Seismic Hazard under Cities – Pleiades Stereo Imagery Data

CEOS SEISMIC DEMONSTRATOR – FINAL REPORT 2022

UNIVERSITY OF LEEDS

DR JOHN ELLIOTT

DR SCOTT WATSON, DR RUTH AMEY

Project Details

Title: Seismic Cities

Lead & Team: Dr John Elliott, Dr Scott Watson & Dr RuthAmey

Partners: Tomorrow's Cities, BGS, Global Earthquake Model (GEM) and COMET (Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics)

Data Providers: CEOS, CNES, Airbus

Host Organisation: University of Leeds, School of Earth & Environment, UK

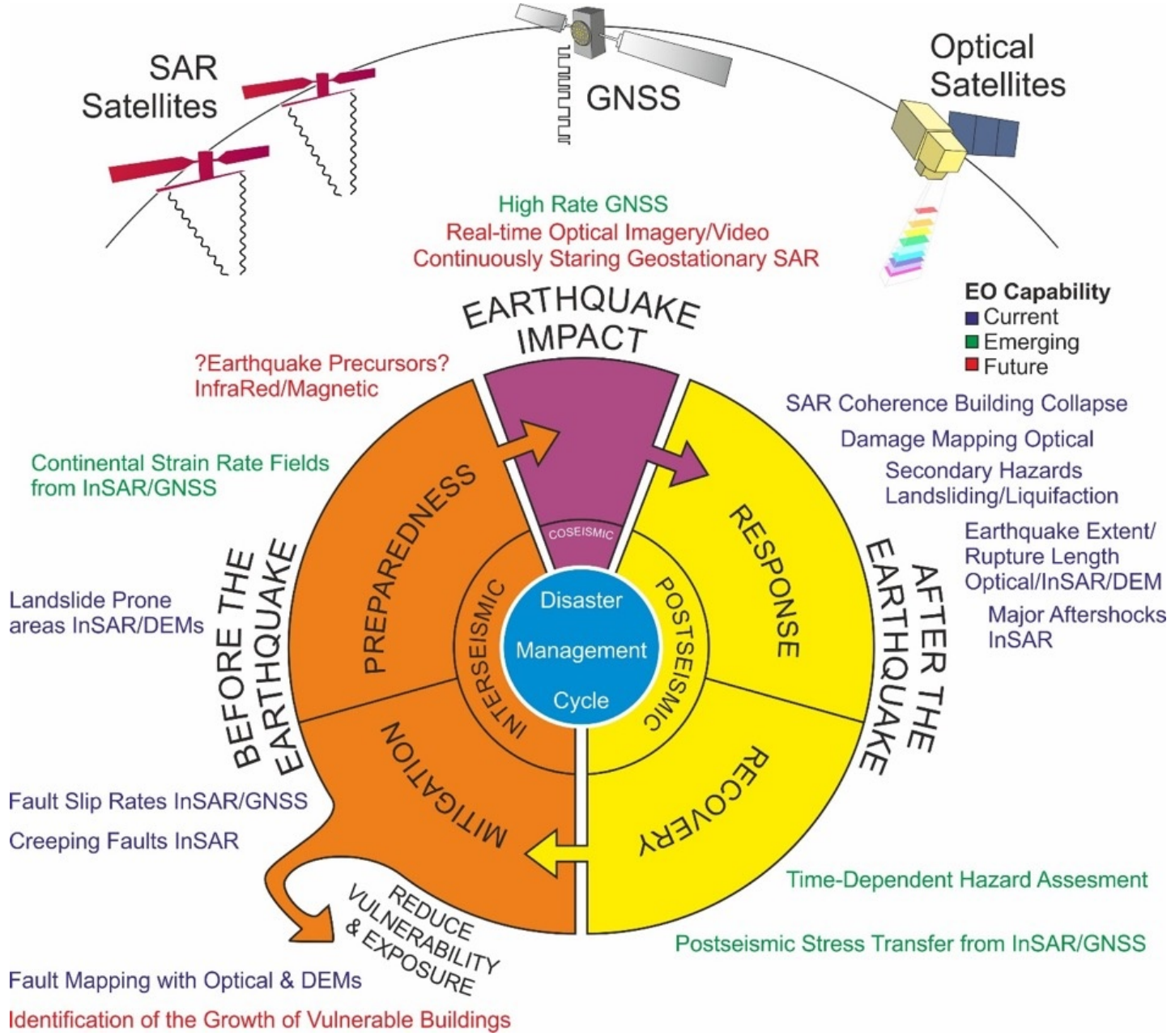
Science Funders: NERC (Global Challenges Research Fund), Royal Society & COMET

Principal theme: Geohazards: seismic hazards, earthquakes & active faulting.

Countries: Kyrgyzstan, Kazakhstan, Ecuador, Nepal, Kenya, China, Iran

Project Aims

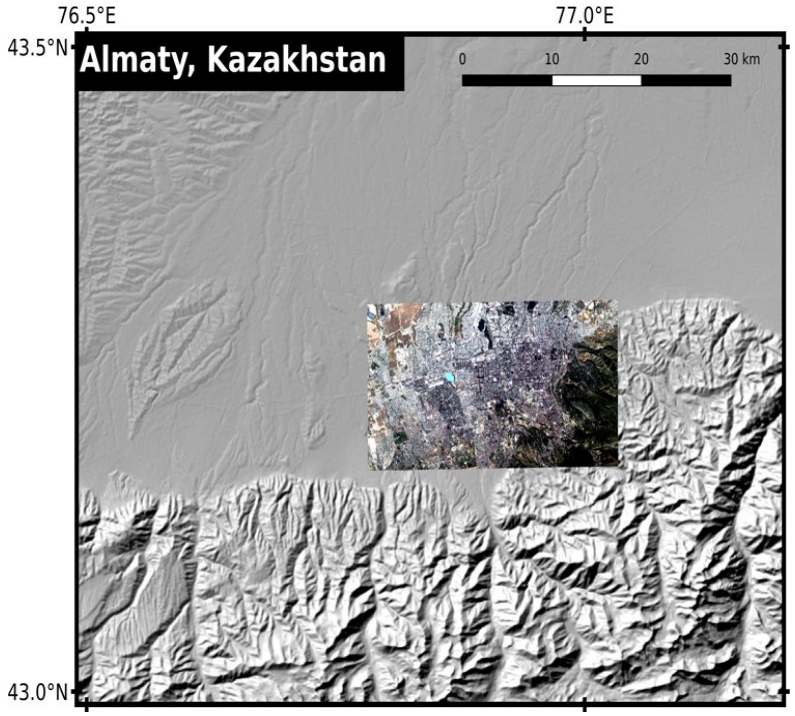
Researching the potential for assessing sources of seismic hazard using earth observation data and improving the identification of earthquake risk from exposure large cities in middle- and lower-income countries.



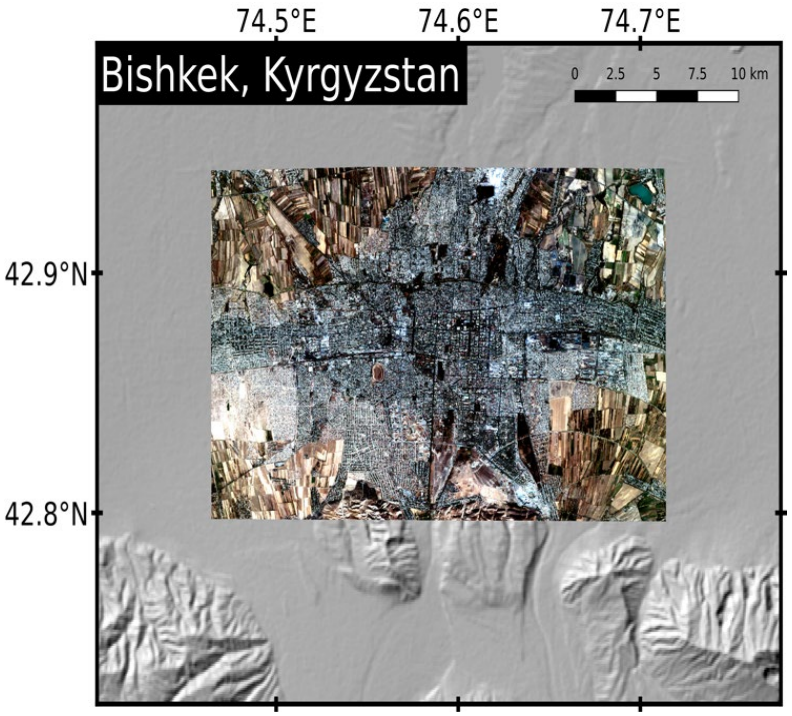
Elliott (2020) - https://link.springer.com/article/10.1007/s10712-020-09606-4

Central Asia – 2322 sq km 2019

2 MILLION INHABITANTS

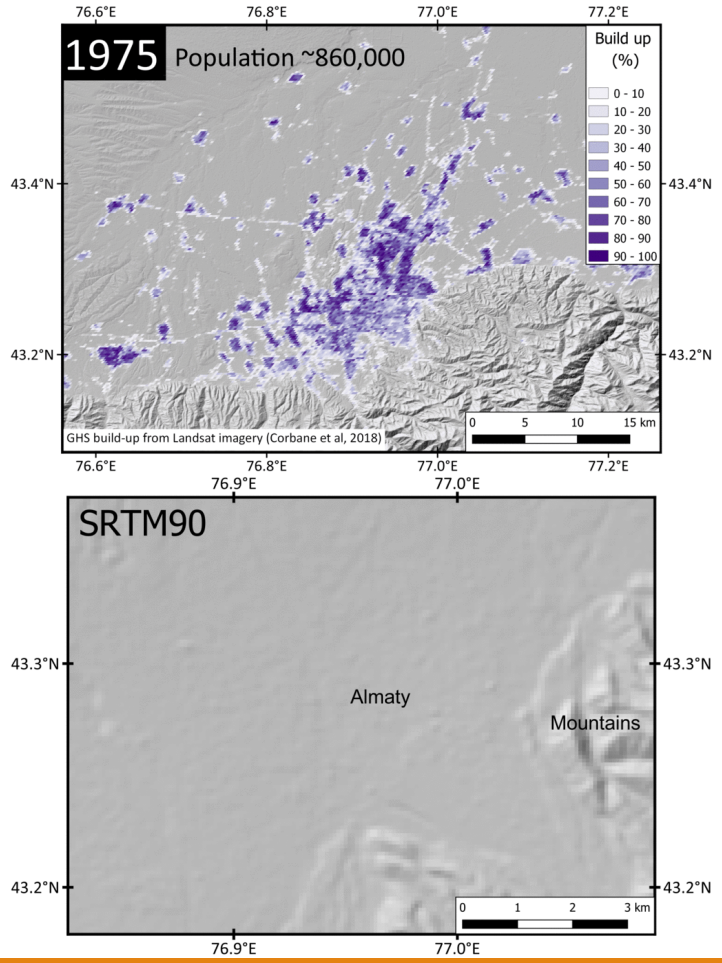


1 MILLION IN HABITANTS



- Use of existing archive Very High Resolution Optical Data in bi and tri-stereo mode to derive digital elevation models of active faulting along the cities of the Northern Tien Shan
- To address the UN sustainable cities and communities global challenge by improving our understanding of earthquake hazard for three major cities along the northern Tien Shan mountains in Kyrgyzstan and Kazakhstan that have been struck by huge earthquakes in the past

Almaty, Kazakhstan



AGU ADVANCING EARTH AND SPACE SCIENCE

Earth and Space Science

RESEARCH ARTICLE
10.1029/2021EA001664

Significant Seismic Risk Potential From Buried Faults Beneath Almaty City, Kazakhstan, Revealed From High-Resolution Satellite DEMs

Ruth M. J. Amey[1], John R. Elliott[1], Ekbal Hussain[2], Richard Walker[3], Marco Pagani[4], Vitor Silva[4], Kanatbek E. Abdrakhmatov[5], and C. Scott Watson[1]

[1]COMET, School of Earth and Environment, University of Leeds, Leeds, UK, [2]British Geological Survey, Natural Environment Research Council, Environmental Science Centre, Nottingham, UK, [3]Department of Earth Sciences, COMET, University of Oxford, Oxford, UK, [4]GEM Foundation, Pavia, Italy, [5]Institute of Seismology, National Academy of Sciences, Bishkek, Kyrgyzstan

Key Points:

- Digital elevation models derived from high-resolution satellite imagery can map active faulting near cities and determine building heights
- Scenario risk calculations show a moderate earthquake on a fault in north Almaty would cause considerable damage and loss due to proximity
- Properly characterizing fault location and geometry close to cities is key to quantifying the relative level of seismic hazard and risk

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

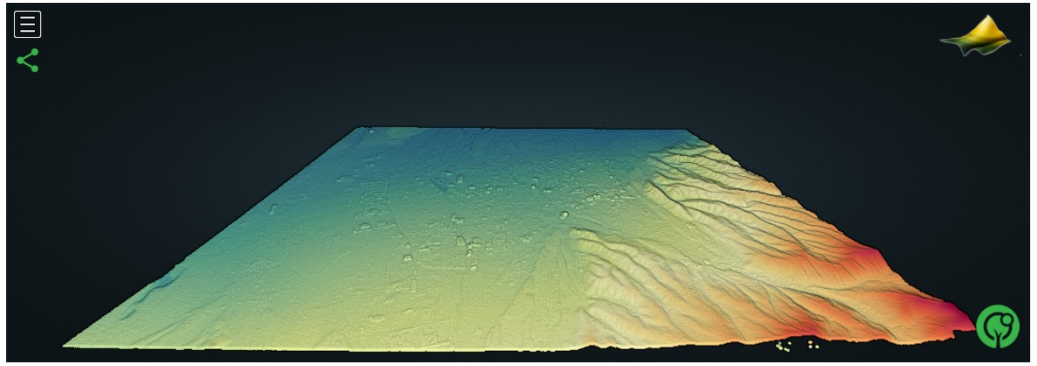
Abstract Major faults of the Tien Shan, Central Asia, have long repeat times, but fail in large (M_w 7+) earthquakes. In addition, there may be smaller, buried faults off the major faults which are not properly characterized or even recognized as active. These all pose hazard to cities along the mountain range front such as Almaty, Kazakhstan. Here, we explore the seismic hazard and risk for Almaty from specific earthquake scenarios. We run three historical-based earthquake scenarios (1887 Verny M_w 7.3, 1889 Chilik M_w 8.0 and 1911 Chon-Kemin M_w 8.0) on the current population and four hypothetical scenarios for near-field faulting. By making high-resolution Digital Elevation Models (DEMs) from SPOT and Pleiades stereo optical satellite imagery, we identify fault splays near and under Almaty. We assess the feasibility of using

Published last year as open access in Earth & Space Sciences

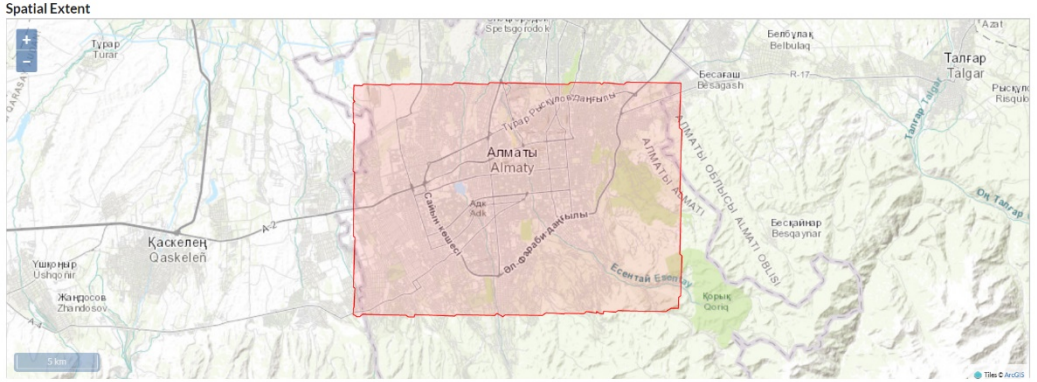
https://doi.org/10.1029/2021EA001664

Final Dataset Products – 3D point clouds

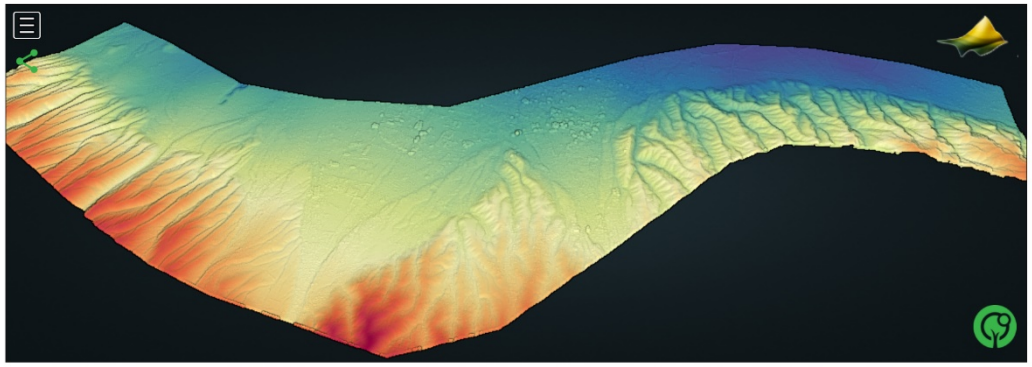
3D Point Cloud Viewer View full screen



Spatial Extent



304 sq km, 1,827,466.735 points, 5.81 pts/sq m



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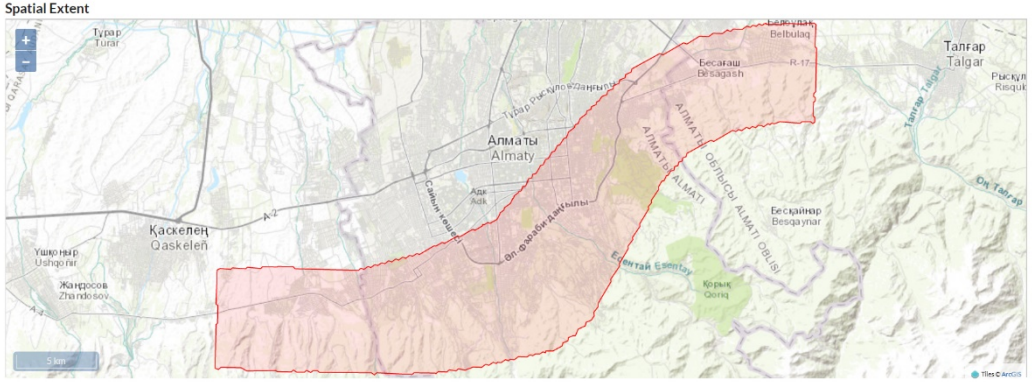


367 sq km, 2,105,680,531 points, 5.84 pts/sq m

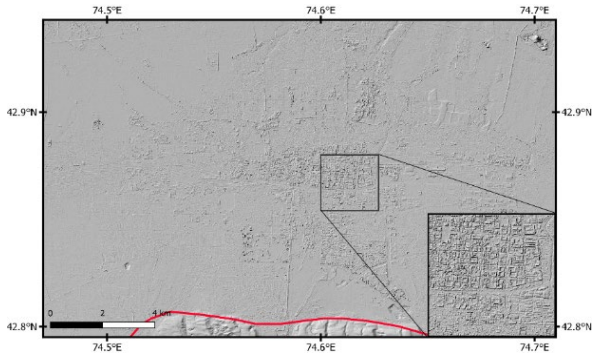
Bishkek

Motivation: World Bank report on seismic risk called for more research on active faulting

Collaborator: Institute of Seismology (embedding local capacity)

End Users: Ministry of Emergency Situations, Ministry of Health and Ministry of Construction

Two Aims with Pleiades imagery & DEMs for calculating risk:
1. Identify Fault Hazards in and around the city
2. Building Classification for updating Exposure



In review with Natural Hazards

Preprint: https://eartharxiv.org/repository/view/2922/

Improving urban seismic risk estimates for Bishkek, Kyrgyzstan, incorporating recent geological knowledge of hazards

Ruth M.J. Amey[1*], John R. Elliott[1], C. Scott Watson[1], Richard Walker[2], Marco Pagani[3], Vitor Silva[3], Ekbal Hussain[4], Kanatbek E. Abdrakhmatov[5], Sultan Baikulov[5] and Gulkaiyr Tilek Kyzy[5]

[1*]COMET, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK.
[2]COMET, Department of Earth Sciences, University of Oxford,Oxford, OX1 3AN, UK.
[3]GEM Foundation, Via Ferrata 1, Pavia, 27100, Italy.
[4]British Geological Survey, Natural Environment Research Council, Environmental Science Centre, Keyworth, Nottingham, NG12 5GG, UK.
[5]Institute of Seismology, National Academy of Sciences, Bishkek, Kyrgyzstan.

*Corresponding author(s). E-mail(s): R.M.J.Amey@leeds.ac.uk;

Abstract

Many cities are built on or near active faults, which pose seismic hazard and risk to the urban population. This risk is exacerbated by city expansion, which may obscure signs of active faulting. Here we estimate the risk to Bishkek city, Kyrgyzstan, due to realistic earthquake scenarios based on historic earthquakes in the region and improved knowledge of the active faulting. We use previous literature and fault mapping, combined with new high-resolution digital elevation models to identify and characterise faults that pose a risk to Bishkek. We then estimate the hazard

Improving urban risk estimates for Bishkek

DOI: https://doi.org/10.5069/G92R3PW6

Platform: Structure from Motion / Photogrammetry

Data Format: Point Cloud

Dataset Acknowledgement: We gratefully acknowledge the Committee for Earth Observing Satellites (CEOS) Seismic Demonstrator for providing Pléiades stereo imagery along the northern Tien Shan, and some Pleiades imagery was purchased through the NERC/ESRC Earthquakes without Frontiers (EwF) consortium. Pleiades images made available by CNES in the framework of the CEOS Working Group for Disasters. © CNES (2012,2014,2017), and Airbus DS, all rights reserved. Please note that this data is not permitted for commercial use.

Dataset Citation: Amey, R., Scott, C., Elliott, J., Walker, R. (2021). Bishkek city, Kazakhstan, 2013 (derived from Pleiades tristereo imagery). Distributed by OpenTopography. https://doi.org/10.5069/G92R3PW6 Accessed: 2022-02-15

Survey Date: 02/11/2013

Survey Area: 353.69 km^2

Publication Date: 09/27/2021

Number of lidar returns: 1,822,453,041 pts

Point Density: 5.15 pts/m^2

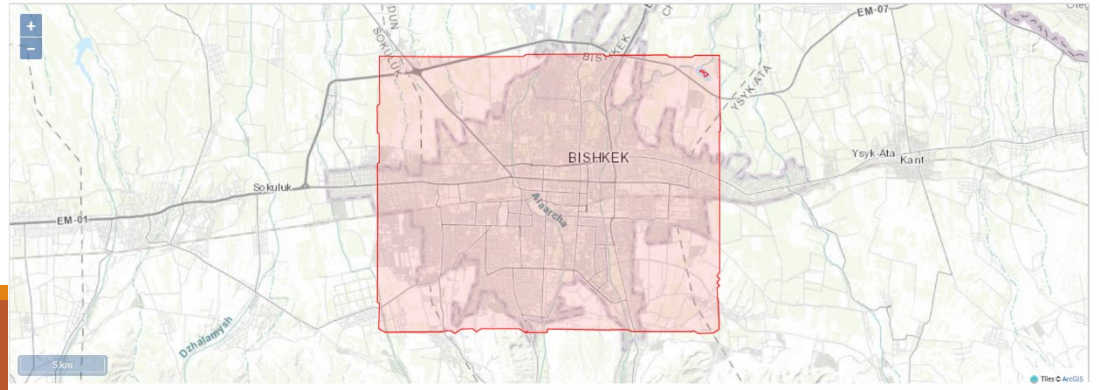
Coordinates System:

Horizontal: WGS 84 / UTM zone 43N [EPSG: 32643]

View more metadata

3D Point Cloud Viewer

Spatial Extent



Bishkek, Kyrgyzstan

Aim: updating exposure datasets for seismic risk modelling

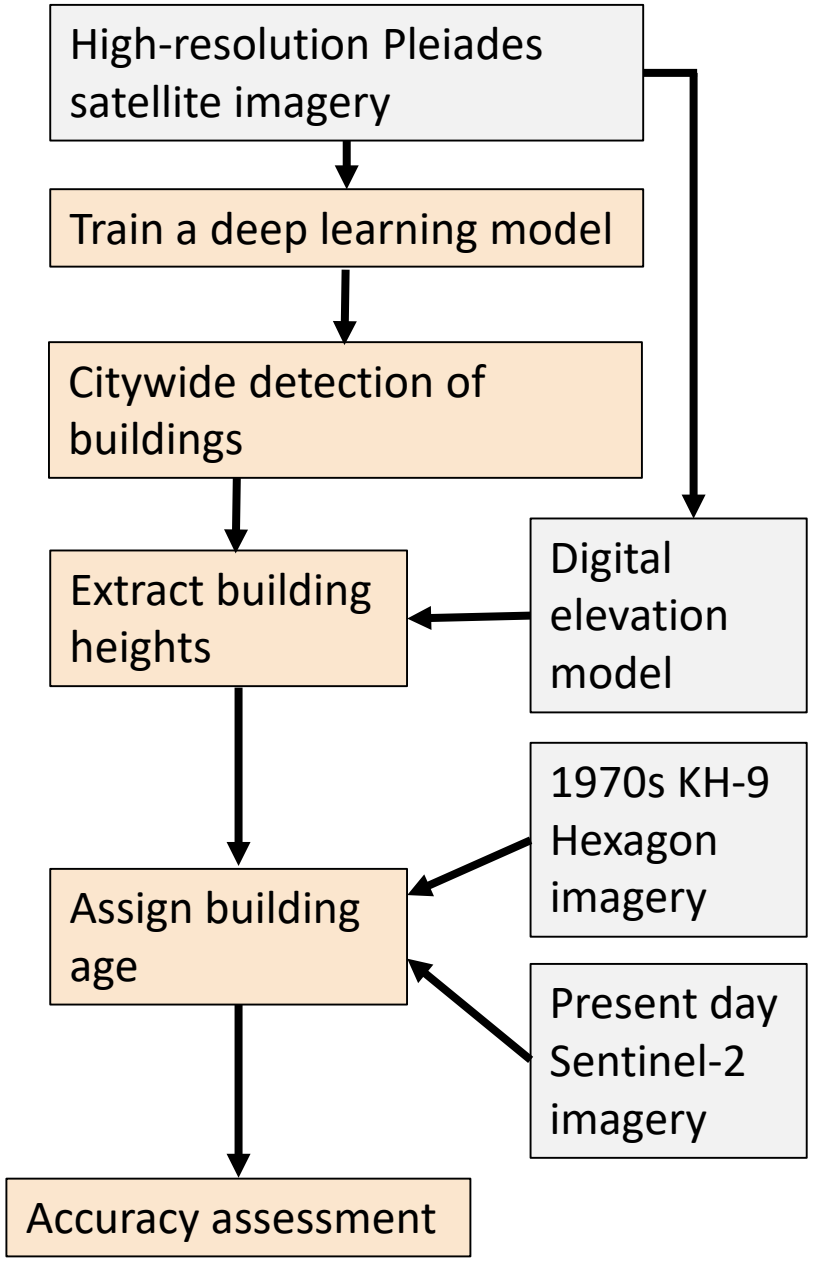
Summary of Pleiades-derived products

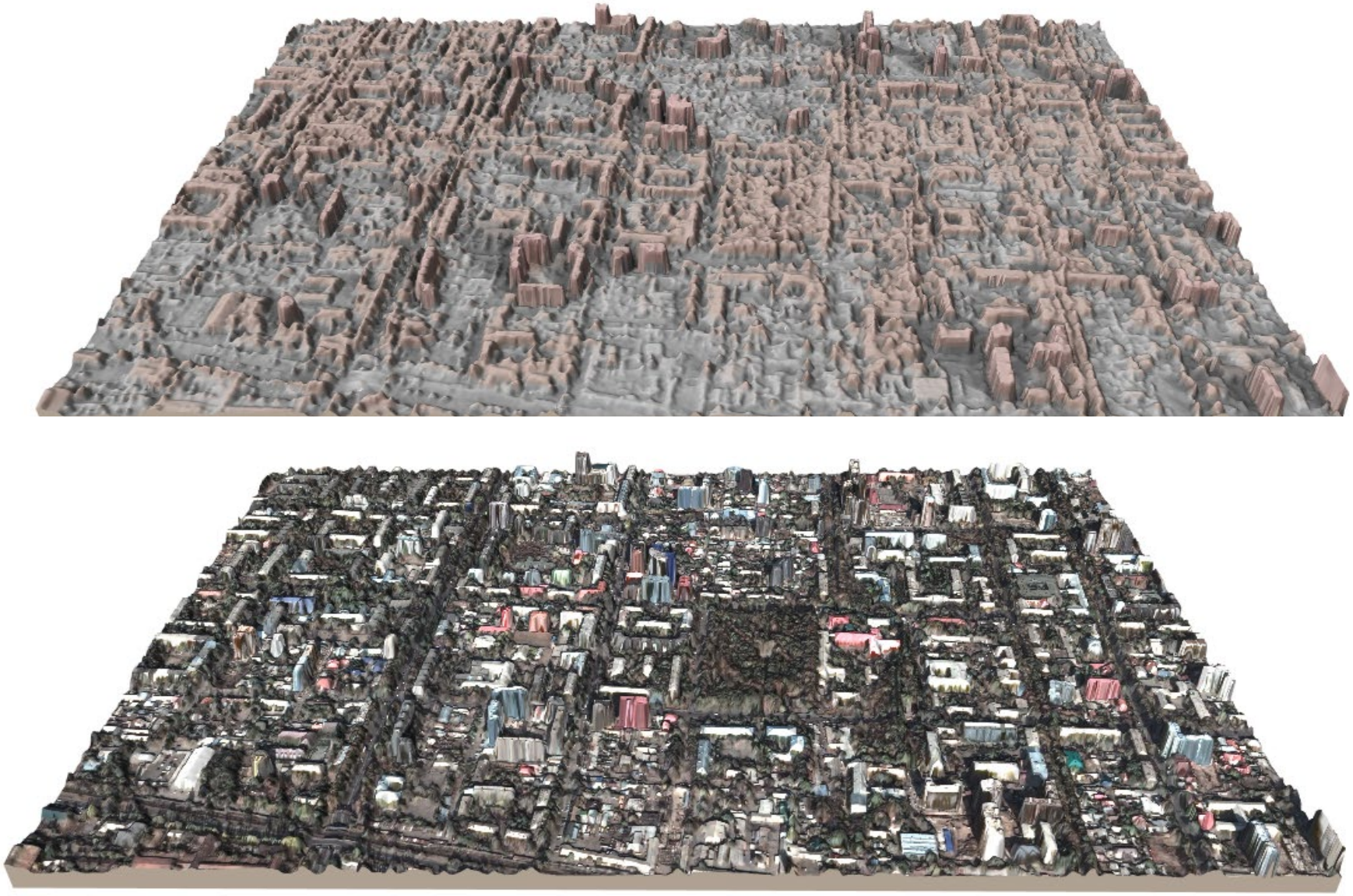
- 1.5 m digital surface model and digital terrain model for Bishkek in 2013
- Building footprint and height dataset (>150,000 buildings)
- Accuracy assessment using WorldView-2, ICESat-2 altimetry data, and field-measurements

- Paper in preparation: *Multi-sensor 4D City Mapping for Updating Exposure to Inform Seismic Risk in Bishkek, Kyrgyzstan*
- Final outputs will be delivered to the Institute of Seismology, National Academy of Sciences, Bishkek, Kyrgyzstan and made open access through online repositories.

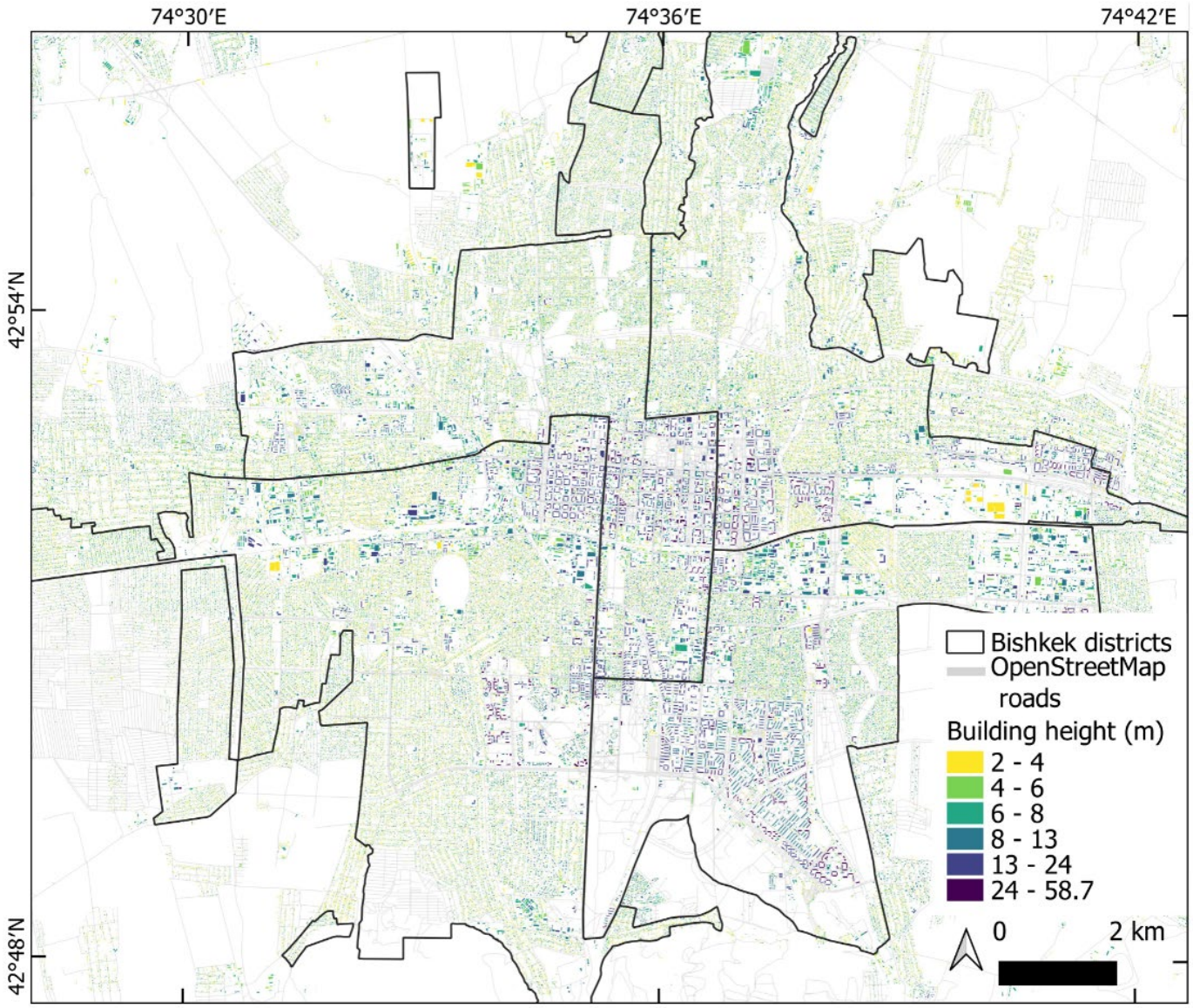
Updating exposure data in Bishkek using satellite data

- Focus on building stock and city redevelopment
- OpenStreetMap data is incomplete and dated





Example 3D views of buildings in central Bishkek derived using Pleiades stereo imagery data

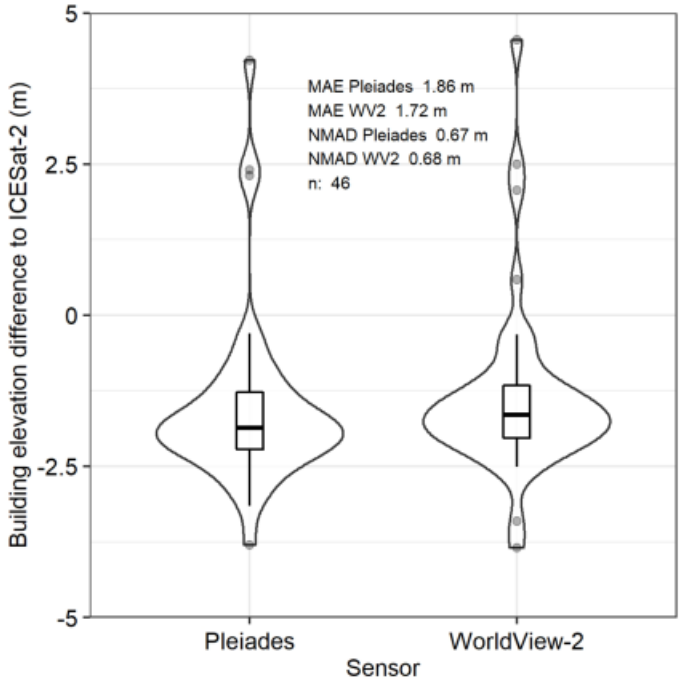


Heights assigned to building polygons in Bishkek using Pleiades digital elevation models

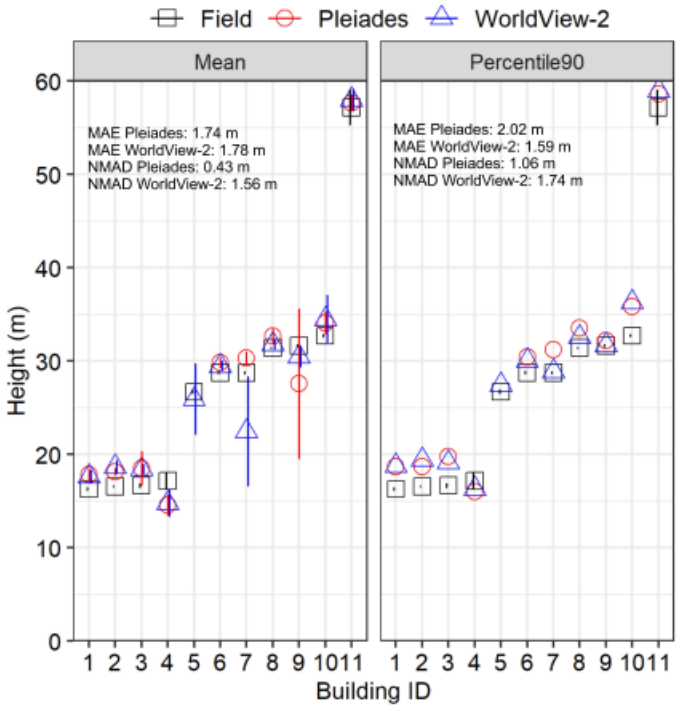
Updated exposure dataset for seismic risk modelling

Building height accuracy assessment

ICESAT-2 ALTIMETRY DATA



HEIGHTS MEASURED IN BISHKEK



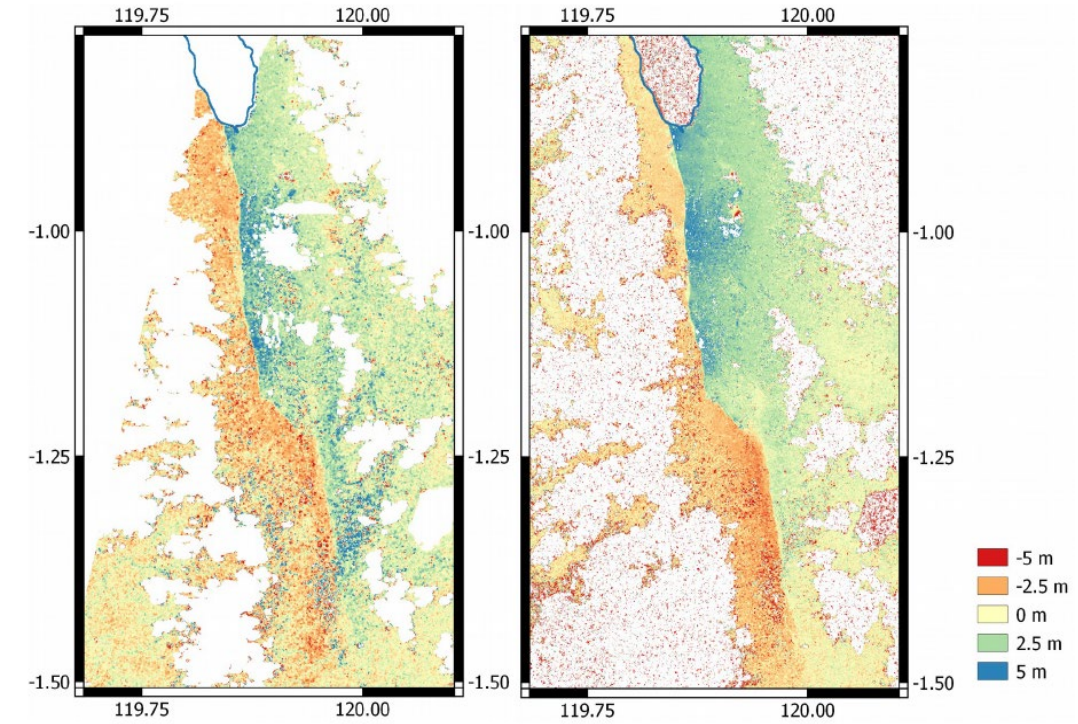


Figure 3. Displacement maps obtained from correlation of Landsat 8 in panchromatic band (band 8) (left) and Sentinel-2 in blue band (band 2) (right) imagery. Close up on the southern part of the rupture.

Palu, Indonesia 316 sqkm

Magnitude 7.5 Earthquake on 28th September 2018 north of the city fo Paul on the Indonesian island of Sulawesi.

Surface rupture meant optical offset tracking gave good results with Landsat-8 and Sentinel-2 data

Aim was to compare the performance of Pleiades imagery using pre- and post- earthquake imagery to determine fault offsets through cross correlation techniques (we were testing two pieces of correlator software MicMac and Cosi-Corr). We also want to compare the performance within a built up environment (Palu city) versus the surrounding rural agriculture and vegetated regions.

Unfortunately the PhD student who was working on this project stopped after one year before the comparison was completed.

Quito, Ecuador, ~3,000 sq km

Aim: assessing multi-hazards and the availability of safe spaces following an earthquake

Summary of Pleiades-derived products

- 1.5 m digital surface model and digital terrain model for Quito in 2020
- Accuracy assessment using ICESat-2 altimetry data
- Greenspace safe space distribution and accessibility around the city
- Greenspace intersection with landslide and flood hazards
- Top 10 disaster risk reduction greenspaces
- Topographic wetness index and association with observed flood events

- Collaboration with *The College of Architects of Ecuador* through the *Tomorrow's Cities* project
  - Outputs were exhibited in the *Museo de la Ciudad and Museo Interactivo de Ciencia, Quito*

- Paper in review:

Enhancing disaster risk resilience using greenspace in urbanising Quito, Ecuador

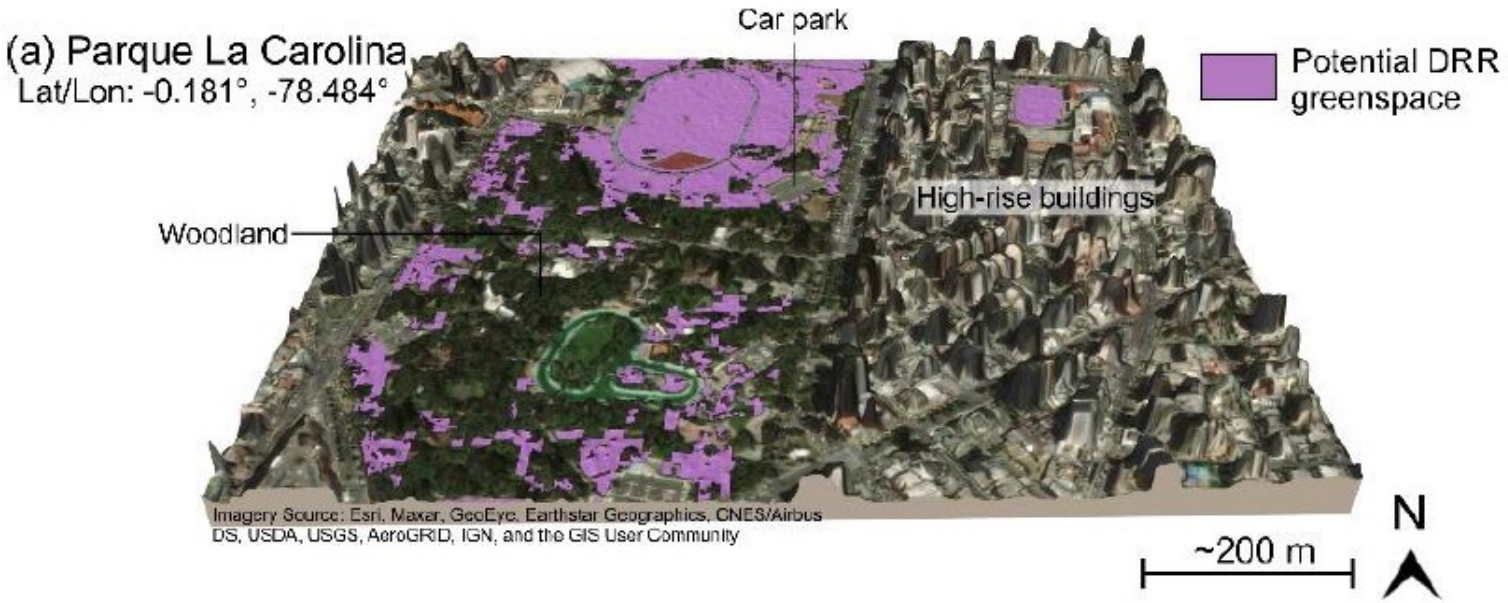
https://nhess.copernicus.org/preprints/nhess-2022-20/

We derived greenspace distribution using a normalised difference vegetation index (NDVI)

Less vegetated — Densely vegetated

Greenspace distribution was combined with topographic information

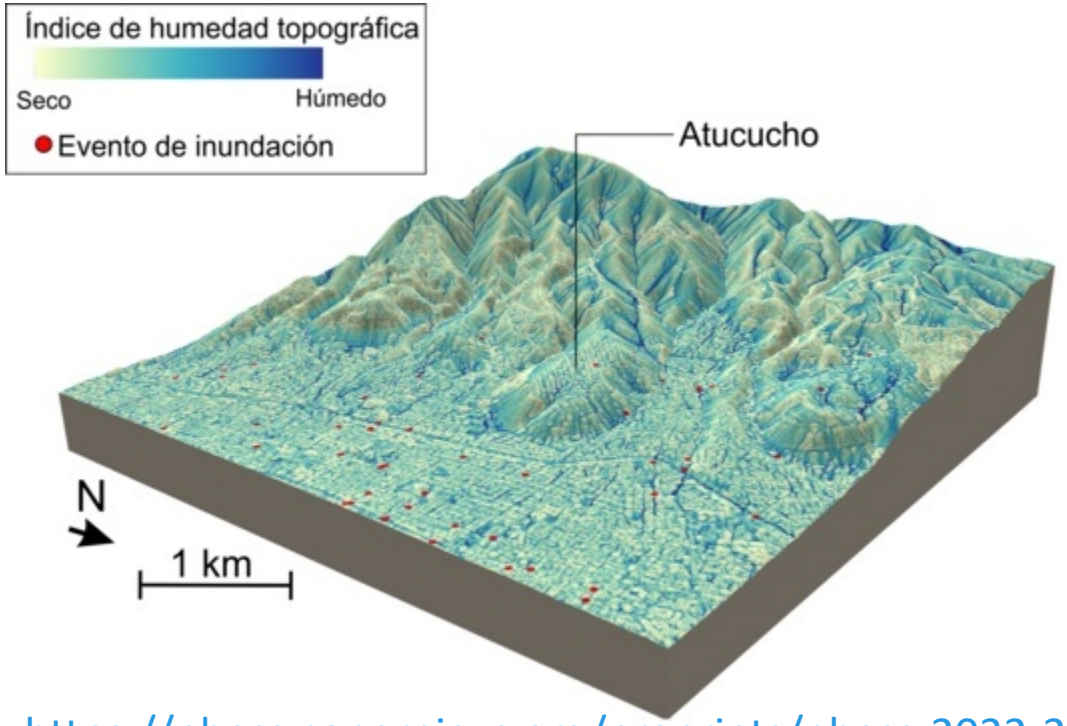
- Collaboration with The College of Architects of Ecuador to investigate the distribution and accessibility of greenspace around Quito
- Derived a methodology to map and evaluate Disaster Risk Reduction (DRR) greenspaces



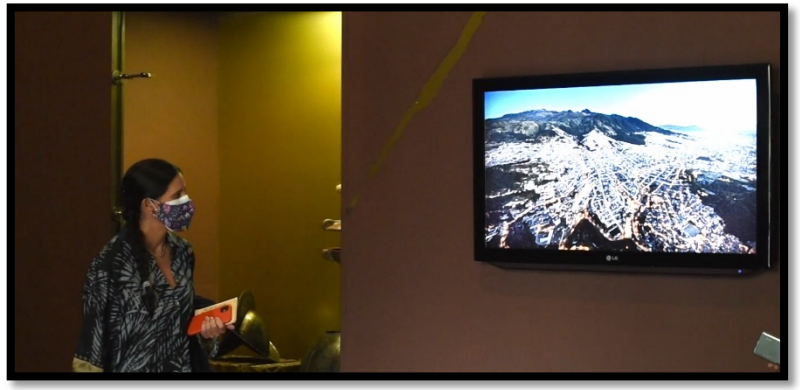
https://nhess.copernicus.org/preprints/nhess-2022-20/

DEMs were used to derive a topographic wetness index (TWI)

- We evaluated the association between TWI and observed flood events
- TWI was used to show movement of water around and into the city
- Data featured in museum exhibits and digital displays



https://nhess.copernicus.org/preprints/nhess-2022-20/



un proyecto de:

con el apoyo de:

Kathmandu, Nepal, ~3,000 sq km

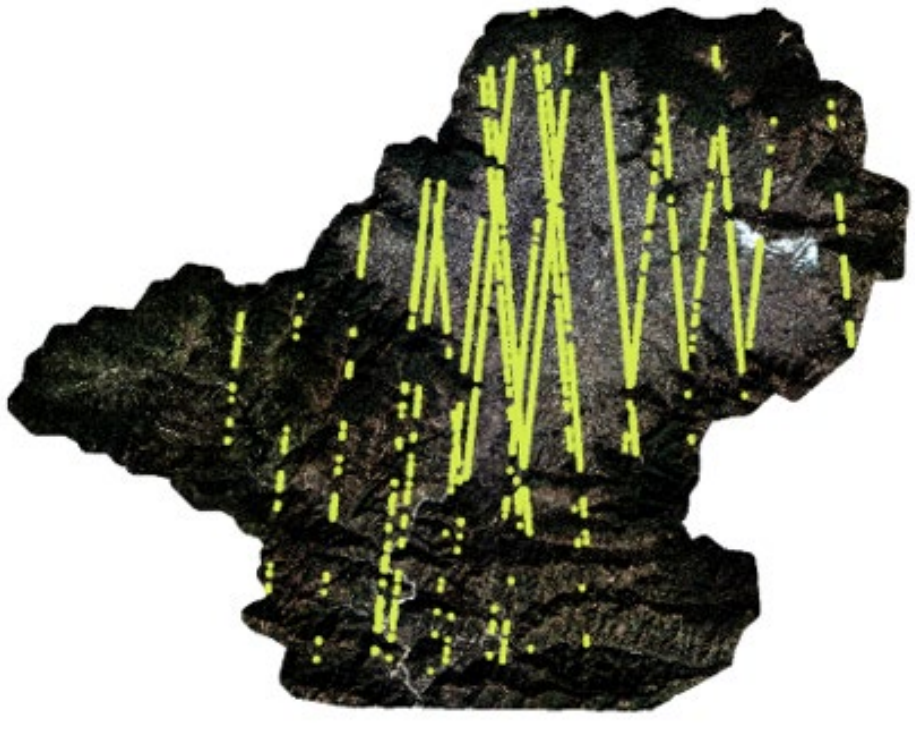
Aim: assessing natural hazards facing future urban areas.

Summary of Pleiades-derived products

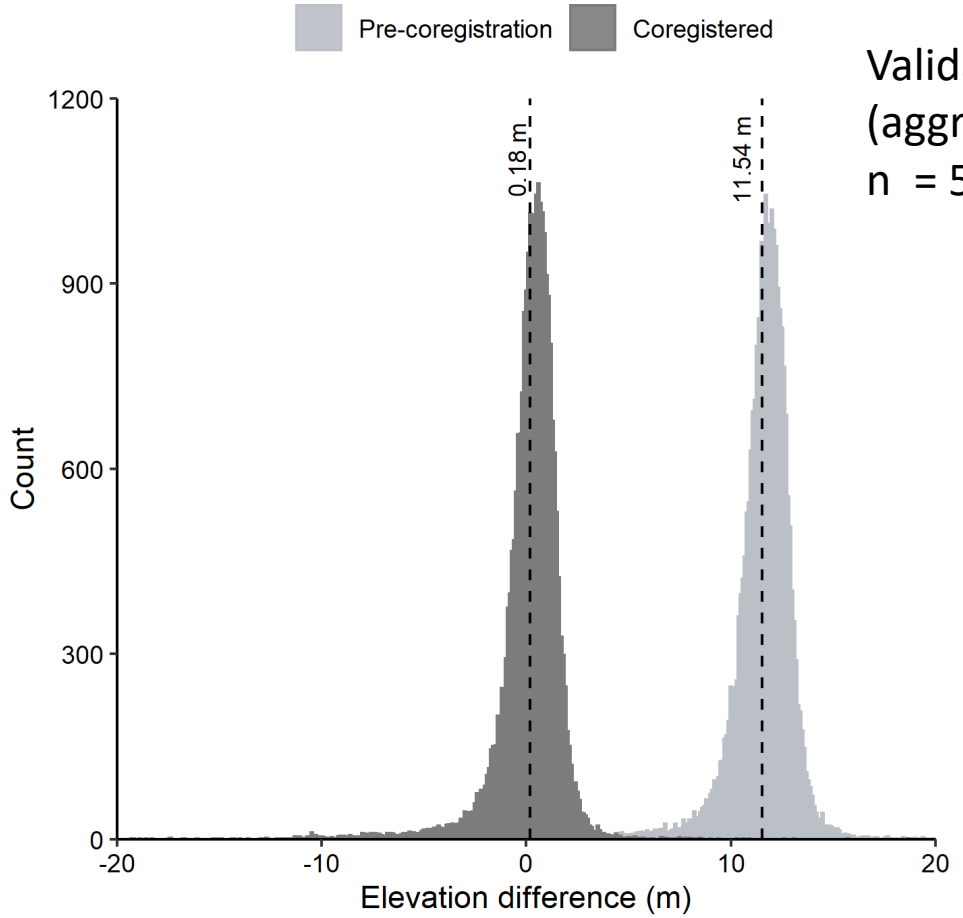
- 1.5 m digital surface model and digital terrain model for Kathmandu in 2019
- Accuracy assessment using ICESat-2 altimetry data
- Flood maps for the Kathmandu basin

- Data were used in the flood and seismic risk modelling work packages of the *Tomorrow's Cities* project
- We expect to apply a similar deep learning workflow to that used in Bishkek to derive building stock datasets for risk modelling.

DEMs compared to ICESat-2 data

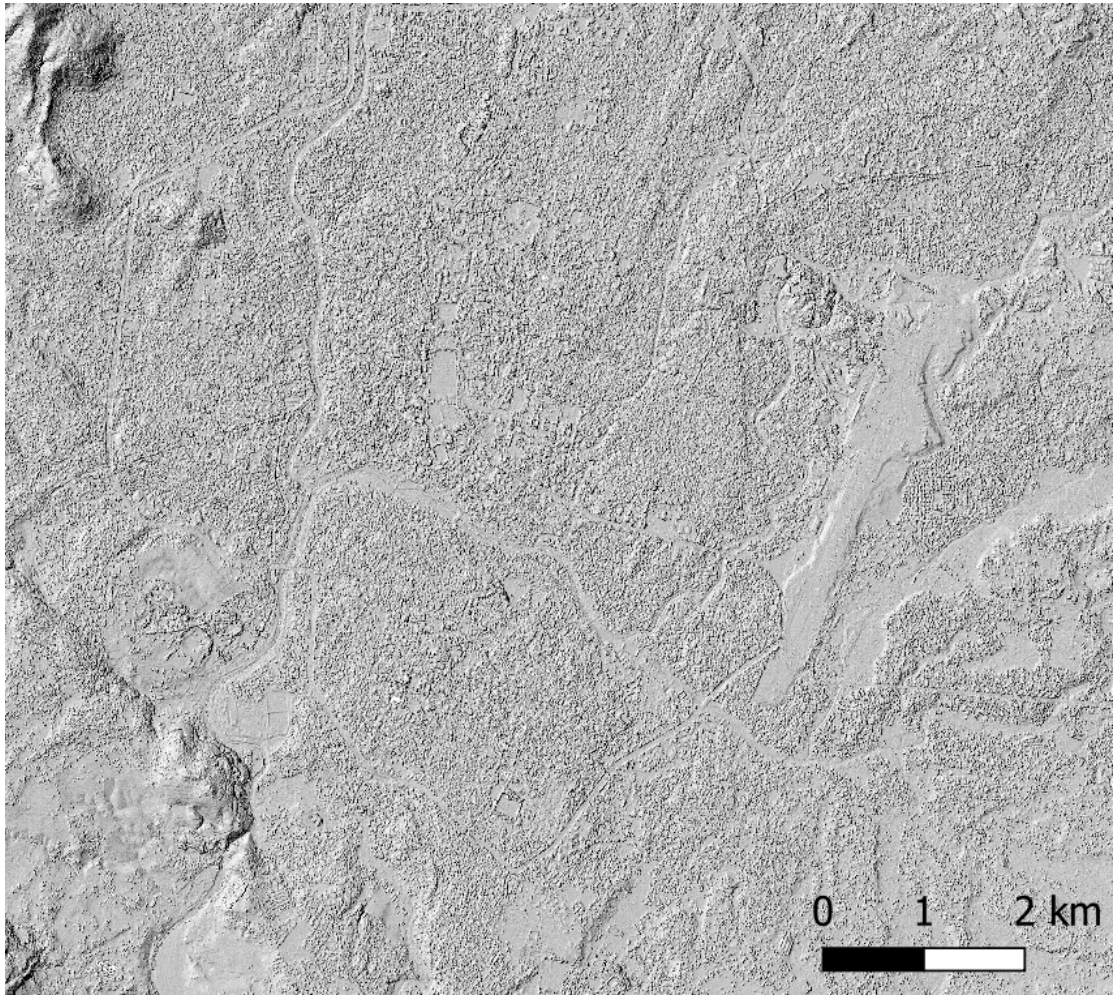


Elevation model mean difference of 0.18 m and standard deviation of 1.67 m relative to ICESat-2 data



Validation cells (aggregated photons) n = 50,577

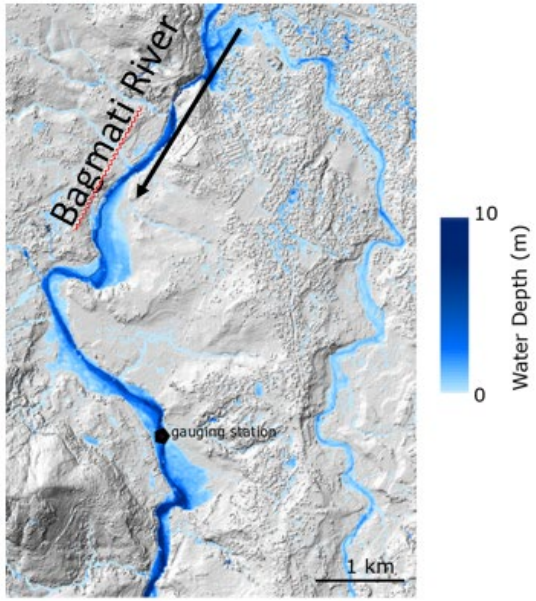
DSMs and DTMs were used for urban flood modelling



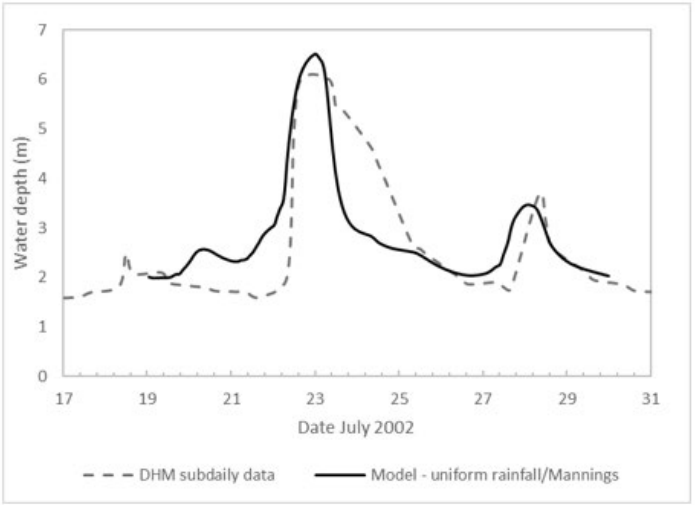
Examples of work done as part of Tomorrow's Cities Kathmandu WP2 (flood modelling) using the Pleiades 2 m Digital Elevation Map (DEM)

Figures produced by
Dr. Maggie J. Creed (University of Glasgow)
Dr. Manoranjan Muthusamy (University of Edinburgh)

In collaboration with
Prof. Simon Mudd and Saraswati Thapa (University of Edinburgh)
Anup Shrestha (Tribhuvan University, Nepal)



Flood extent near Khokana for 1 in 20 year flood



Calibrating discharge at Khokana against DHM stage readings

River channel post-processing to hydrologically correct the surface

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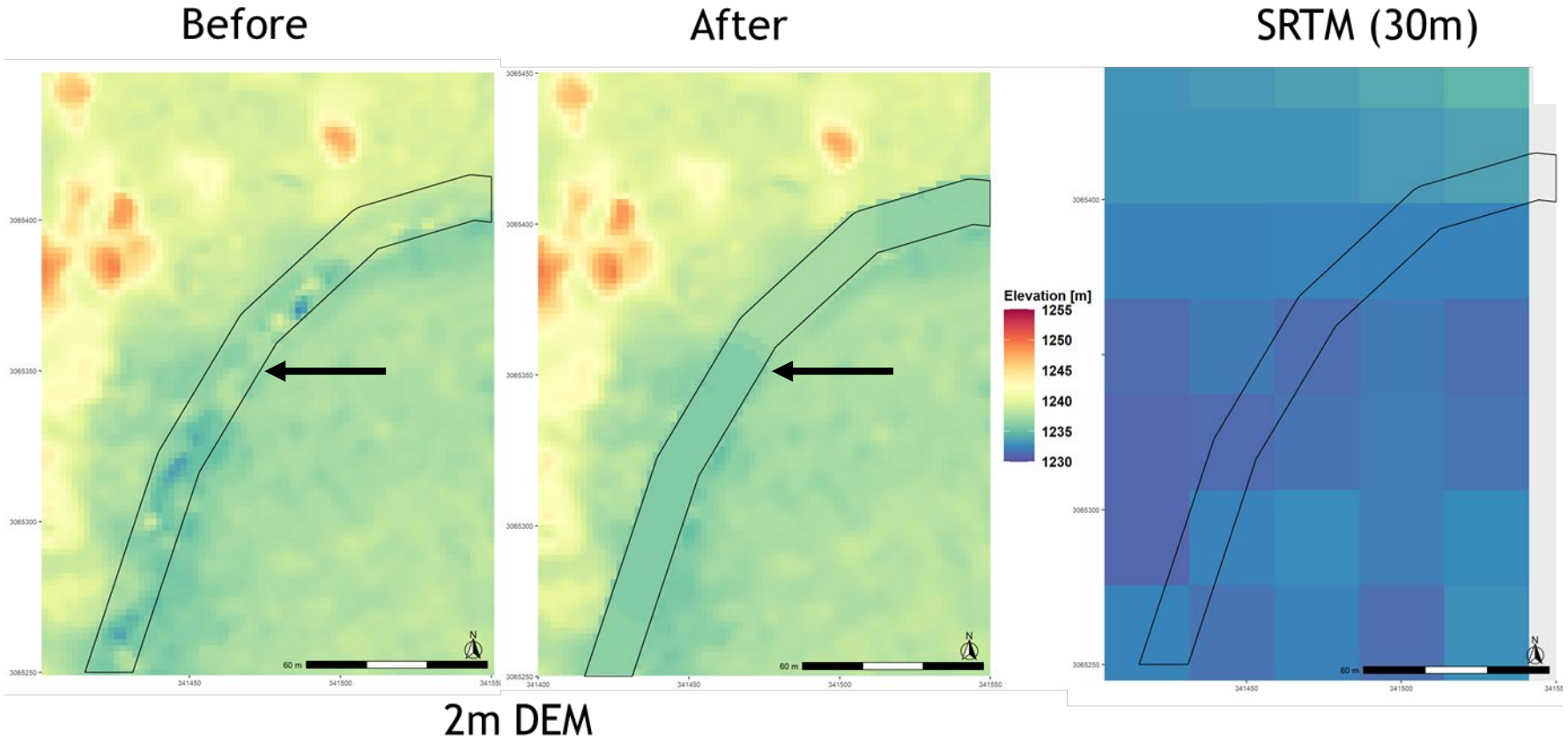

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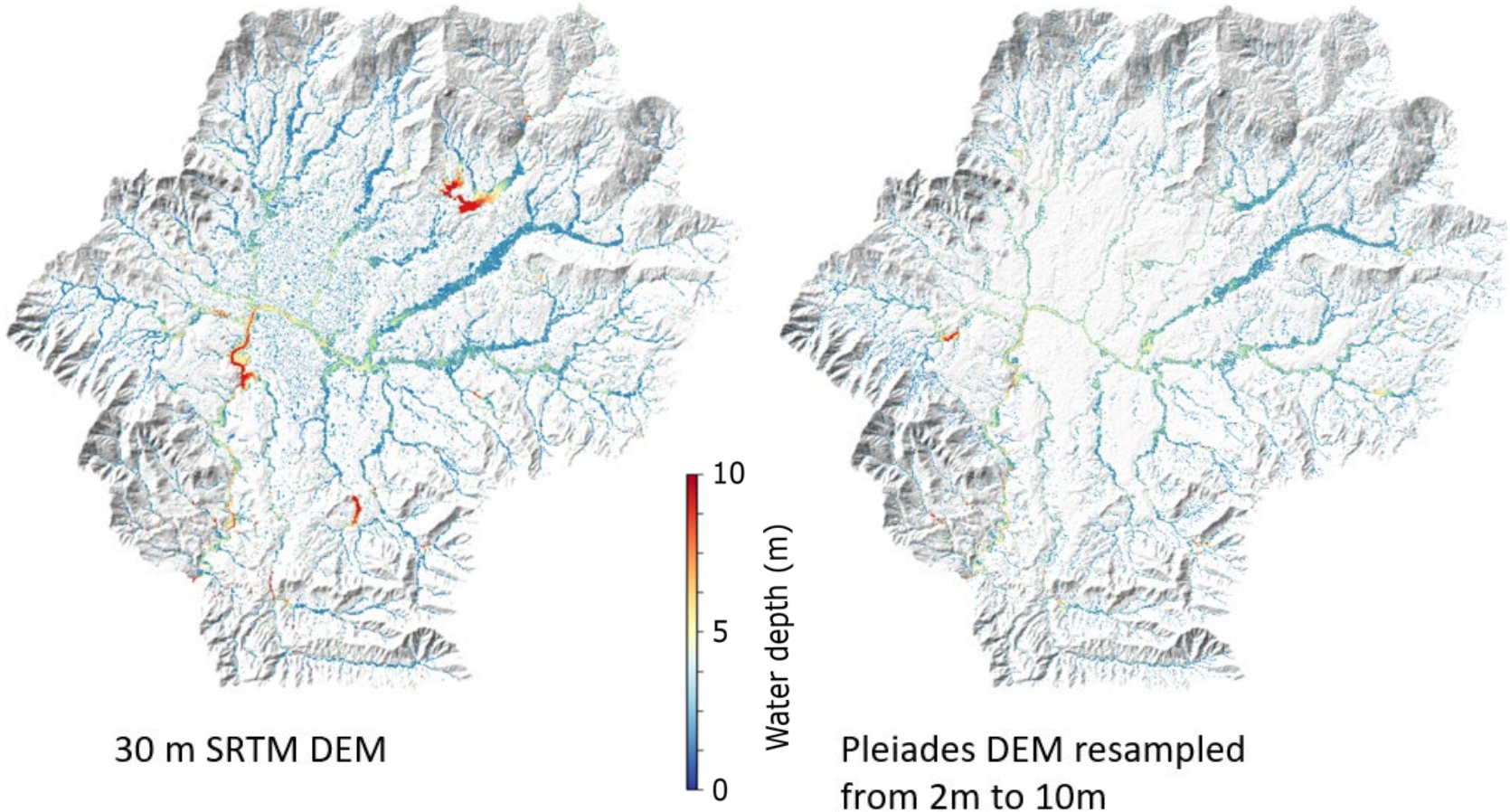
Anup Shrestha (Tribhuvan University, Nepal)

Flood maps of Kathmandu generated using 2D flood modelling (20 yr. return period flood)



30 m SRTM DEM

Pleiades DEM resampled from 2m to 10m

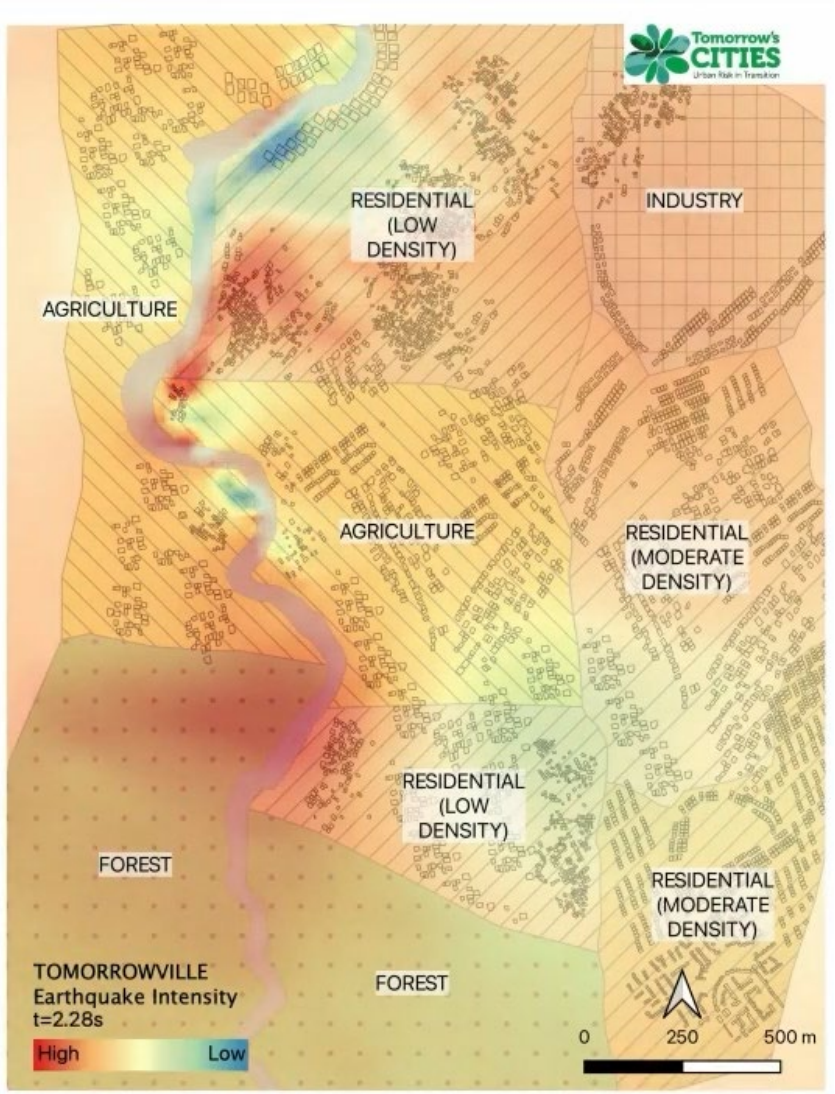
Pleiades-derived topography formed the basis of a hypothetical future city

The future city was subjected to synthetic disasters modelled at high resolution using state of the art physics-based simulations

A video summarizing the Tomorrow's Cities project was presented at COP26, Glasgow, UK

Climate change adaptation through multi-hazard risk sensitive urbanization – COP26

https://www.youtube.com/watch?v=2LMXxaR7bJY&t=6s



Climate change adaptation through multi-hazard risk sensitive urbanization – COP26

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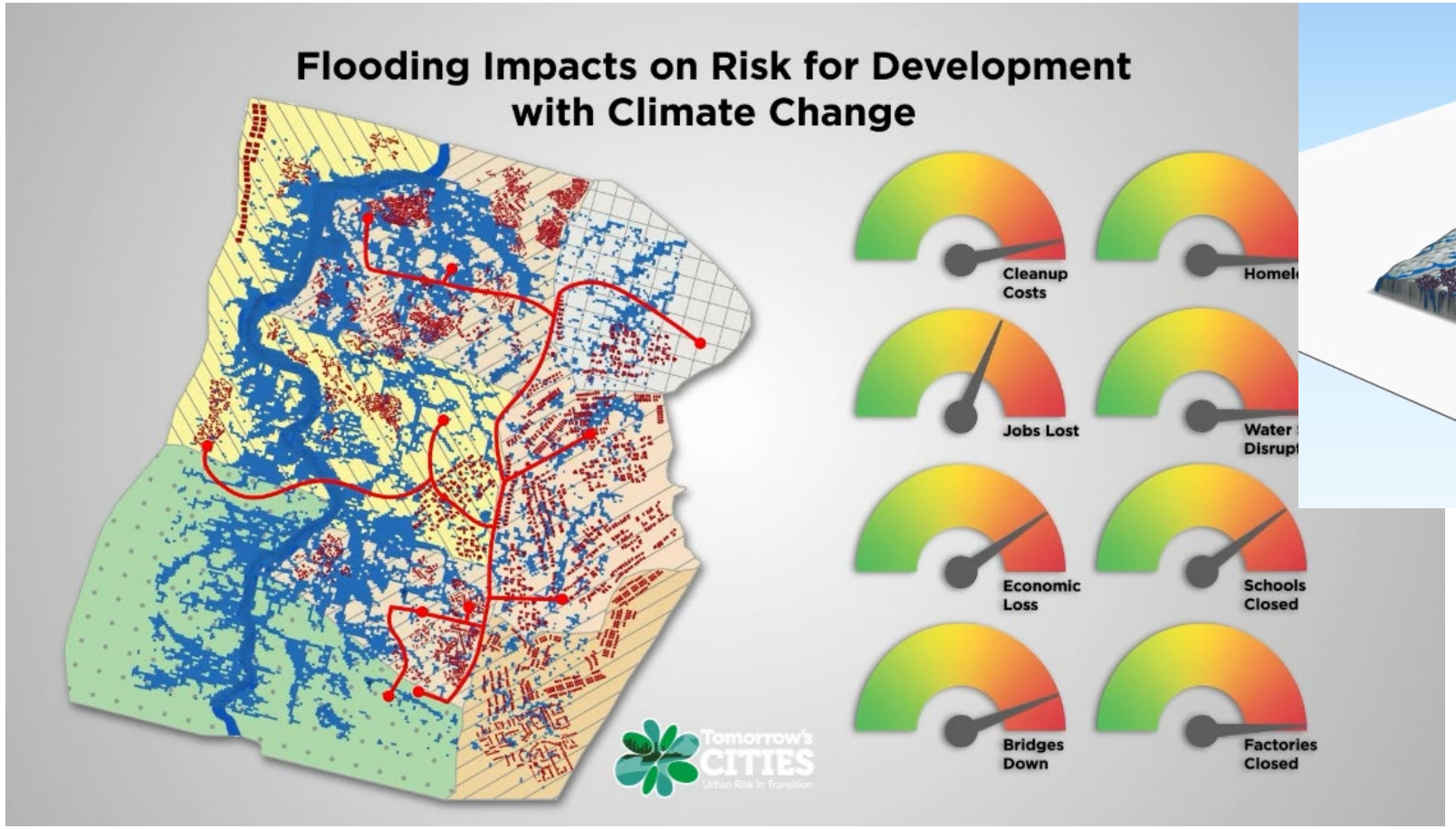
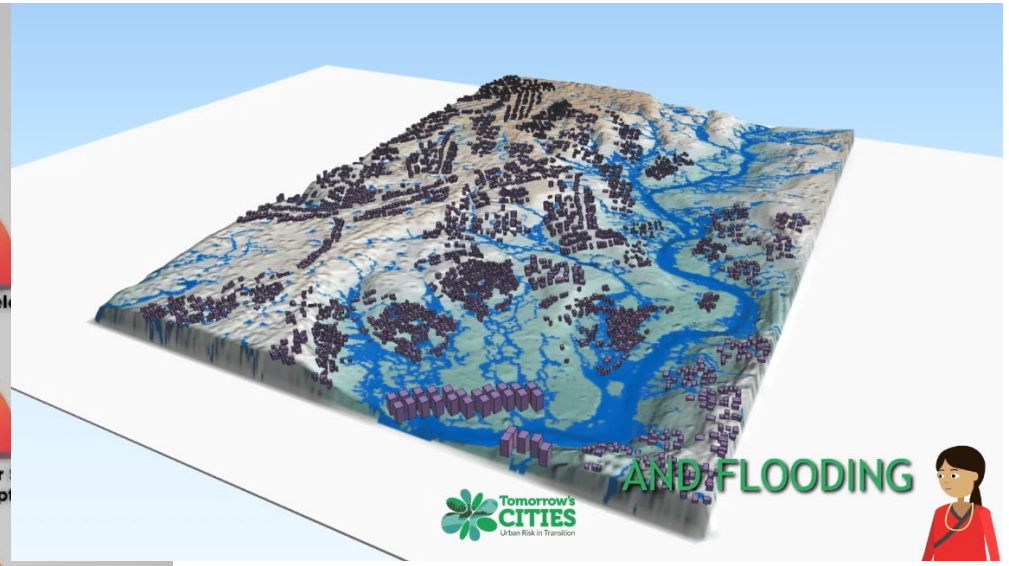




Nairobi, Kenya, ~3,000 sq km

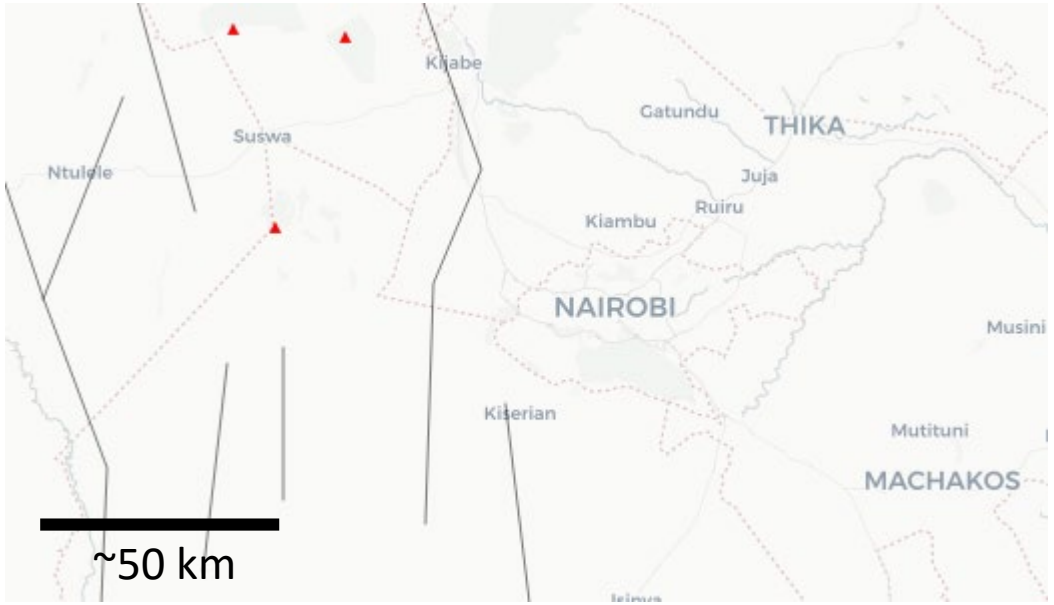
Aim: reduce urban disaster risk from earthquakes, flooding, fires, and volcanoes

- Pleaides data acquisition still in progress (4 out of 5 scenes acquired – still missing the one over Nairobi city)

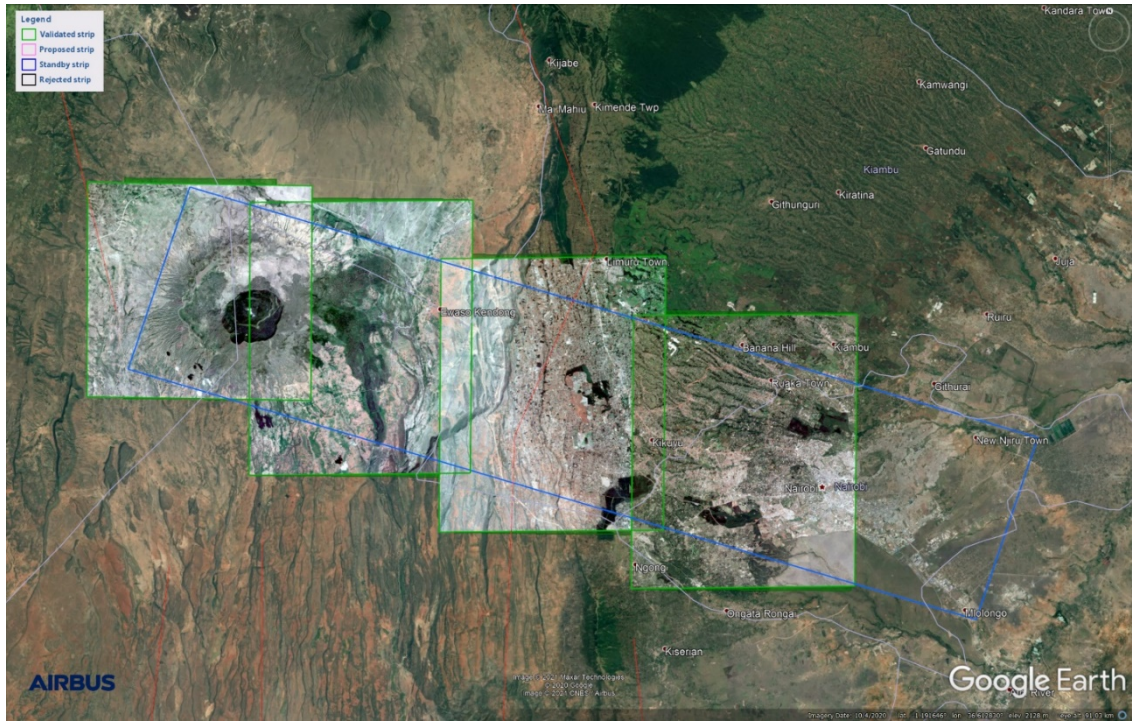
We expect to:

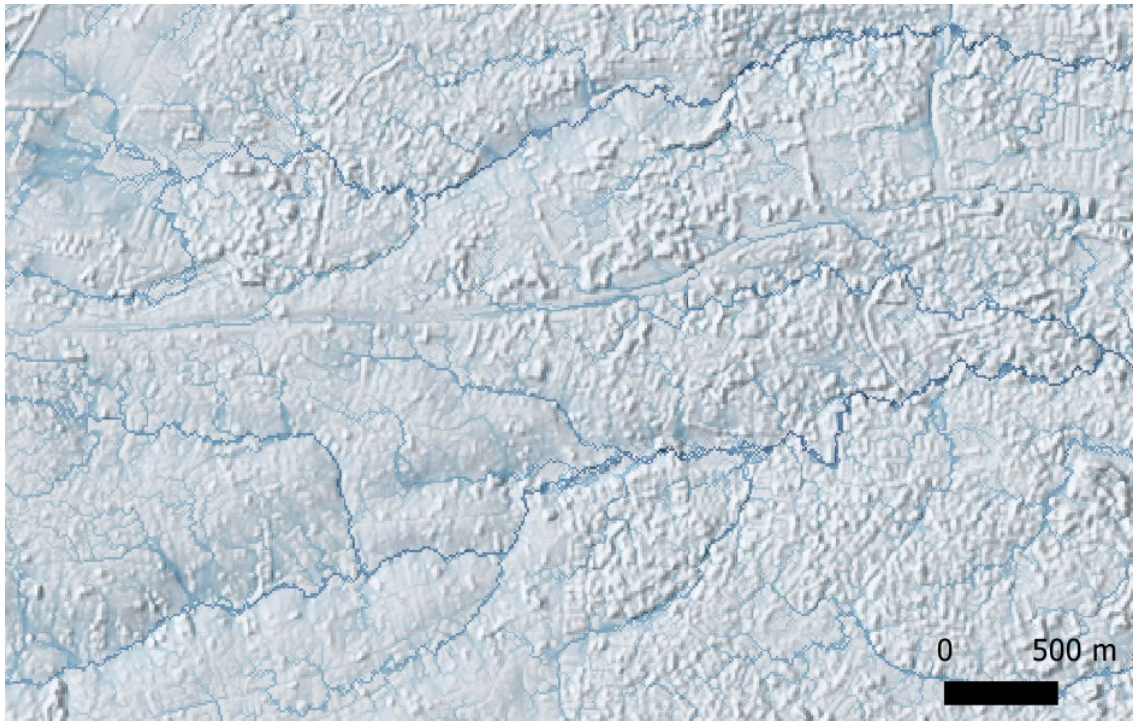
- Apply a similar deep learning workflow to that used in Bishkek to derive building stock datasets for risk modelling.
- Work with the Tomorrow's Cities team to integrate high resolution DEMs into flood and other risk modelling scenarios.

Volcanoes and active faults (GEM)



Current Pleiades acquisitions (left) and example of catchment runoff modelling in an area of east Nairobi (right)





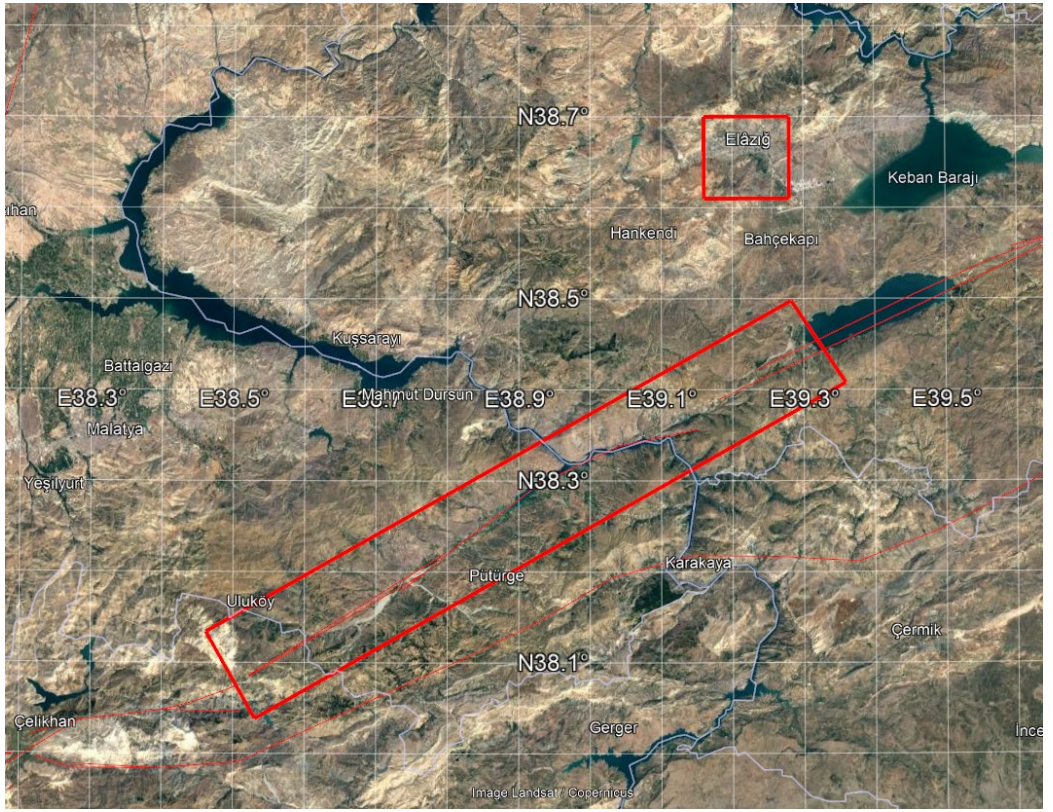
Due to length of time taken to acquire whole AOI, request to Airbus was made for early receipt of data prior to completion so research could commence, and data was received in January 2022.

Elazig, Turkey

2020 January 24th Mw 6.7 Elazig earthquake rupture along the East Anatolian Fault zone

University of Leeds asked to co-ordinate CEOS request on behalf of a number of interested groups

Pleaides Stereo Tasking requested over fault rupture zone and city of Elazig but no successful stereo imagery was acquired in the specified acquisition period

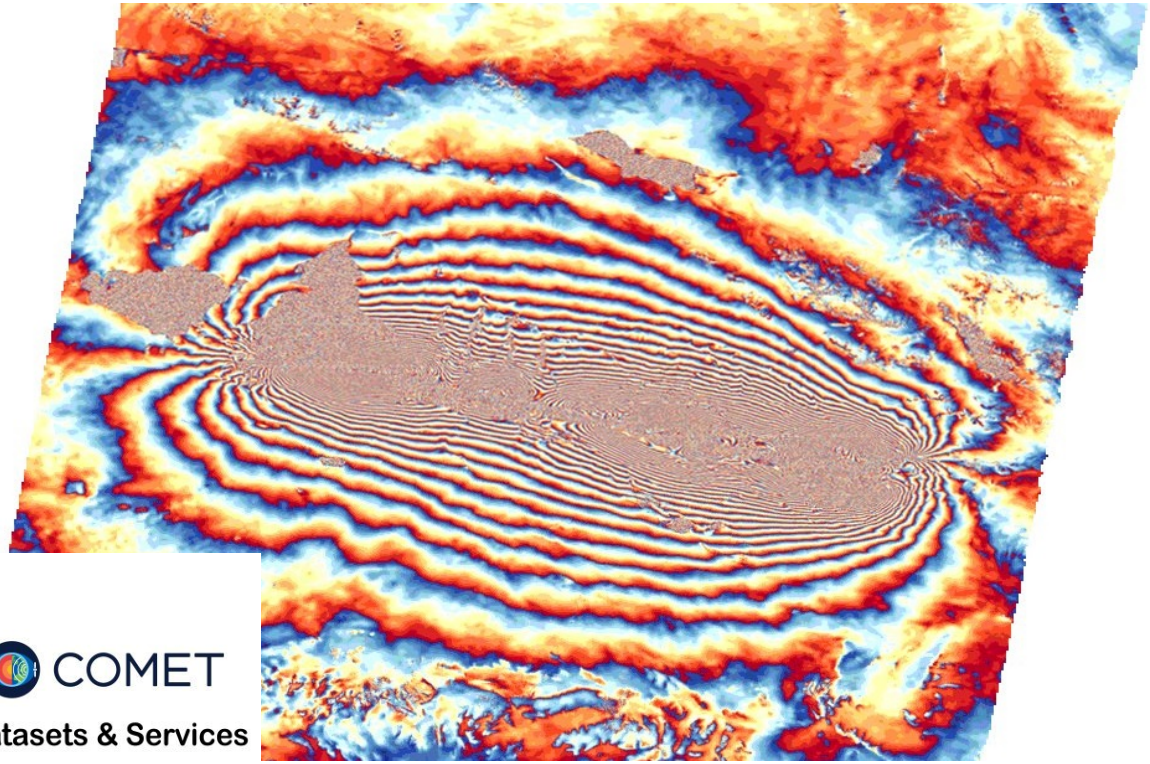


Qinghai, China 2421 sq km

Aim: derive 3D displacements following the May 2021 earthquake rupture

Progress:

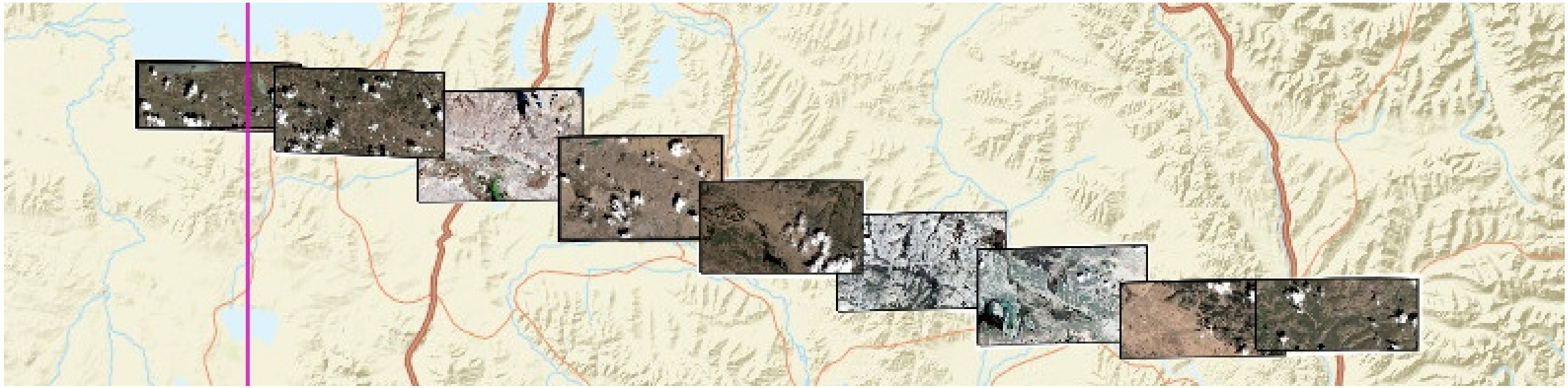
- Issues were identified in several acquisitions requiring Airbus/CNES technical support. Investigation is still ongoing.
- Not all of the AOI was was acquired cloud free before acquisition end date (due to snow) so incomplete coverage



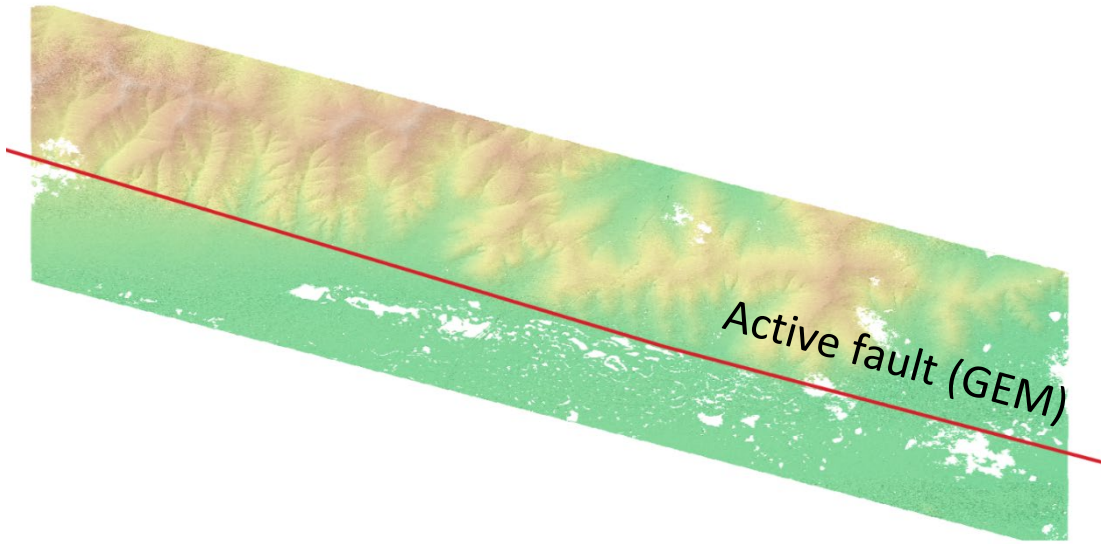
USGS Information:

Location	Date.Time.UTC	Magnitude	Depth.km
Southern Qinghai, China	2021-05-21 18:04:13	7.4	10

Pleiades acquisitions

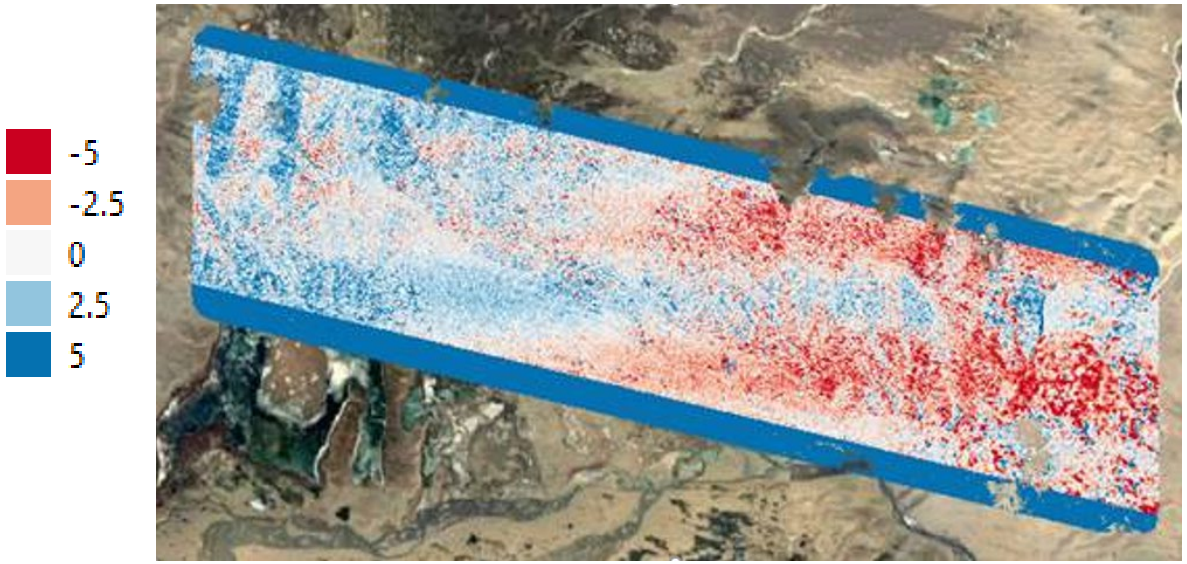


DEM generation



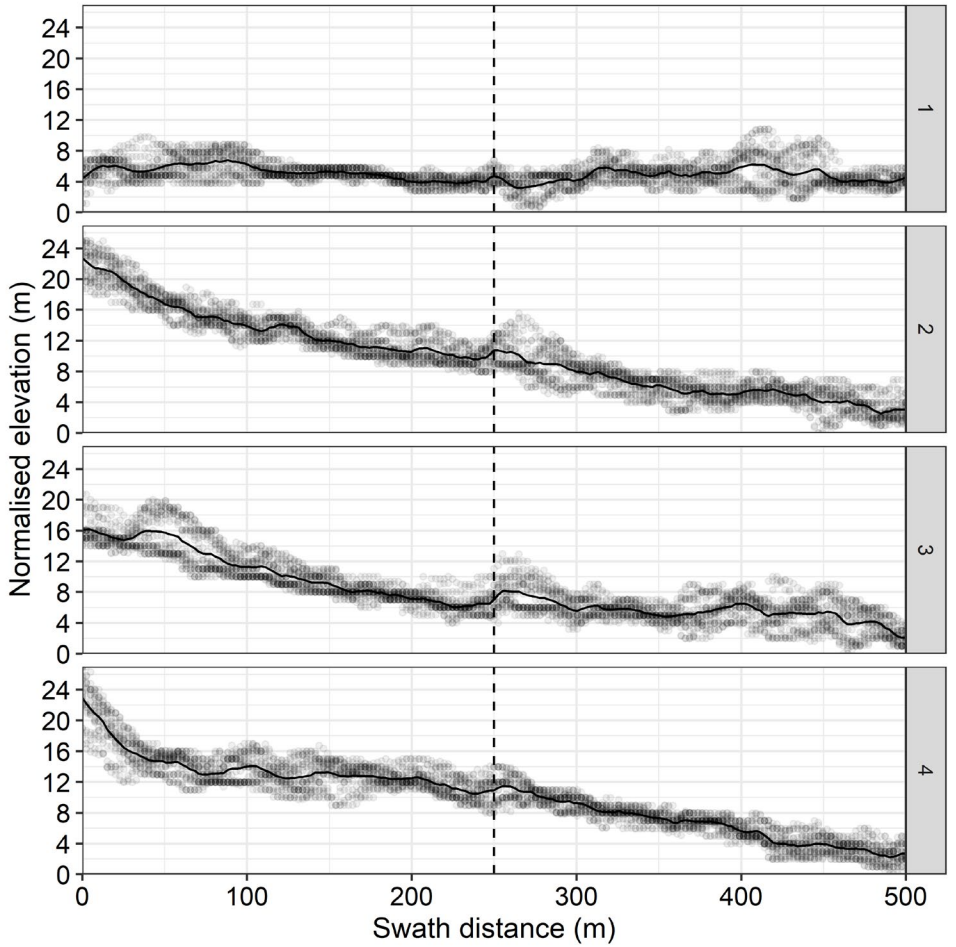
Investigation of issues of banding in DEMs of difference (left) and step artefacts in the 5 m ALOS World DEM (right)

Elevation difference (m) of the 5 m ALOS DEM subtracted from the Pleaides DEM. Scale is saturated at +/- 5 m:



The banding appears associated with poor tie point distribution/quality during image alignment.

Swath profiles showing a ~1 m step (dashed) in the 5 m ALOS DEM



Tehran, Iran 3,900 sq km

Archive Imagery (2014) over capital City of Iran (population 12 million)– high risk from major earthquakes

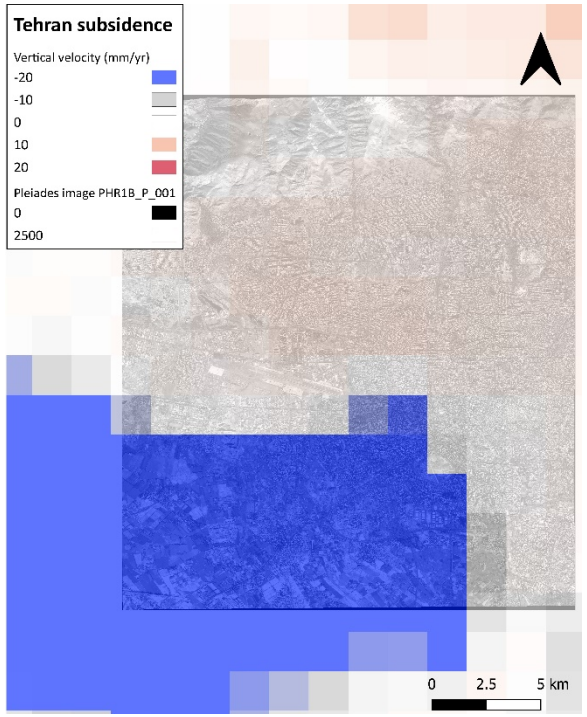
Received January 2022 so anyslsis only just initiated.

Aims are to generate DEMs over the city and:

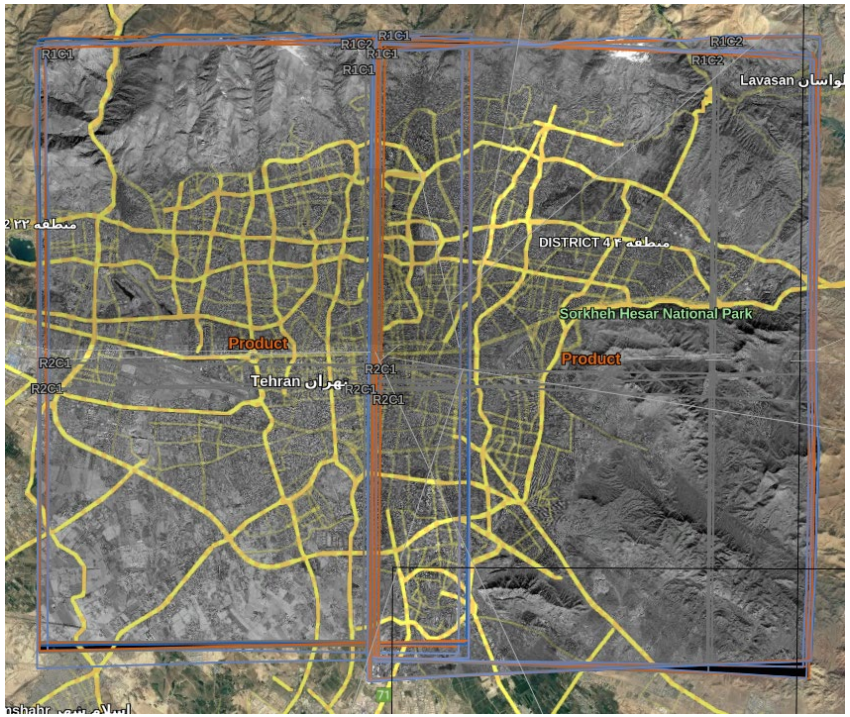
- Examine growth of anticlines and buried earthquake faults within city of Tehran
- Compare the quality of DEMs in the overlap region between Pleiades 1A & 1B
- Acquire new data in 202 to compare with 2014 dataset here for long term subsidence rates of basins due to water extraction (and compare with Sentinel-1 InSAR data and ICESAT-2 laser altimetry).

Tehran, Iran 3,900 sq km

SW TEHRAN VERTICAL VELOCITIES CALCULATED FROM 2015-2021 SENTINEL-1 INSAR TIME-SERIES DATA SHOWING BASIN SUBISDENCE



PLEIADES 0.5M PANCHROMATIC OPTICAL IMAGERY OF TEHRAN OVERLAYING GOOGLE EARTH OPTICAL IMAGERY. ROADS AND PLACE NAMES FOR REFERENCE.



Thanks

A huge thanks to CEOS and CNES for making available such great high resolution optical imagery datasets for the seismic hazard analysis.

Our experience with the data support from CEOS WG Disasters Seismic Demonstrator has been fantastic and the provision of Pleiades imagery data has been critical to underpinning much of our recent research. The Demonstrator has made important contributions to our recent and pending publications on seismic hazard and risk faced by cities in low and middle income countries that has enabled us to address the UN Sustainability Goals for Sustainable and Resilient Cities and Communities faced with seismic hazards.

Conclusions

The datasets have proved extremely useful in our research on seismic hazard.

- Without this opportunity, such dataset would have been prohibitive to secure by other means and we would not have been able to focus on as many case studies, nor over such large areas as needed for big scale tectonic and seismic hazard studies.
- They also underpin large parts of PhD datasets which train remote sensing specialists to subsequently work within the field of earth observation and natural hazard analysis.

Our predominant use of the data is for the derivation of DEMs from the stereo imagery, which is where we put in the most value added in terms of DEM generation, quality control and validation, and then subsequent interpretation of active faulting (hazard) and quantitative measurements for cities (exposure).

- This has meant we have move from not only considering the seismic hazard part of risk, but also looking at the exposure element in terms of the buildings from the DEM, imagery and machine learning analysis.
- The tri-stereo imagery from Pleiades has proven to be more successful for extracting buildings than from normal stereo which is a large advantage over other systems.

Conclusions

The datasets are of use to disciplines beyond that of solely seismic hazard, as we move into identifying multi-hazards within a DRR framework. Examples where we have collaborated on flooding have been shown.

The nature of the studies undertaken and acquisition of data means that such datasets have proven not to be as useful in terms of short-term rapid response of scientific understanding, but more the long term contribution to scientific knowledge – these data (stereo imagery) would need to be made available through the Disaster Charter for such rapid use.

The terms of imagery licences means we have had to carefully manage the distribution of the datasets to make sure we remain within the signed EULA agreements. This makes it harder to collaborate widely with overseas institutes and make sure we retain control of where the data is. This is where an Open Data policy would make such collaborative initiative easier.

We very much look forward to whether Pleaides Neo becomes part of any future process as we are excited to see what extra this higher resolution datasets can offer as it will in particular help within dense built environments.