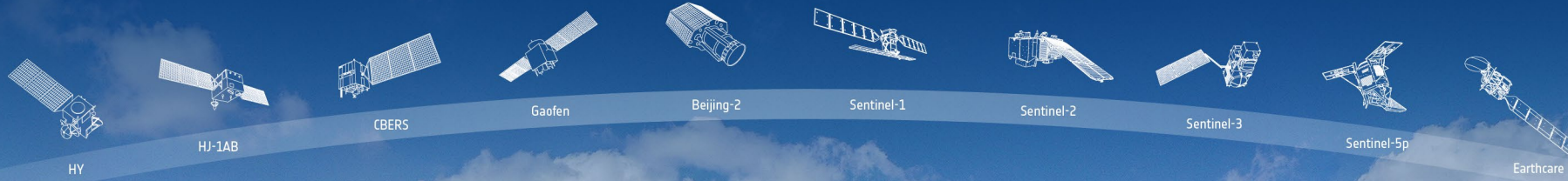




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2025 DRAGON 6 SYMPOSIUM

14-18 JULY 2025

PROJECT ID. 95374

**STAI4CH: SPATIO-TEMPORAL AI-BASED EO DATA MINING TO ASSESS
ANTHROPOGENIC IMPACTS AND SUSTAINABILITY MEASURES ON
CULTURAL HERITAGE ALONG ANCIENT AND MODERN WATERWAYS**



2025 Dragon 6 Symposium



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Wednesday, 16 July 2025 – h. 09:00 - 10:30

ID. 95374

PROJECT TITLE: **STAI4CH: SPATIO-TEMPORAL AI-BASED EO DATA MINING TO ASSESS ANTHROPOGENIC IMPACTS AND SUSTAINABILITY MEASURES ON CULTURAL HERITAGE ALONG ANCIENT AND MODERN WATERWAYS**

PRINCIPAL INVESTIGATORS: **Dr. Francesca CIGNA** [PI Europe], National Research Council (CNR) – ISAC, Italy
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Dr. Chenxiao ZHANG [Co-PI China], Wuhan University, China
Mr. Ming ZHAO [YS China], Wuhan University, China
Mr. Haoru WU [YS China], Wuhan University, China
Ms. Jennifer L. MAKOVICS [Co-PI Europe], Newcastle University, UK
Ms. Hope K. IRVINE [YS Europe], Newcastle University, UK



PRESENTED BY: Dr. Francesca CIGNA [PI Europe] & Dr. Chenxiao ZHANG [Co-PI China]

Dragon 6 – STAI4CH Project objectives



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For centuries, **waterways were strategic infrastructure** for communication, transportation, agriculture, mobility and trade of ancient Empires, both in Western and Eastern countries

They are **now embedded in modern landscapes** and represent a cultural heritage (CH) to safeguard from modern challenges (e.g. urbanization, development, mass tourism)

Physical transformations and surface changes cause a complete modification of land use and skyline in the buffer area surrounding the waterways and the heritage assets (e.g. historical buildings, green spaces, archaeological areas) distributed along them



Arc bridges across the Tiber River, Rome



The Grand Canal near its northern end in Beijing



View of the Grand Canal in Suzhou

STAI4CH's scientific goals

- Detect landscape transformations occurring across wide areas and with high temporal rates using EO optical and SAR data from Copernicus, ESA TPM and Chinese missions
- Develop Artificial Intelligence (AI) and Deep Learning (DL) methods to make the change detection task more cost-effective and replicable, and generate value-added maps
- Demonstrate and validate the developed methods to assess anthropogenic impacts on CH sites and waterways in Italy, China and Iraq

Dragon 6 – STAI4CH Use-cases



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Waterways and waterscapes of natural or manmade origin, for which the most recent UNESCO World Heritage Site (WHS) State of Conservation reports highlight modern transformations that may alter their outstanding universal value, the integrity of properties and visibility/connectivity corridors

- **Tiber river in Italy**

Crossing the Historic Centre of Rome UNESCO WHS and its hinterland up to the sea; the third-longest river in Italy (406 km) and the main watercourse of the city of Rome, capital of the Roman Empire, founded on its eastern banks



Sant'Angelo bridge crossing the Tiber river in Rome

- **Grand Canal WHS in China**

The longest artificial river in the world (1,794 km); a vast waterway system running from Beijing in the N to Zhejiang province in the S; conceived as a unified means of communication for the Empire for the first time in the 7th century AD (Sui dynasty)



Guangji bridge crossing the Grand Canal at ancient town of Tangqi

- **Ahwar (marshes) of Southern Iraq WHS**

Also known as the Iraqi Marshlands, refuge of biodiversity and the relict landscape of the Mesopotamian cities; made up of 3 archaeological sites (Uruk, Ur, Eridu) and 4 wetland marsh areas (Huwaizah, East and West Hammar and Central Marshes); one of the world's largest inland delta systems, in an extremely hot and arid environment



Waterways – Iraqi marshlands

Dragon 6 – STAI4CH EO data delivery



Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since June 2024) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

ESA/Copernicus Missions	No. Scenes
1. Sentinel-1 IW C-band SAR	14 / 550
2. Sentinel-2 MSI L2	28 / 1310
3.	
Total:	42 / 1860
Issues:	
- None Sentinel-1/2 images are being downloaded via Copernicus Data Space Ecosystem	

ESA Third Party Missions	No. Scenes
1. SkySat basic/ortho 0.5m	0 / 1250 km ²
2. ICEYE X-band SAR Spot 0.25m	0 / 60
3.	
Total:	60 + 1250 km ²
Issues:	
- TPM quotas not yet assigned by ESA/CSTEC Image acquisition tasking is due at the study sites for fine-tuning of the methods and validation	

Chinese EO data	No. Scenes
1. SDGSAT-1 MSI Multispectral Imager	0 / 210
2.	
3.	
Total:	0 / 210
Issues:	
- Quotas not yet assigned by ESA/CSTEC The methods development depend on these data. At the moment, the project team is working on test imagery delivered by CBAS (Research Center of Big Data for SDGs) via an external license	

MR and HR big data stacks for AI/DL-based LCC analysis, aiming to 6 month-long change detection periods, from the missions' background acquisition scenarios

VHR data for local scale CH detection and mapping, and fine-scale tuning and validation of the AI/DL-based LCC methodology

Google Maps, Bing Maps and Mapbox open imagery + *in kind* VHR COSMO-SkyMed SAR data acquired on the WHS in Italy and Iraq might also be analysed via synergy with other research projects led by the EU team



STAI4CH will exploit 3 methodological approaches

- i. Semantic segmentation Neural Network (NN) for CH sites based on EO self-supervised learning
- ii. CH sites change detection NN based on multi-source EO images
- iii. Spatial-temporal data organization and mining model of canal CH sites based on a data cube

Team experience

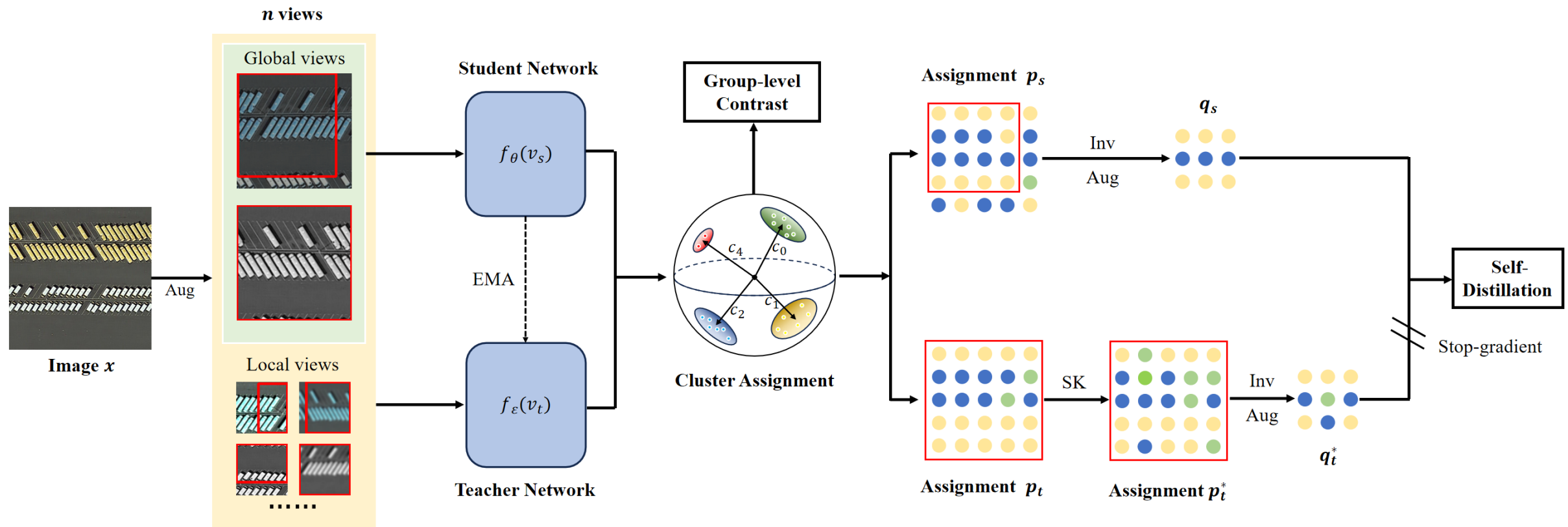
The Wuhan University team has a long experience in the development of AI and DL methods for multi-temporal Land Cover Change (LCC) detection, geospatial AI and geographic computing AI optimization, spatio-temporal information services, and a record of publications on these methods, including jointly with the CNR-ISAC and ASI teams:

- ZHANG C., YUE P., CIGNA F., TAPETE D. 2025. **OCA: Object-based Change Augmentation for few shot building change detection in very high-resolution remote sensing images**. *IEEE Transactions on Geoscience and Remote Sensing*, doi:10.1109/TGRS.2025.3584092
- GAO F., YUE P., CAO Z., ZHAO S., SHANGGUAN B., *et al.* 2022. **A multi-source spatio-temporal data cube for large-scale geospatial analysis**. *Int. J. Geogr. Inform. Sci.*, 36(9), 1853-1884
- YUE P., SHANGGUAN B., HU L., JIANG L., ZHANG C., CAO Z., PAN Y. 2022. **Towards a training data model for artificial intelligence in Earth observation**. *Int. J. Geogr. Inform. Sci.*, 36(11), 2113-2137
- ZHANG C., FENG Y., HU L., TAPETE D., PAN L., LIANG Z., CIGNA F., YUE P. 2022. **A domain adaptation neural network for change detection with heterogeneous optical and SAR remote sensing images**. *Int. J. Appl. Earth Obs. Geoinf.*, 109, 102769
- ZHANG C., YUE P., TAPETE D., JIANG L., SHANGGUAN B., HUANG L., LIU G. 2020. **A deeply supervised image fusion network for change detection in high resolution bi-temporal remote sensing images**. *ISPRS J. Photogr. Remote Sens.*, 166, 183-200



Semantic segmentation Neural Network (NN) for CH sites based on EO self-supervised learning

- *A Cluster based Self-supervised Pre-training Method for Semantic Segmentation of Remote Sensing Images*



Dragon 6 – STAI4CH Methodologies



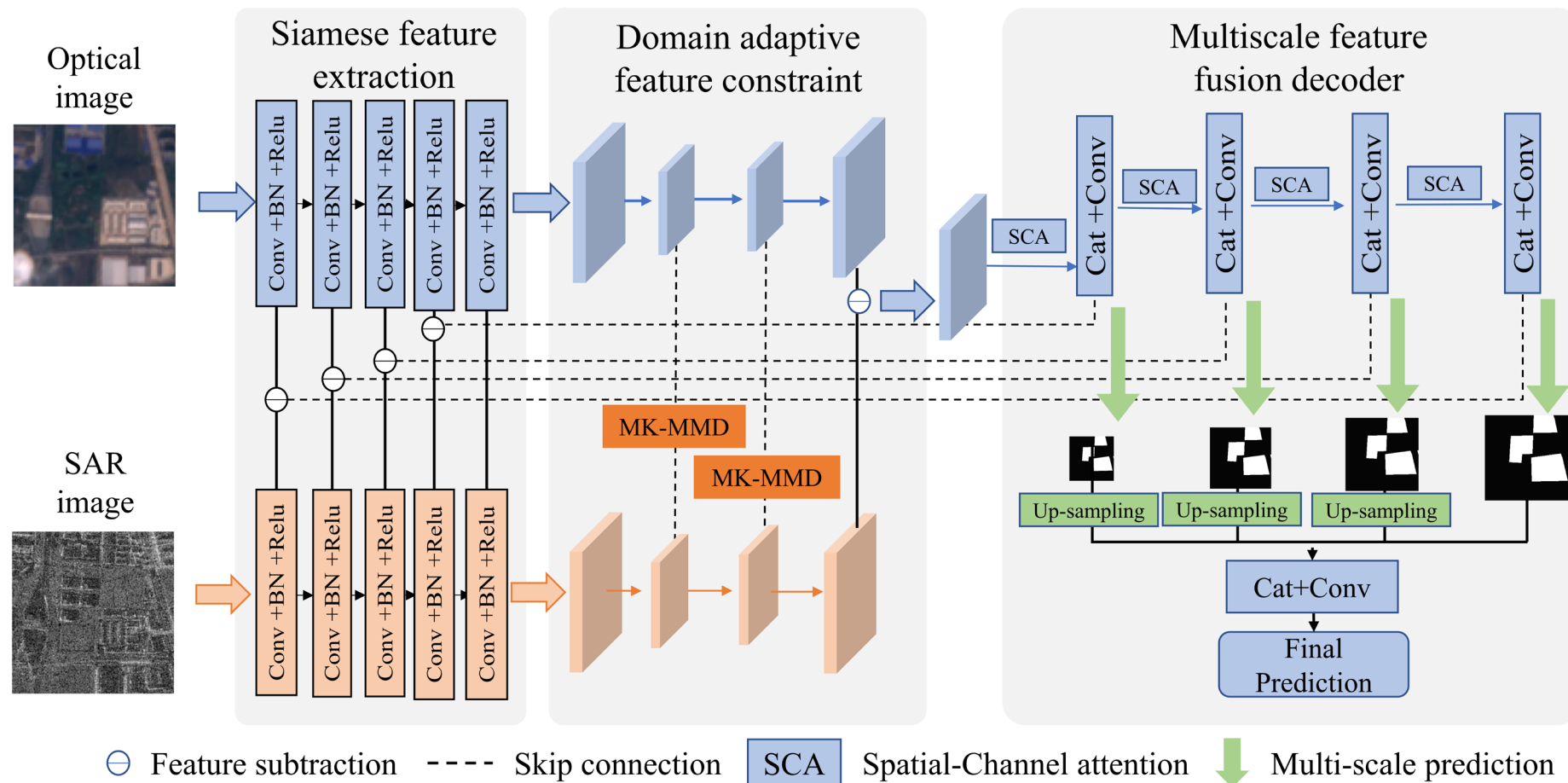
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CH sites change detection NN based on multi-source EO images

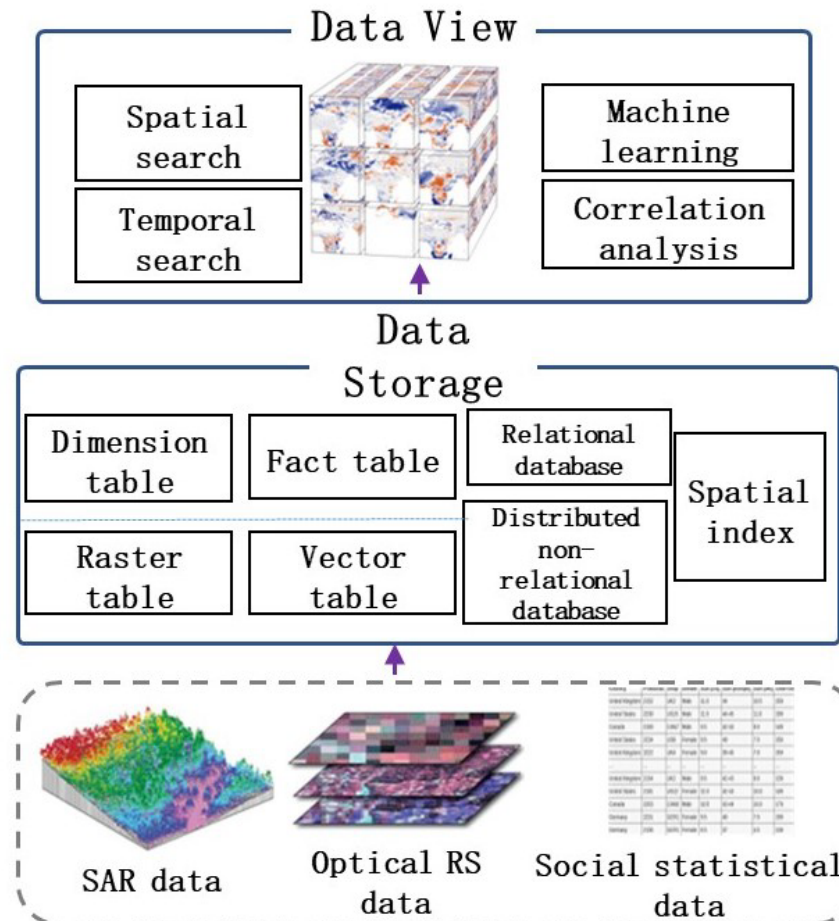
- A domain adaptation neural network for change detection with heterogeneous optical and SAR remote sensing images*





Spatial-temporal data organization and mining model of canal CH sites based on a data cube

- *A multi-source spatio-temporal data cube for large-scale CH geospatial analysis*



Dragon 6 – STAI4CH First experiments

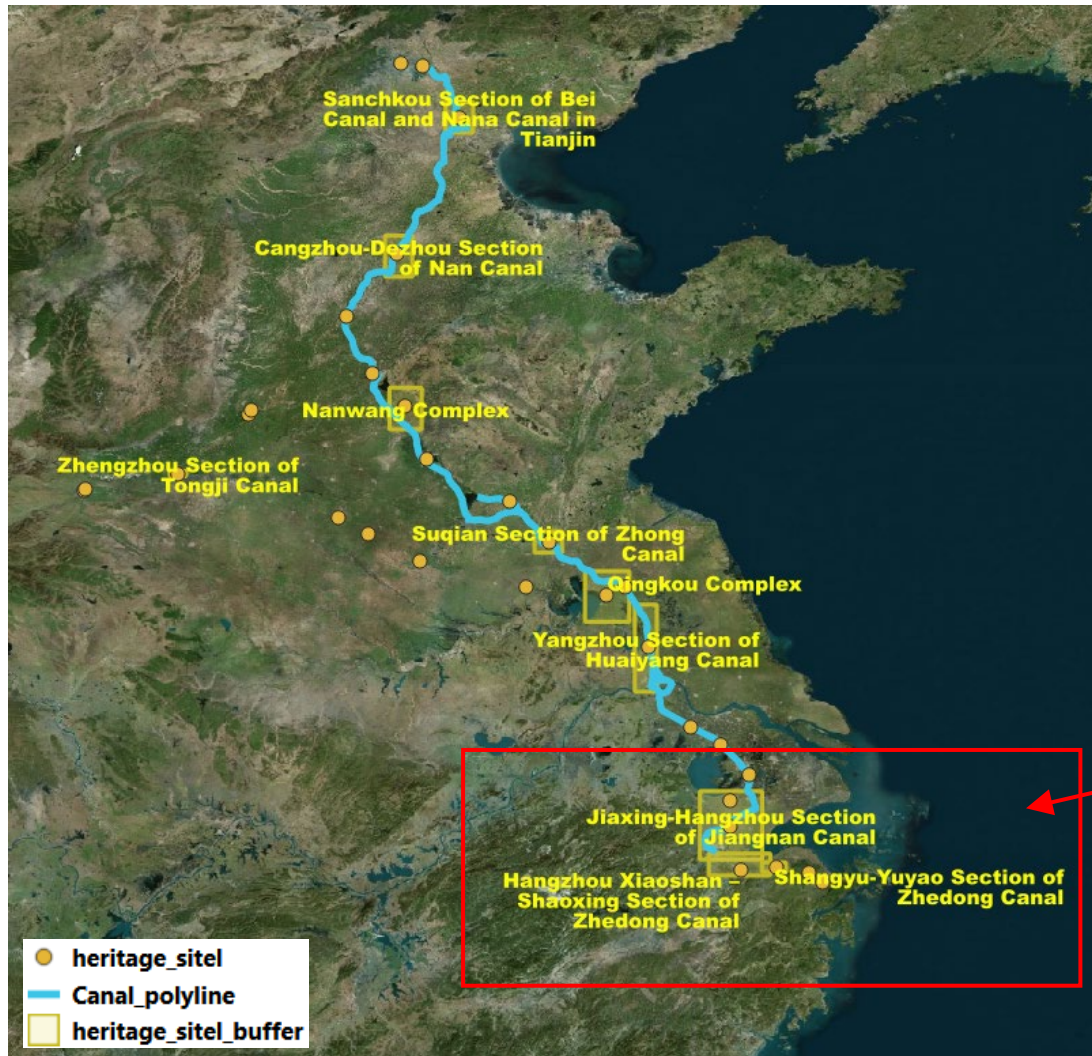


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Study area: **Grand Canal WHS**



HERITAGE

31 heritage sites (based on UNESCO World Heritage Convention website (<https://whc.unesco.org/en/list/1443/maps/>)), among which, **10 interest regions** (“buffer” sites) were selected

GOAL

To easily observe the changes in river runoff, two satellite observation windows each year were selected:

- June to August (**Rain season**)
- October to February (**Dry season**)

TESTING AOI

Southern sector, including 3 interest regions:

- ID 1443bis-016: Jiaxing-Hangzhou Section of Jiangnan Canal
- ID 1443bis-018: Hangzhou Xiaoshan-Shaoxing Section of Zhedong Canal
- ID 1443bis-019: Shangyu-Yuyao Section of Zhedong Canal

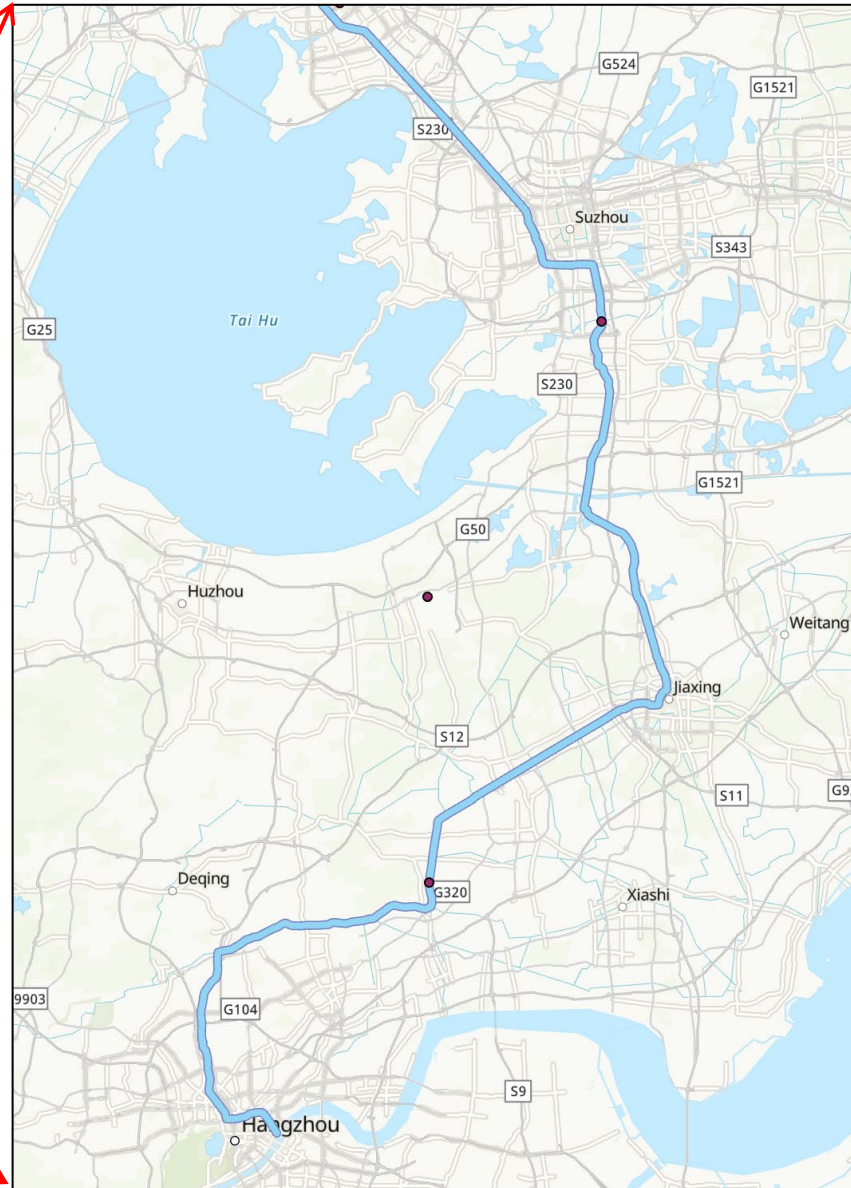
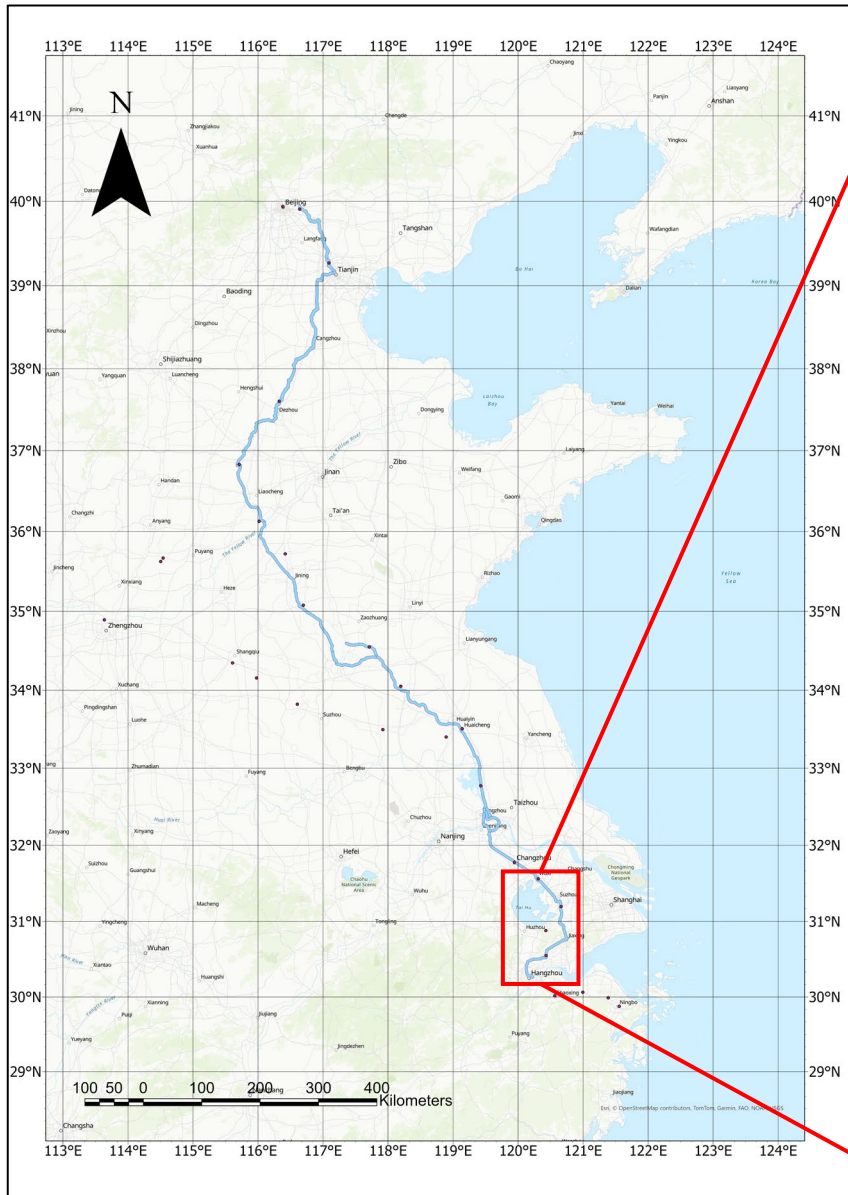
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Study area:
South of the Grand Canal

About **1/8** length of the Grand
Canal

Start at **WuXi** city,
end at **HangZhou** city

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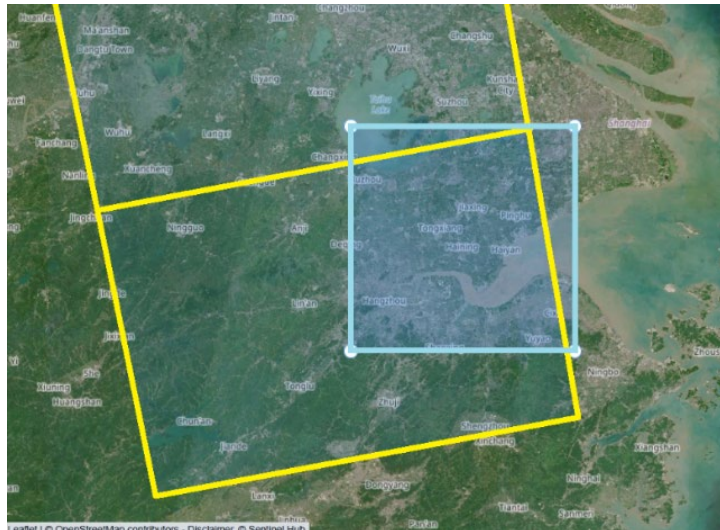


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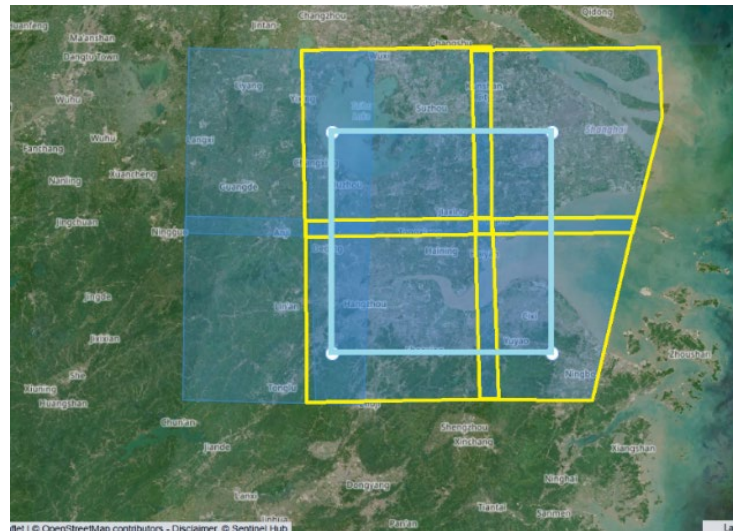
EO data

To start the first trials of land use classification and change detection, we explored the satellite image catalogues for multispectral and SAR data at medium resolution:

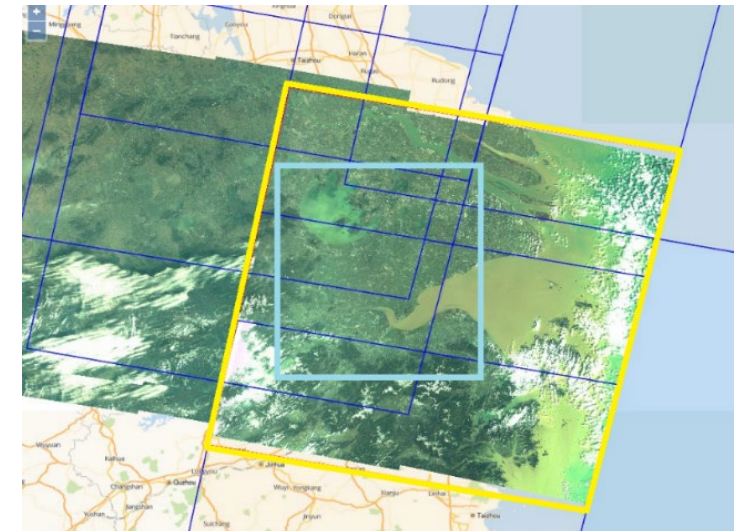
Copernicus Sentinel-1 Synthetic Aperture Radar (SAR), IW mode, dual polarization (VV,VH), ascending orbit
Level-1 (ground range detected)
10 m resolution



Copernicus Sentinel-2 Multi-Spectral Imager (MSI)
Level 2A (calibrated, orthorectified, surface reflectance)
10 m resolution



SDGSAT-1 Multispectral Imager (MII)
Level-4A (calibrated, orthorectified)
10 m resolution
Accessed via external license with CBAS; not through Dragon-6



Dragon 6 – STAI4CH First experiments



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EO data

Satellite & sensor	Acquisition date	File names	Tile location	Size
Sentinel-1 SAR	06/02/2022	S1A_IW_GRDH_1SDV_20220206T100327_20220206T100352_041791_04F952_F244.SAFE.zip S1A_IW_GRDH_1SDV_20220206T100302_20220206T100327_041791_04F952_A201.SAFE.zip	north south	3.2 GB
	24/07/2022	S1A_IW_GRDH_1SDV_20220724T100334_20220724T100359_044241_0547C5_B4B4.SAFE.zip S1A_IW_GRDH_1SDV_20220724T100309_20220724T100334_044241_0547C5_A590.SAFE.zip	north south	3.2 GB
	20/01/2023	S1A_IW_GRDH_1SDV_20230120T100333_20230120T100358_046866_059EA8_15E6.SAFE.zip S1A_IW_GRDH_1SDV_20230120T100308_20230120T100333_046866_059EA8_1C90.SAFE.zip	north south	3.2 GB
Sentinel-2 MSI	27/02/2022	S2B_MSIL2A_20220227T023639_N0510_R089_T51RTQ_20240518T170448.SAFE.zip S2B_MSIL2A_20220227T023639_N0510_R089_T51RUQ_20240518T170448.SAFE.zip S2B_MSIL2A_20220227T023639_N0510_R089_T51RTP_20240518T170448.SAFE.zip S2B_MSIL2A_20220227T023639_N0510_R089_T51RUP_20240518T170448.SAFE.zip	north-west north-east south-west south-east	4 GB
	27/07/2022	S2B_MSIL2A_20220727T023529_N0400_R089_T51RTQ_20220727T054649.SAFE.zip S2B_MSIL2A_20220727T023529_N0400_R089_T51RUQ_20220727T054649.SAFE.zip S2B_MSIL2A_20220727T023529_N0400_R089_T51RTP_20220727T054649.SAFE.zip S2B_MSIL2A_20220727T023529_N0400_R089_T51RUP_20220727T054649.SAFE.zip	north-west north-east south-west south-east	4 GB
	28/01/2023	S2A_MSIL2A_20230128T023951_N0510_R089_T51RTQ_20240811T193200.SAFE.zip S2A_MSIL2A_20230128T023951_N0510_R089_T51RUQ_20240811T193200.SAFE.zip S2A_MSIL2A_20230128T023951_N0510_R089_T51RTP_20240811T193200.SAFE.zip S2A_MSIL2A_20230128T023951_N0510_R089_T51RUP_20240811T193200.SAFE.zip	north-west north-east south-west south-east	4 GB
SDGSAT-1 MII	24/02/2022	KX10_MII_20220224_E121.17_N30.58_202200110123_L4A.zip	-	10.4 GB
	27/07/2022	KX10_MII_20220727_E120.14_N30.15_202200124366_L4A.zip	-	9.9 GB
	27/01/2023	KX10_MII_20230127_E120.12_N31.27_202300013440_L4A.zip	-	10.8 GB

Dragon 6 – STAI4CH First experiments

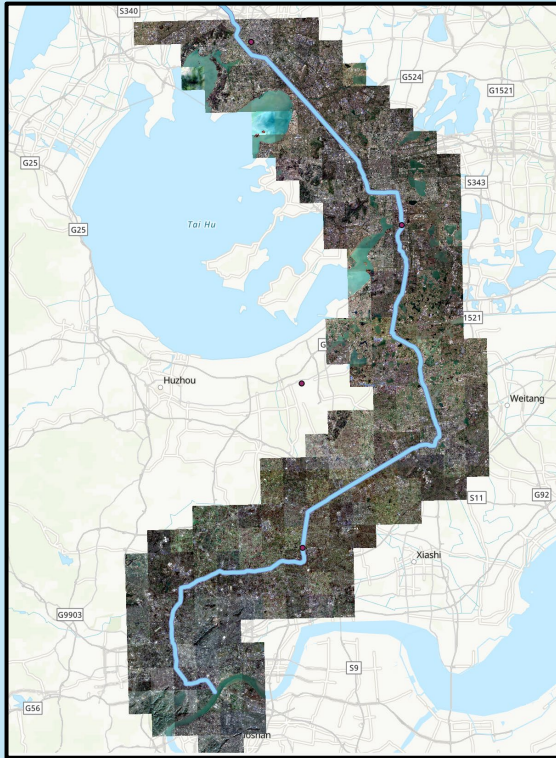


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Training and testing data split



Manually labeled 226 images

Training image size:
512*512



Sentinel-2 RGB
Time: 20220227



Sentinel-2 RGB
Time: 20220727



Sentinel-2 RGB
Time: 20230128

Testing images size: 15000*20982

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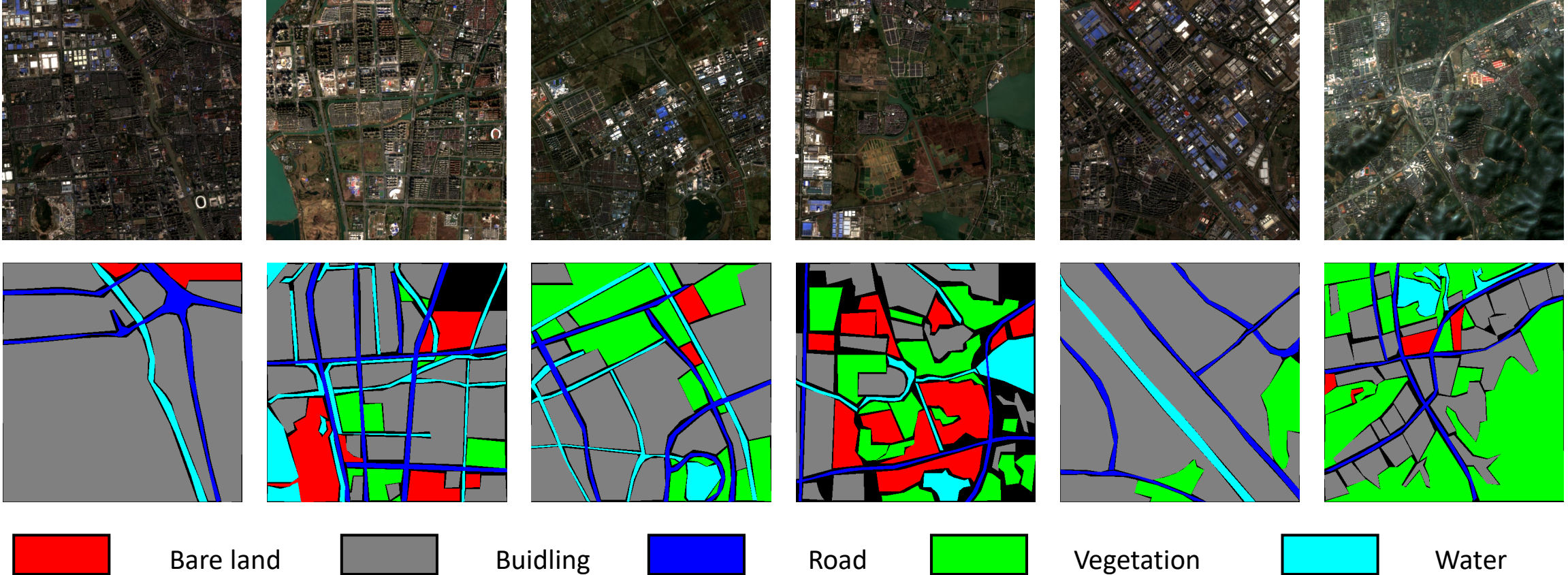


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Labeled image examples



Five major land covers were labeled considering the low-resolution of Sentinel-2 RGB image (10 m)

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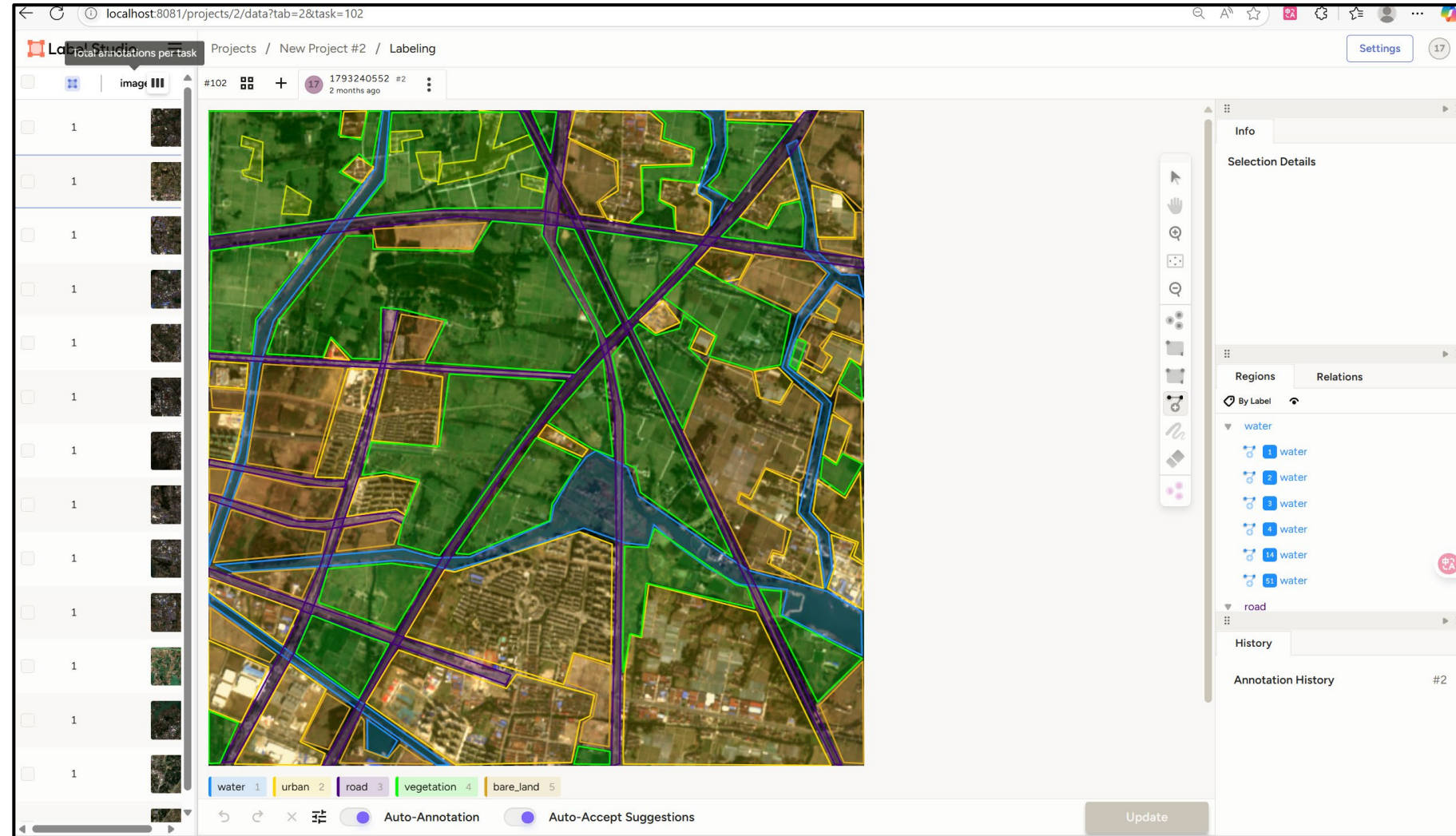


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Label land cover with LabelStudio+SAM

We used **LabelStudio** as the labeling tool.

1. Split large image into small patches
2. Load patches into **LabelStudio**
3. Draw boundary of each segment
4. Assign the category of each segment
5. Export labeled results as json files
6. Convert json files to 2d png files



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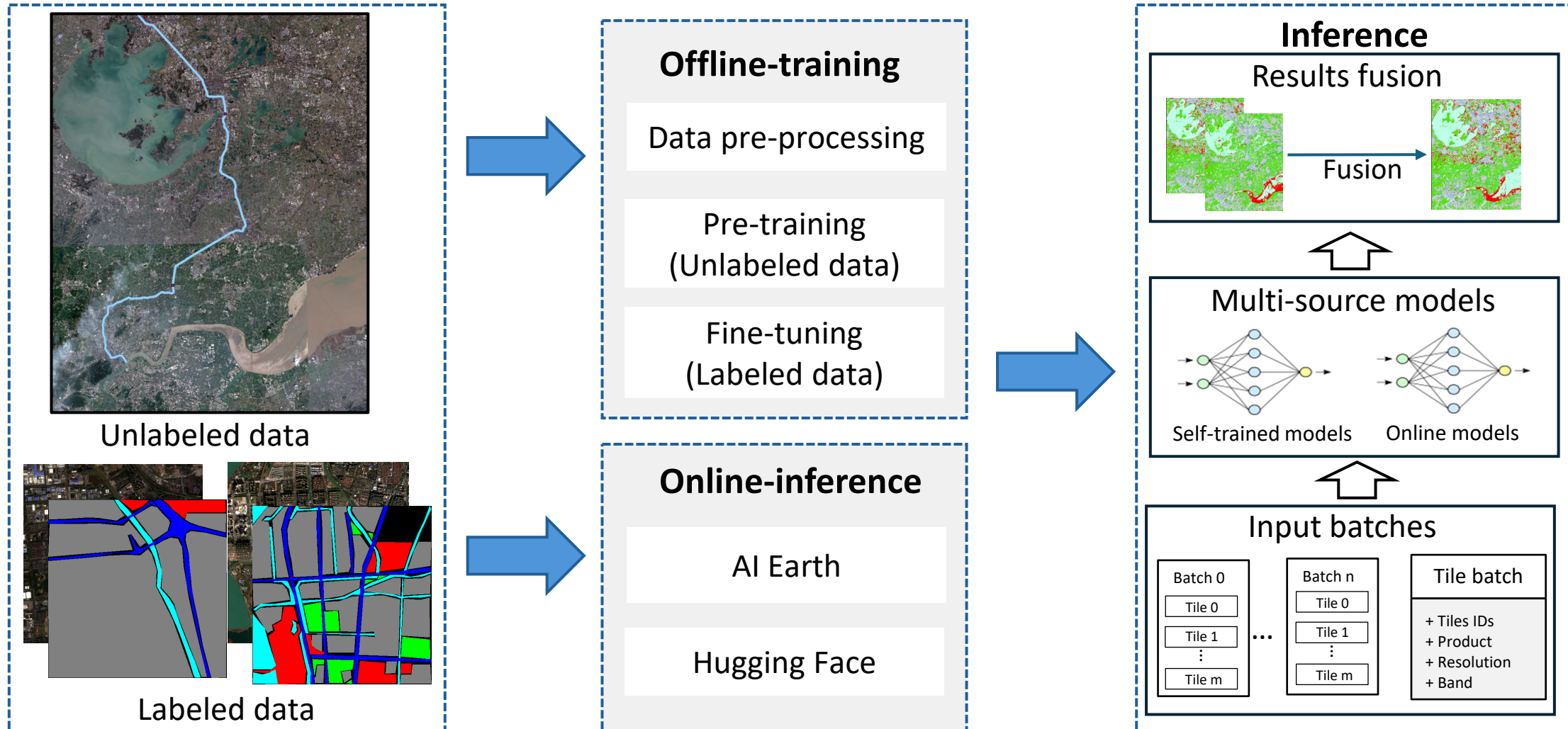


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Large-scale land cover classification based on multi-model fusion



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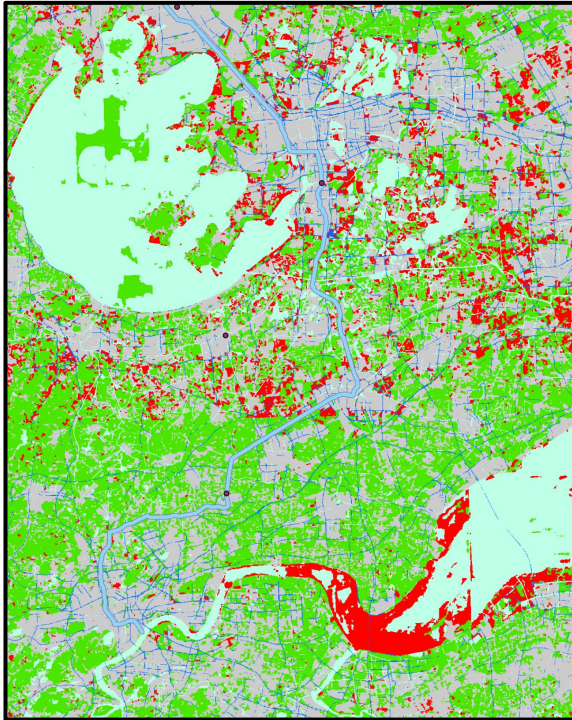
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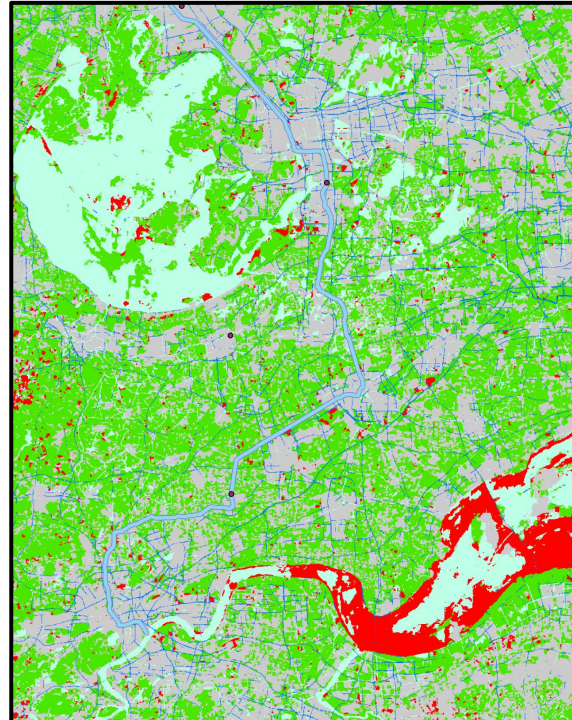
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Preliminary land cover classification results

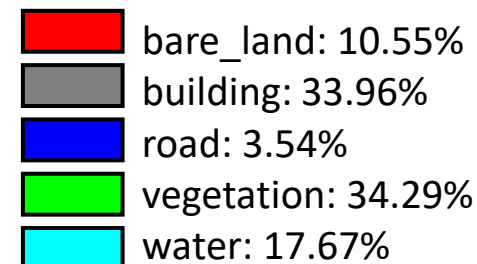
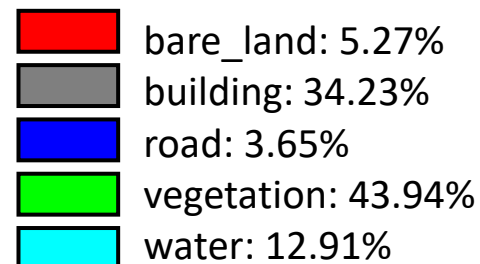
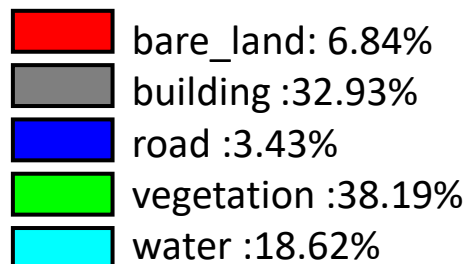
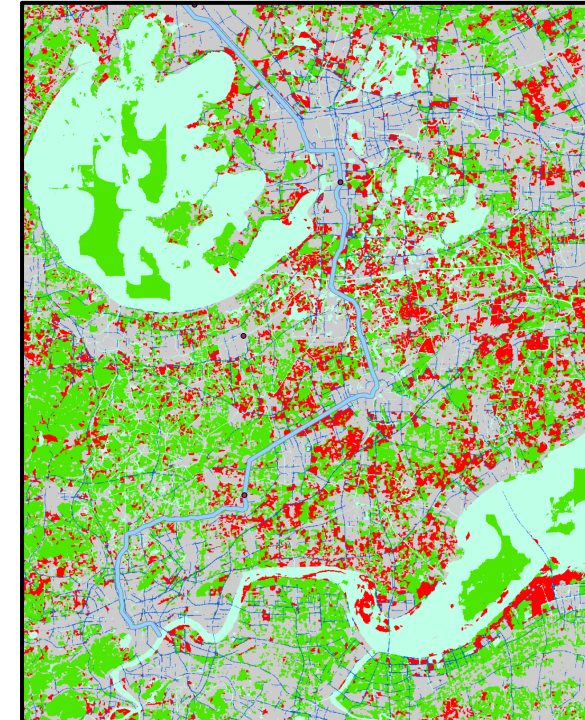
Time: 20220227



Time: 20220727



Time: 20230128



Segmentation model:
Swin-transformer



Next steps

Models:

1. Modify/design segmentation models for low-resolution images (10 m or lower)
2. Investigate multi-source (e.g., SAR, RGB, ...) fusion models
3. Investigate robust domain transfer learning approaches

Data:

1. Introduce crowd sourced datasets (e.g., OpenStreetMap) for automatic labeling
2. Conduct satellite image preprocessing to alleviate domain discrepancy (e.g., histogram matching)

Chinese Young Scientists contributions in Dragon 6



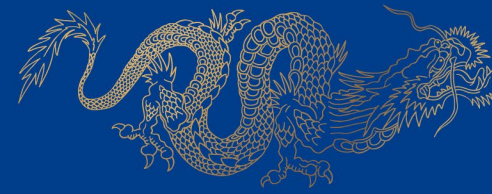
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Name	Institution	Poster title	Contribution including period of research
Mr. Haoru WU	Wuhan University	-	• PhD scholarship funded by Wuhan University on geospatial information engineering • Is training on big geospatial data infrastructure and deep learning-based EO methods • Will develop a data cube method for large-scale CH sites multi-source data management
Mr. Ming ZHAO	Wuhan University	-	• PhD scholarship funded by Wuhan University on geospatial intelligence • Will be trained on deep learning-based EO methods and remote sensing image interpretation • Is developing robust segmentation and change detection models
Mr. Hanwen XU	Wuhan University	id.185 - A clustering-based pre-training method for remote sensing semantic segmentation	• PhD scholarship funded by Wuhan University on remote sensing image processing • Is developing a pre-trained model for remote sensing segmentation task • Will develop an open-set segmentation model for remote sensing images

Overview of Chinese YSs research



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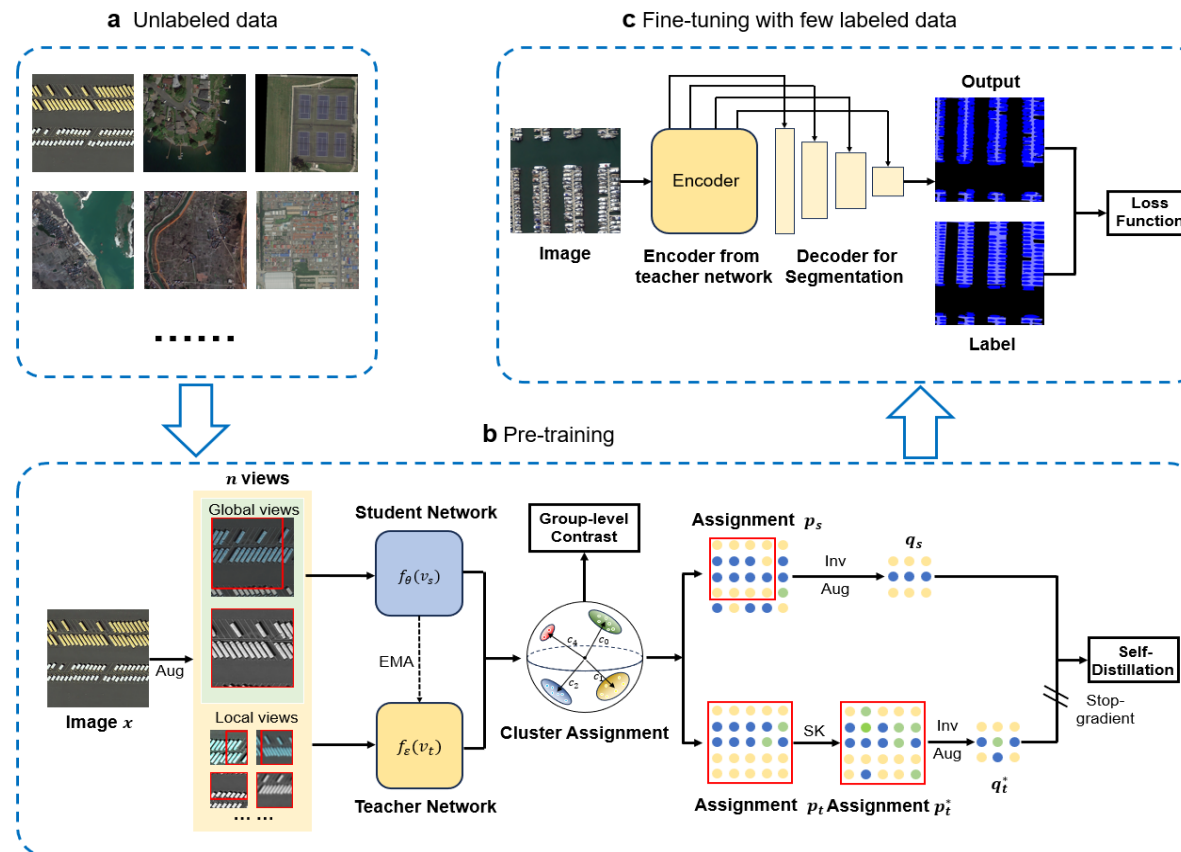
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A clustering-based pre-training method for remote sensing semantic segmentation (poster 185)

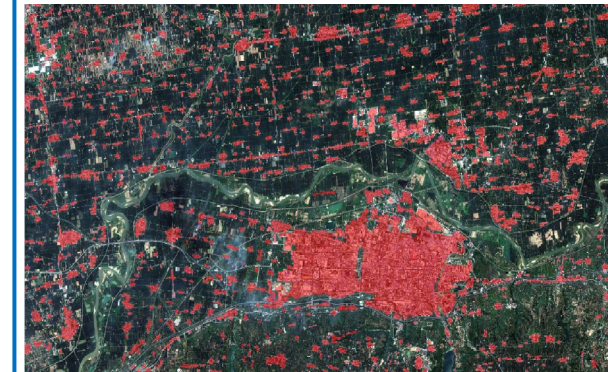
Hanwen XU, Wuhan University

Propose a clustering-based pre-training method to address the issue that semantic segmentation models require large amounts of labeled samples during application.

- **Unlabeled data:** Data for pre-training.
- **Pre-training:** Five parts: augmentation, Siamese networks, assignment, self-distillation training, and clustering constraint.
- **Fin-tuning:** Fine-tuning with few labeled data.



Results





STAI4CH will exploit different data sources for validation

- i. Extensive specialist literature on the 3 study areas, especially in relation to mapping CH and tracking past landscape changes
- ii. Previously collected field evidence and independent EO-based observations from other projects (e.g. in Italy and Iraq)
- iii. Field data observations directly collected at the 3 study areas during the project's lifetime (e.g. in China and Italy)

Team experience

The CNR-ISAC, ASI and Newcastle University teams have a long experience in multi-source EO optical and SAR image analysis, landscape archaeology and CH monitoring, mapping natural/anthropogenic hazards in urban/rural environments, and a track record of projects and joint publications on these topics, including with a focus on sites in Rome and Iraq:

- CIGNA F., RAYNE L., MAKOVICS J.L., IRVINE H.K., JOTHERI J., ALGABRI A., TAPETE D. 2025. **Environmental challenges and vanishing archaeological landscapes: Remotely sensed insights into the climate–water–agriculture–heritage nexus in southern Iraq.** *Land*, 14 (5), 1013
- CIGNA F., TAPETE D., RAYNE L., MAKOVICS J.L., IRVINE H.K., DE GRUCHY M.W., JOTHERI J. 2024. **Assessing anthropogenic and climate change threats to archaeological landscapes in Iraq using Earth observation.** *Proc. IEEE M2GARSS 2024*, 424-428
- CIGNA F., BALZ T., TAPETE D., CASPARI G., FU B., ABBALLE M., JIANG H. 2024. **Exploiting satellite SAR for archaeological prospection and heritage site protection.** *Geo-spatial Inform. Sci.*, 27 (3), 526-551
- TAPETE D., CIGNA F. 2022. **Detection, morphometric analysis and digital surveying of archaeological mounds in Southern Iraq with CartoSat-1 and COSMO-SkyMed DEMs.** *Land*, 11 (9), 1406
- TAPETE D., TRAVIGLIA A., DELPOZZO E., CIGNA F. 2021. **Regional-scale systematic mapping of archaeological mounds and detection of looting using COSMO-SkyMed high resolution DEM and satellite imagery.** *Remote Sens.*, 13 (16), 3106

European Young Scientists contributions in Dragon 6



Name	Institution	Poster title	Contribution including period of research
<i>To be recruited</i> (delayed given that ESA's contract was signed only in June 2025)	CNR-ISAC	-	• Scholarship to be funded through Dragon-6 on EO data analysis and validation of AI-based change detection datasets • Will be trained on optical and SAR data analysis and interpretation • Will contribute to Dragon-6 Symposia with YS posters [2026–2028]
Ms. Hope K. IRVINE	Newcastle University	id.117 - Mapping ancient irrigation systems in southern Iraq using high-resolution satellite imagery	• PhD scholarship funded by UK Engineering & Physical Sciences Research Council (EPSRC) on image recognition algorithms to detect heritage in the Middle East/North Africa region [2024–ongoing] • Contributes to validating AI-based change detection datasets in Iraq

Overview of European YSs research



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Mapping ancient irrigation systems in southern Iraq using high-resolution satellite imagery (poster id.117)

Hope K. IRVINE, Newcastle University

Goal

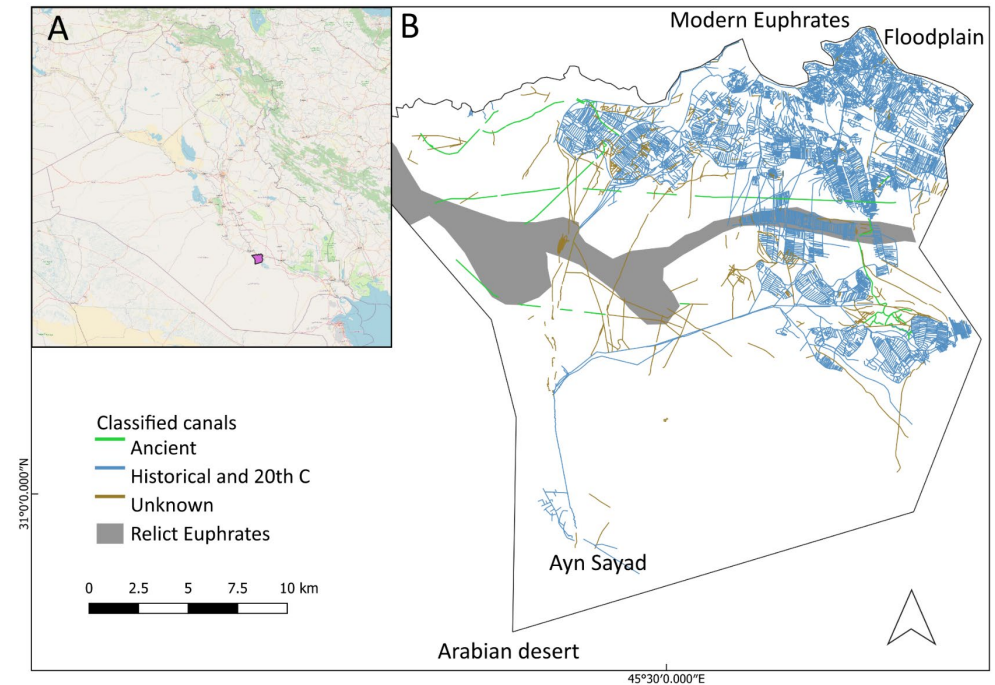
To map ancient water management features in archaeological landscapes of southern Iraq to generate a robust satellite-based validation layer to test the novel AI and DL methods being developed within STAI4CH

EO Data & Processing

- Declassified HEXAGON (KH-9) 1974-1981 photographs, 0.6 m resolution
- Pléiades Neo 2022-2024 images; 6 bands pansharpened to the 0.3 m panchromatic band with Gram-Schmidt algorithm
- Landsat (from 1985) and Sentinel-2 (from 2018) multispectral imagery obtained via Google Earth Engine
- Google Earth VHR imagery & SRTM digital surface model

Chronological classification	Description
Ancient canals	3 rd to 1 st millennium B.C. canals connected to the relict Euphrates
Historical canals	Sassanian, Early Islamic, Ottoman but can be in use until 20 th century. Connected to the modern Euphrates or Ayn Sayed
20 th century canals	Canals supply active field systems in HEXAGON
Modern canals	Not present in HEXAGON, present in Pléiades Neo/Google Earth

Chronological classification of canals



Analysis & Classification Key

- A standardised image interpretation approach and a classification key based on imagery characteristics and abstraction points were developed to separate the systems; the mapping provides a proxy for field system locations

Existing research collaboration on southern Iraq



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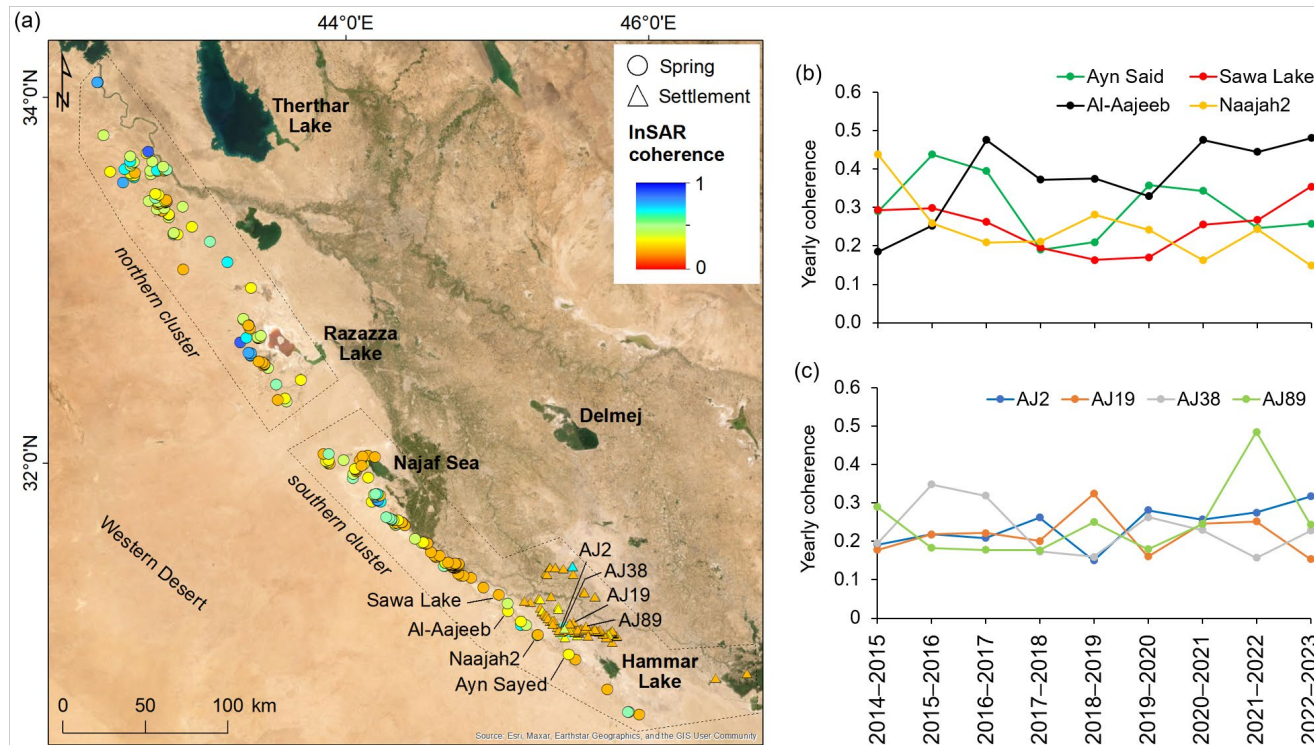


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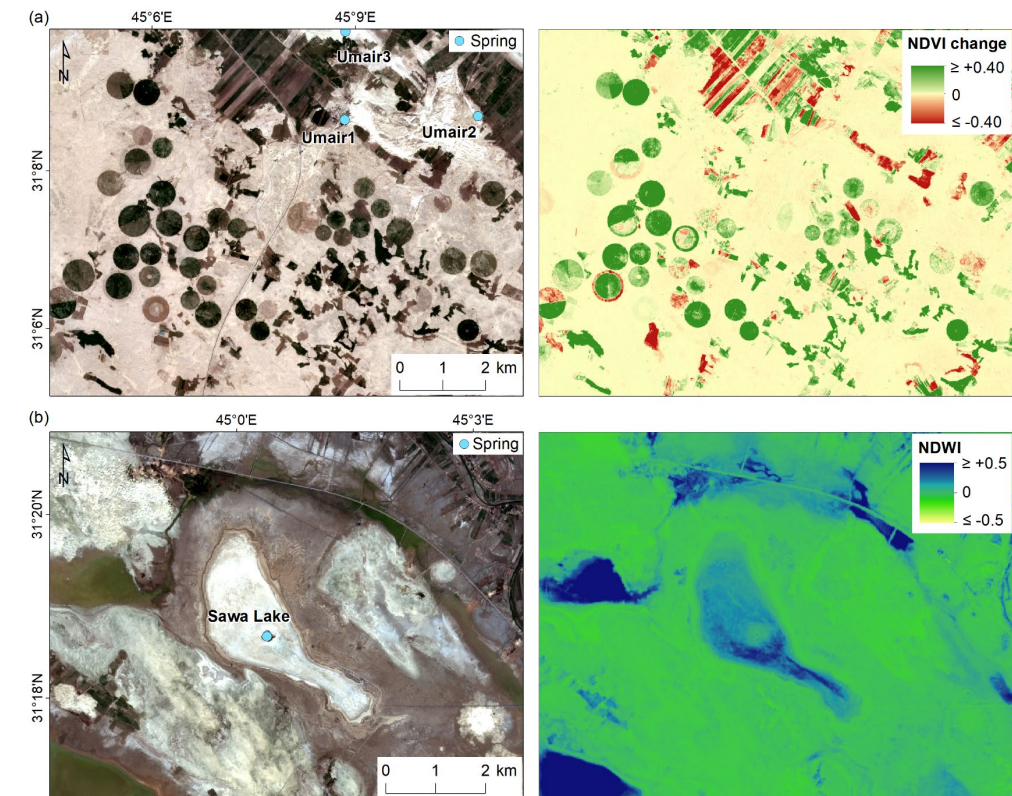
Bilateral CNR/Royal Society of the UK project 2023-2024

“Vanishing archaeological landscapes under anthropogenic and climate change threats”

CNR PI: Francesca Cigna; UNEW PI: Louise Rayne

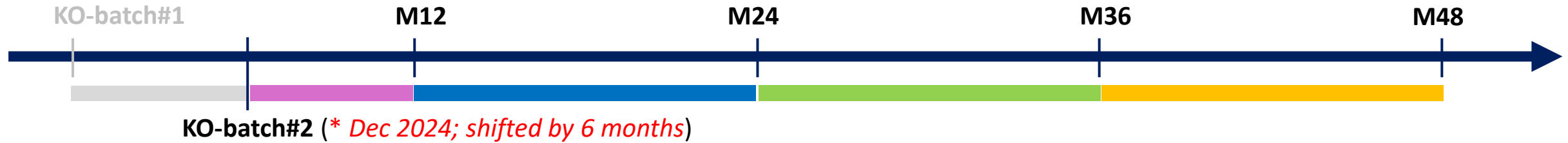


Sentinel-2 (a) true-colour 2022 and NDVI change in 2021–2022 at centre-pivot systems close to ancient spring locations in the area southwest of Samawah town and (b) true-colour and NDWI at Sawa Lake in 2023.



Sentinel-1 InSAR coherence based change detection study: average yearly change at the 194 ancient springs along the Abu Jir lineament and 94 ancient settlements and tells west of Uruk

Dragon 6 – STAI4CH Revised project timeline



YEAR 1 *

- Initial EO data collection and quality checking for 1 of the 3 AOIs – **workaround adopted to mitigate delayed kick-off and EO data issues**
- Development of initial versions of the AI and mining methods: high-generalization monitoring method of CH feature coverage, and the multi-source EO AI-based change detection method for CH combining the advantages of optical and SAR through data fusion

YEAR 2

- Further EO data collection for the 3 AOIs, EO data acquisition tasking and improvement of the developed algorithms – **conditional upon the provision of ESA TPM and Chinese EO data**
- Running of the use-cases via CH mapping, results interpretation and generation of geodatabases and change maps

YEAR 3

- Development of the spatio-temporal data cube organization and data mining approach
- Comprehensive categorization of CH types in the 3 UNESCO WHS waterways and LCC due to anthropogenic processes
- Organisation of multi-source heterogeneous data in the form of CH cubes, and provision of efficient multi-dimensional data query services

YEAR 4

- Mapping of large-scale and long-term analysis tasks to slice data under the same spatio-temporal network
- Generation of the output prototype LCC maps and geodatabases in each WHS
- Assessment of product accuracy via ground-truth data from collaborating projects or *ad hoc* validation surveys
- Assessment of the AI-based method adaptability to suit CH applications at different spatio-temporal scales by comparing the 3 use-cases, to unveil commonalities and differences in CH conservation challenges

Dragon 6 – STAI4CH Expected results



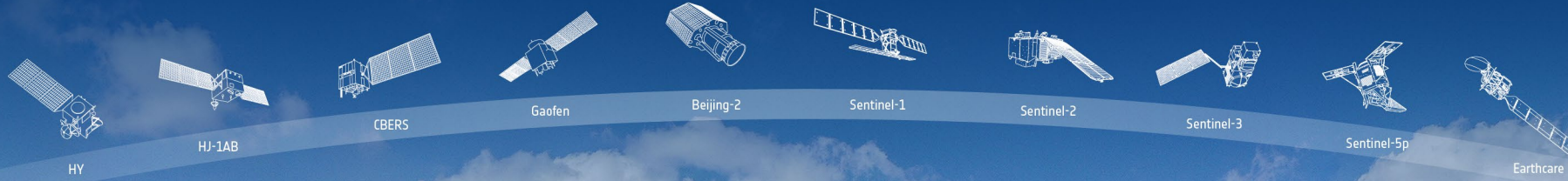
- **Validated and replicable novel methods exploiting MR to VHR EO optical and SAR data**
 - 1) Highly generalized monitoring method to identify CH features based on remote sensing-AI
 - 2) AI change detection method of CH surfaces based on multi-source EO data
 - 3) Spatio-temporal data cube organization and knowledge mining method to inform CH protection along ancient waterways, supported by robust demonstration and validation use-cases
- **Digital maps outlining anthropogenic threats** in each study site, and geodatabases depicting zones and CH assets potentially at risk, advancing the knowledge and cultural awareness, and stimulating awareness of heritage bodies and decision makers
- **A remote sensing AI-based CH prototype** supported by the new online platform Open Geospatial Engine (OGE), developed by the Wuhan University team and laid on GeoCube and Cloud computing, that will serve as a spatial data infrastructure tool to support CH data management, analysis, and visualization
- **Joint scientific presentations** at: (i) Dragon-6 yearly reporting symposia, and (ii) specialist national/international Earth science, CH and remote sensing conferences (e.g. IEEE IGARSS, CAA, LAC)
- **Joint journal publications** on the developed AI-based methods, key findings and observations drawn for the use-cases, both in (i) ESA-CSTEC Dragon-6 publications in 2026 and 2028, and (ii) top-ranked international journals
- **Trained European and Chinese YSs**, via on-the-job training, MSc/PhD internships and theses projects, specialist training courses including Dragon-6 training events



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Thank you!

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