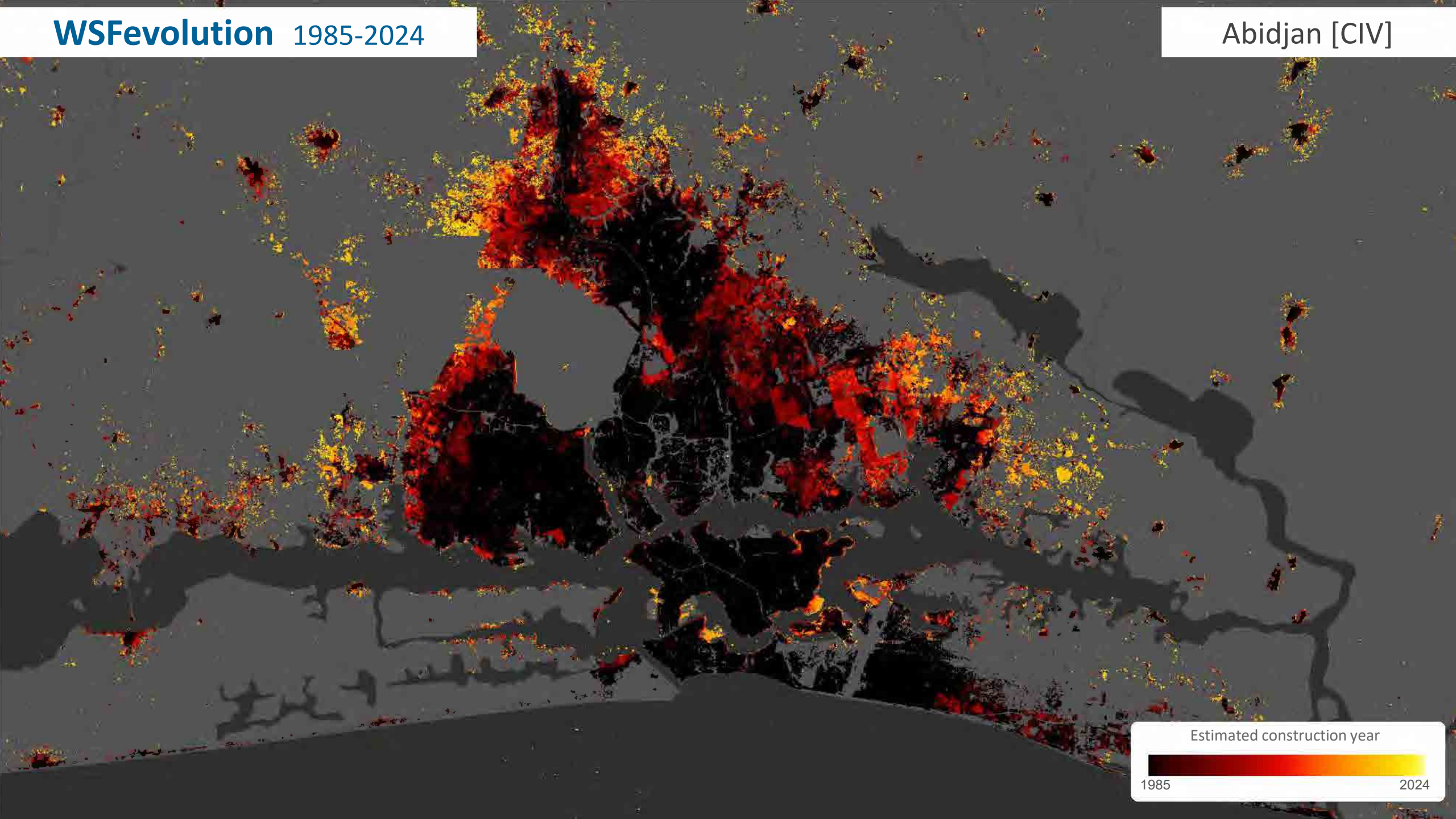
- 2016-07
- 2017-01
- 2017-07
- 2018-01
- 2018-07
- 2019-01
- 2019-07
- 2020-01
- 2020-07
- 2021-01
- 2021-07
- 2022-01
- 2022-07
- 2023-01
- 2023-07
- 2024-01



# WSFevolution 1985-2015

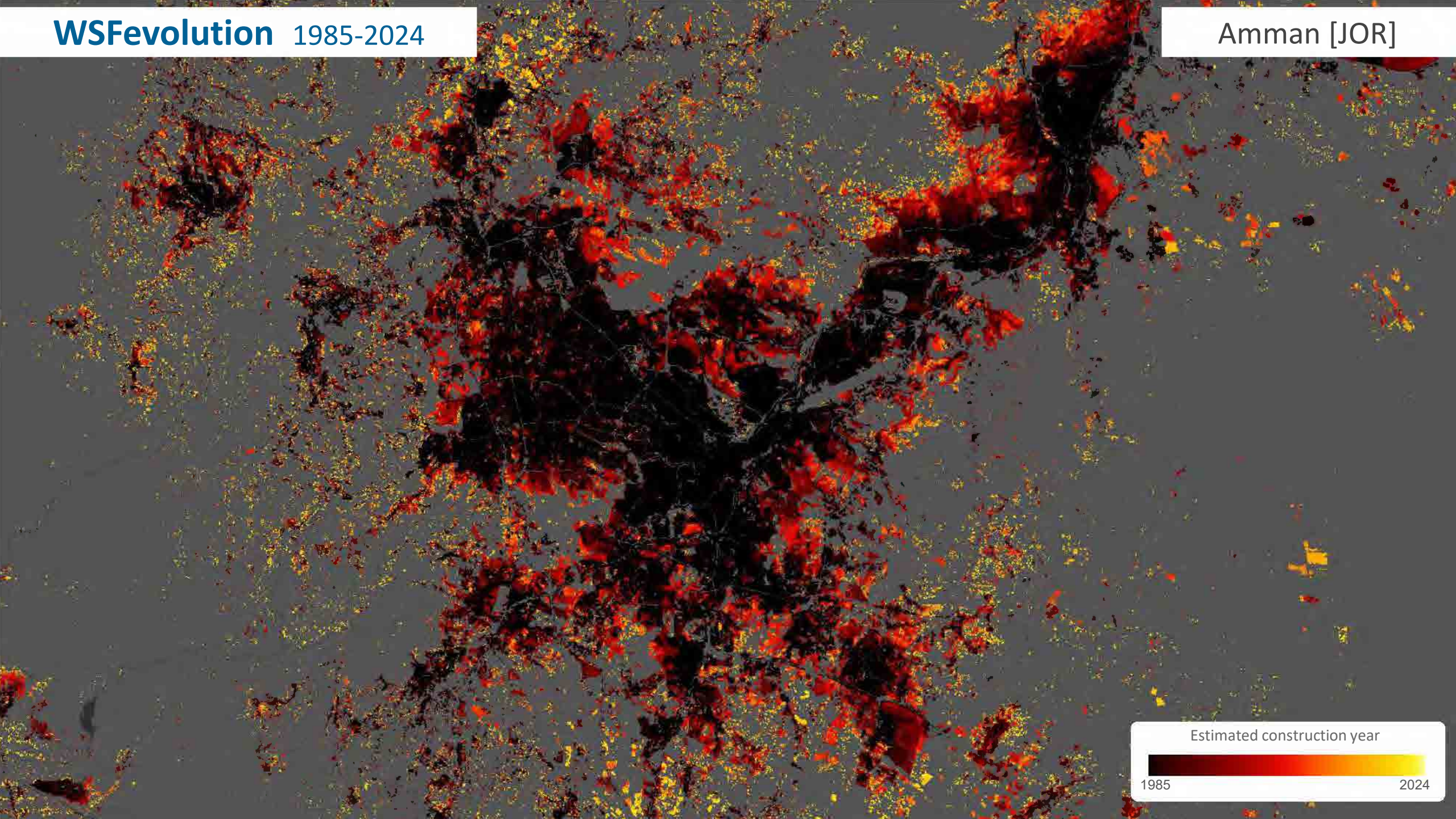




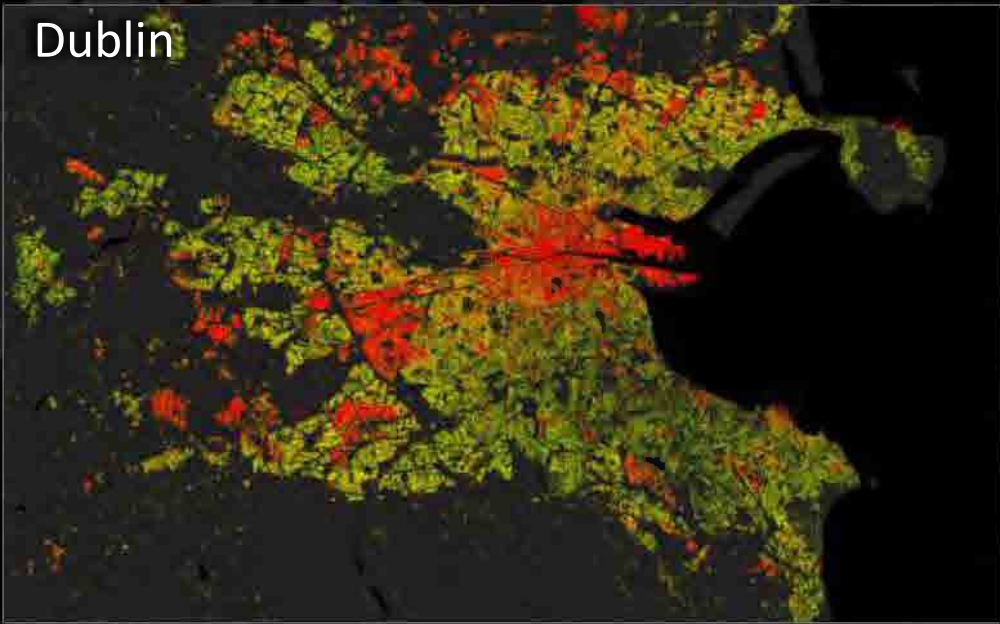


WSFevolution 1985-2024

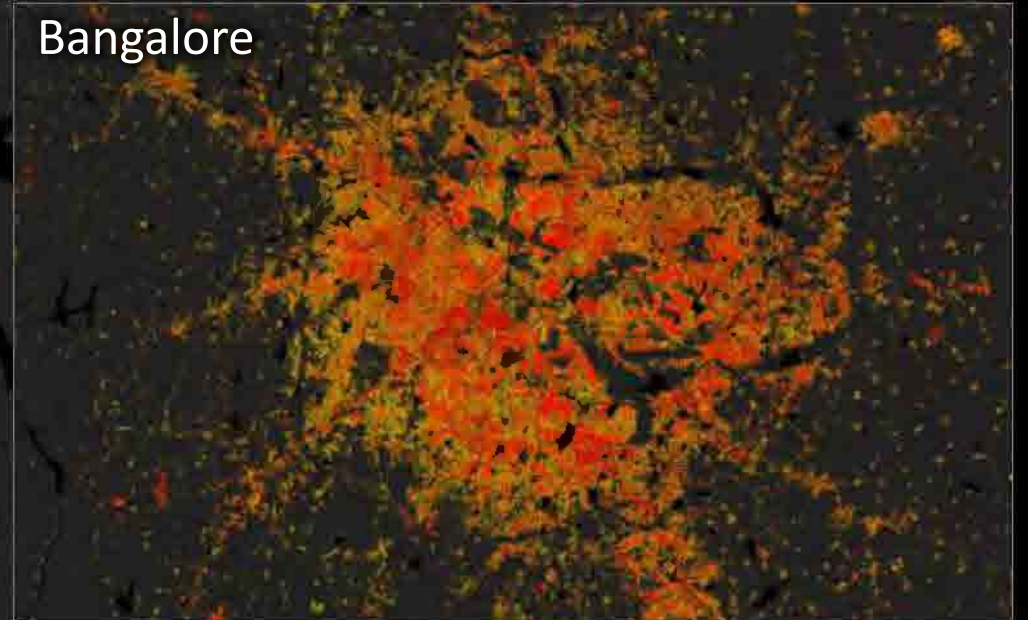
Amman [JOR]



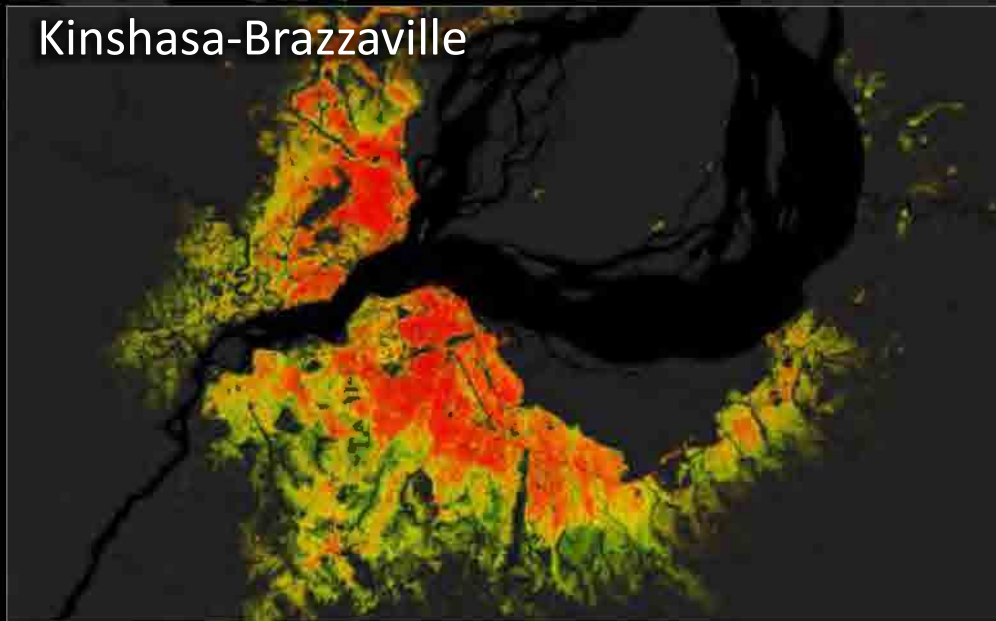
Dublin



Bangalore



Kinshasa-Brazzaville





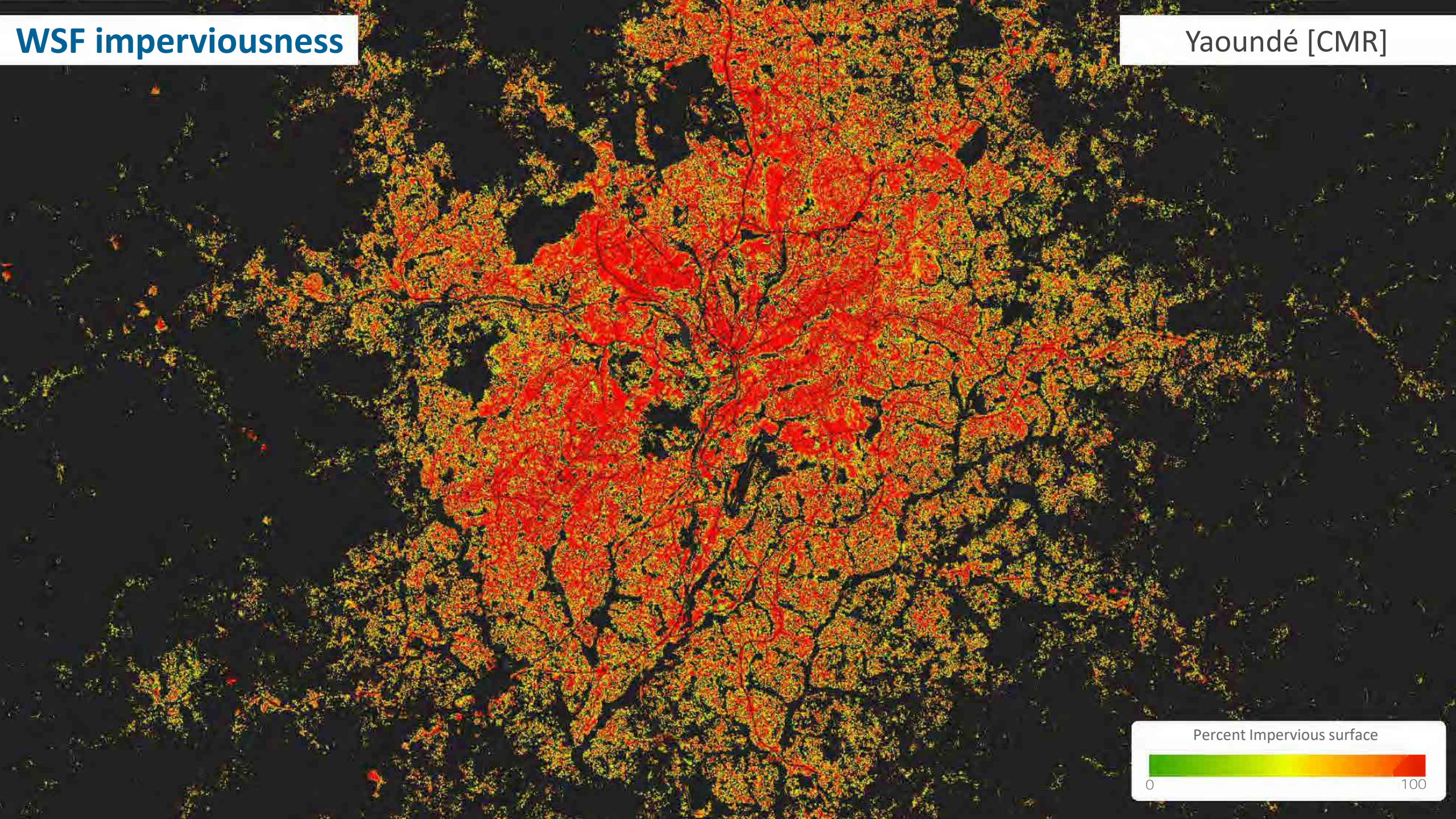
# WSF imperviousness

Nairobi [KEN]



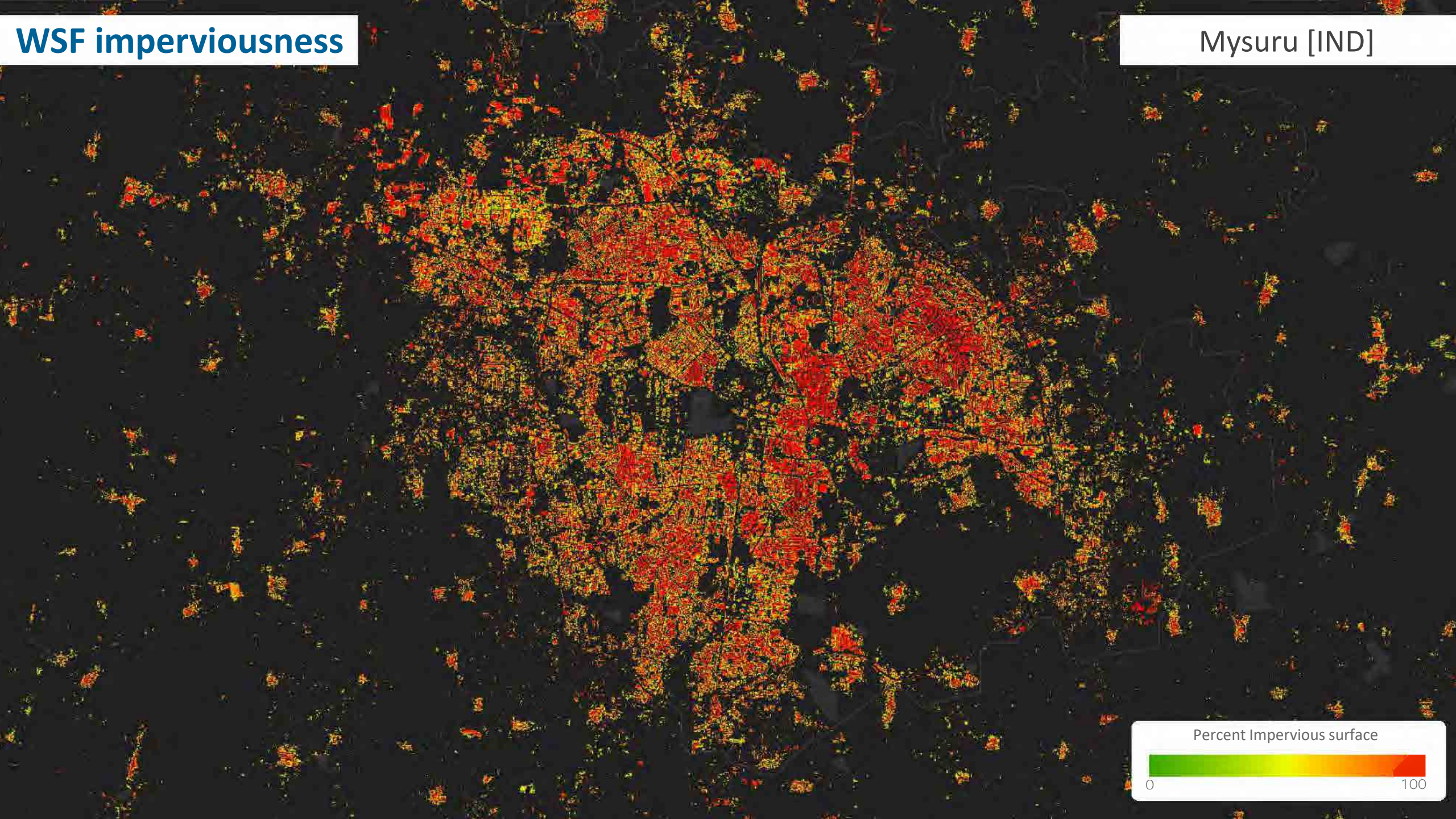
# WSF imperviousness

Yaoundé [CMR]



# WSF imperviousness

Mysuru [IND]



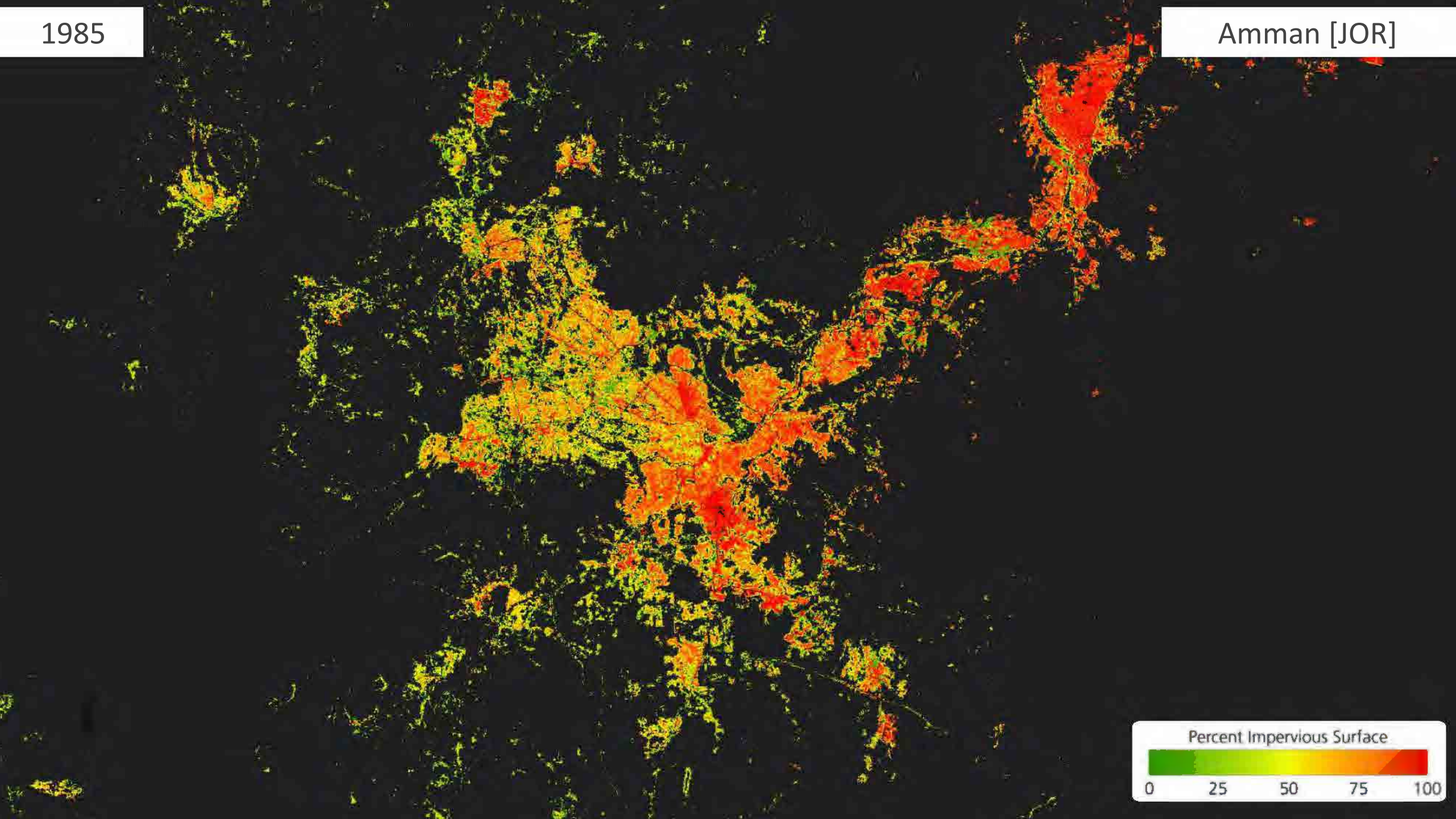
# WSF imperviousness

Niamey [NER]



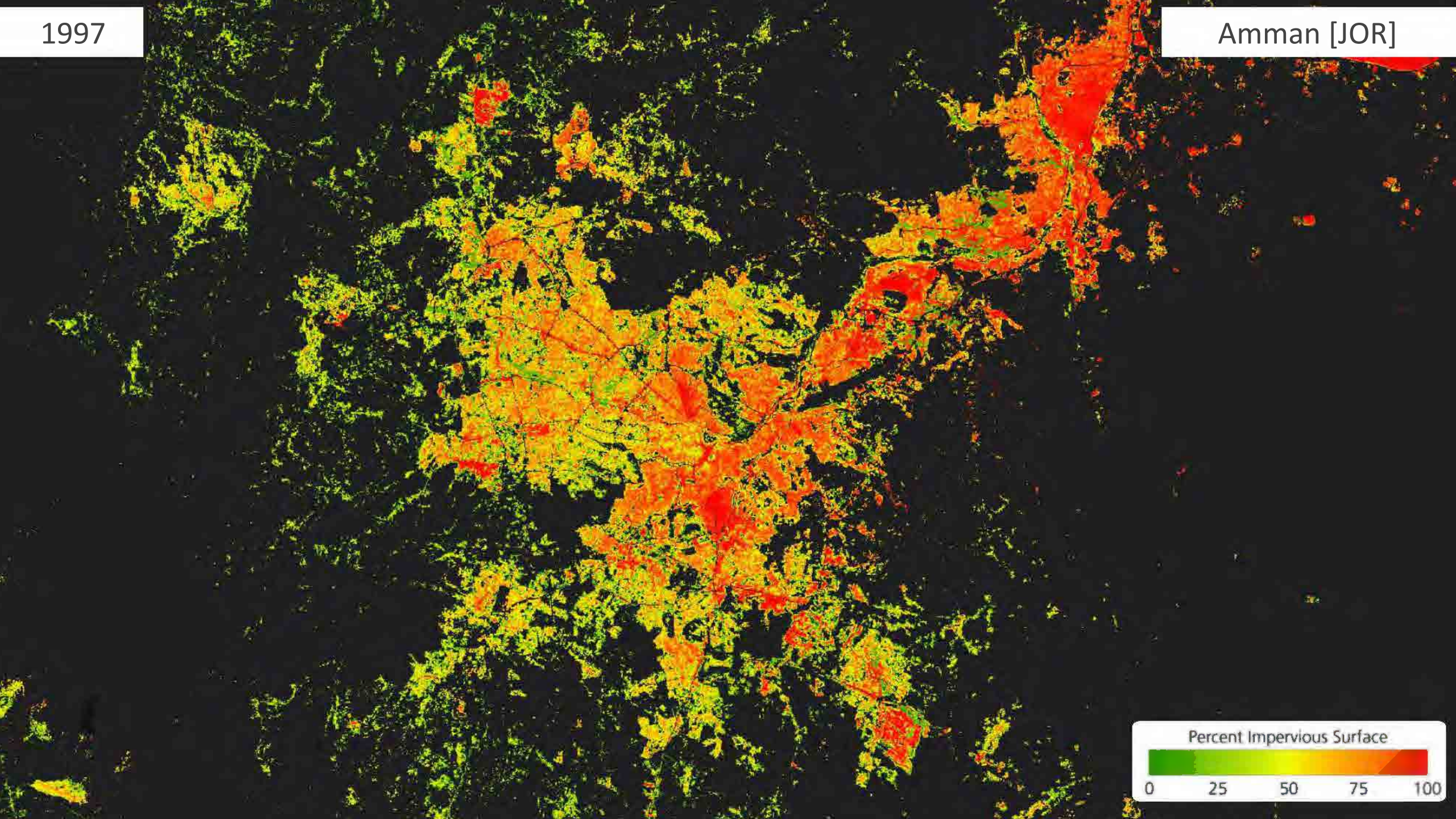
1985

Amman [JOR]



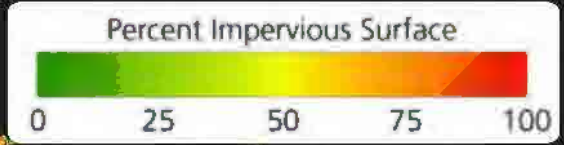
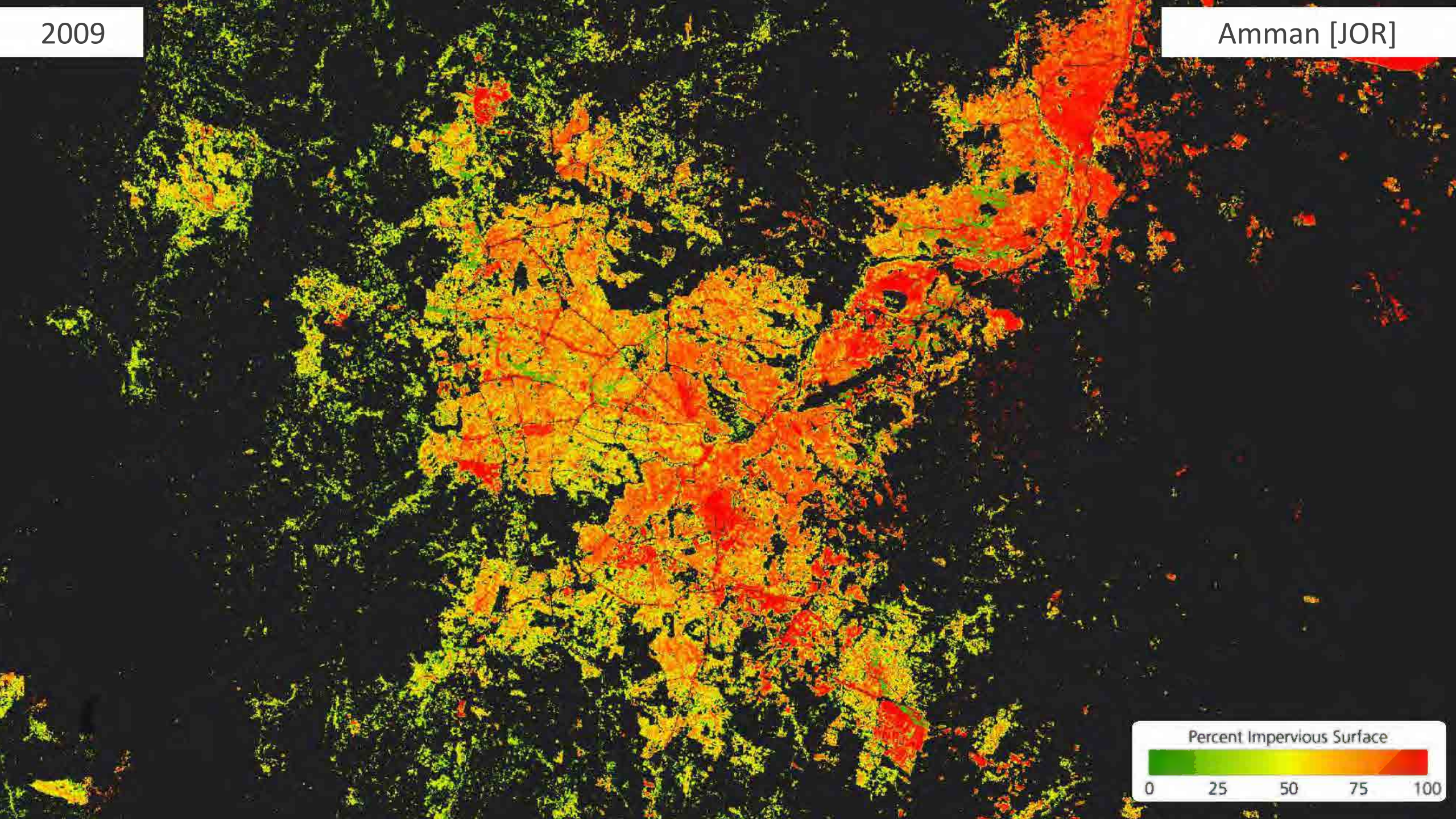
1997

Amman [JOR]



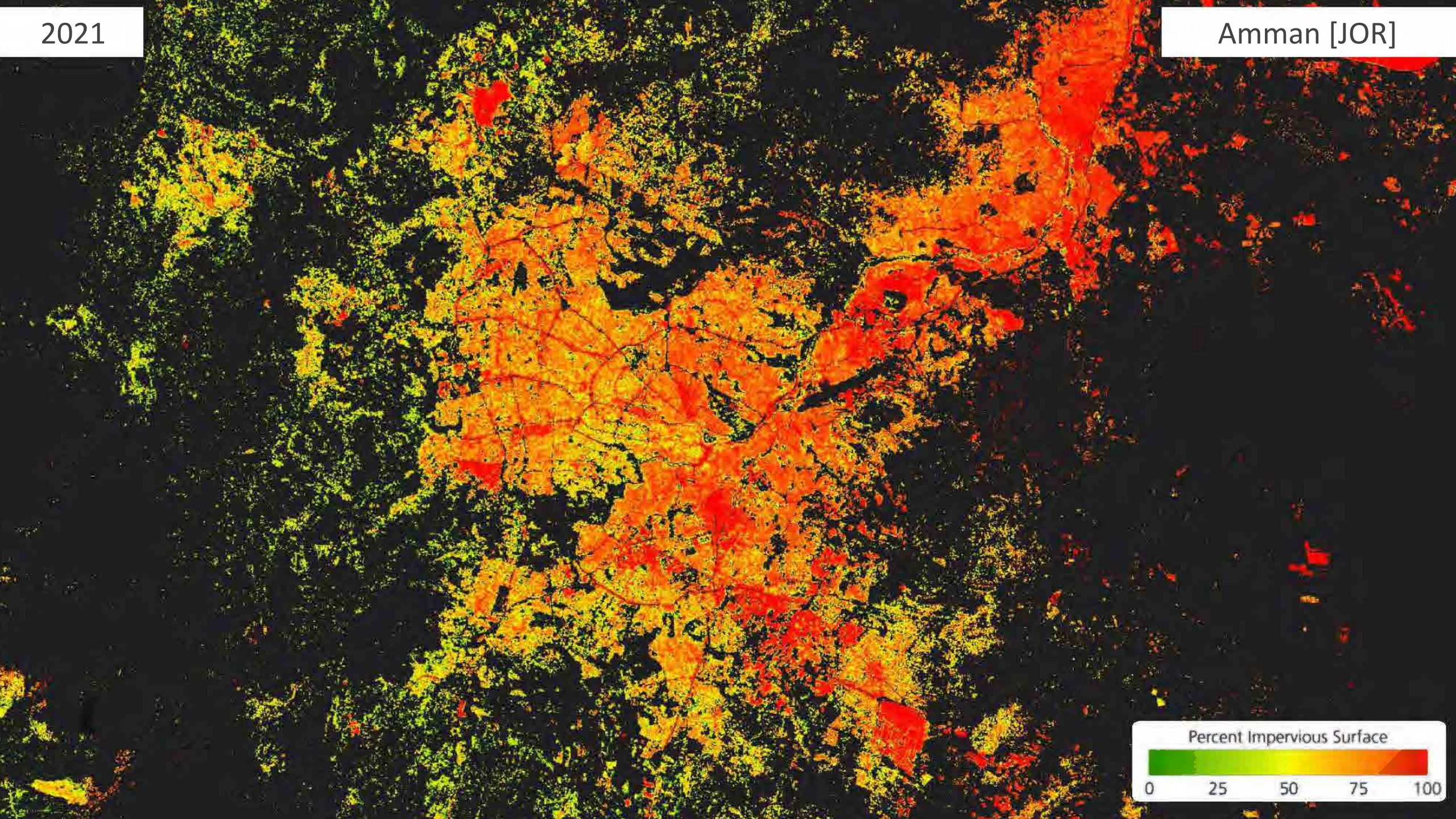
2009

Amman [JOR]



2021

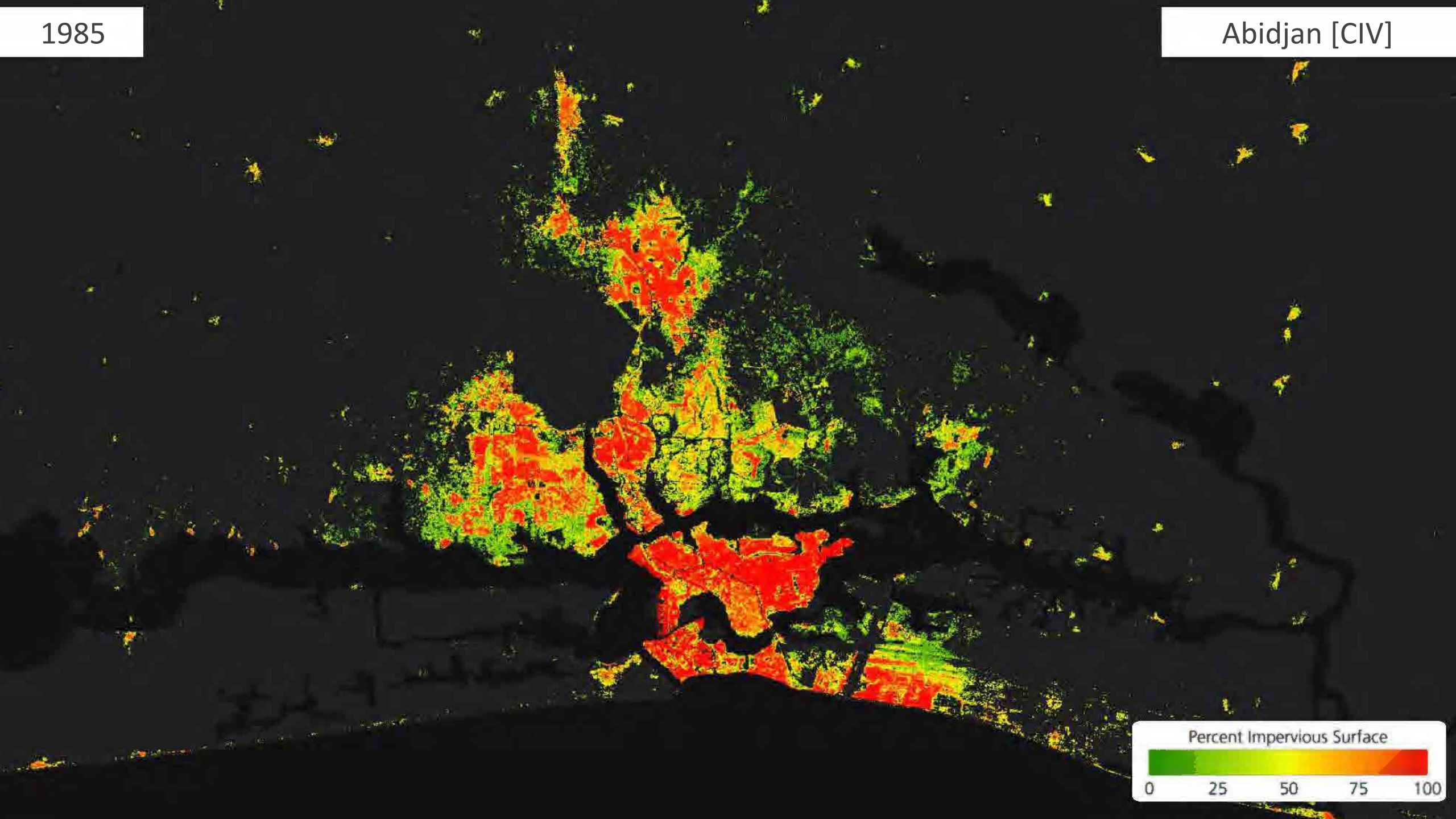
Amman [JOR]





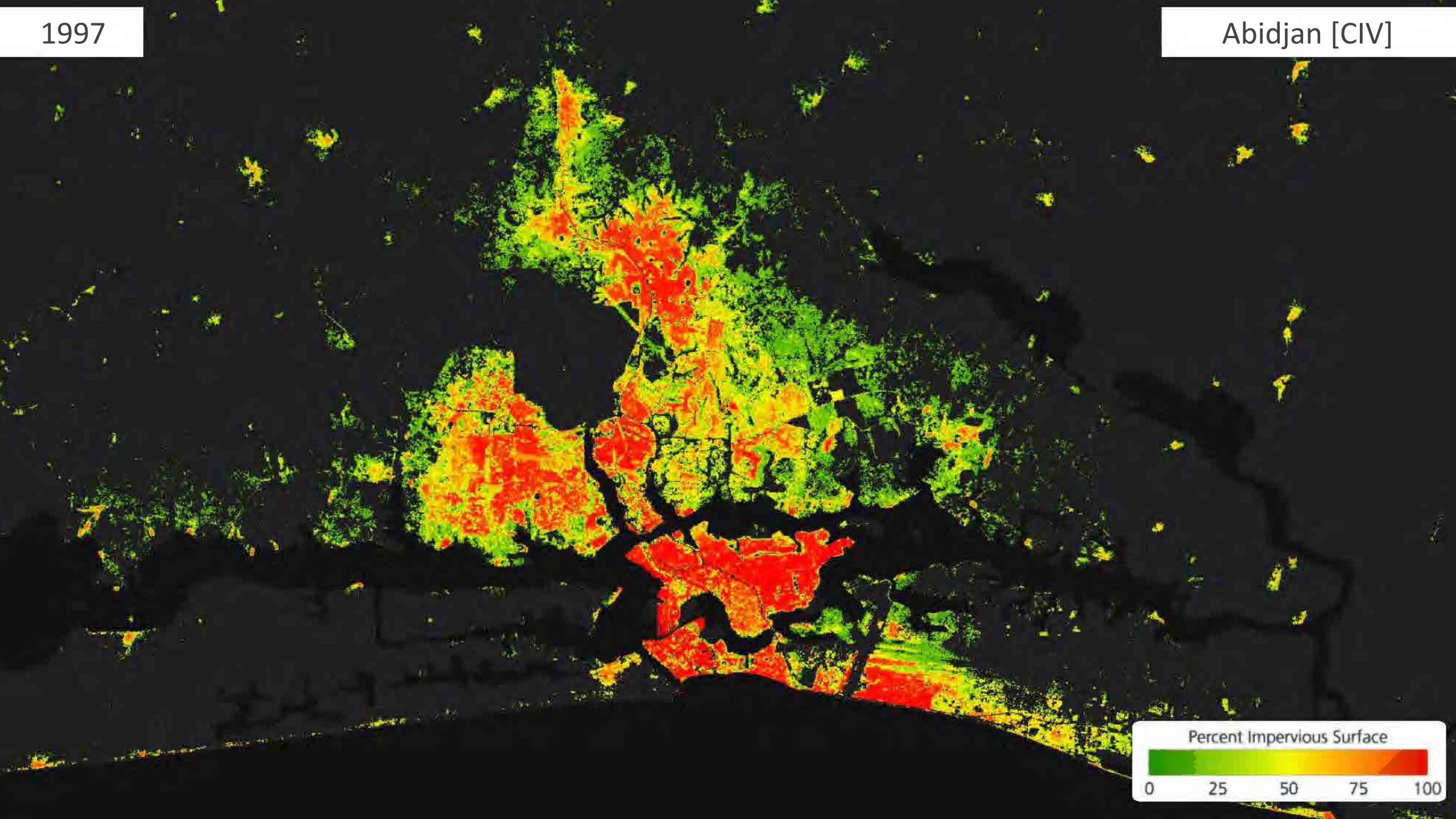
1985

Abidjan [CIV]



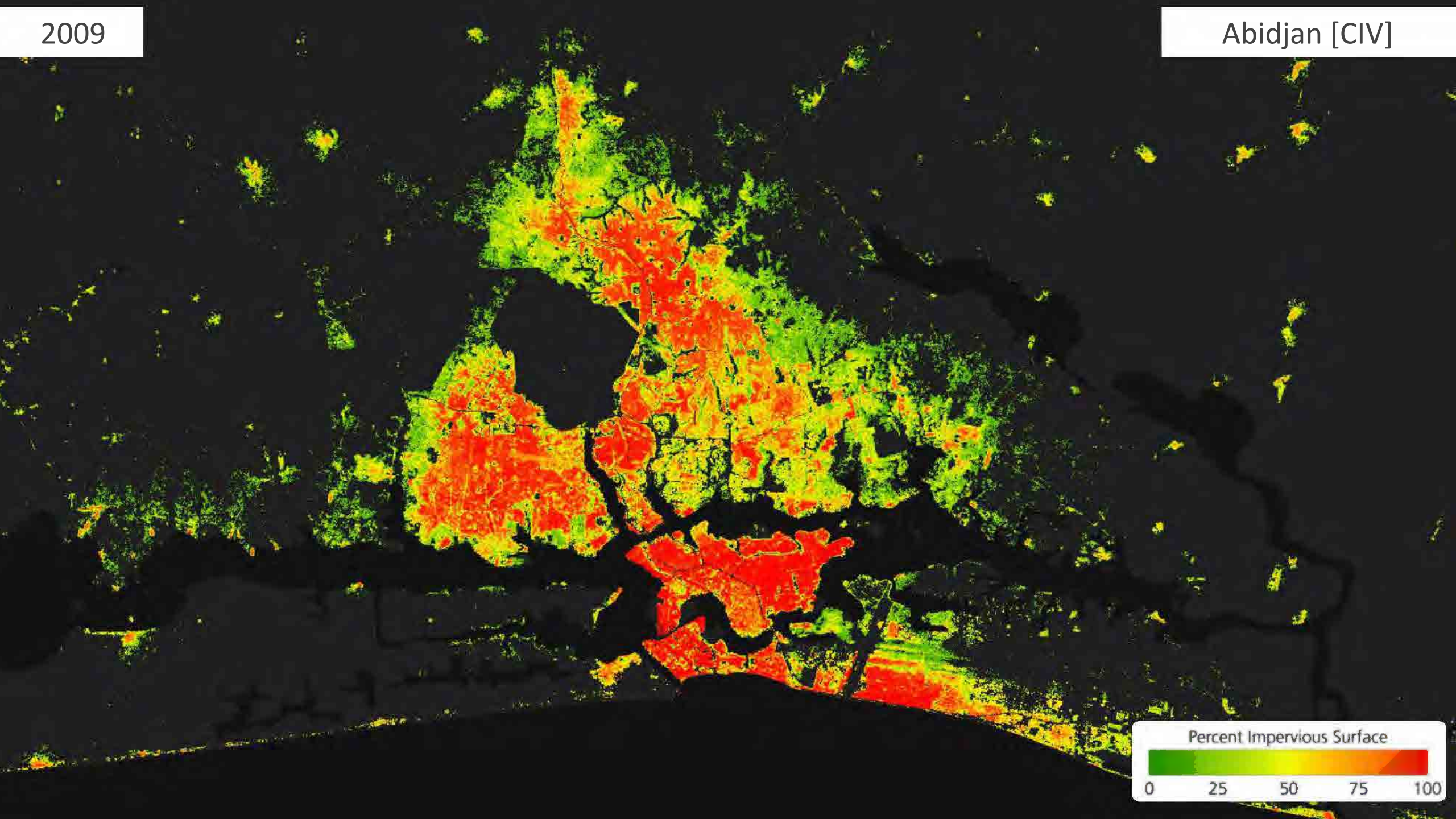
1997

Abidjan [CIV]



2009

Abidjan [CIV]

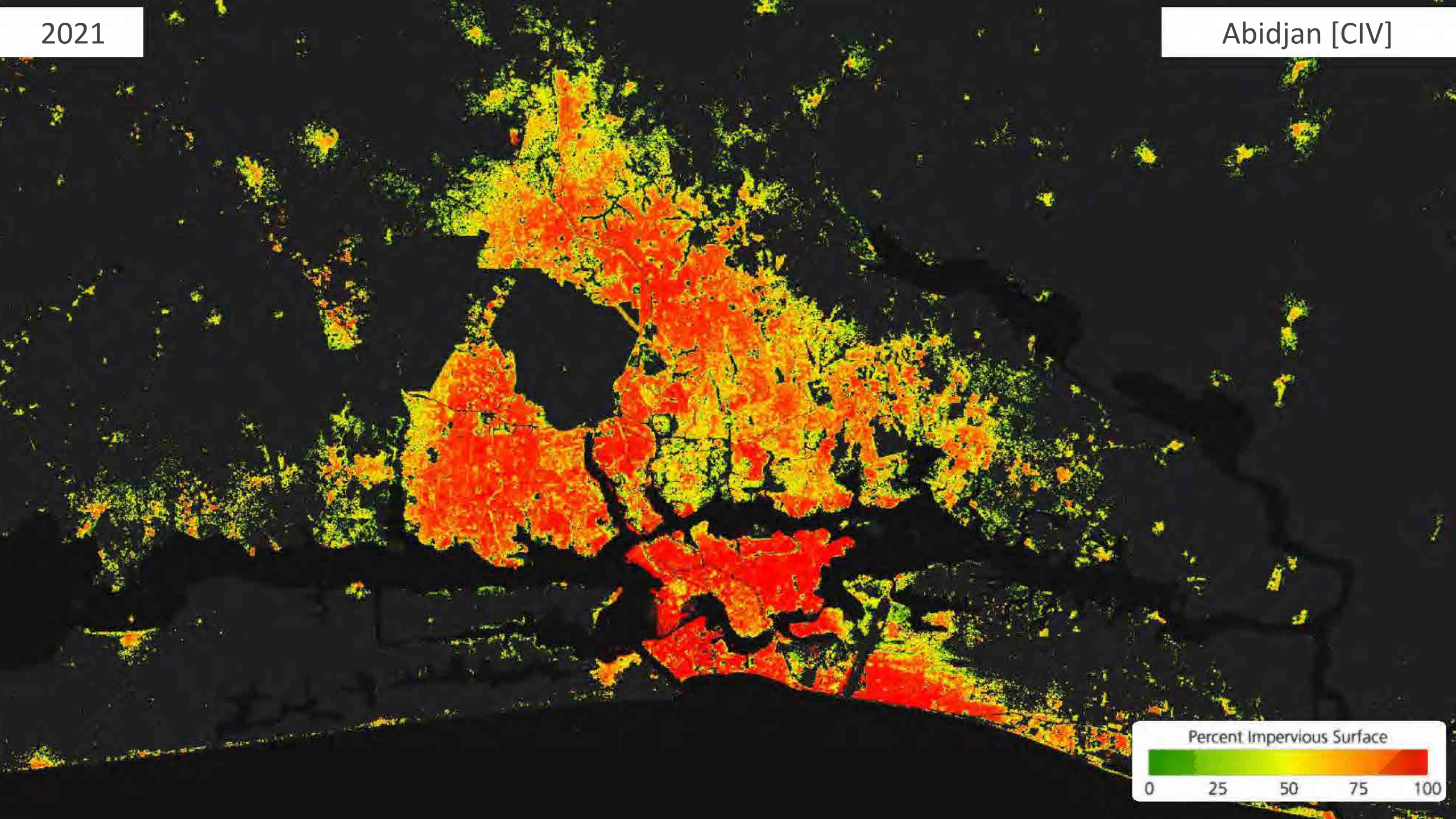


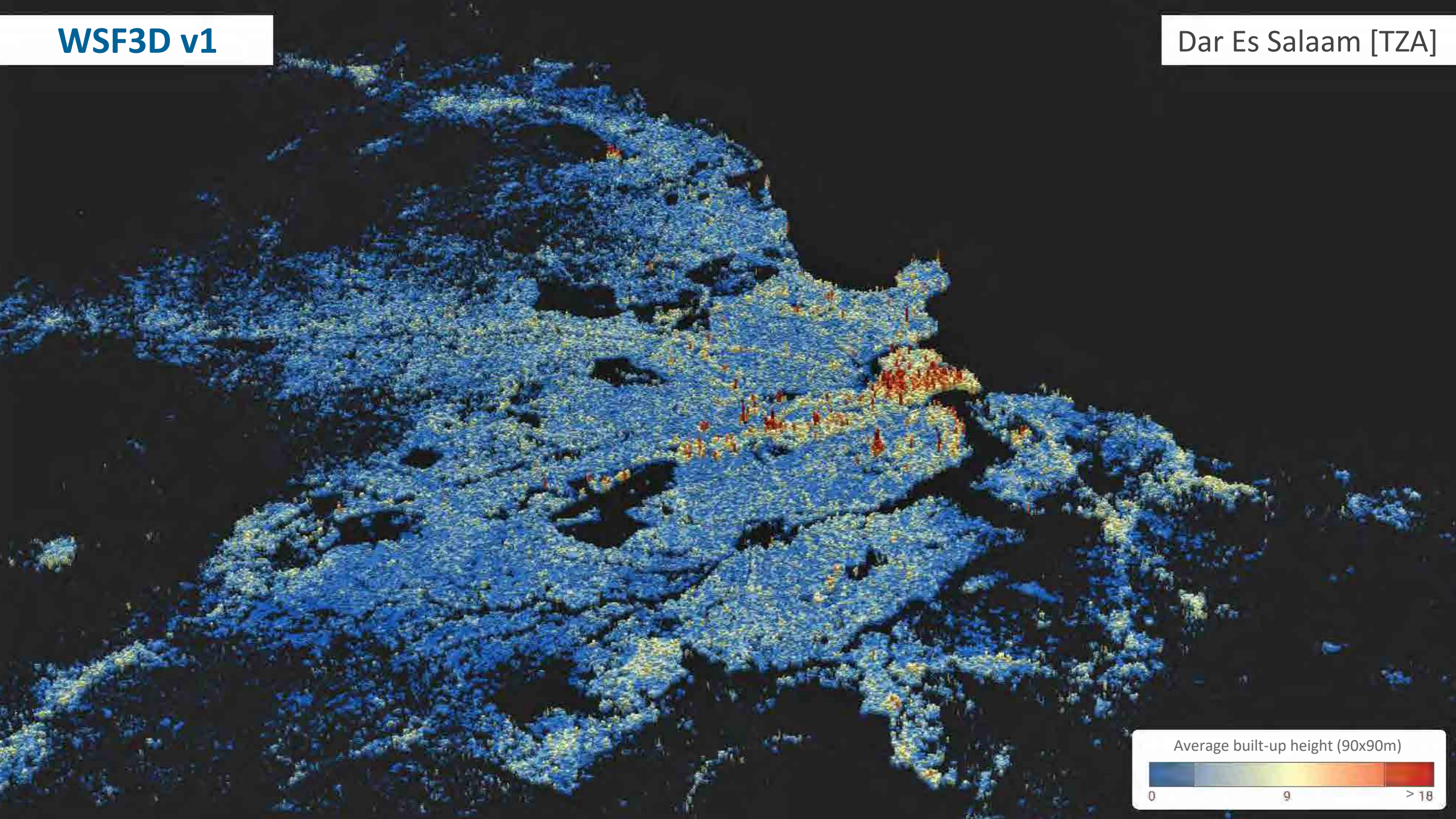
Percent Impervious Surface



2021

Abidjan [CIV]





Average built-up height (90x90m)

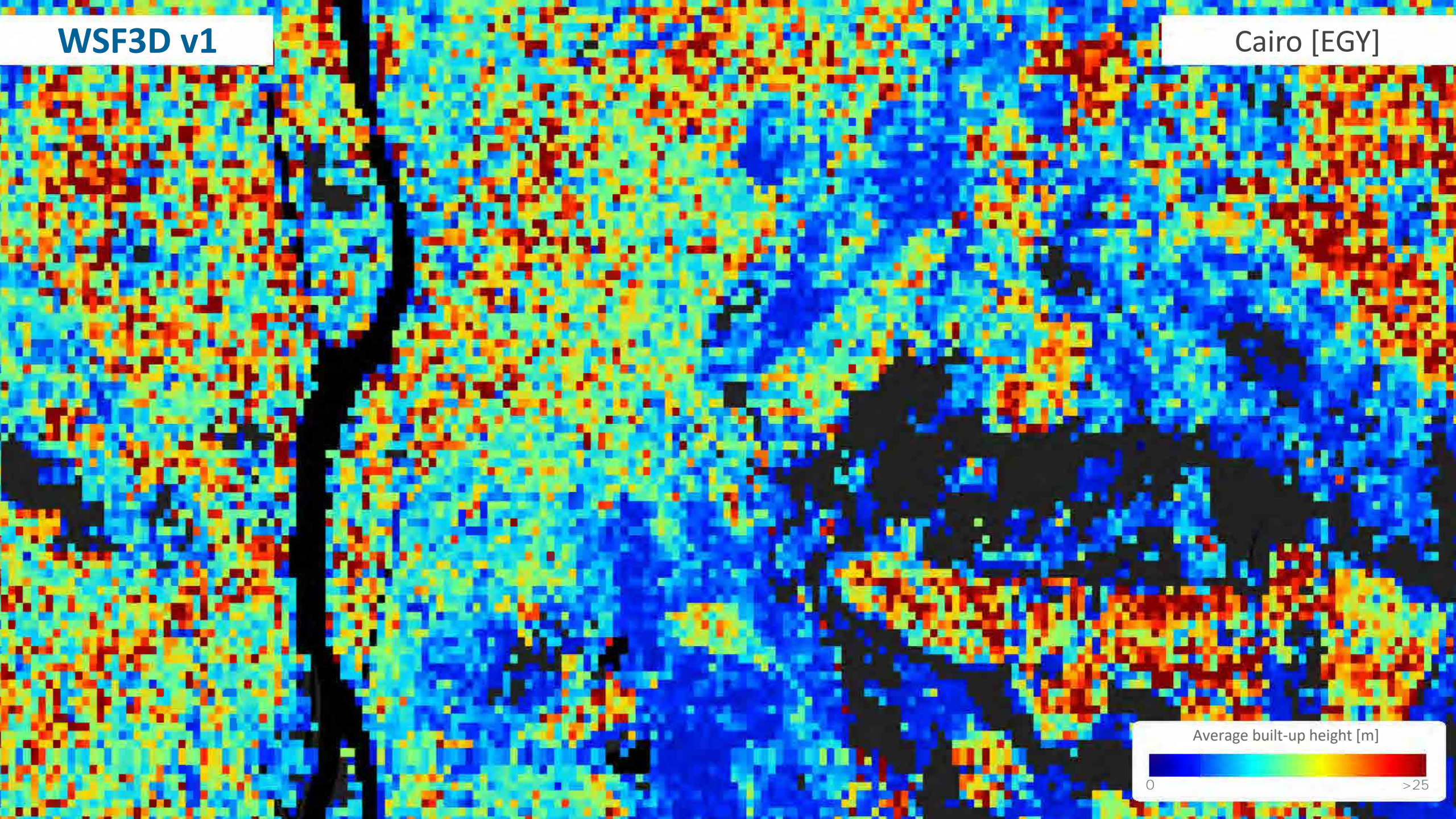


Cairo [EGY]



WSF3D v1

Cairo [EGY]

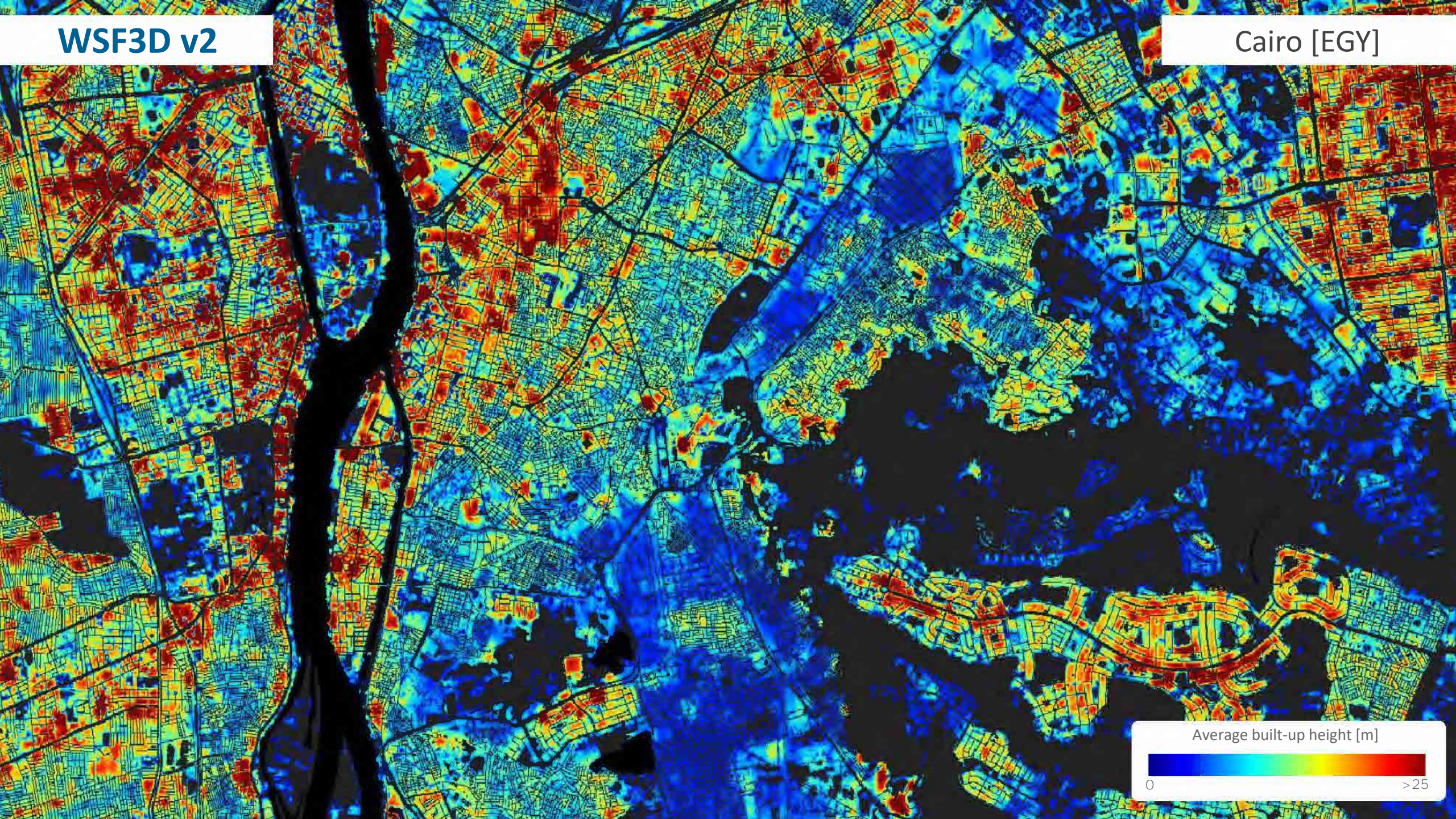


Average built-up height [m]



WSF3D v2

Cairo [EGY]



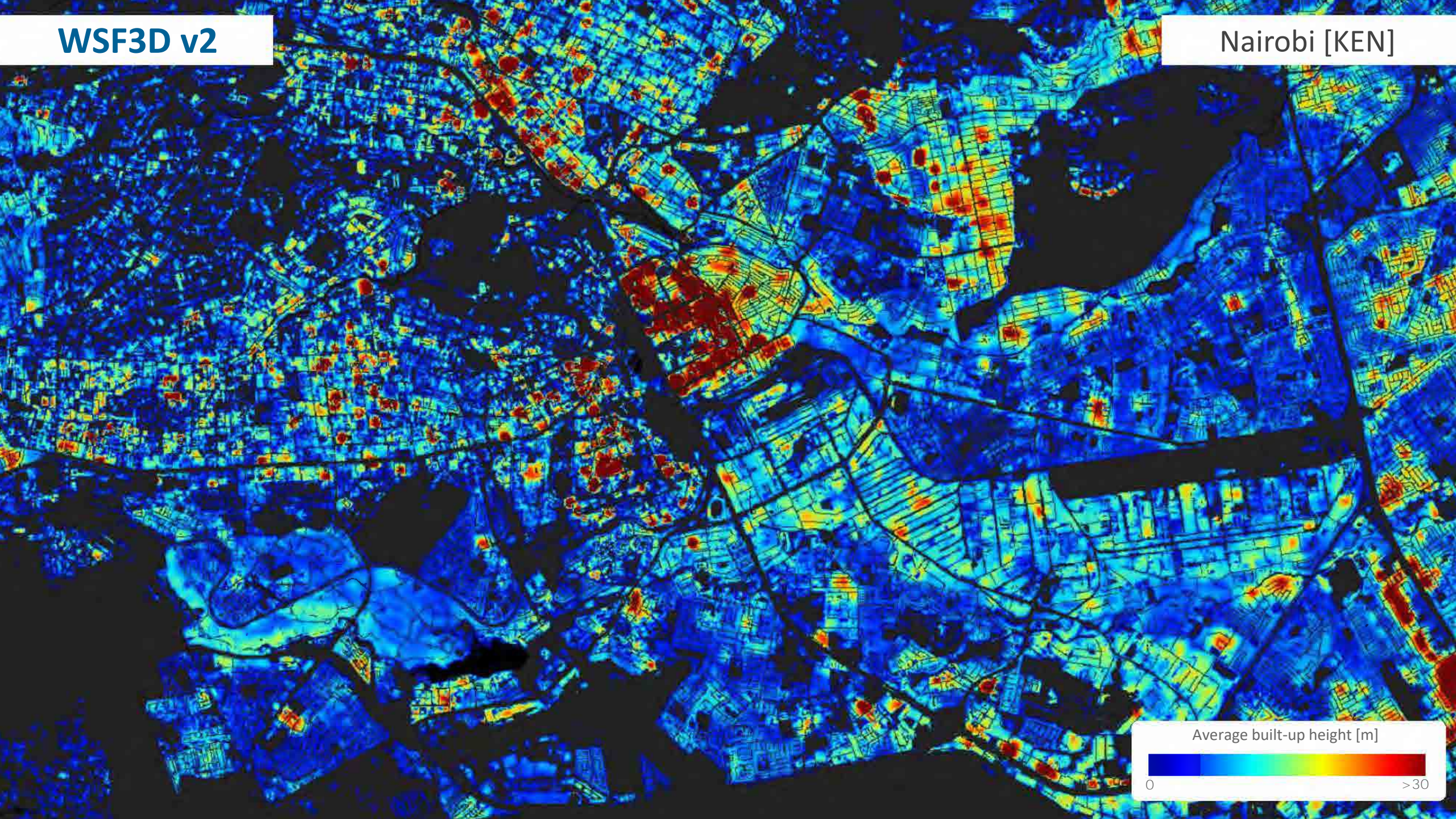
Average built-up height [m]





WSF3D v2

Nairobi [KEN]

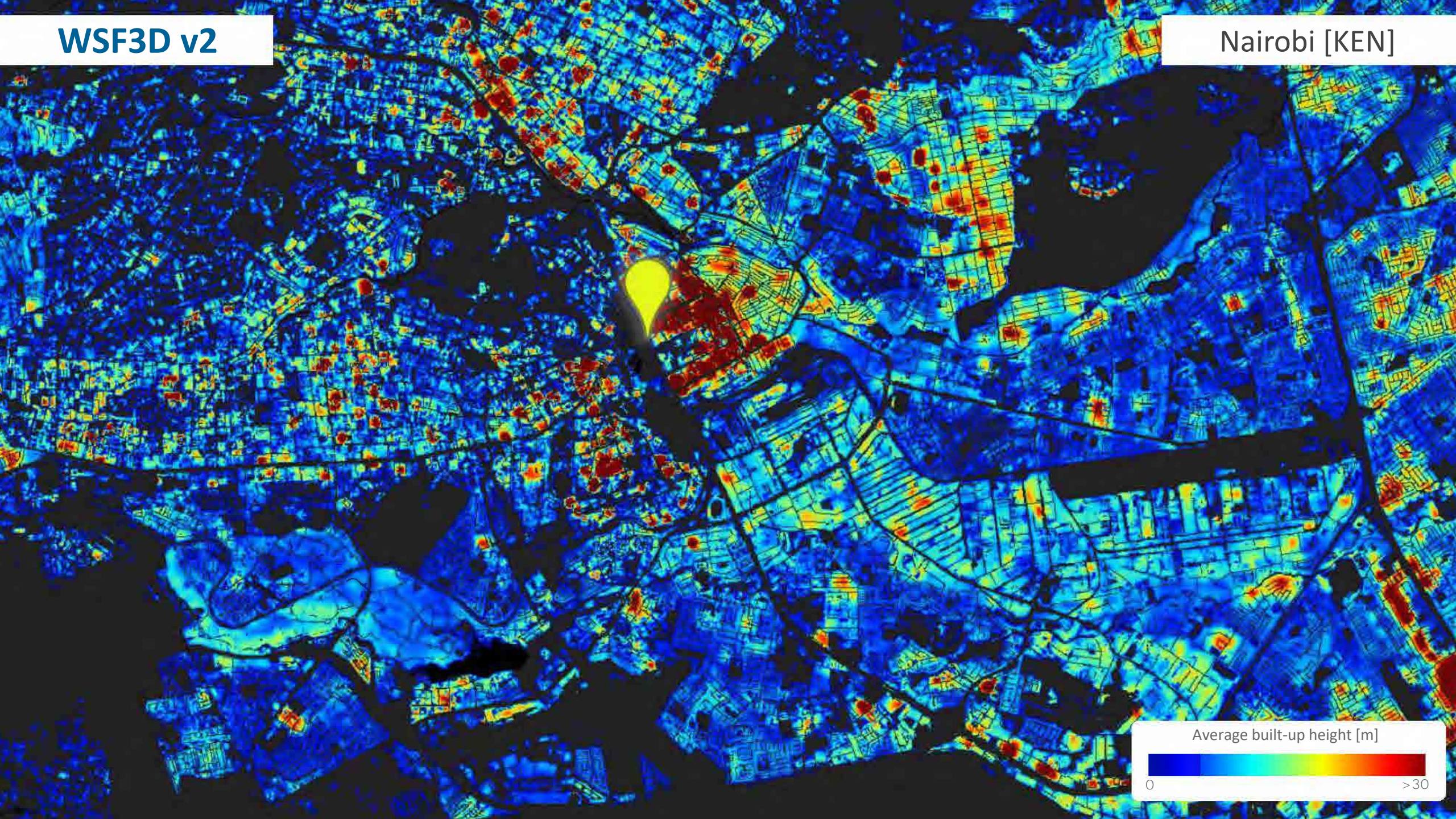


Average built-up height [m]



WSF3D v2

Nairobi [KEN]



Average built-up height [m]





Nairobi Expy

Nairobi, Nairobi County

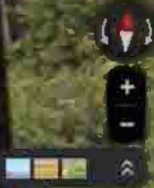
Google Street View

May 2022

See more dates

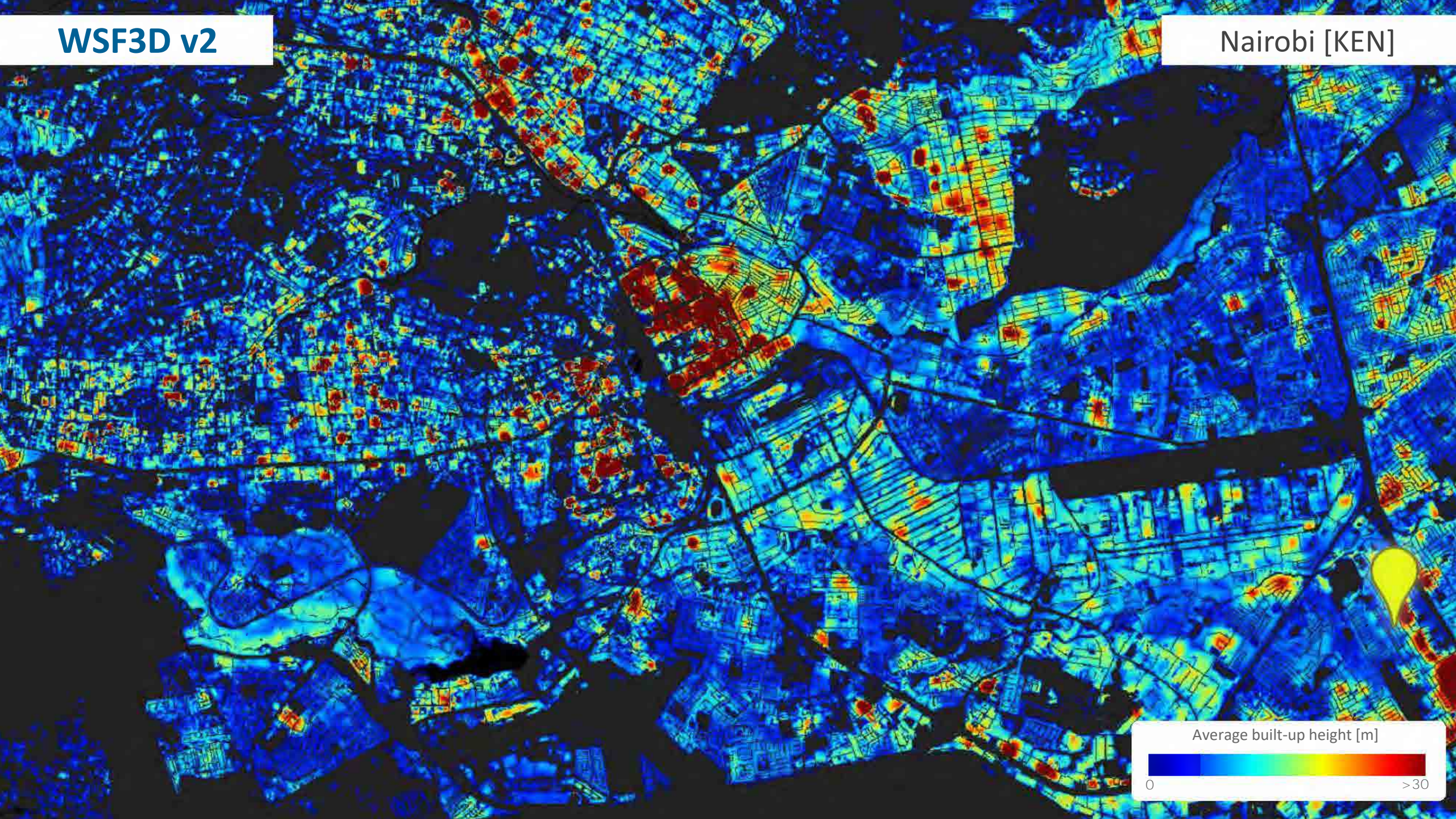


Street View Photo Path Photo Sphere  
Click highlighted areas to see images Learn more



WSF3D v2

Nairobi [KEN]



Average built-up height [m]





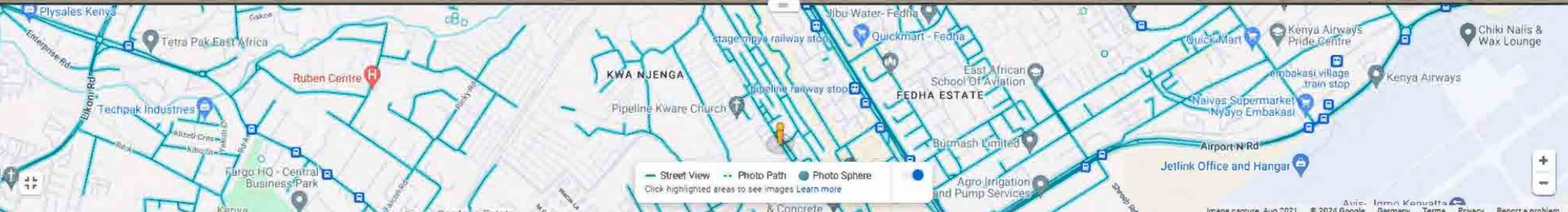
Nairobi, Nairobi County



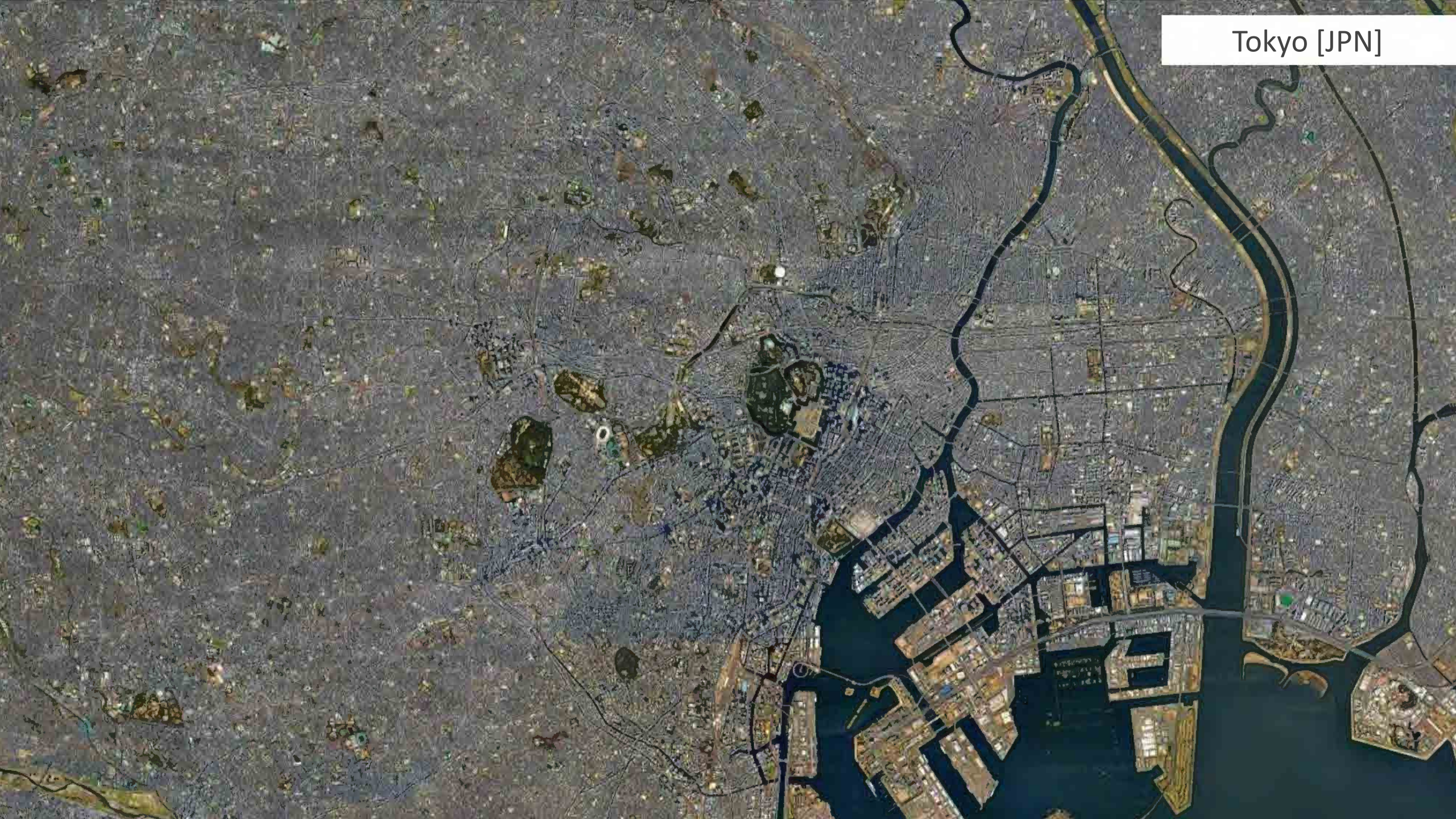
Google Street View

Aug 2021

See more dates

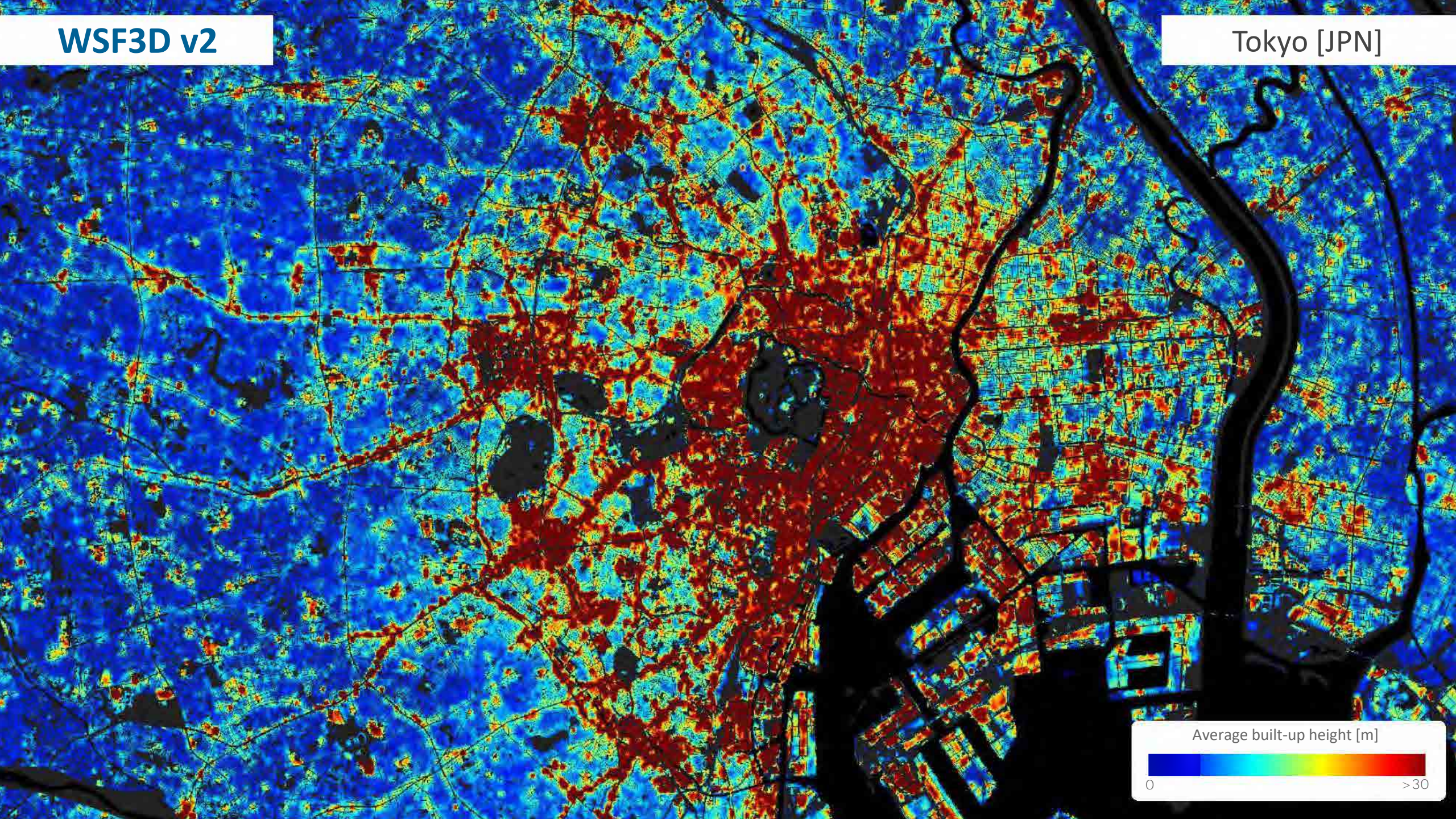


Tokyo [JPN]



WSF3D v2

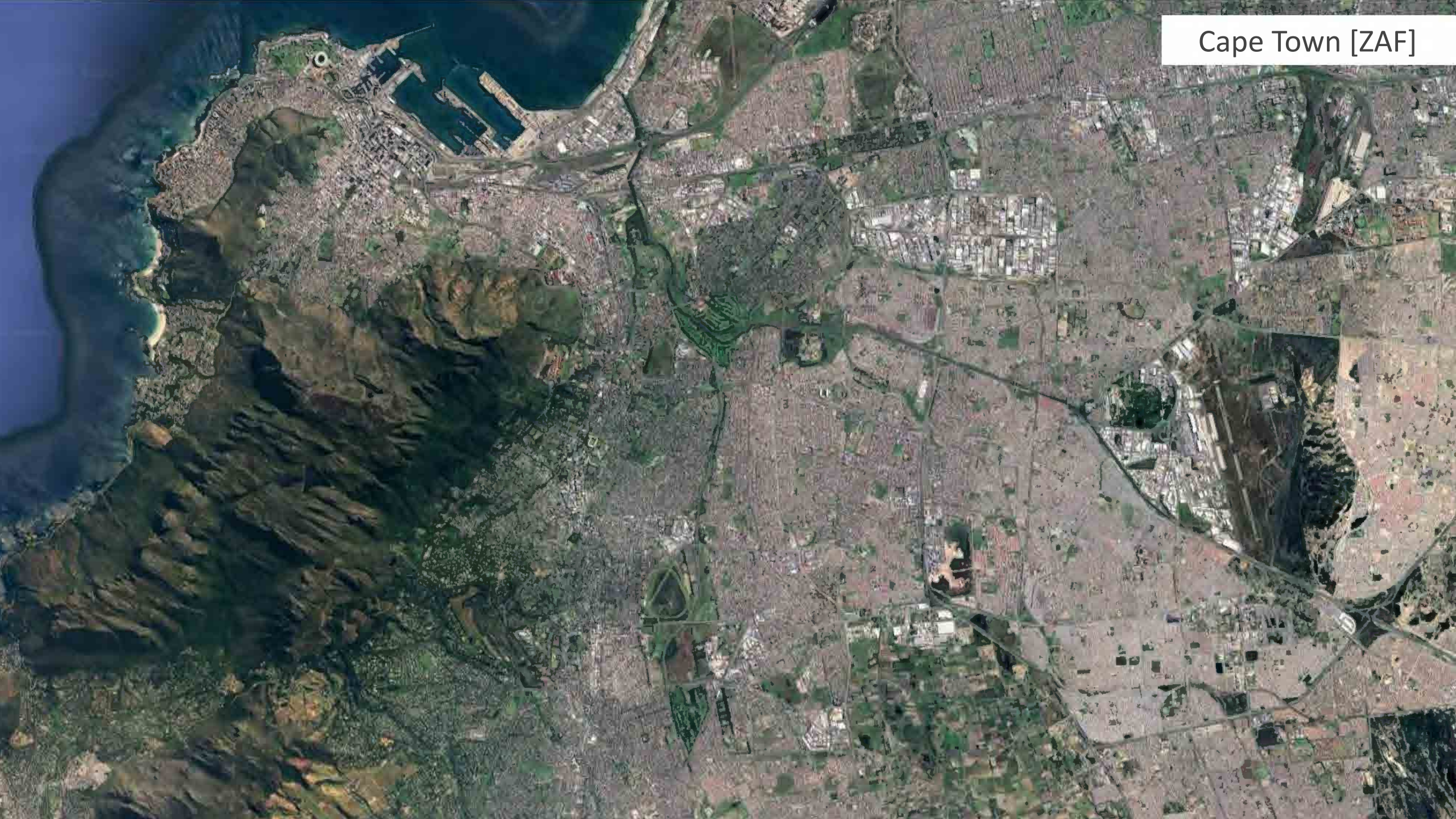
Tokyo [JPN]



Average built-up height [m]



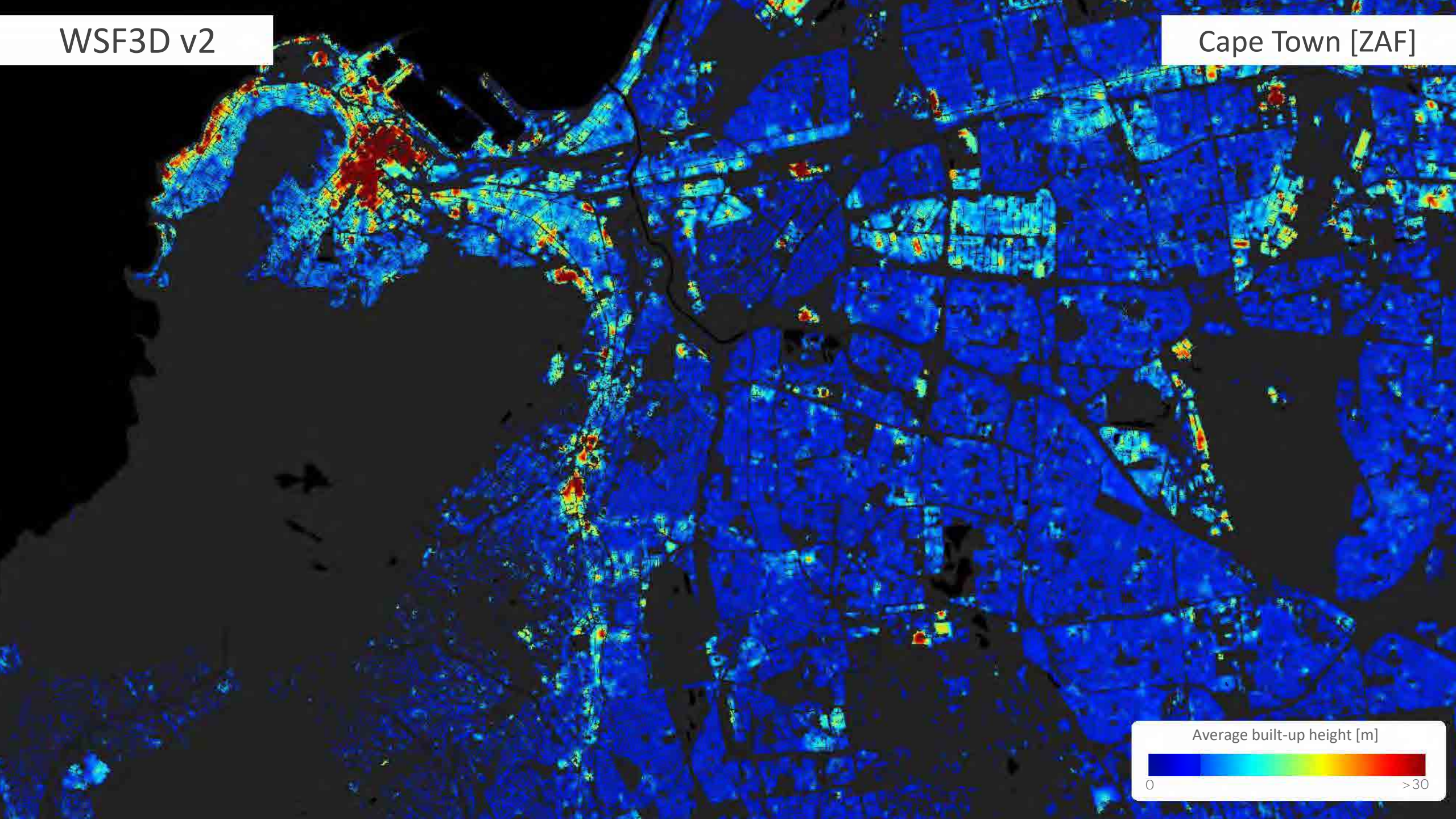
Cape Town [ZAF]



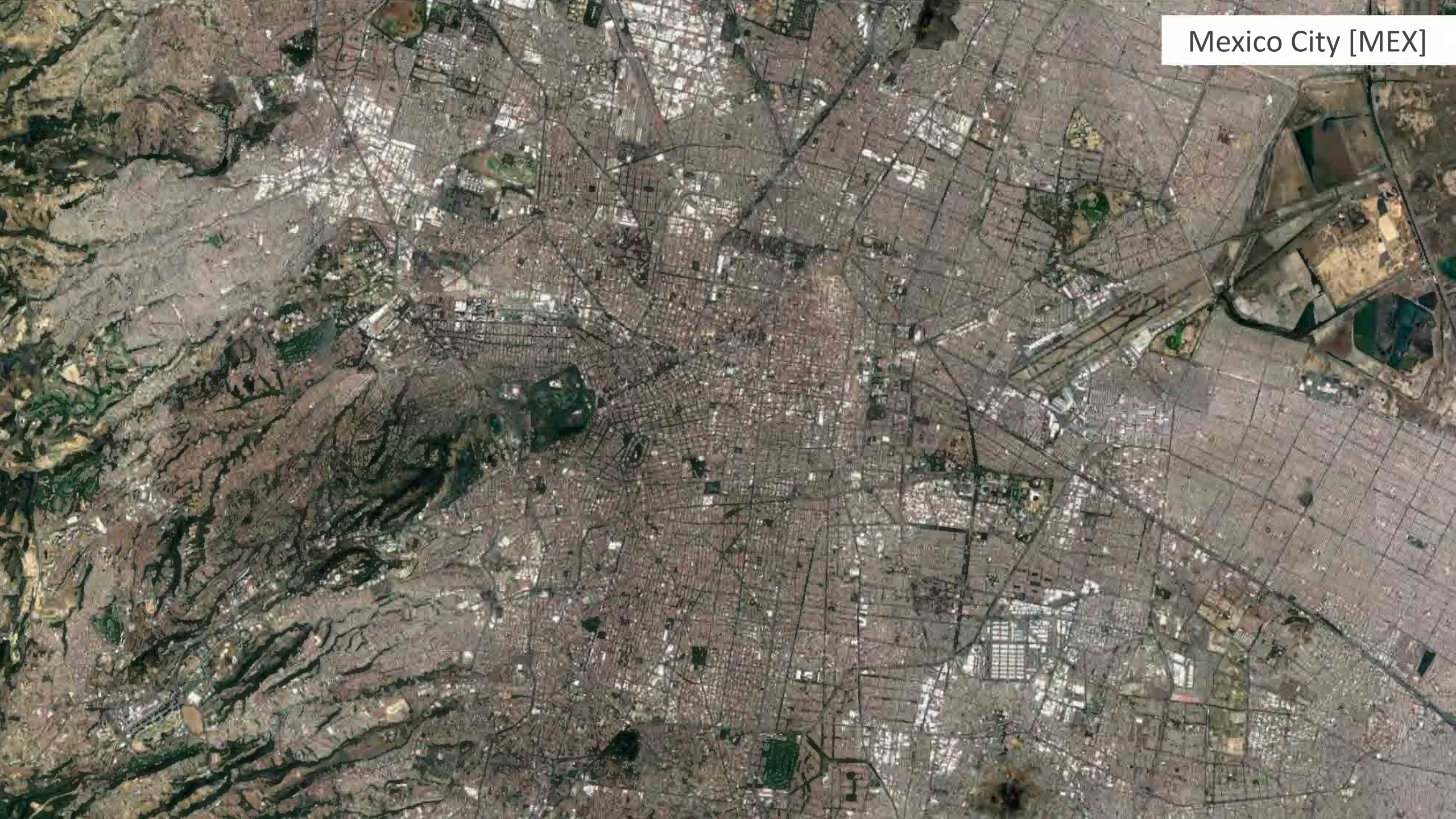


WSF3D v2

Cape Town [ZAF]

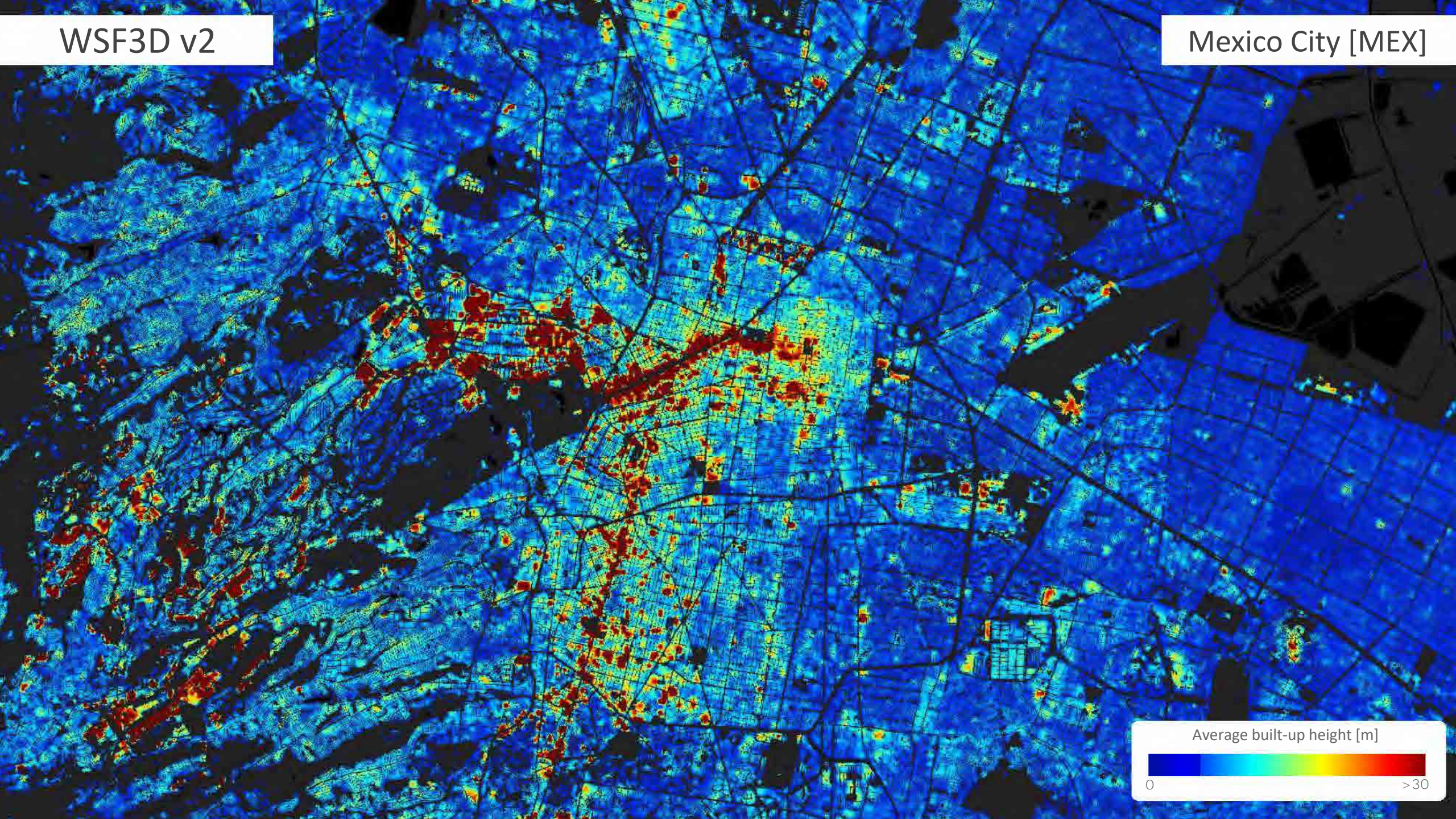


Mexico City [MEX]



WSF3D v2

Mexico City [MEX]



Average built-up height [m]

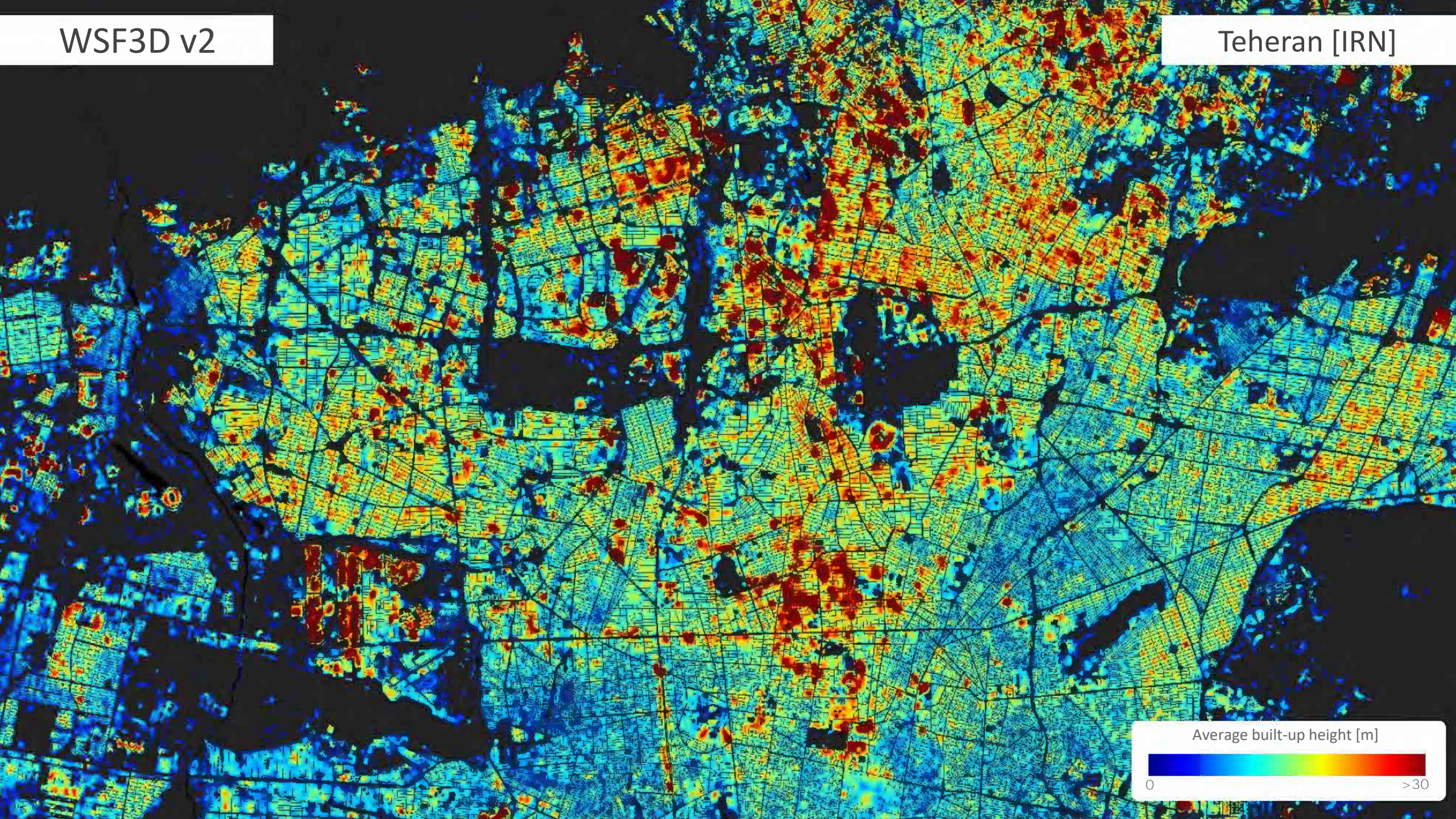


Teheran [IRN]



WSF3D v2

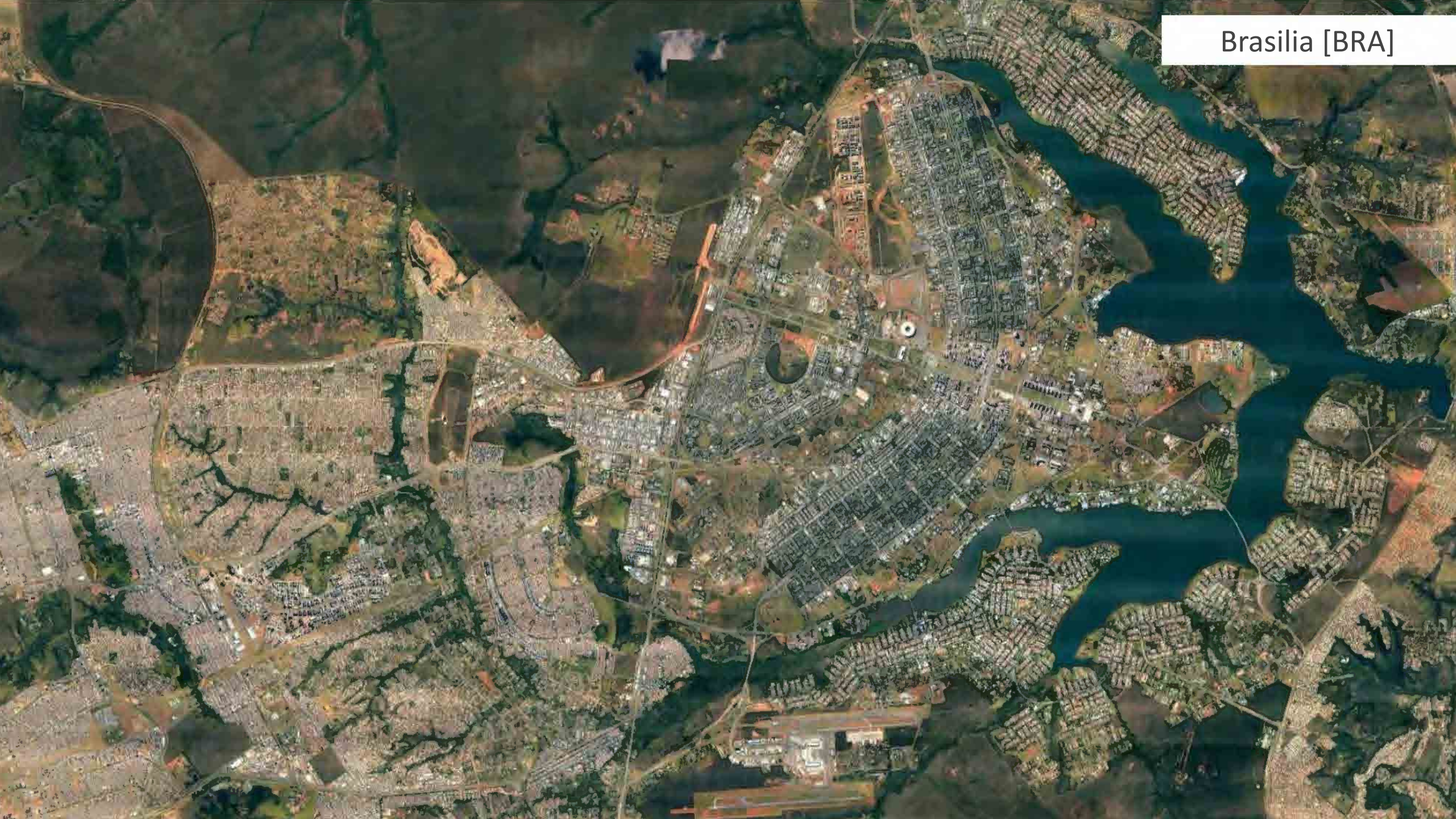
Teheran [IRN]



Average built-up height [m]

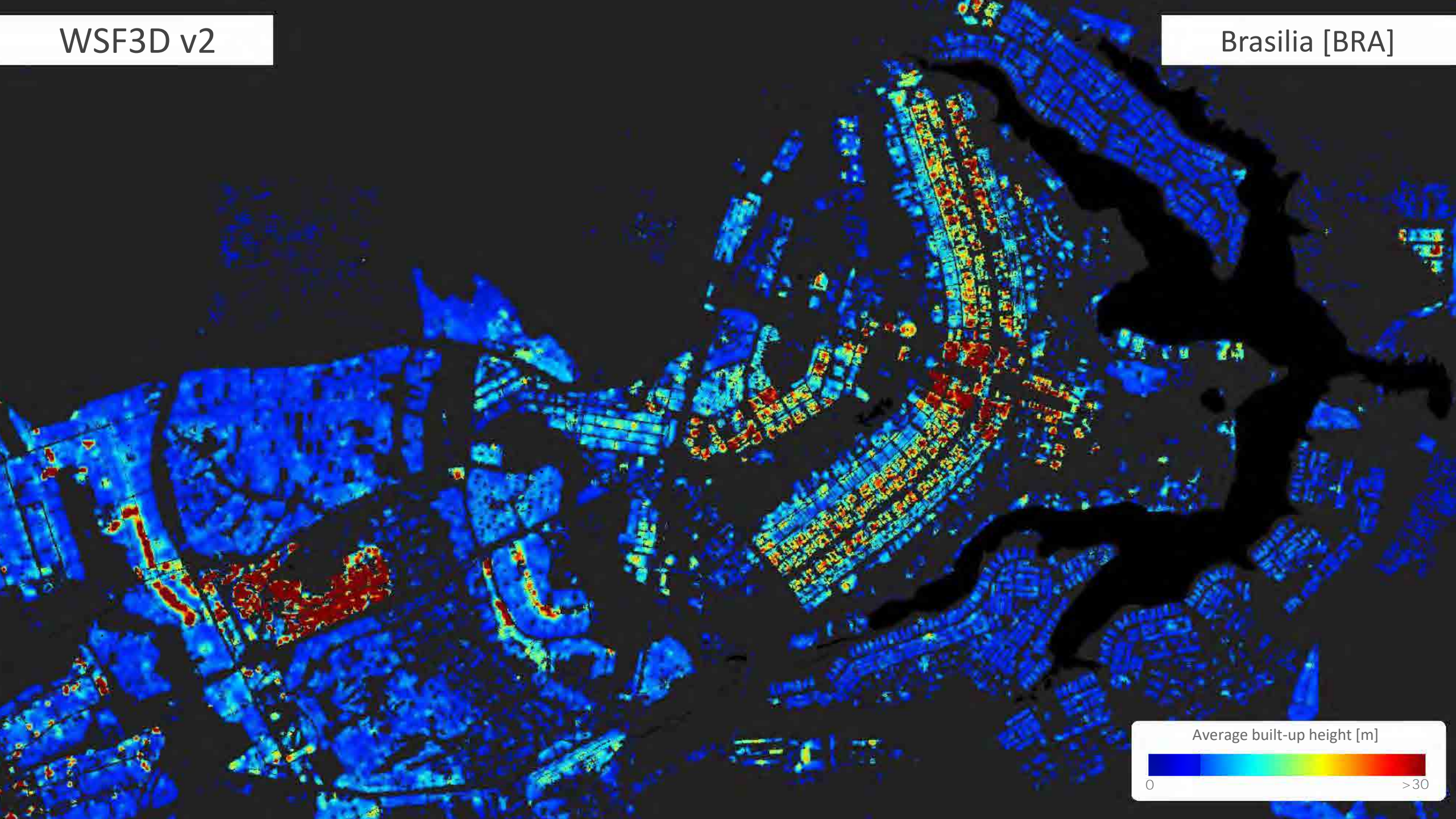


Brasilia [BRA]



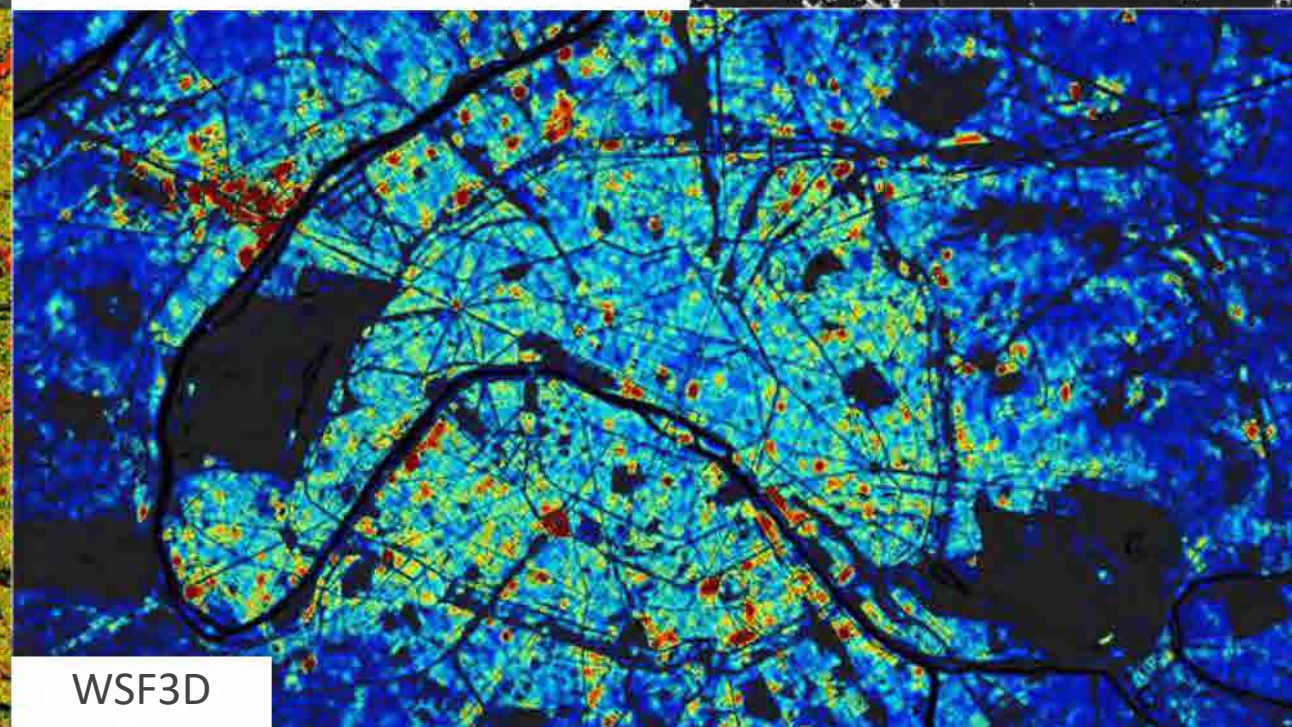
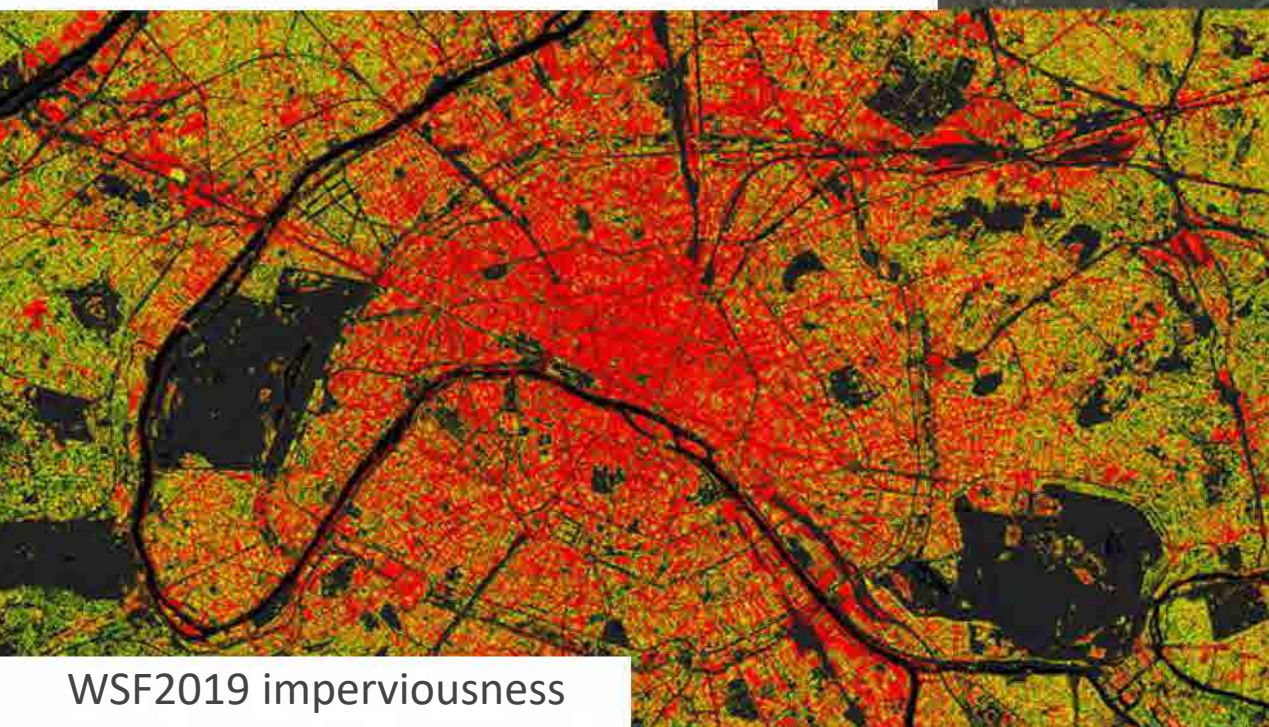
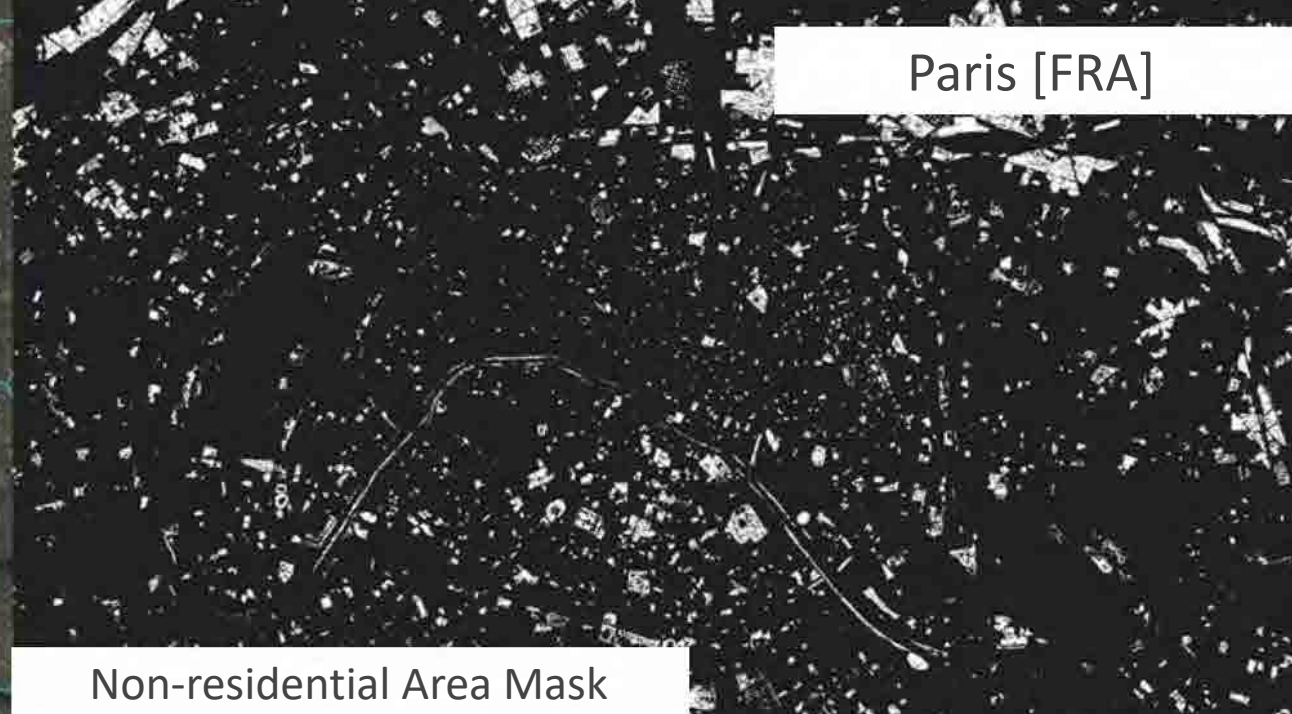
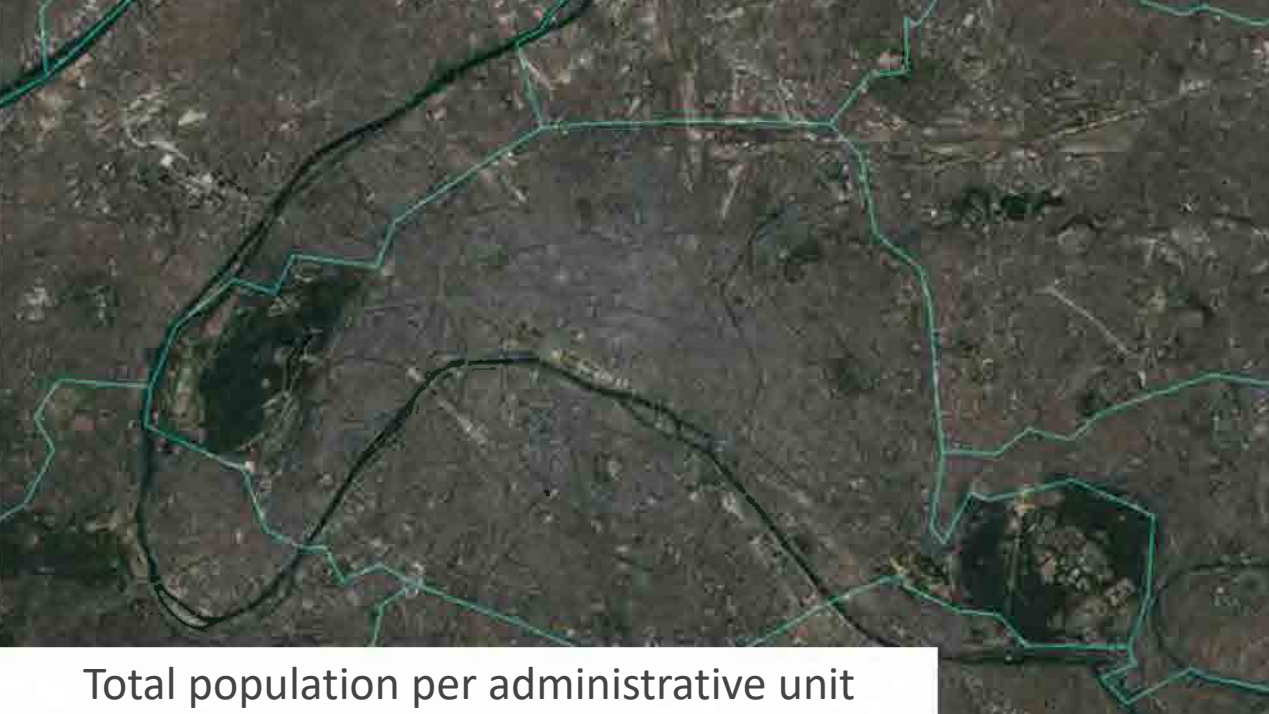
WSF3D v2

Brasilia [BRA]



Average built-up height [m]

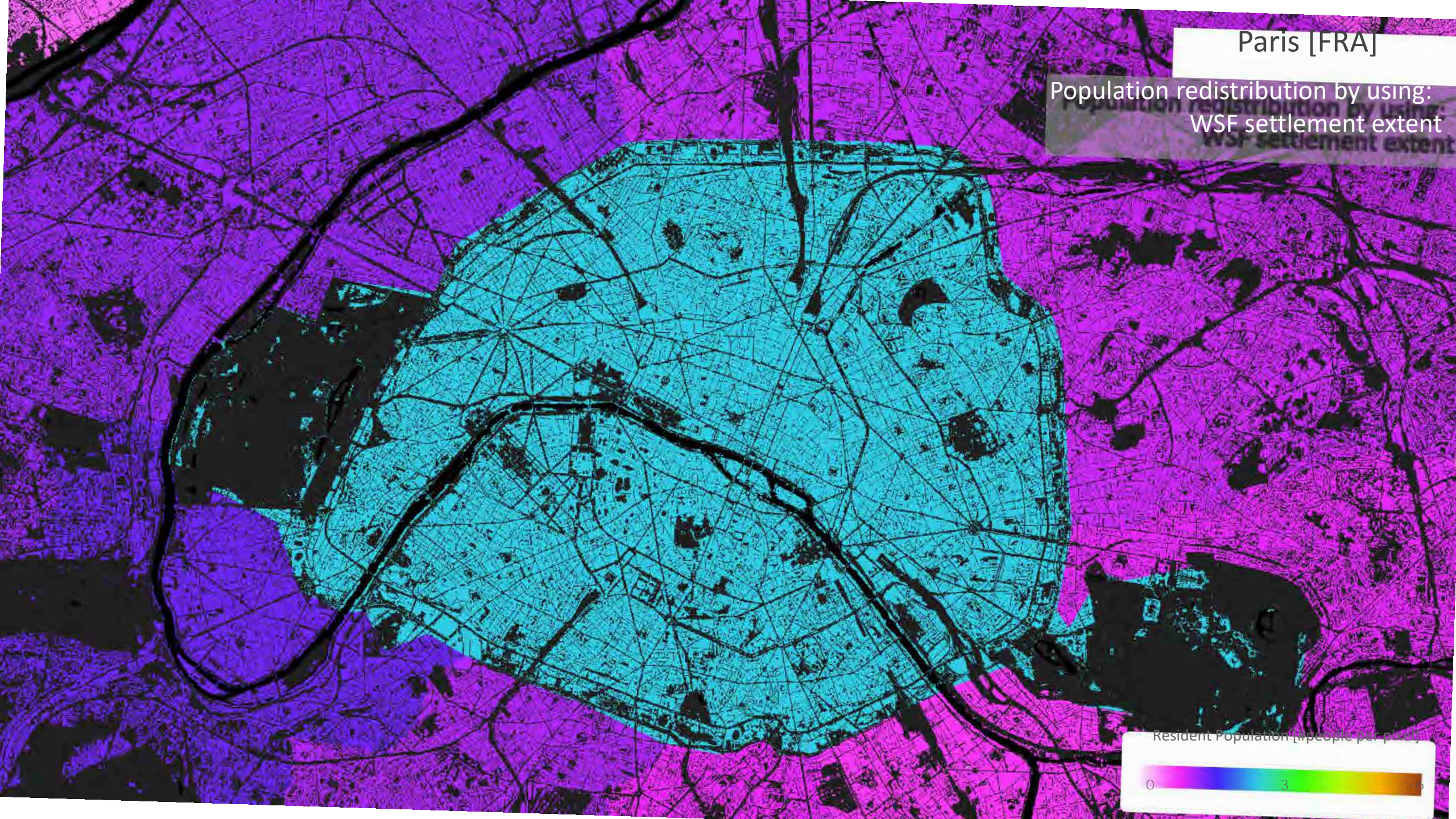






Paris [FRA]

Population redistribution by using:  
WSF settlement extent



# Paris [FRA]

Population redistribution by using:  
WSF settlement extent +  
ancillary building use mask



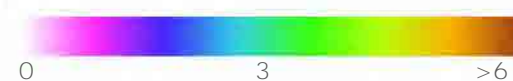
Resident Population [#people per pixel]

0 3 >6

## Paris [FRA]

Population redistribution by using:  
WSF imperviousness +  
ancillary building use mask

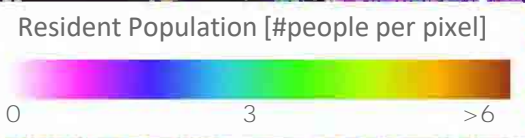
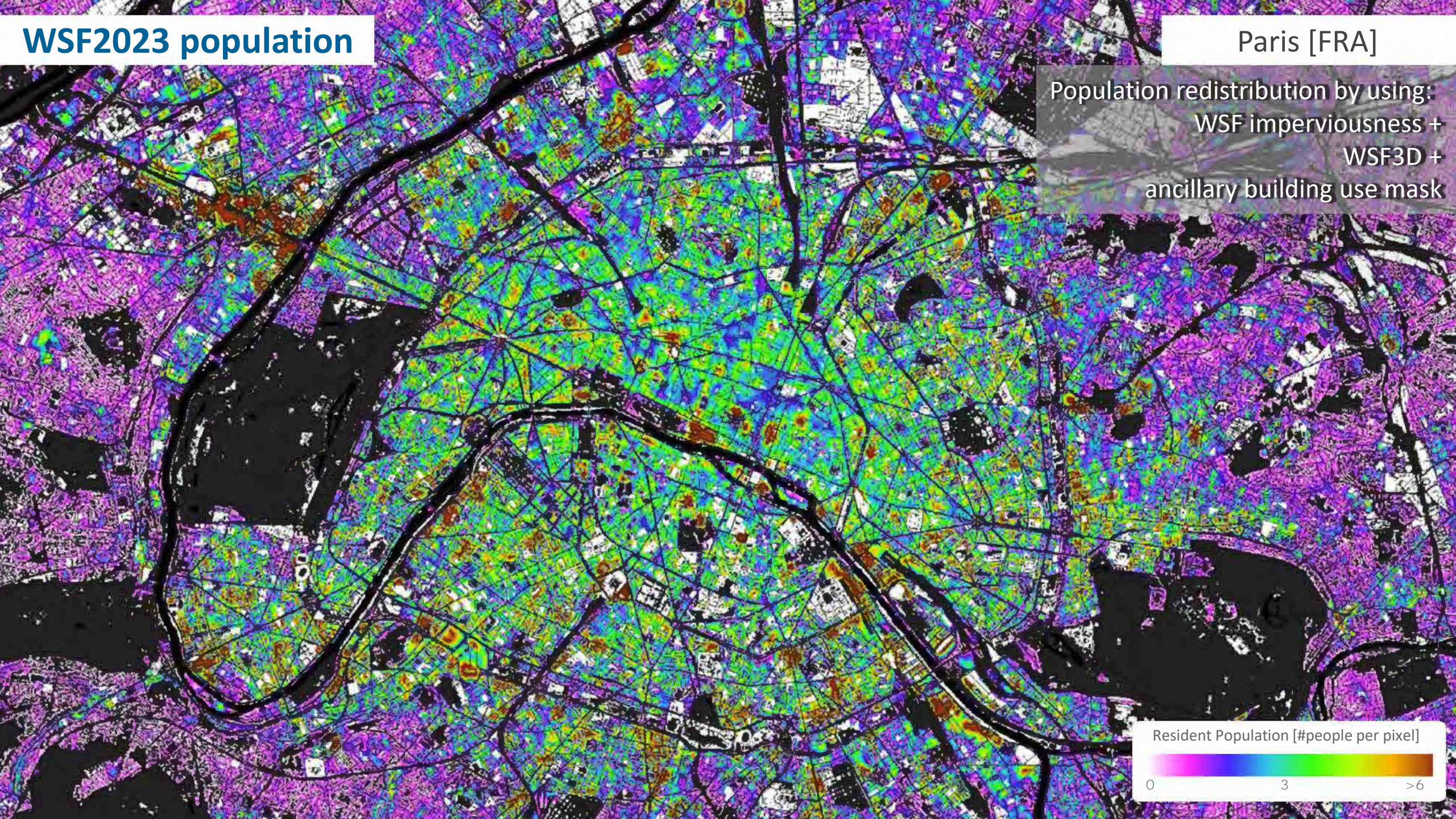
Resident Population [#people per pixel]



# WSF2023 population

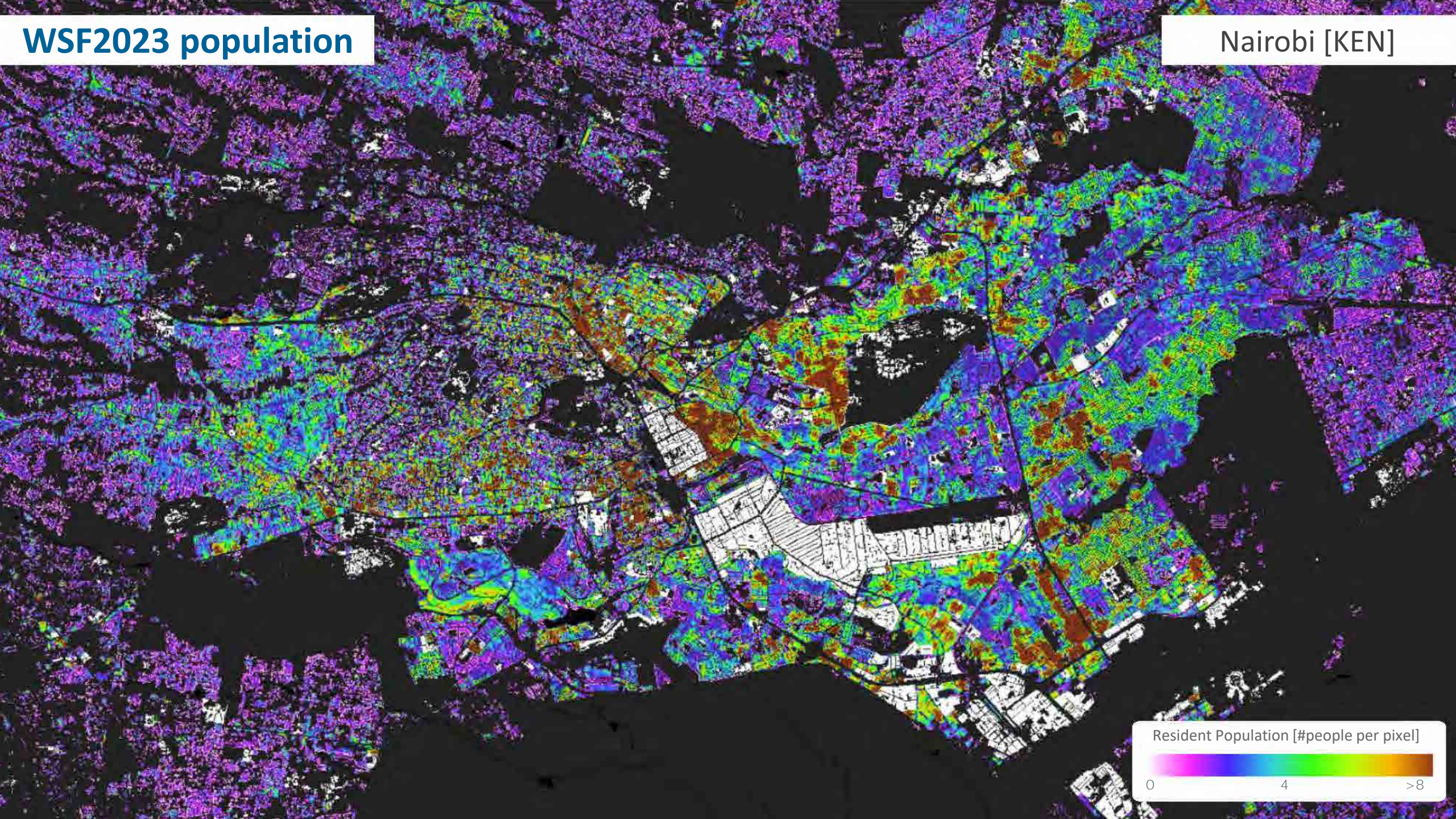
Paris [FRA]

Population redistribution by using:  
WSF imperviousness +  
WSF3D +  
ancillary building use mask



WSF2023 population

Nairobi [KEN]

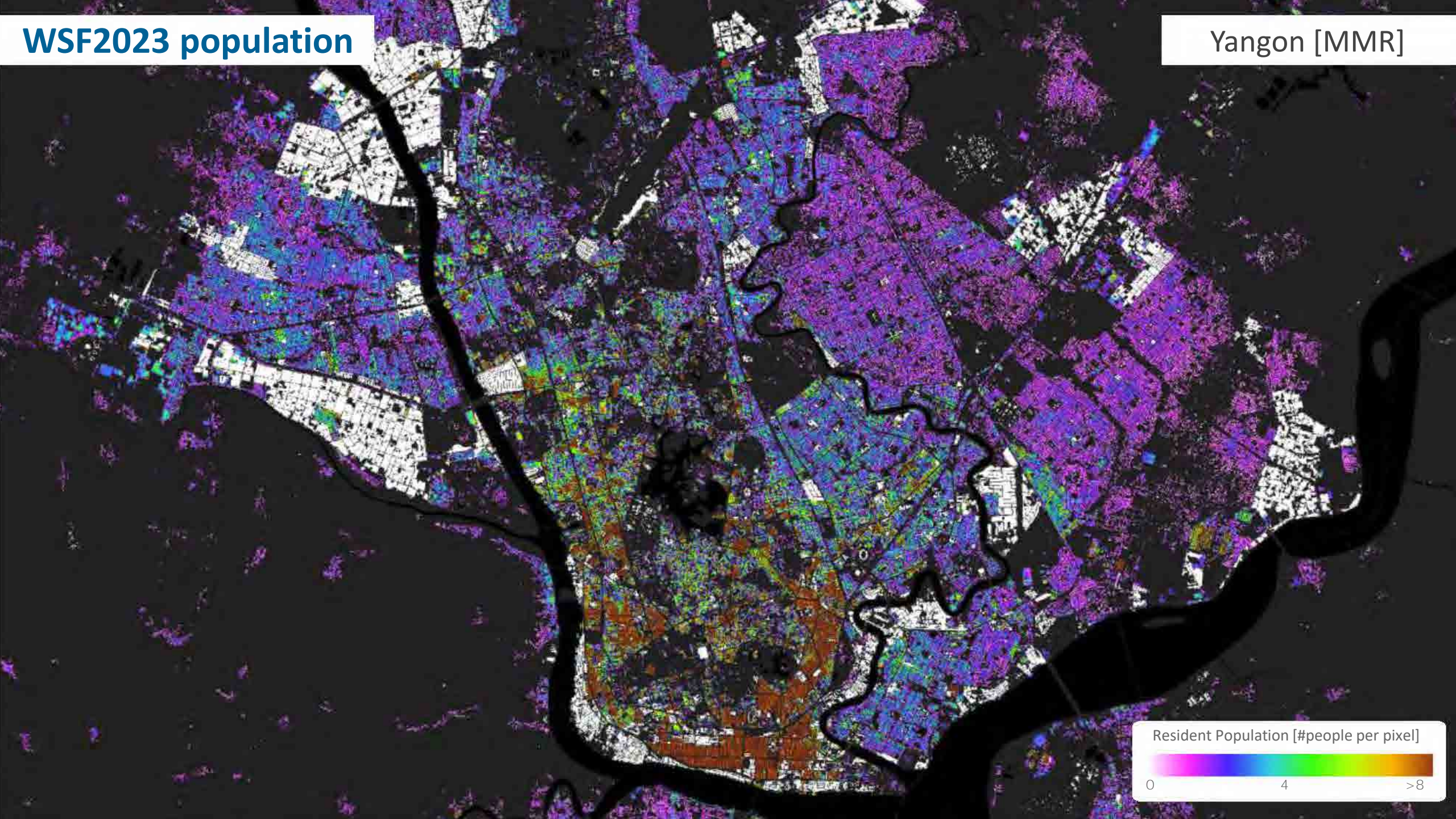


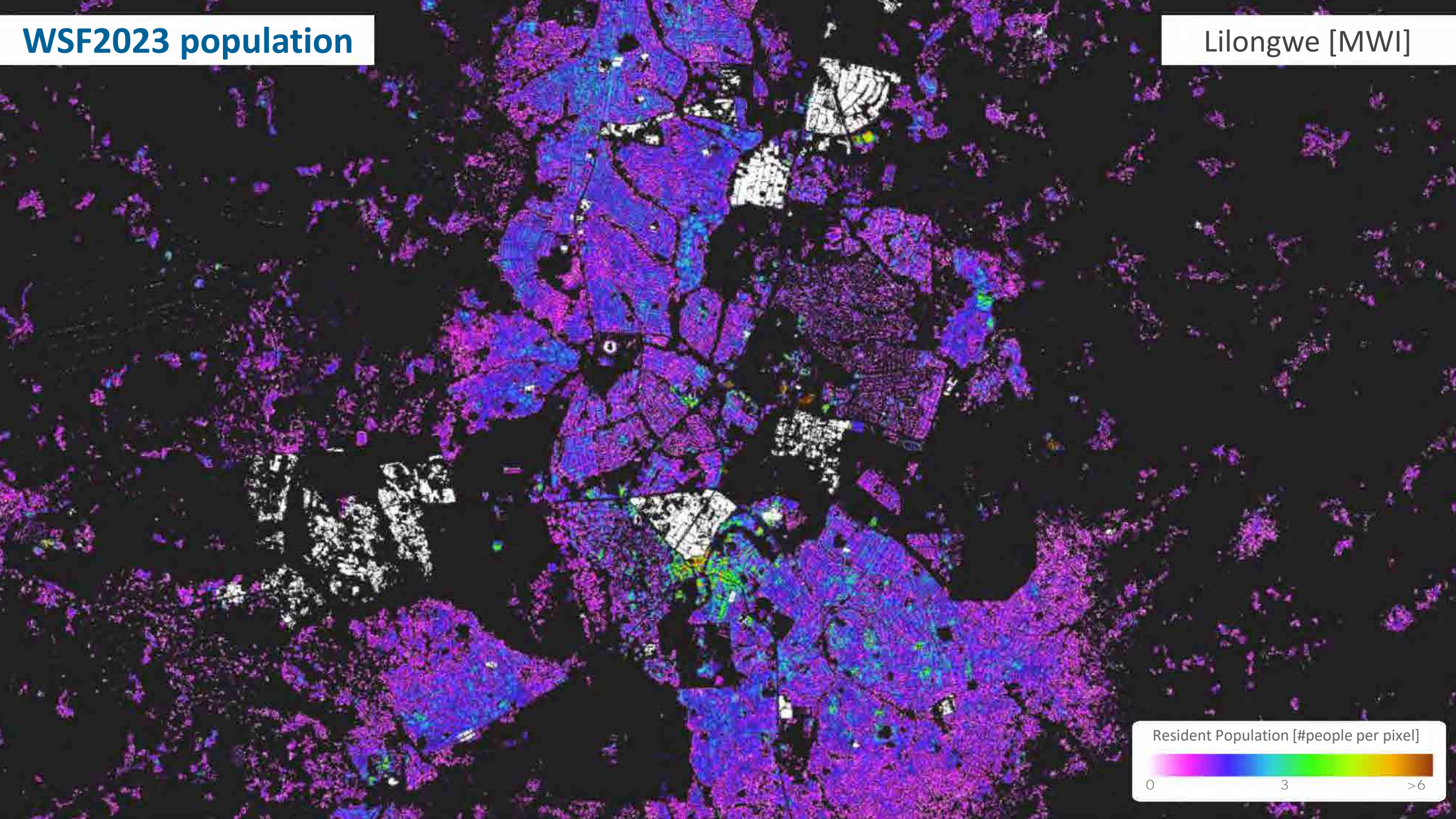
Resident Population [#people per pixel]

0 4 >8

WSF2023 population

Yangon [MMR]





Resident Population [#people per pixel]



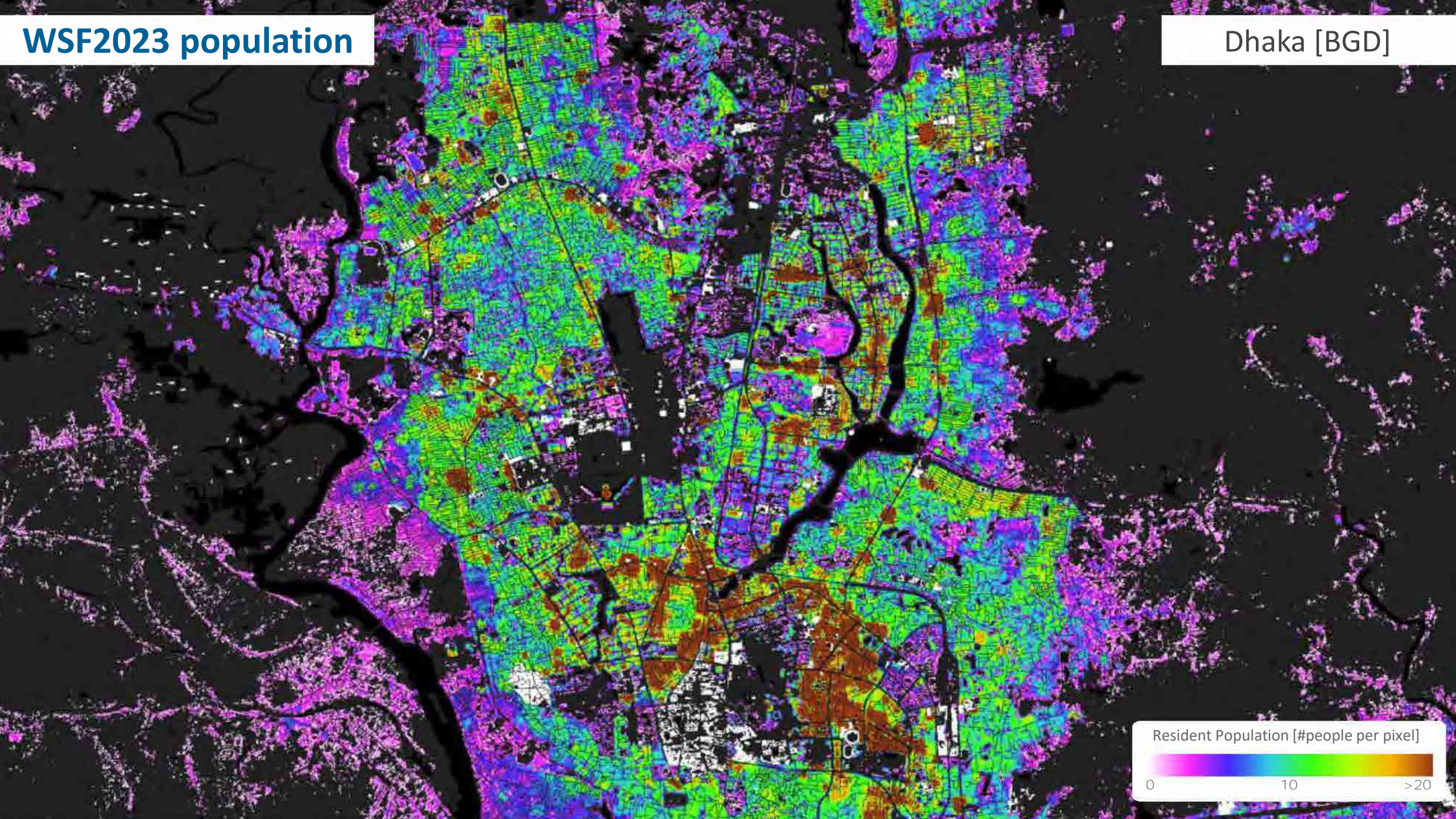
0

3

>6

WSF2023 population

Dhaka [BGD]



Resident Population [#people per pixel]

0 10 >20





*That's all Folks!*