The Rise of AI for Earth Observation

Φ-lab team @ philab.phi.esa.int
pierre.philippe.mathieu@esa.int

Sentinel-1 as seen by Artificial Intelligence
ESA philweek.esa.int (2018). Courtesy: deepart.io, ESA/ATG medialab

V03

European Space Agency

- The AI Renaissance —> The Rise of AI4EO

- Tool for Vision
  - Detection, Classification (ConvNet)
  - Self-supervised Learning
  - Super-resolution

- Tool for Discovery
  - Earth System Modelling Data Science
  - Digital Twin Earth (DTE)
  - Physics-Informed Neural Net (PINNs)

- Tool for Operations
  - Spacecraft Health & Safety
  - Time Series analysis (anomaly detection)
  - Mars Express energy management

- Tools for Enabling Communities
  - AI Pipeline Management
  - Data-centric AI Challenge with OPS-SAT
  - MLOPS for rapid flood detection

- Tools for Intelligence in Orbit
  - Edge Computing & phi-sat
  - Cognitive Cloud Computing

- Concluding Remarks
  - AI Renaissance, Challenges & Opportunities
  - Research Agenda

The AI Renaissance

AI everywhere!

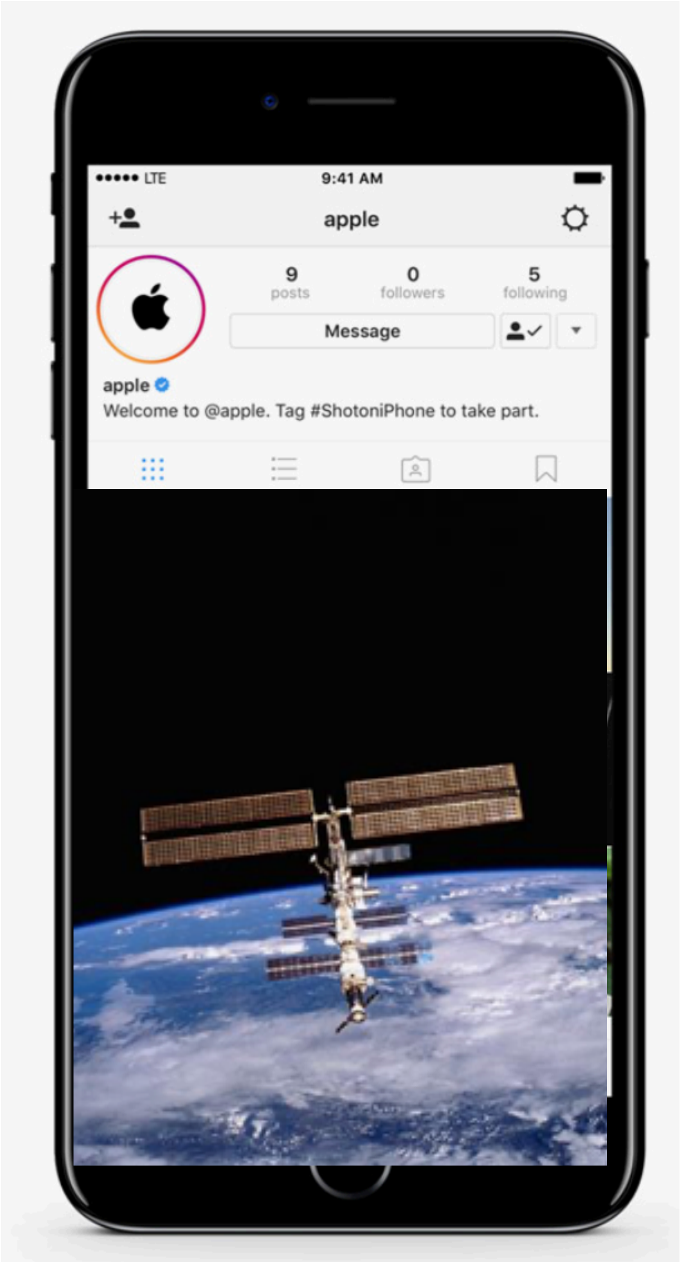
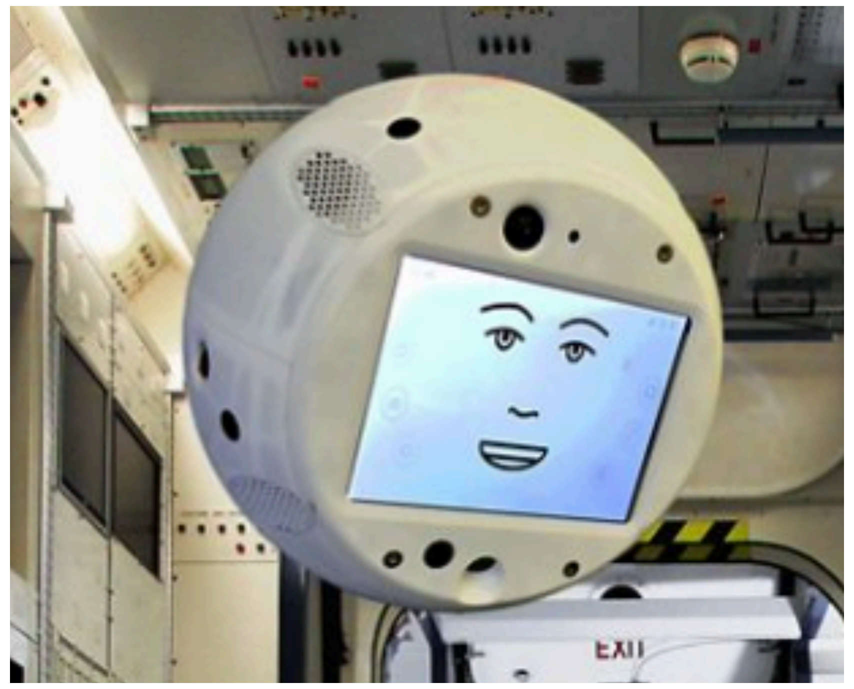
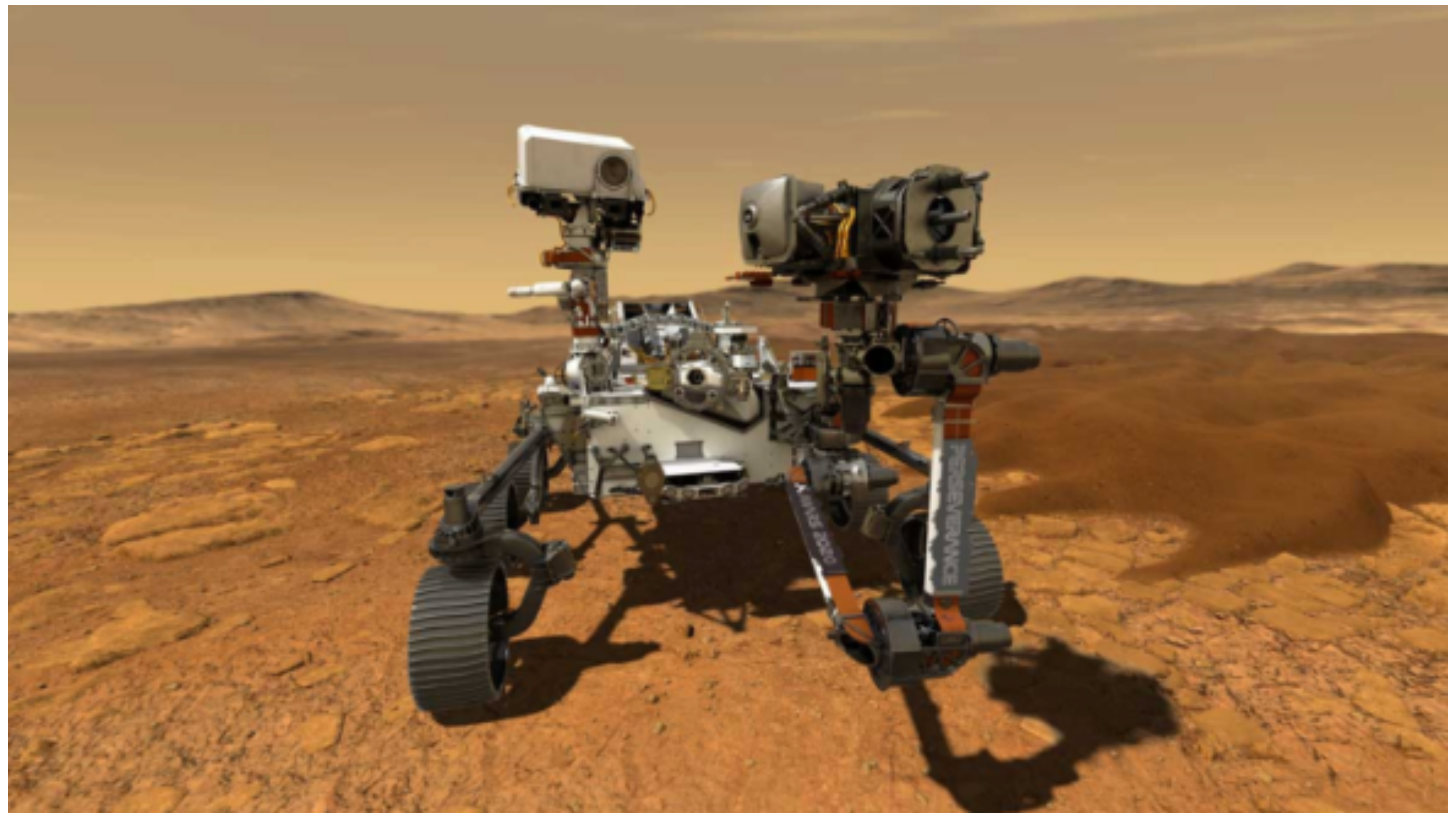


Image Processing, Classification, Recognition, Inpainting,



CMON (ISS)

Quality Assurance

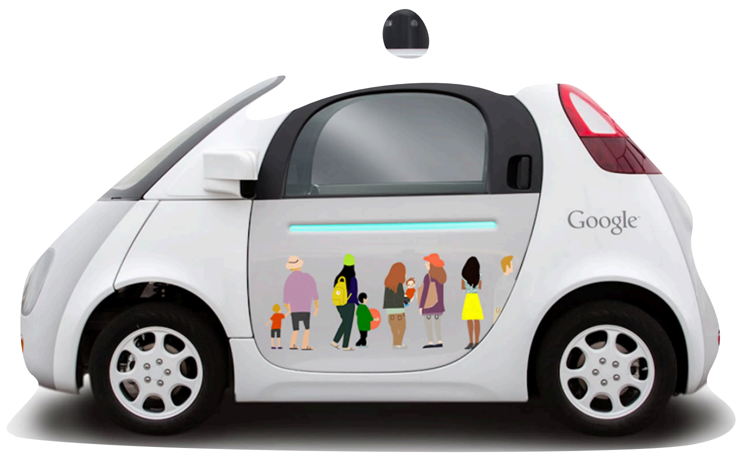


Computer vision & Autonomy

Digital Assistant (NLP)

Gaming

Autonomous Driving



What is AI?

Artificial Intelligence (AI)

=

Machine Learning (ML)

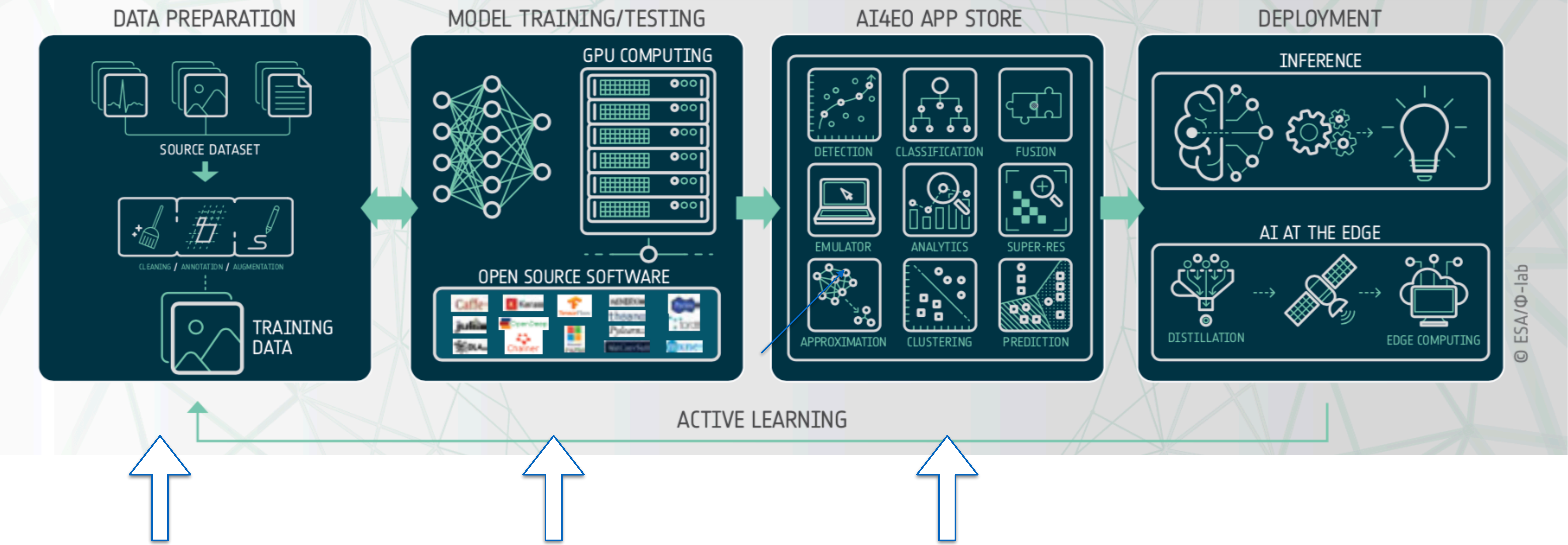
+

Automatic Reasoning

AI - Why it matters? Why New Paradigm?

Automation of Computer Programming
(Software 2.0)

Towards adaptative AI pipeline



Label, Invariance, EO, IoT, Synthetic Data

Suite of architectures, Physics-informed Neural Nets (PINNs)

Pre-trained models, (Foundation Models)

Our Main Focus here

Augmented Intelligence (AI)

=

Machine Learning (ML)

+

Human in the Loop (Crowdsourcing)

The rise of AI4EO

Apollo 17, 1972

Taking the Pulse of our Planet

Global Data to address
Global Challenges

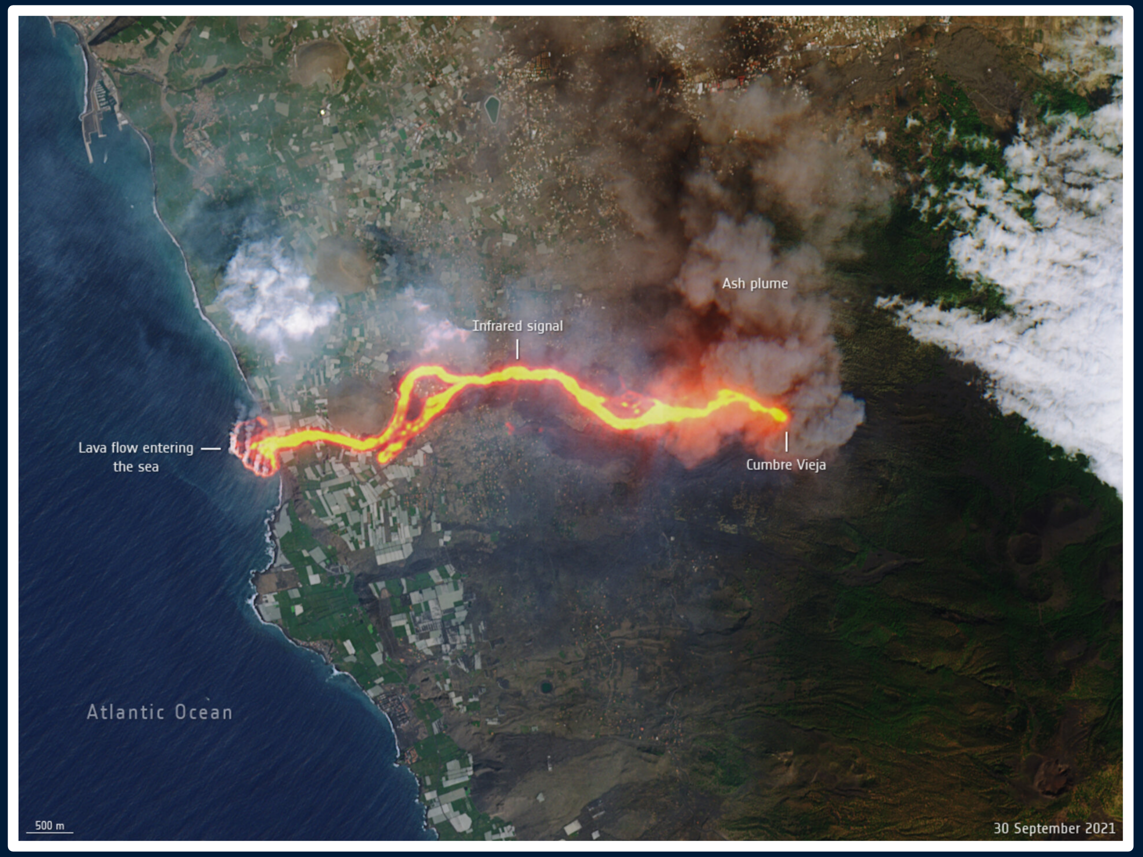
e.g. climate change, sustainable development and use of resources

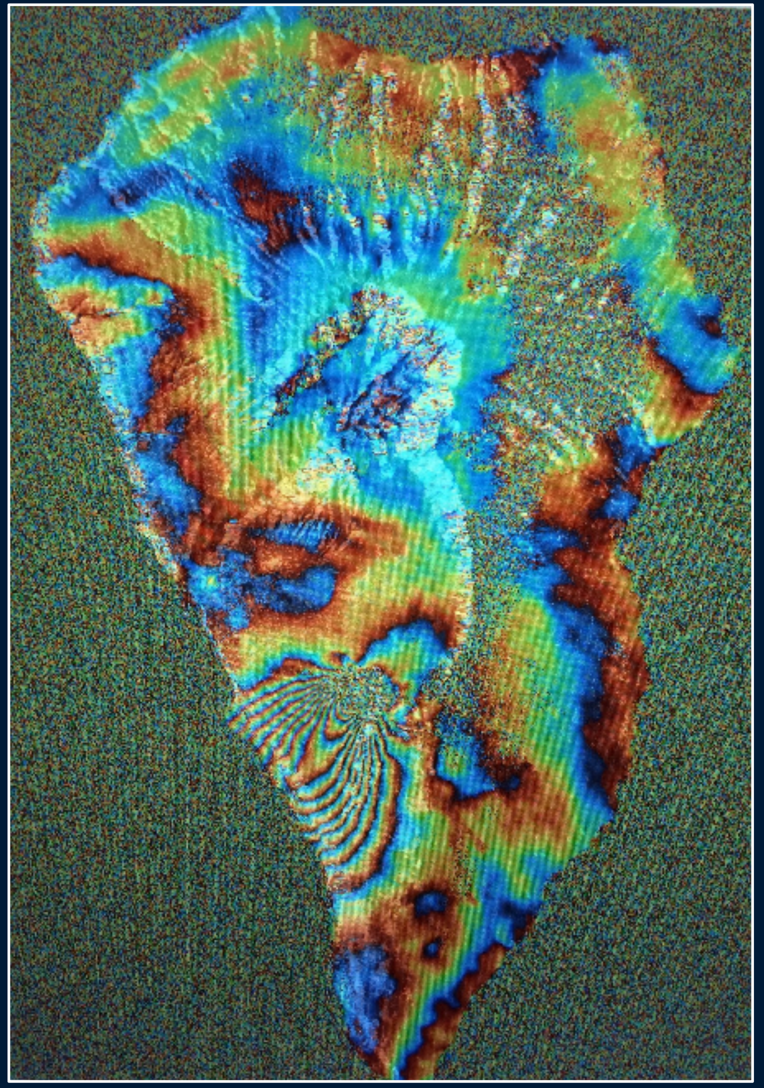
Multi-Sensors EO Landscape - System of Systems

Addressing diverse Sensing

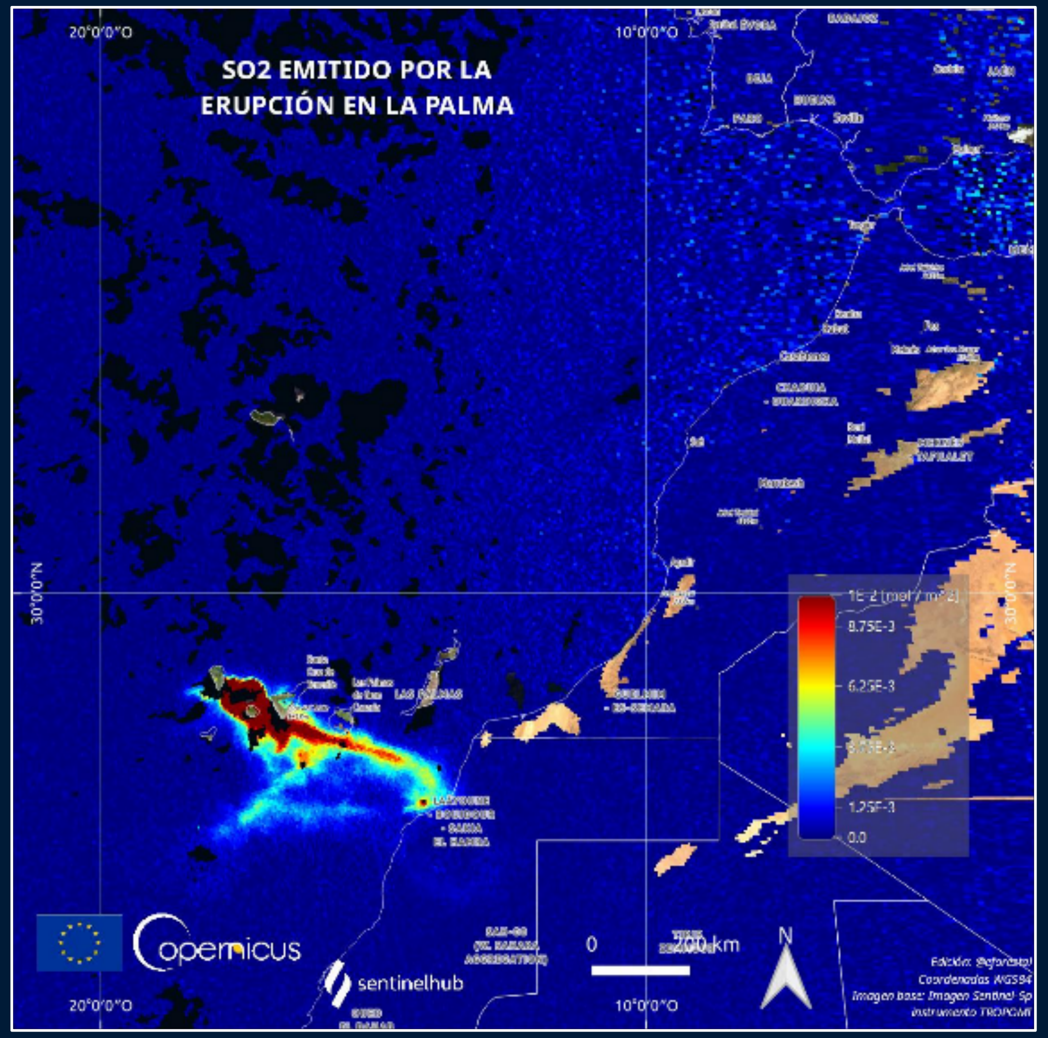
Eruption in La Palma (Canary islands, Spain)

Eruption started on 19 September 2021





Sentinel-1 *interferogram (14-20 Sep)*
[courtesy Pablo J. González]



Sentinel-5P *(SO2, 20 September)*

First lava map produced by Copernicus Emergency Management Service

Based on ***Sentinel-1 Cosmo-Skymed*** *data*

AI4EO = the perfect Match

PLANETARY HEALTH

Observation

Quantify
Understand

Model

Prediction

Action

Enhanced Observation

Better Model

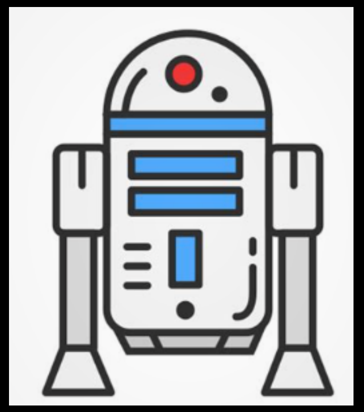
More Accurate Prediction

Informed Action

Splitting a Big Prob into Small Probs

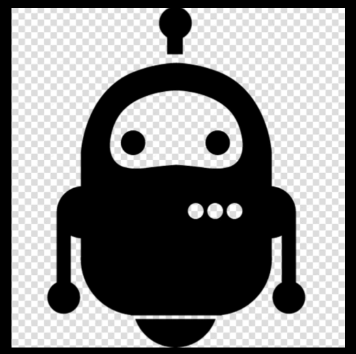
Observation

* Optimise sampling
* Understand Patterns
* Infer Causes



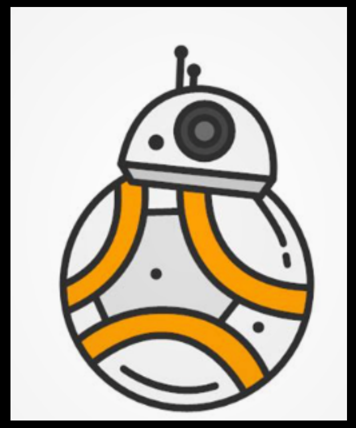
Action

Model

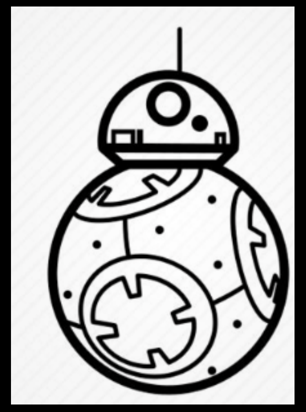


* Classify
* Quantify
* Understand

* Decision Support
* Assess Impact



Prediction

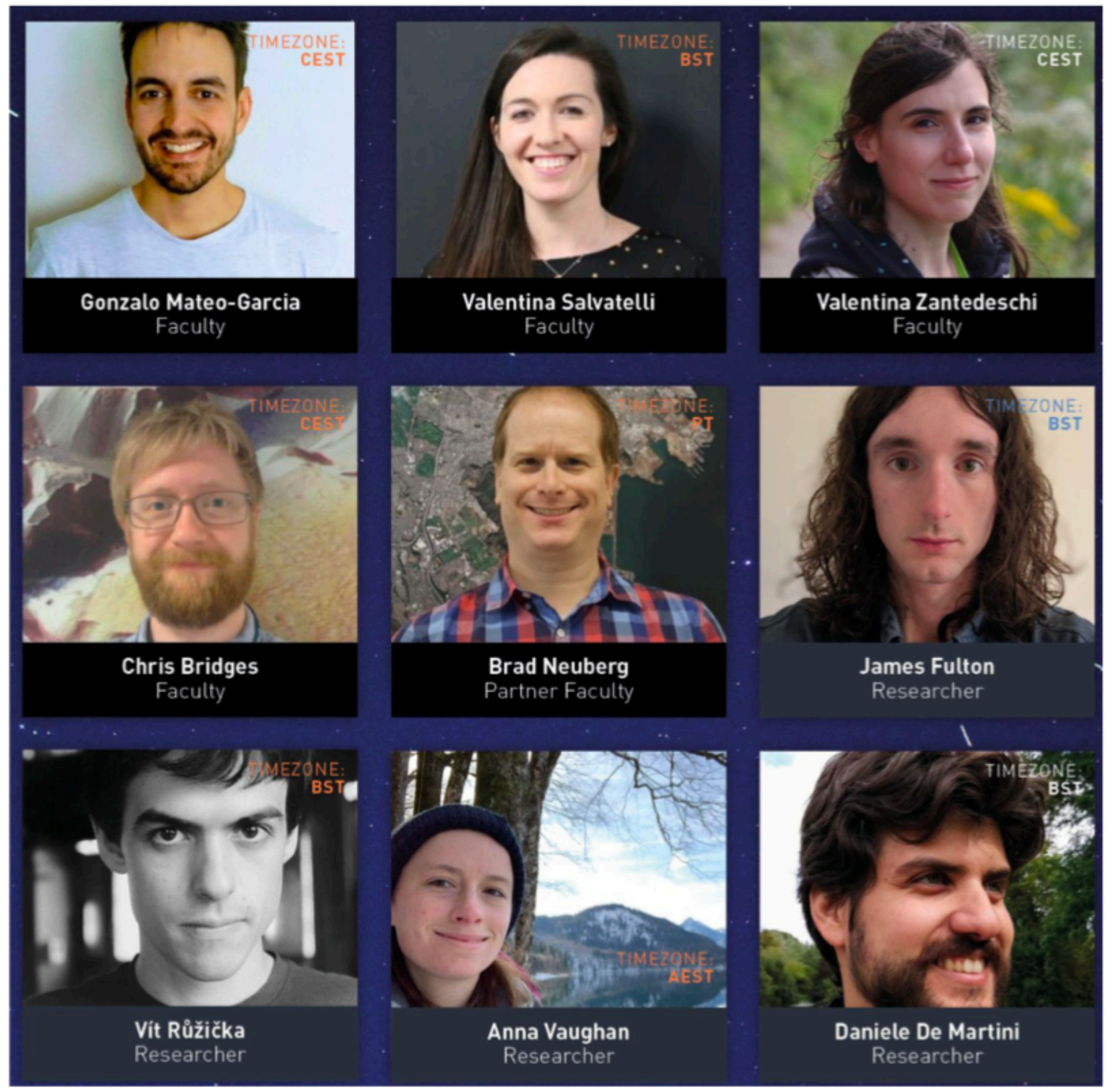


* Accelerate Simulations
* Emulate
* Parameterize

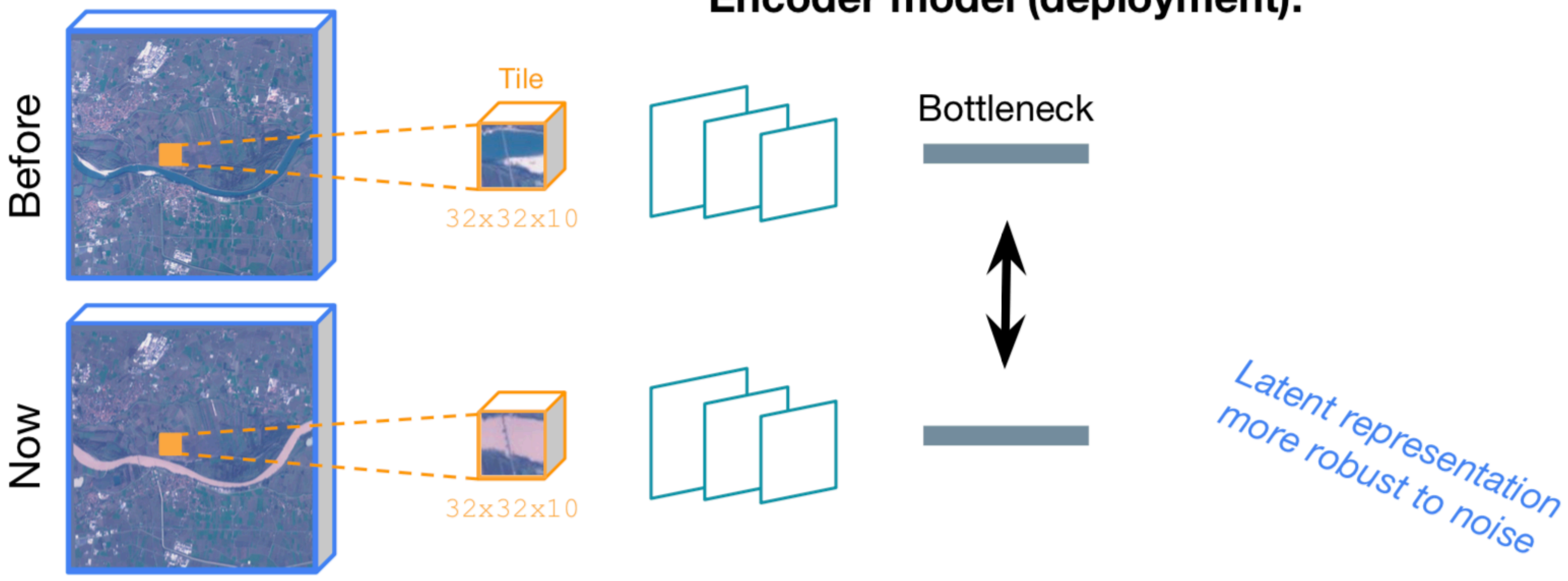
New Tool for Vision

Quantifying Risk & Impact of Floods

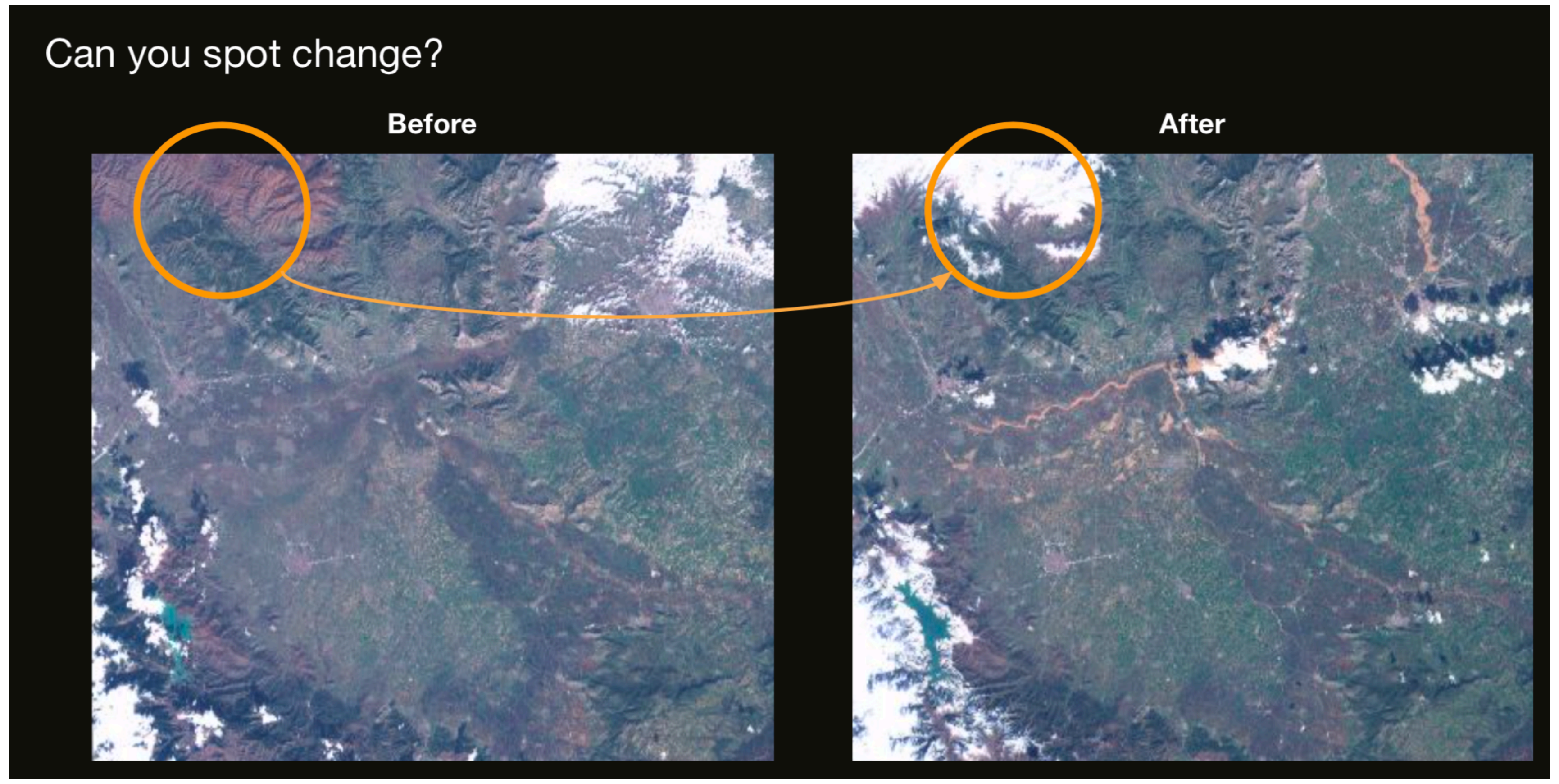

BEFORE
HURRICANES
LANDSLIDES
FIRES
OIL SPILL
VOLCANOES
FLOODS
DISASTER PREVENTION
FDL 2019
AFTER

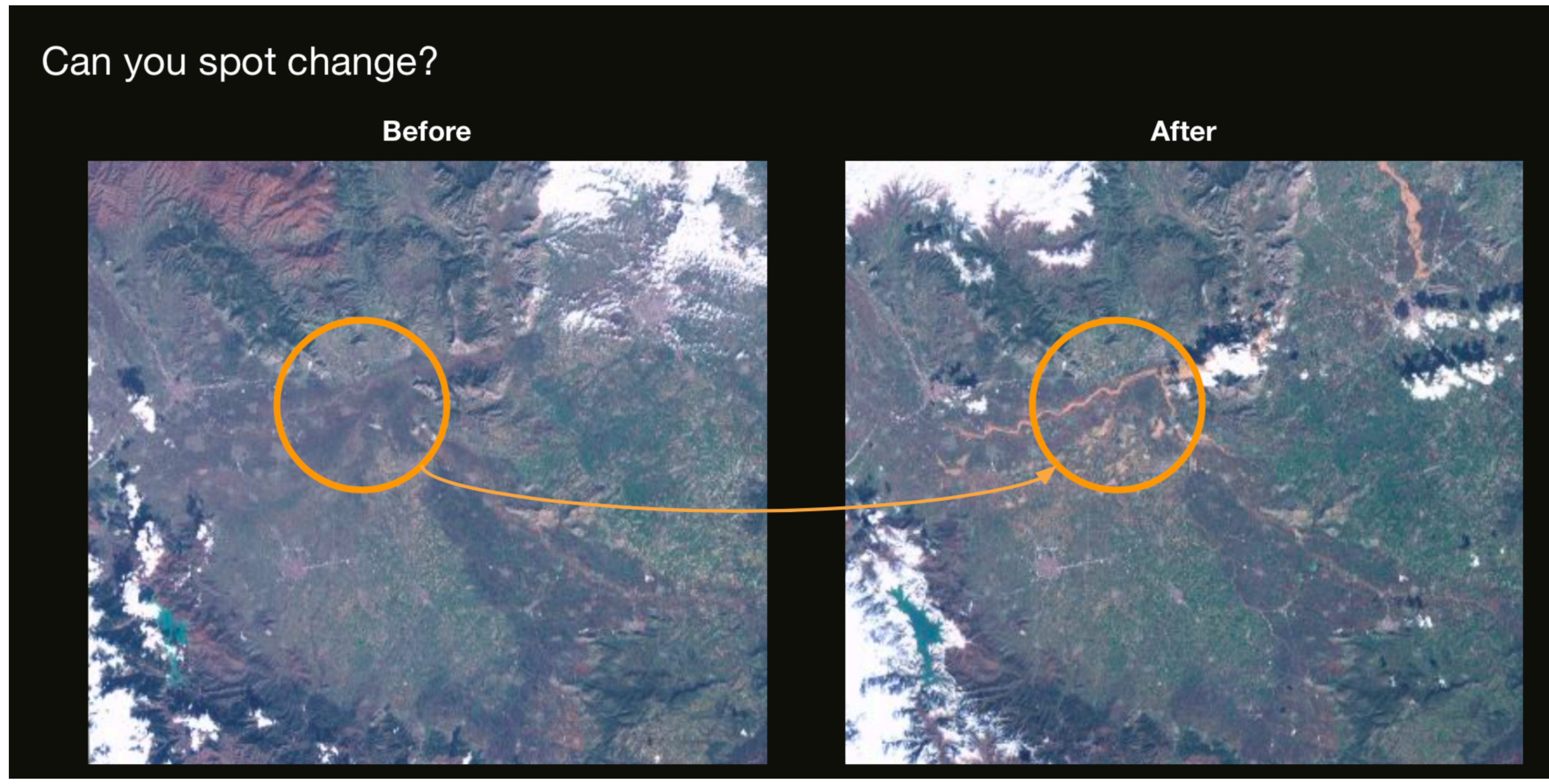


Methodology: Detecting change



Latent space
comparison





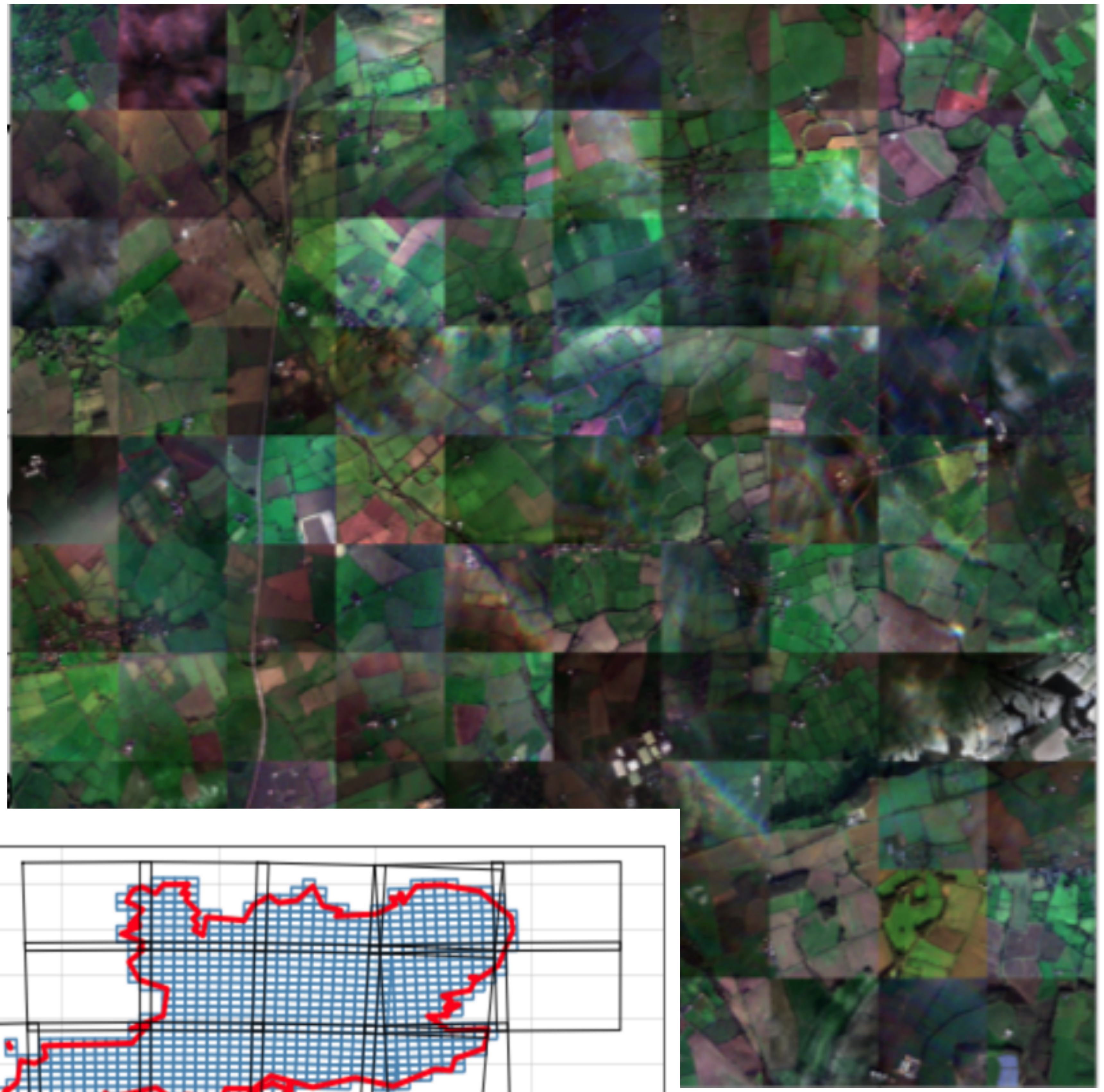
SatExtractor

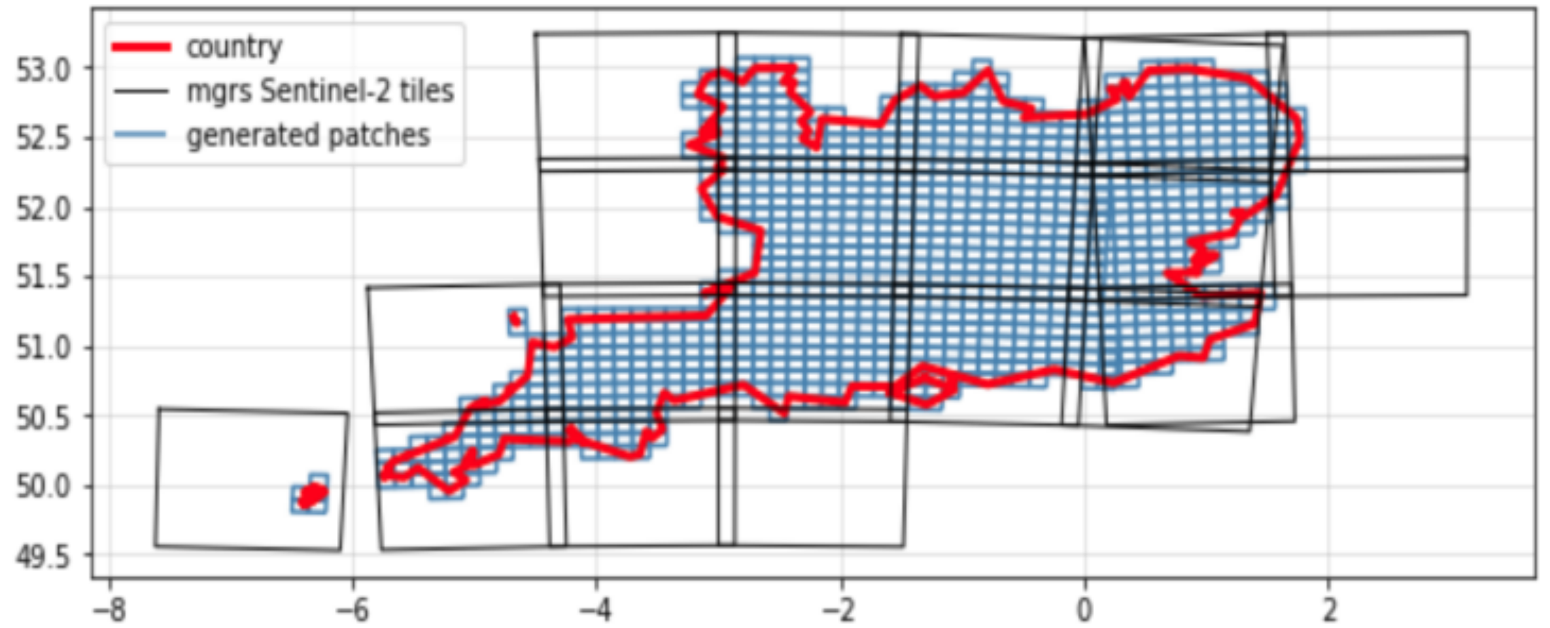
Extract everything from everywhere

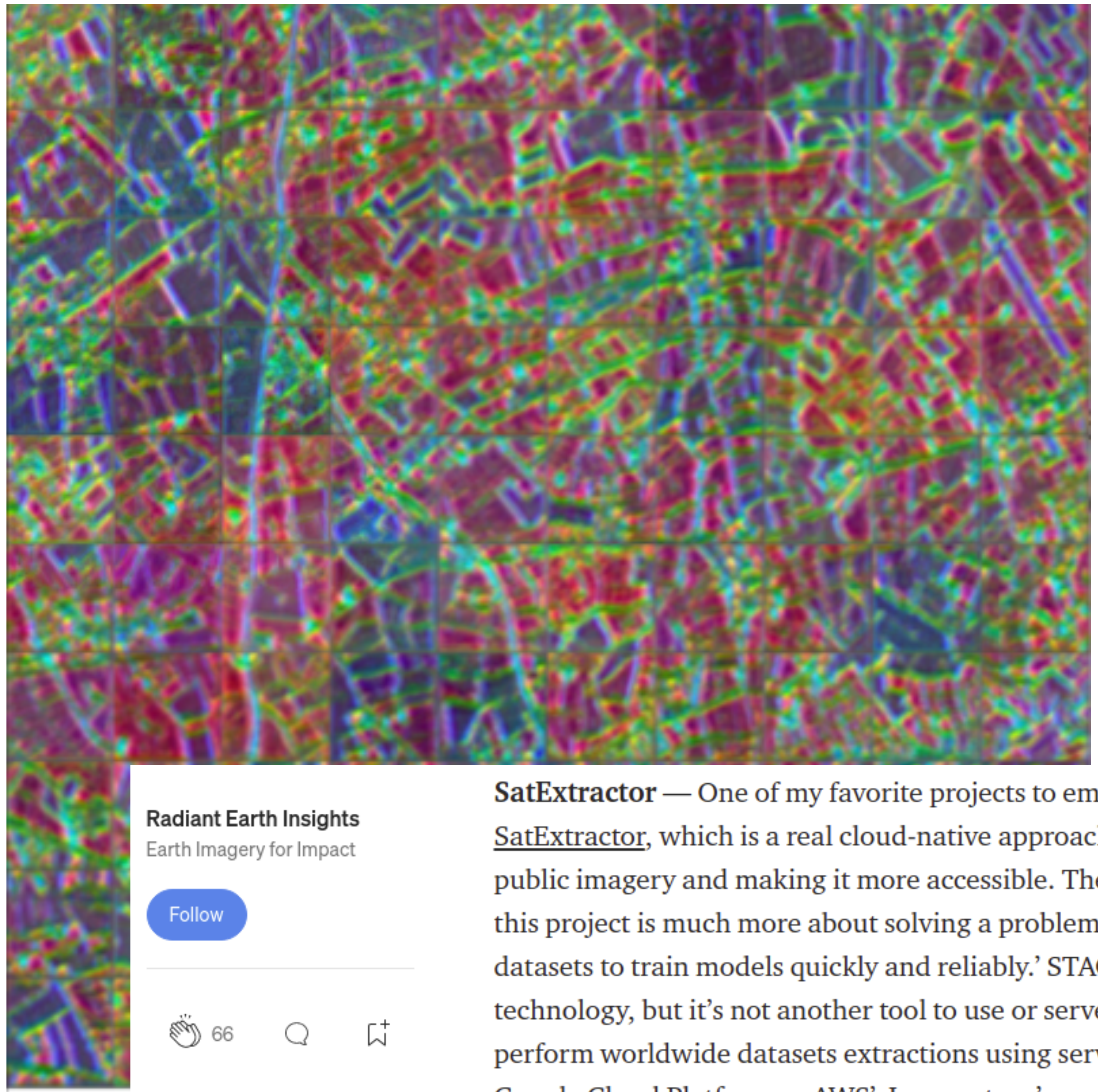
https://github.com/FrontierDevelopmentLab/sat-extractor

https://medium.com/radiant-earth-insights/stac-updates-fall-2021-ac97e66edb48

self-supervised semantic information







Radiant Earth Insights

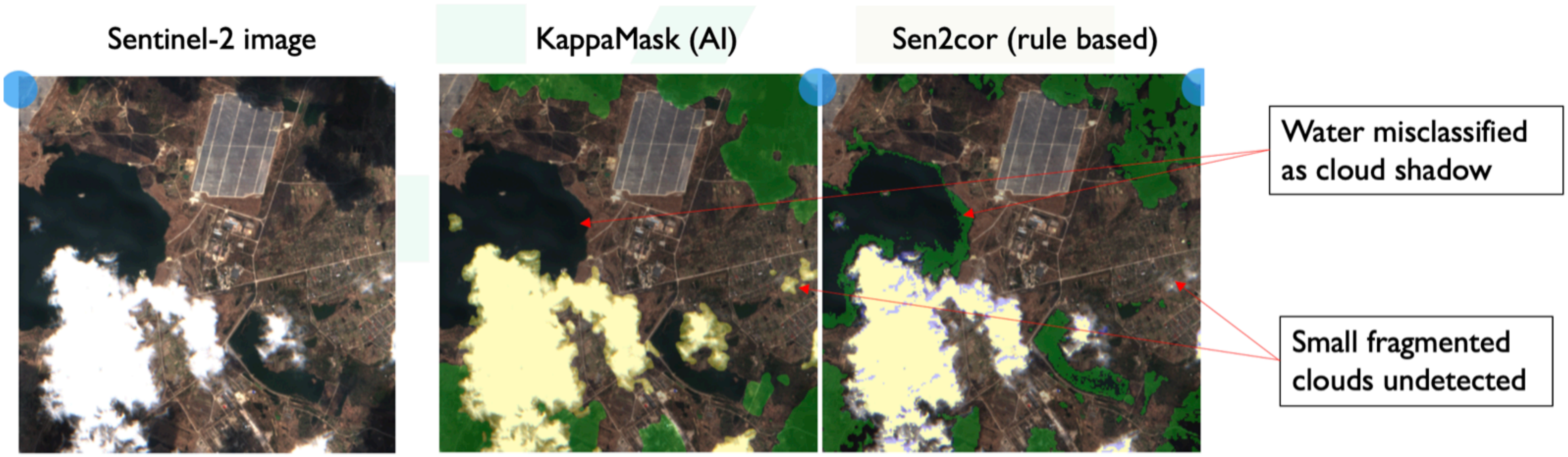
Earth Imagery for Impact

Follow

66

SatExtractor — One of my favorite projects to emerge recently is SatExtractor, which is a real cloud-native approach to grabbing diverse public imagery and making it more accessible. The cool thing to me is that this project is much more about solving a problem: it is 'difficult to create datasets to train models quickly and reliably.' STAC is a key enabling technology, but it's not another tool to use or serve STAC, it's a tool to ' perform worldwide datasets extractions using serverless providers such as Google Cloud Platform or AWS'. I suspect we're going to soon see more projects that show real innovation on top of the foundation STAC provides.

Data Augmentation - Active Learning



- See more at: https://kappazeta.ee/cloudcomparison

Legend:
Yellow – cloud
Green – cloud shadow

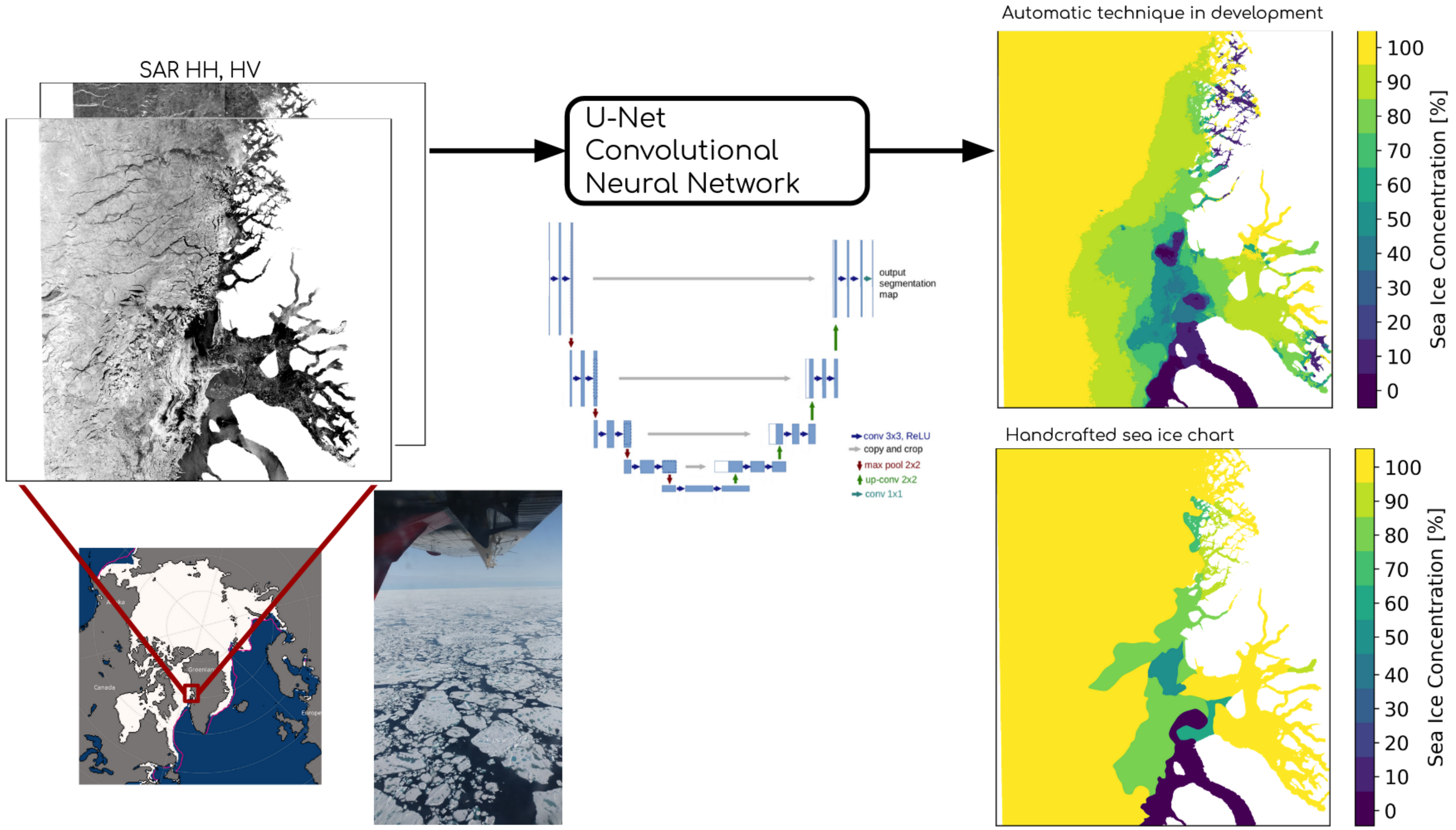
6

Adressing the long tail! Generalisation is in extreme case

Supervised Learning (ConvNet)

Automatic Arctic Sea Ice Charting

Credit: Andreas Stokholm, Andrzej Kucik, Nicolas Longépé



- Investigate approaches to overcome ambiguous SAR signatures
- Automatically produce multiparameter charts
- Map sea ice automatically from satellite imagery for use in operational maritime navigation

Graph Neural Networks for Climate Change

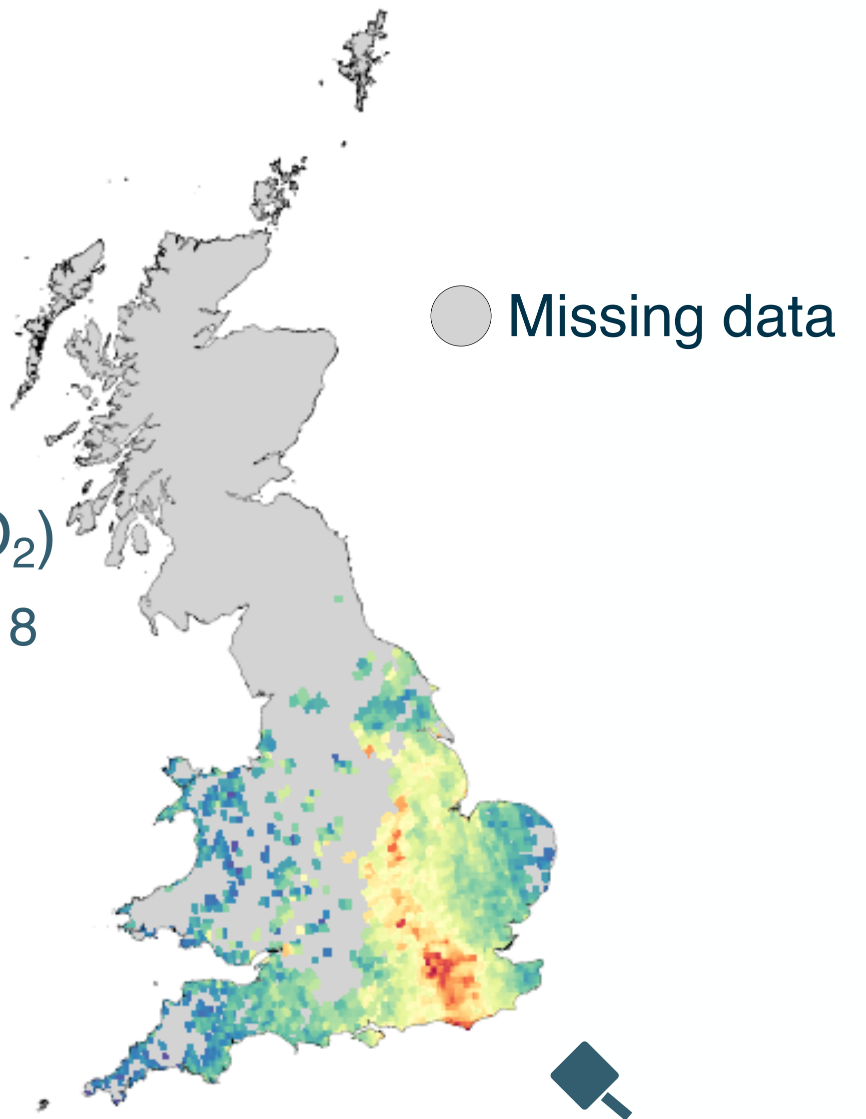
esa

esa

Sentinel-5P

Nitrogen Dioxide (NO_2)

Great Britain, 01 Oct. 2018



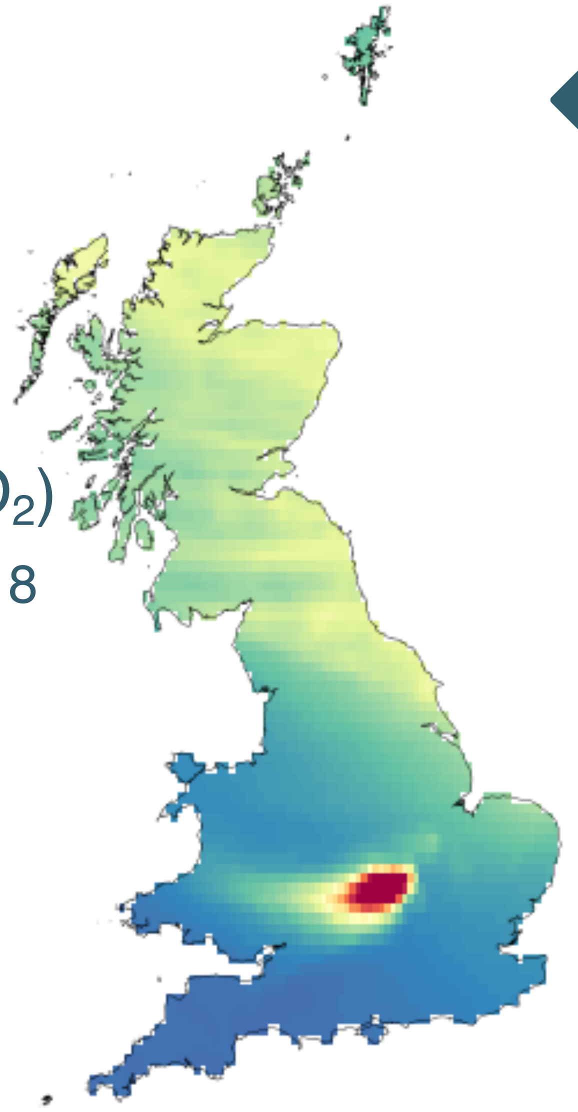
opernicus

Europe's eyes on Earth

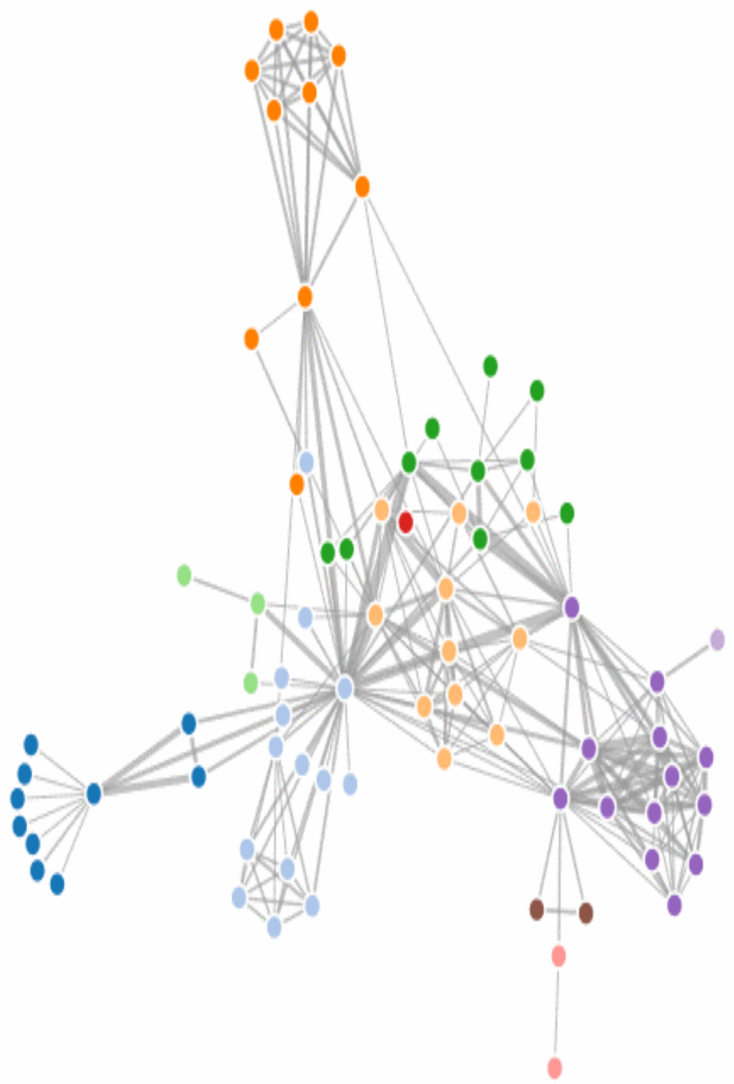
CAMS Europe

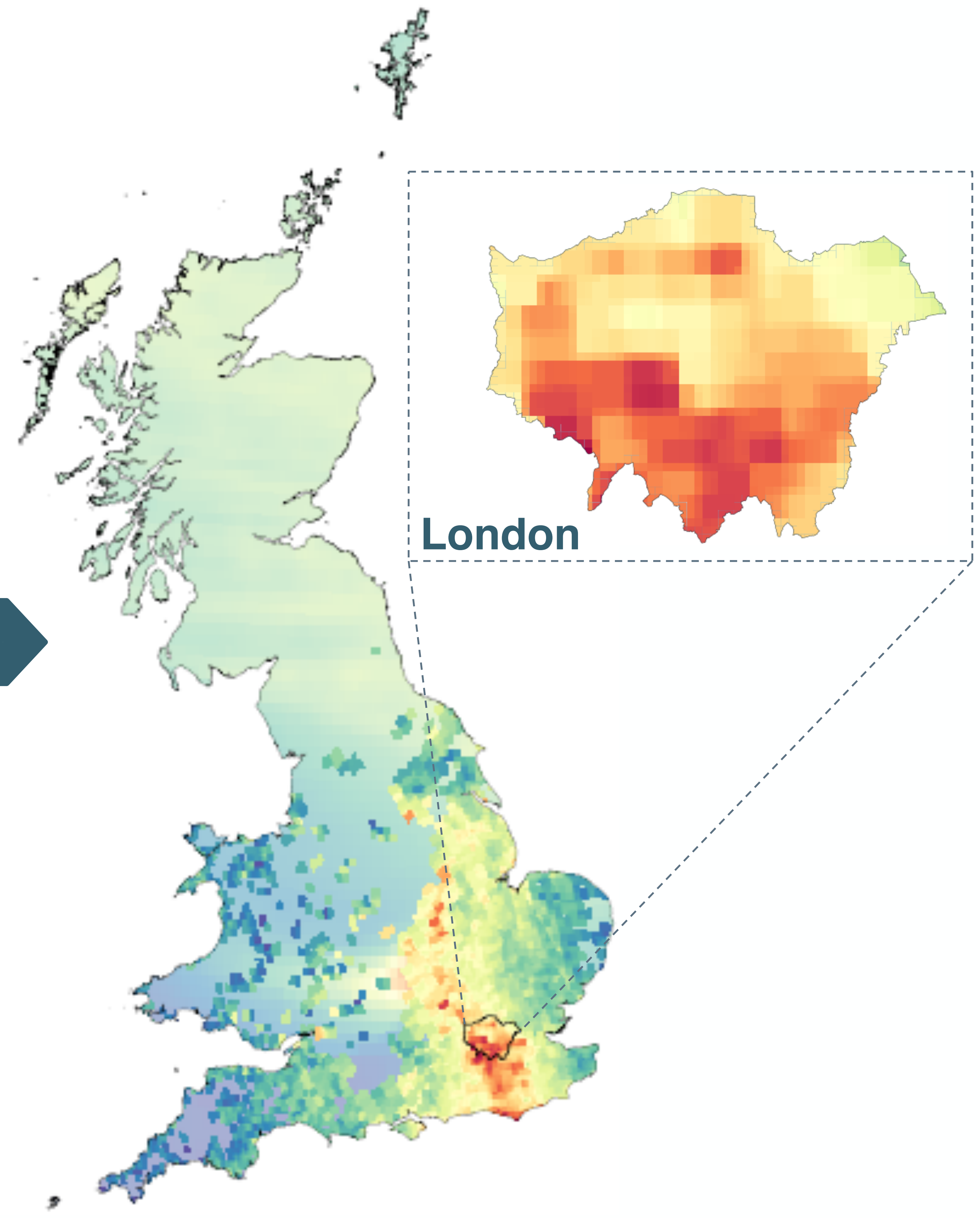
Nitrogen Dioxide (NO_2)

Great Britain, 01 Oct. 2018

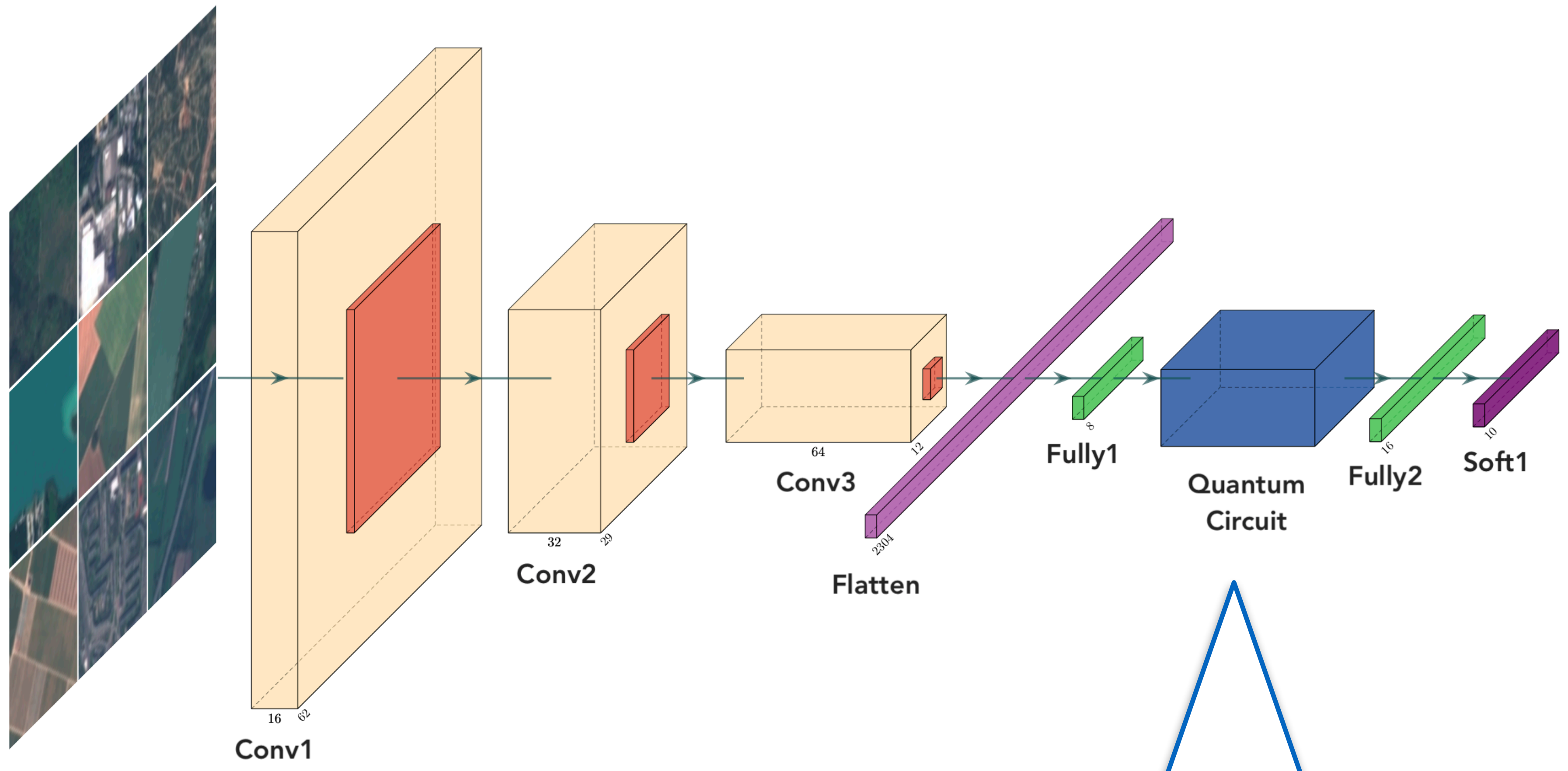


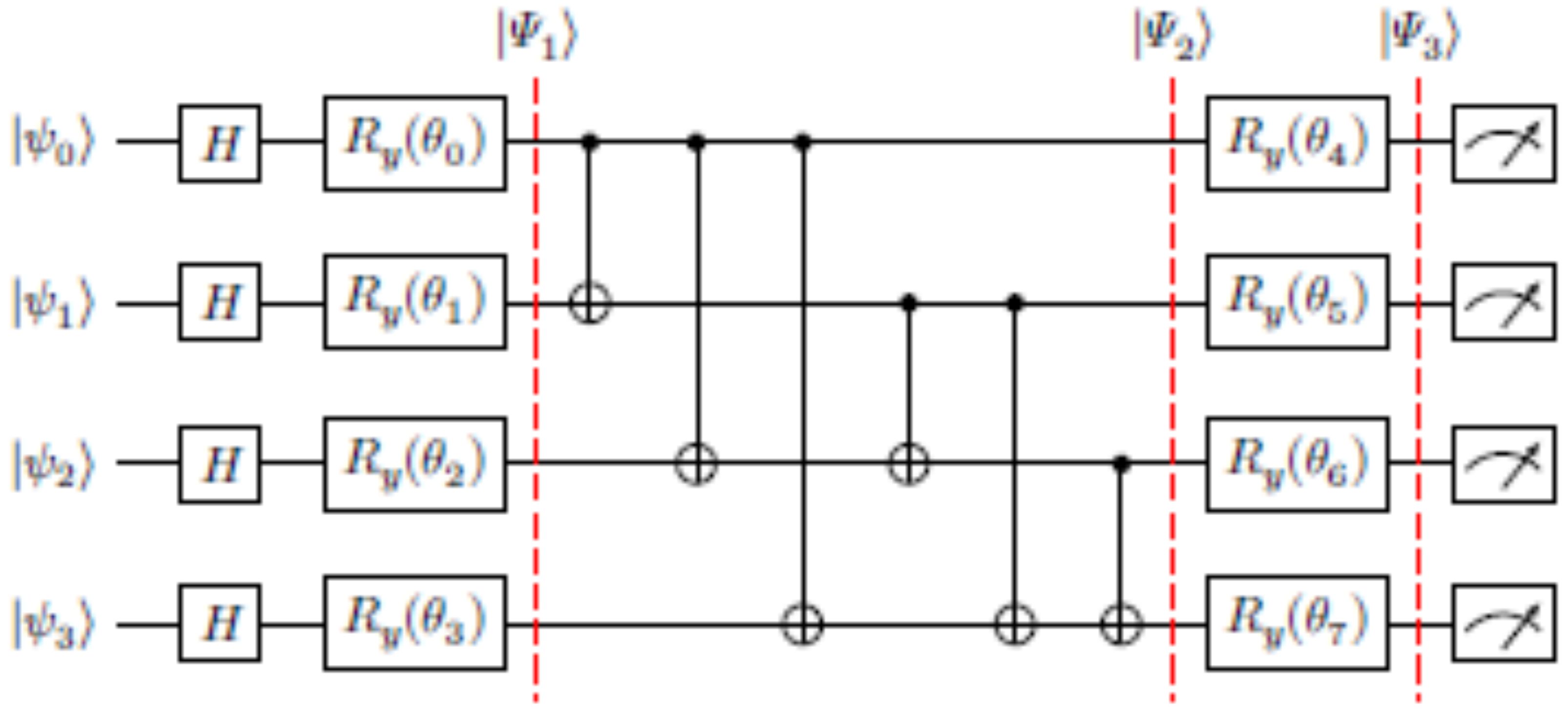
Missing data imputation using Graph Neural Networks

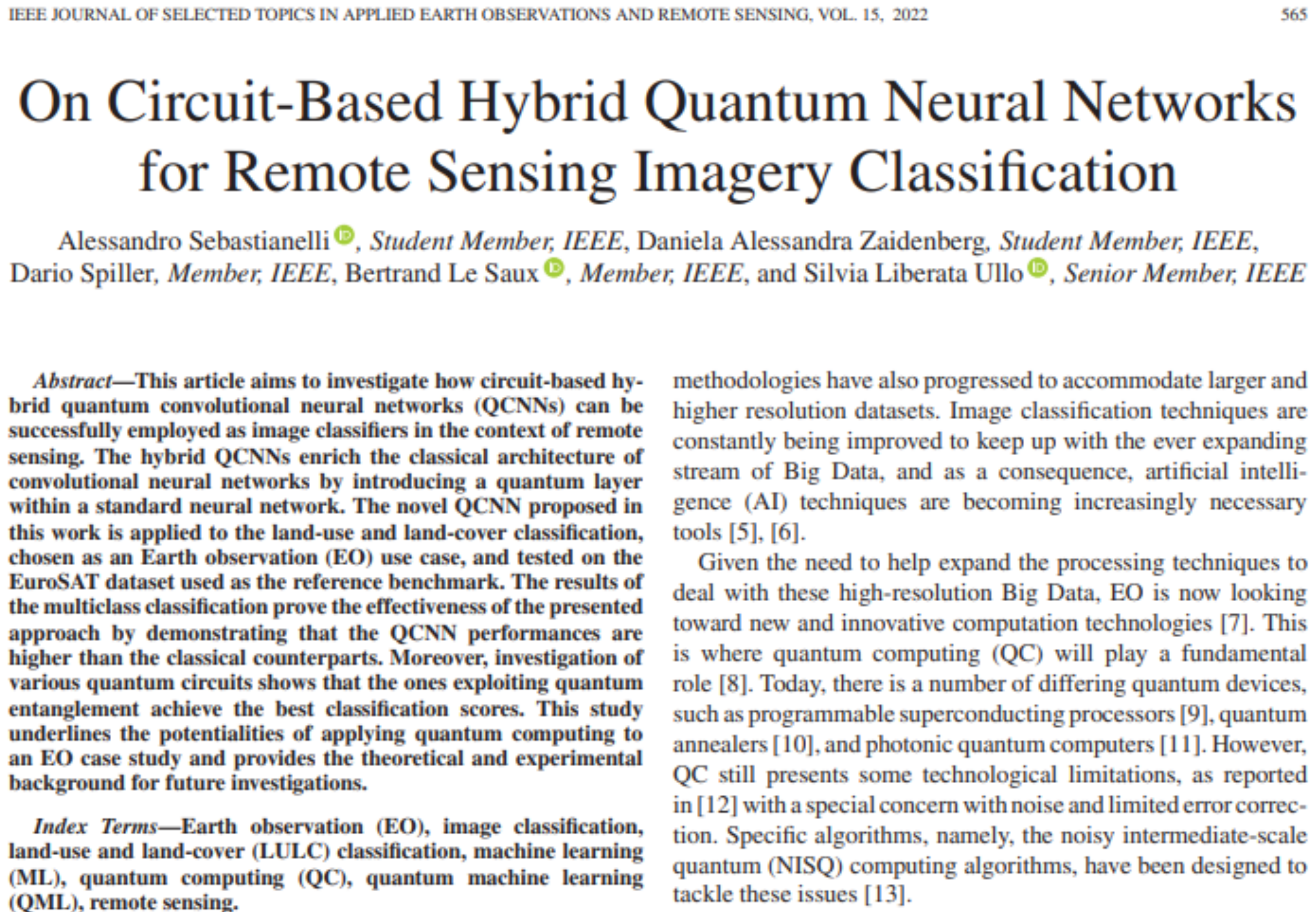




Hybrid Quantum Machine Learning (QML)







IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 15, 2022 565

On Circuit-Based Hybrid Quantum Neural Networks for Remote Sensing Imagery Classification

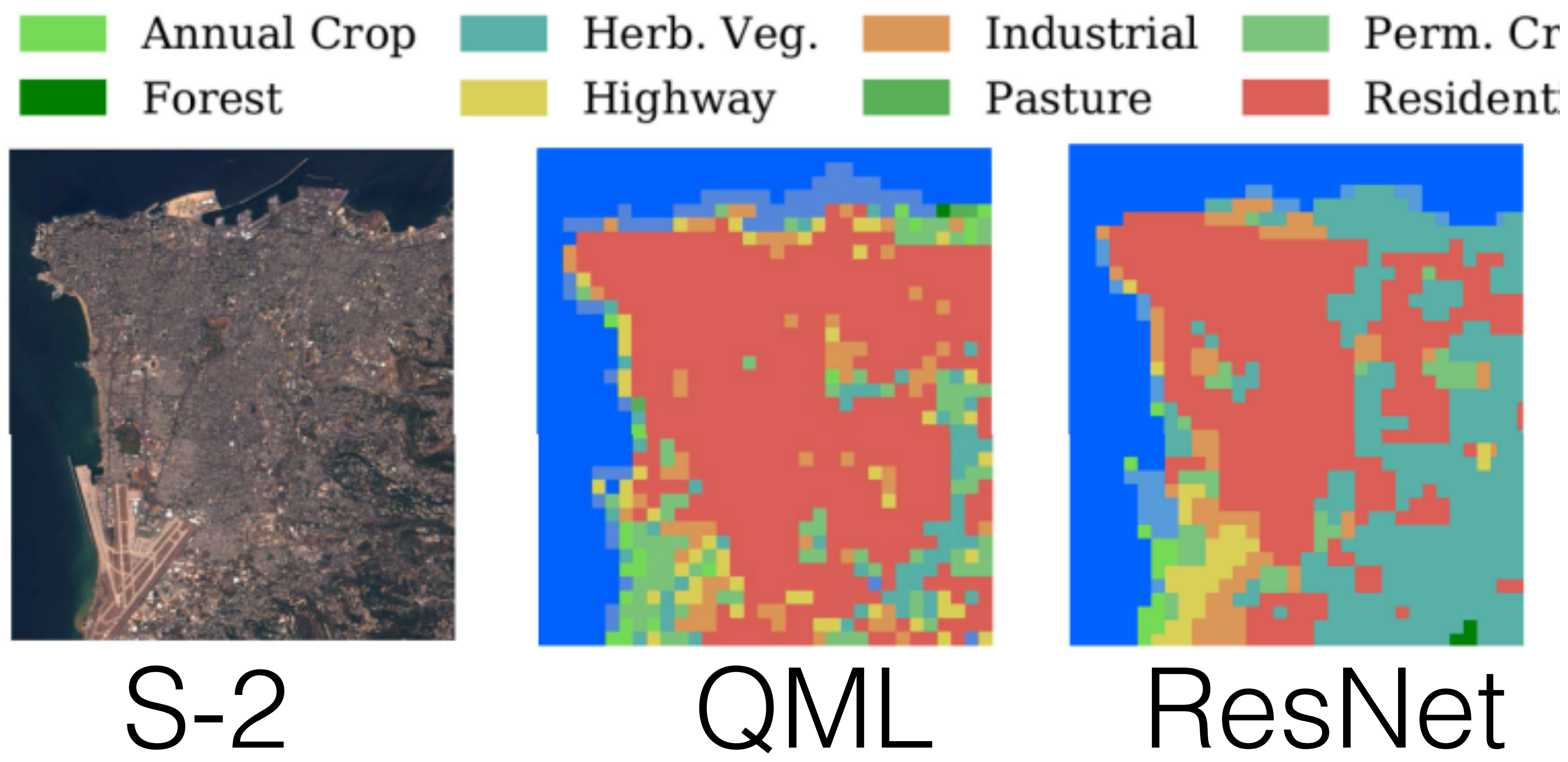
Alessandro Sebastianelli, *Student Member, IEEE*, Daniela Alessandra Zaidenberg, *Student Member, IEEE*, Dario Spiller, *Member, IEEE*, Bertrand Le Saux, *Member, IEEE*, and Silvia Liberata Ullo, *Senior Member, IEEE*

***Abstract*—This article aims to investigate how circuit-based hybrid quantum convolutional neural networks (QCNNs) can be successfully employed as image classifiers in the context of remote sensing. The hybrid QCNNs enrich the classical architecture of convolutional neural networks by introducing a quantum layer within a standard neural network. The novel QCNN proposed in this work is applied to the land-use and land-cover classification, chosen as an Earth observation (EO) use case, and tested on the EuroSAT dataset used as the reference benchmark. The results of the multiclass classification prove the effectiveness of the presented approach by demonstrating that the QCNN performances are higher than the classical counterparts. Moreover, investigation of various quantum circuits shows that the ones exploiting quantum entanglement achieve the best classification scores. This study underlines the potentialities of applying quantum computing to an EO case study and provides the theoretical and experimental background for future investigations.**

***Index Terms*—Earth observation (EO), image classification, land-use and land-cover (LULC) classification, machine learning (ML), quantum computing (QC), quantum machine learning (QML), remote sensing.**

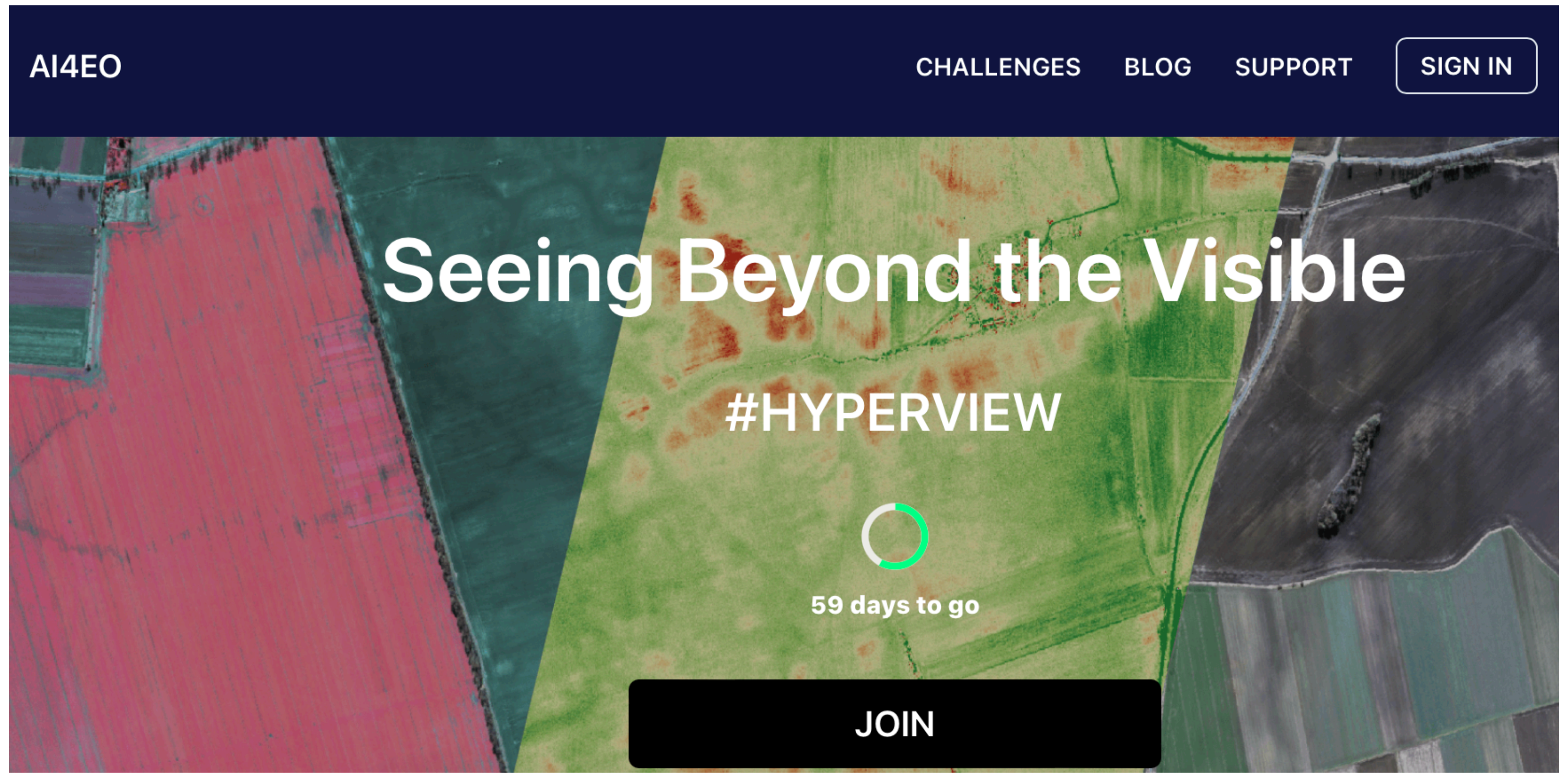
methodologies have also progressed to accommodate larger and higher resolution datasets. Image classification techniques are constantly being improved to keep up with the ever expanding stream of Big Data, and as a consequence, artificial intelligence (AI) techniques are becoming increasingly necessary tools [5], [6].

Given the need to help expand the processing techniques to deal with these high-resolution Big Data, EO is now looking toward new and innovative computation technologies [7]. This is where quantum computing (QC) will play a fundamental role [8]. Today, there is a number of differing quantum devices, such as programmable superconducting processors [9], quantum annealers [10], and photonic quantum computers [11]. However, QC still presents some technological limitations, as reported in [12] with a special concern with noise and limited error correction. Specific algorithms, namely, the noisy intermediate-scale quantum (NISQ) computing algorithms, have been designed to tackle these issues [13].



Community Challenges

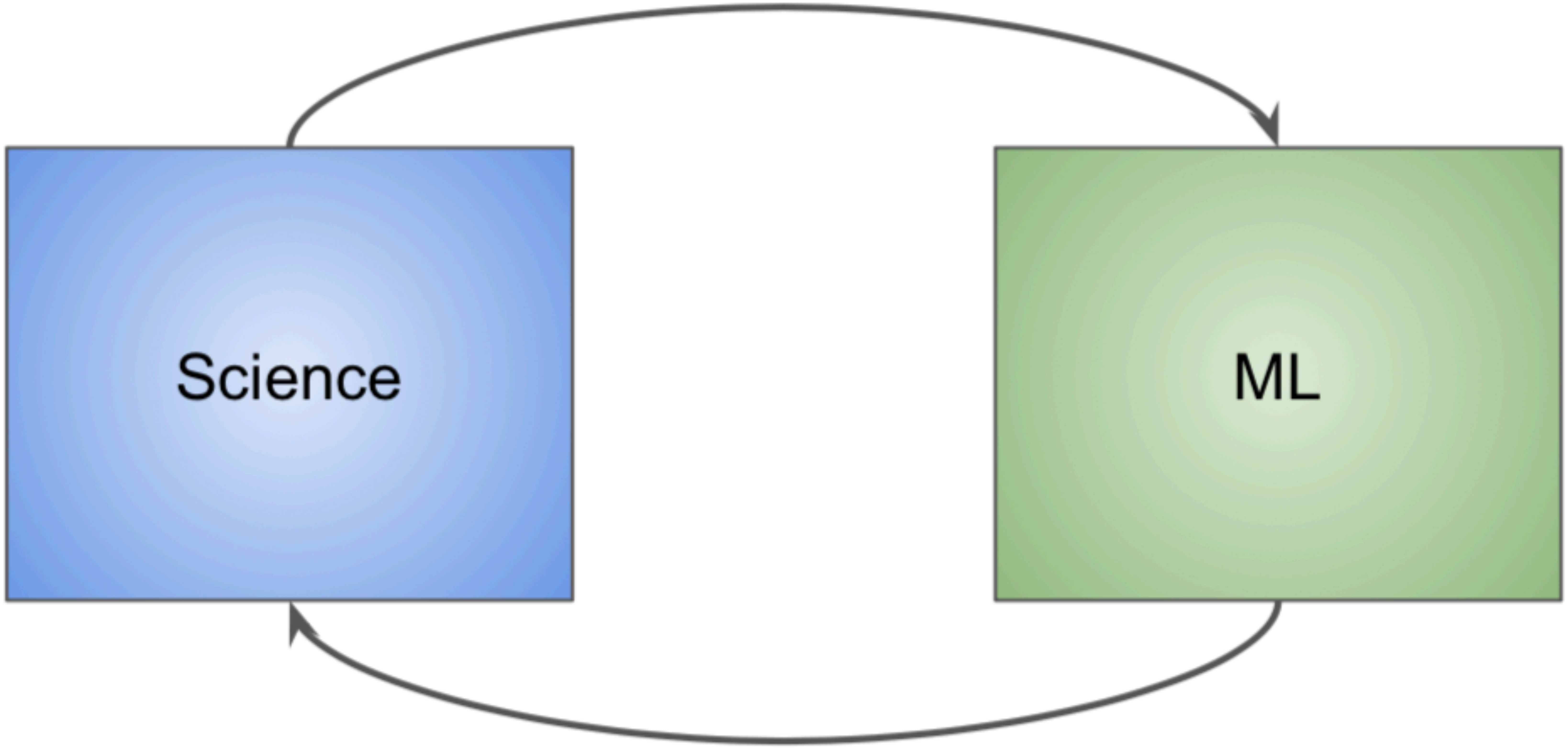
ai4eo.eu



KP Labs data set from airborne survey on soil properties with hyper spectral sensing

New Tool for Discovery

SciML




nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio

Archive > Volume 538 > Issue 7623 > News Feature > Article

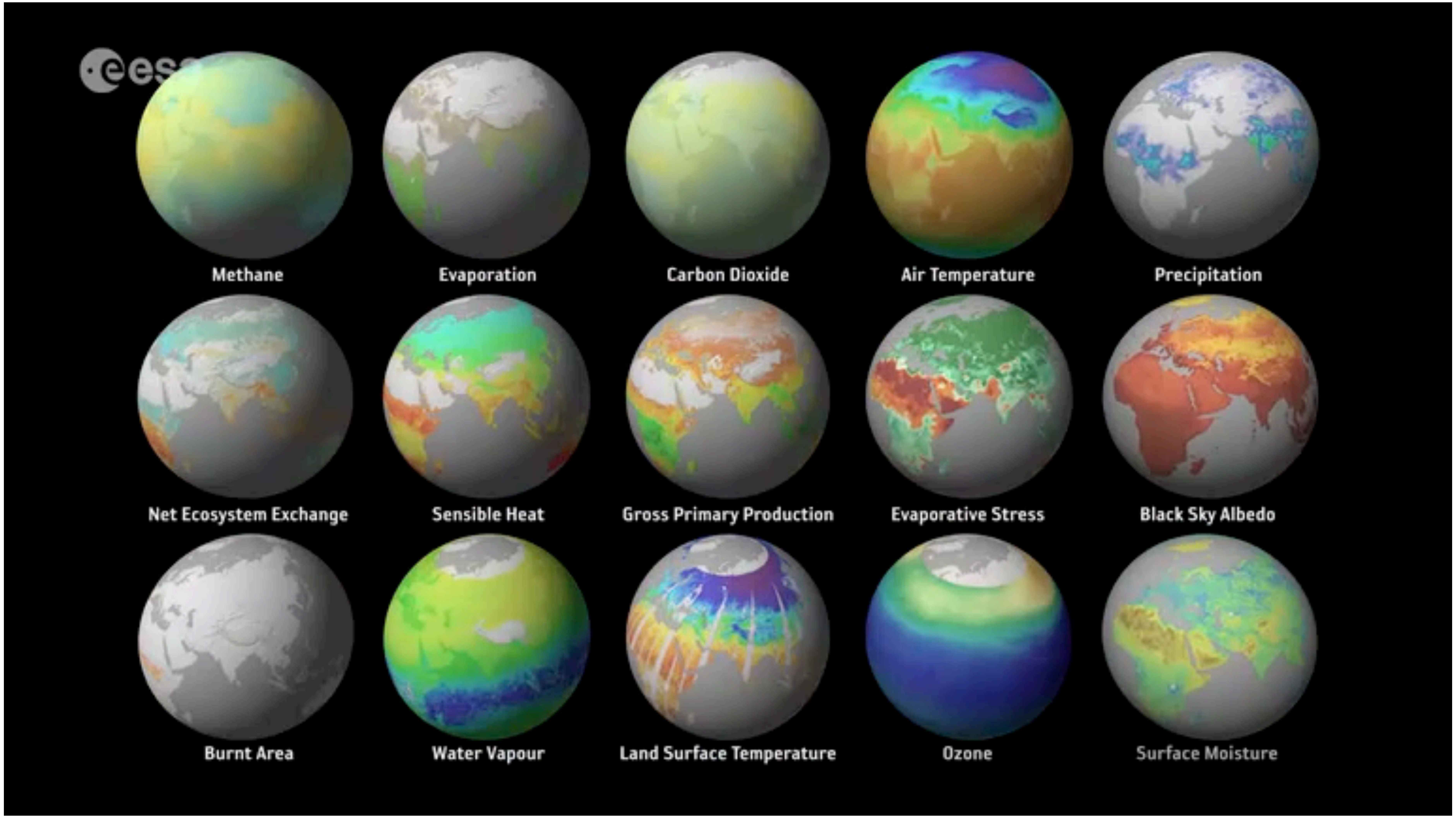
NATURE | NEWS FEATURE

Can we open the black box of AI?

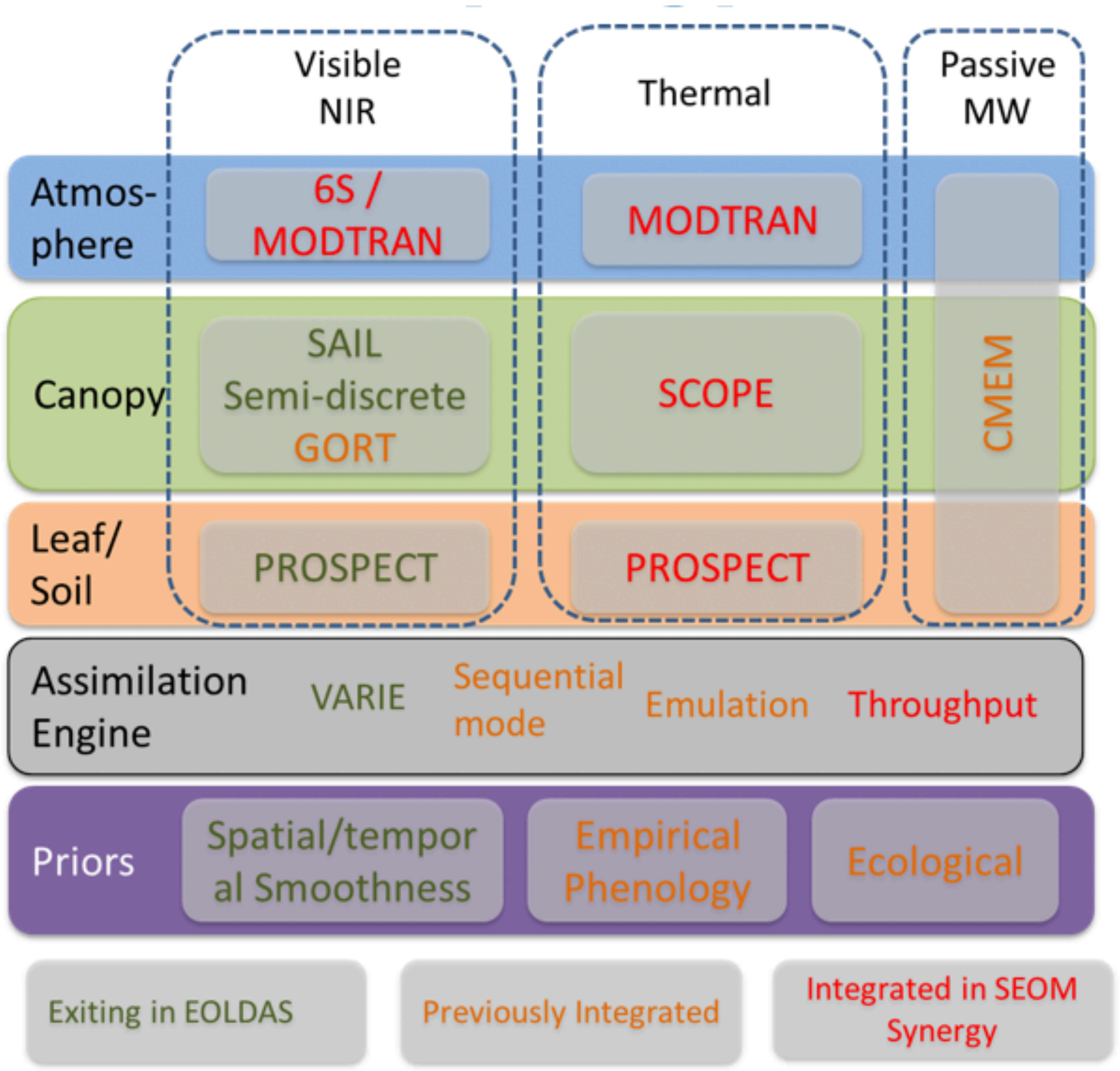
Artificial intelligence is everywhere. But before scientists trust it, they first need understand how machines learn.

Davide Castelvecchi

Earth System Data Lab

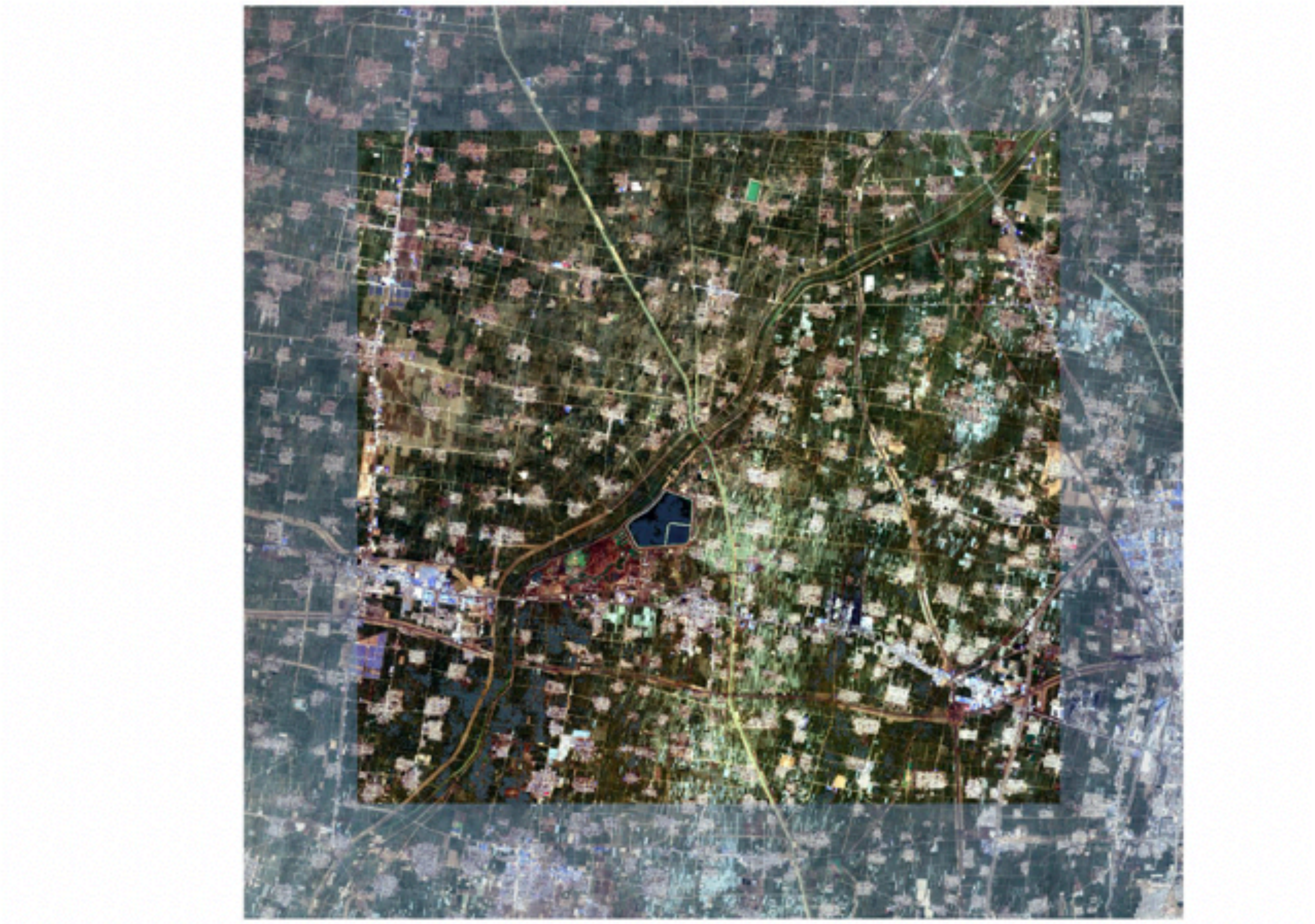


https://www.earthsystemdatalab.net



Fast Emulator / Surrogates for Obs Operators

(retrievals, atm correct, benchmarking)



Atmospheric correction (centre part) of Sentinel-2 data over China with very high aerosol loading

Emulators (Surrogate Models)

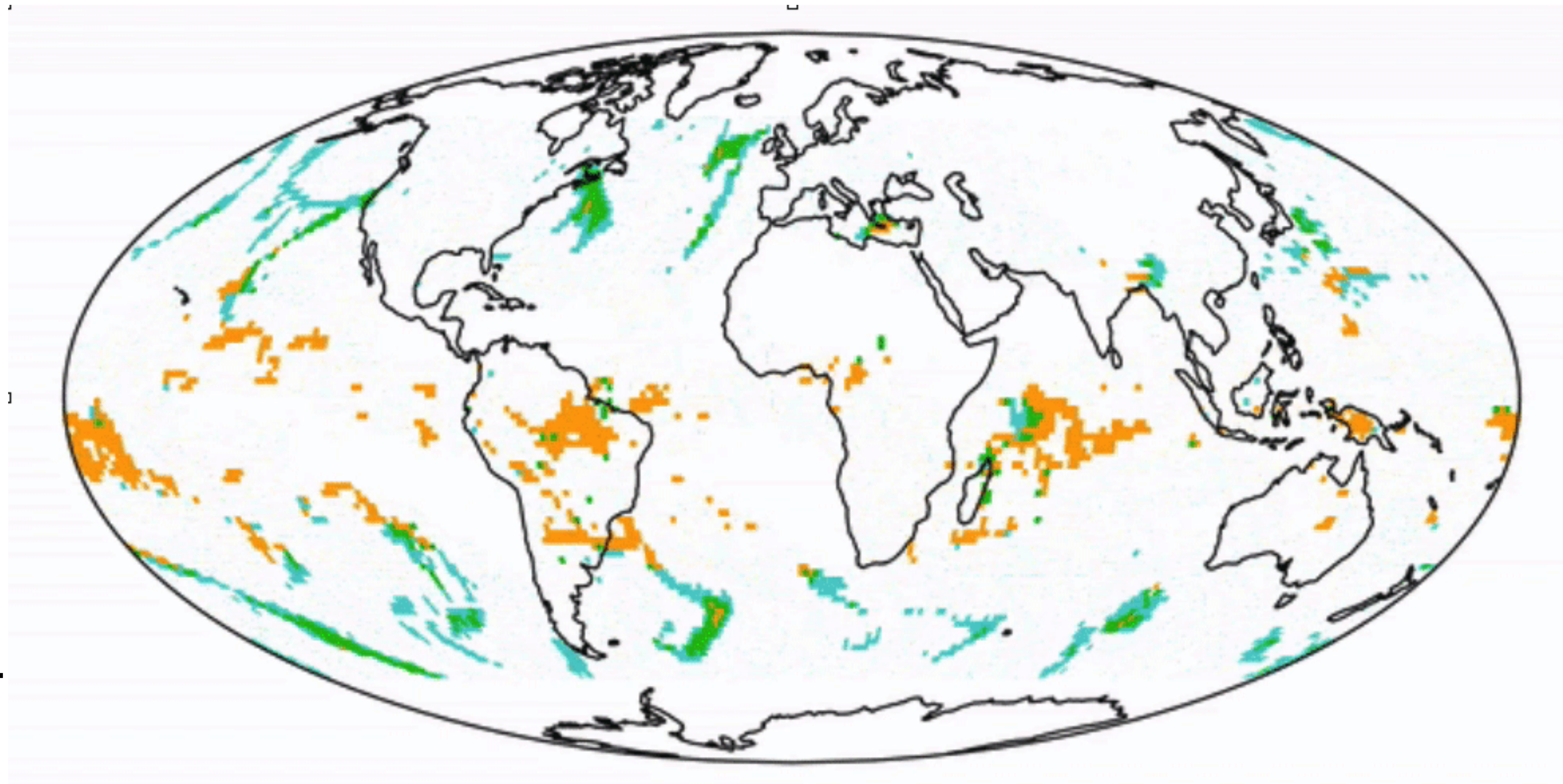
TOA radiance

Emulator

PyRain

Trained on ECMWF Reanalysis

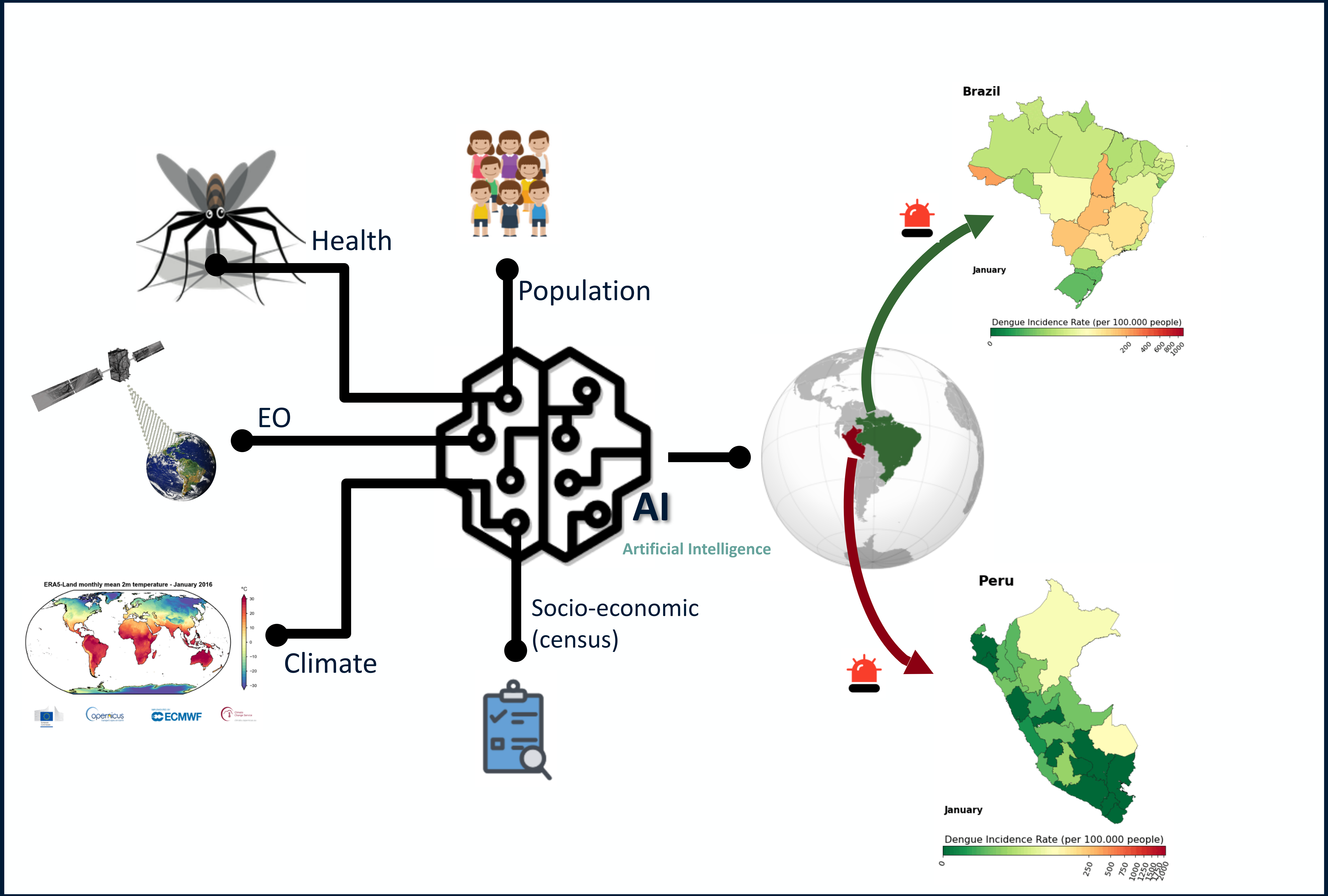
Global Forecast (precip)



https://ai4earthscience.github.io/neurips-2020-workshop/papers/ai4earth_neurips_2020_19.pdf

Quantifying health-risk with EO data and AI
(application to Dengue)

Living Planet Symposium 2022 esa



UNESCO | IRCAI Global AWARD

Top 100 AI solution for SDGs SUSTAINABLE DEVELOPMENT GOALS

to Φ-lab team for their work on forecasting dengue outbreaks with UNICEF

GLOBAL TOP 100
PROMISING PROJECT

"This project is a perfect example of collaboration between a humanitarian organisation and a research entity to support the UN SDGs."

Dohyung Kim
Lead Data Scientist at the UNICEF Office of Global Innovation

unicef INNOVATION

Observation

Computer Vision, Enhancement
Pattern Detection

Earth System

Digital Twin Earth

Data Assimilation

Targeted Obs

Machine Learning

Prediction

Emulators,
Physics-informed AI
Parameterizations

MEETING REPORT OPEN

coming soon!

ESA-ECMWF workshop report: Machine Learning for Earth System Observation and Prediction - recent progress and research directions

Rochelle Schneider[1,2*], Massimo Bonavita[2], Alan Geer[2], Rossella Arcucci[3], Peter Dueben[2], Claudia Vitolo[1], Bertrand Le Saux[1], Begüm Demir[4], and Pierre-Philippe Mathieu[1]

[1] European Space Agency, Frascati, 00044, Italy
[2] European Centre for Medium-Range Weather Forecast, Reading, RG2 9AX, UK
[3] Imperial College London, London, SW7 2AZ, UK
[4] Technische Universität Berlin, Berlin, 10587, Germany
* rochelle.schneider@esa.int

Workshop website

This paper provides a short summary of the outcomes the workshop on Machine Learning (ML) for Earth System Observation and Prediction (ESOP / ML4ESOP) organised by the European Space Agency (ESA) and the European Centre for Medium-Range Weather Forecasts (ECMWF) between 15 and 18 November 2021. The 4-days workshop had more than 30 speakers and 30 poster-presenters, attracting over 1,100 registrations from 85 countries around the world. The workshop aimed to demonstrate where and how the fusion between traditional ESOP applications and ML methods has shown limitations, outstanding opportunities, and challenges based on the participant's feedback. Future directions were also highlighted from all thematic areas that comprise the ML4ESOP domain.

THEMATIC AREAS

1. Enhancing Satellite Observation with Machine Learning (ML)
2. Hybrid Data Assimilation - ML approaches
3. Geophysical Forecasting with ML and Hybrid Models
4. ML for Post-Processing and Dissemination

2022
3rd edition
confirmed!

OVERVIEW

- Over 1,100 registrations from 85 countries around the world. Germany, Italy, and the UK large representation.
- Pierre-Philippe Mathieu (ESA) and Andy Brown (ECMWF) - vision to enable both ESA and ECMWF's Member and Co-operating States to benefit from ML advances to satellite observations, and weather, and climate modelling.
- 1st-3rd days - devoted to 33 oral presentations from experts across Thematic Areas. 4th day - listen to the participants, coming from both academic and industry backgrounds with rich experiences and expertise on current ML methods for ESOP applications.

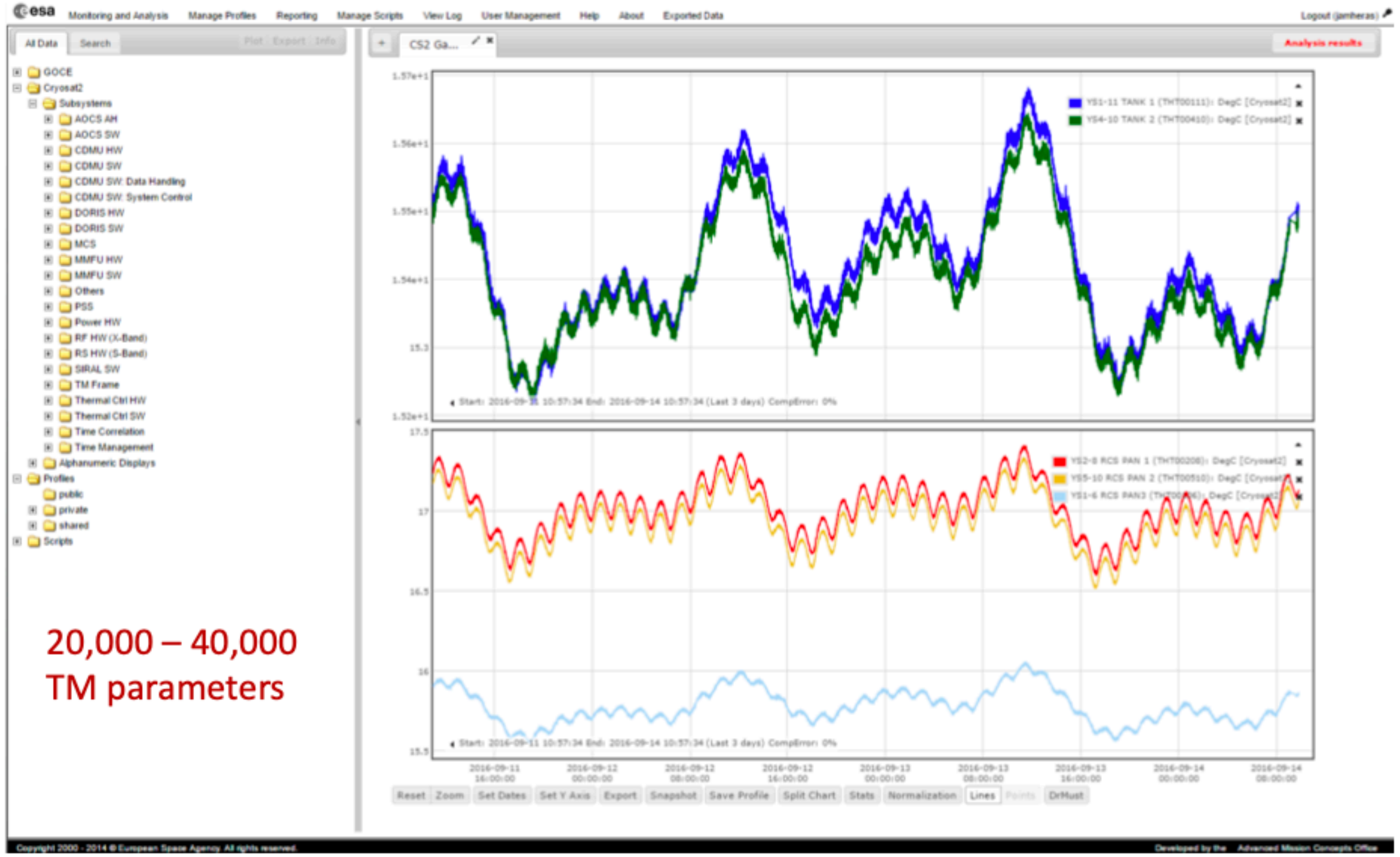
KEY MESSAGES

- Importance of advancing on explainable ML tools and understand the inner-functioning of the model, tackling the 'black-box' challenge.
- New ML in Earth Science agenda - revolutionise the value extracted from Earth Observation (EO) satellite images/videos: event recognition (cultural events vs manifestations) and building permission control based on text mining from urban planning regulations.
- ECMWF's Senior Scientist Dr Geer stressed how EO products are essential to Data Assimilation systems, providing the initial conditions and parameter estimates of the geophysical atmospheric state to describe complex physical dynamics needed to make geophysical forecasts.
- The incorporation of ML methods into Earth System's Data Assimilation can attempt to emulate the whole or part of the dynamical system.
- ML limitations: very task-oriented methods - difficulties making predictions about physical processes (e.g., volcanic activity), since they lack prior knowledge about the system they want to describe.
- ML limitation: need for more AI-ready datasets and access to pre-trained ML models that need to be customised for a specific application.
- Standard ML benchmark seen as a Triade: limitation, opportunity, and challenge
- Private sector - reluctance on the operational/user services to explore ML approaches due to the strong interpretability and trustworthiness of (benchmark) statistical methods, and the concern about possible service disruptions due to unforeseen ML model issues.
- Future direction: ML generalisation capacity *(a real game-changer!)*, known as Transfer Learning – apply a trained-ML model to different geographical regions or temporal periods to the same or a similar problem (e.g., food security, climate change mitigation).
- Future direction: ML techniques learn causal relationships rather than associations or patterns such as between climate variables.
- Future direction: More scientists who can do both, ML and Earth system science - linking two communities.
- Future direction: Adjust the ML models to widen the magnitude of their prediction range to capture severe events (e.g., flooding, Climate Change) due to their catastrophic impact on society and economy.
- Further opportunities: explore the future digital twin engines provided by the Destination Earth initiative.
- Final remarks: participants feedback reinforced the call to produce replicable, explainable, and sustainable ML methods

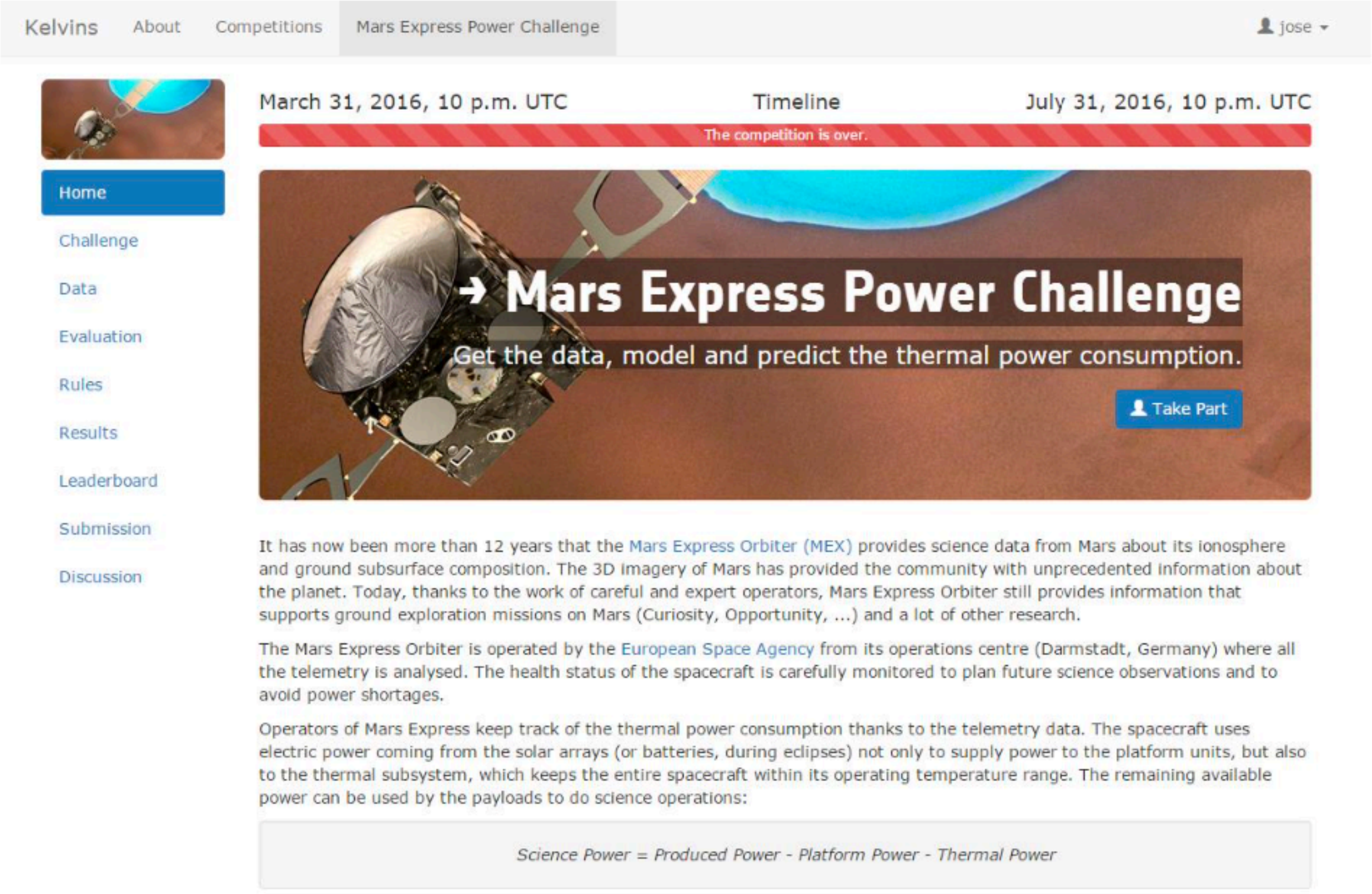
Spacecraft Health

AI for Predictive Maintenance (ESOC)

ML in Space Operations



Mars Express


Kelvins About Competitions Mars Express Power Challenge jose

Home
Challenge
Data
Evaluation
Rules
Results
Leaderboard
Submission
Discussion

March 31, 2016, 10 p.m. UTC — Timeline — July 31, 2016, 10 p.m. UTC

The competition is over.

It has now been more than 12 years that the Mars Express Orbiter (MEX) provides science data from Mars about its ionosphere and ground subsurface composition. The 3D imagery of Mars has provided the community with unprecedented information about the planet. Today, thanks to the work of careful and expert operators, Mars Express Orbiter still provides information that supports ground exploration missions on Mars (Curiosity, Opportunity, ...) and a lot of other research.

The Mars Express Orbiter is operated by the European Space Agency from its operations centre (Darmstadt, Germany) where all the telemetry is analysed. The health status of the spacecraft is carefully monitored to plan future science observations and to avoid power shortages.

Operators of Mars Express keep track of the thermal power consumption thanks to the telemetry data. The spacecraft uses electric power coming from the solar arrays (or batteries, during eclipses) not only to supply power to the platform units, but also to the thermal subsystem, which keeps the entire spacecraft within its operating temperature range. The remaining available power can be used by the payloads to do science operations:

Science Power = Produced Power - Platform Power - Thermal Power

SPACE AND ARTIFICIAL INTELLIGENCE

Online Conference, September 4th, 2020
Organized by CLAIRE and ESA, in association with ECAI2020

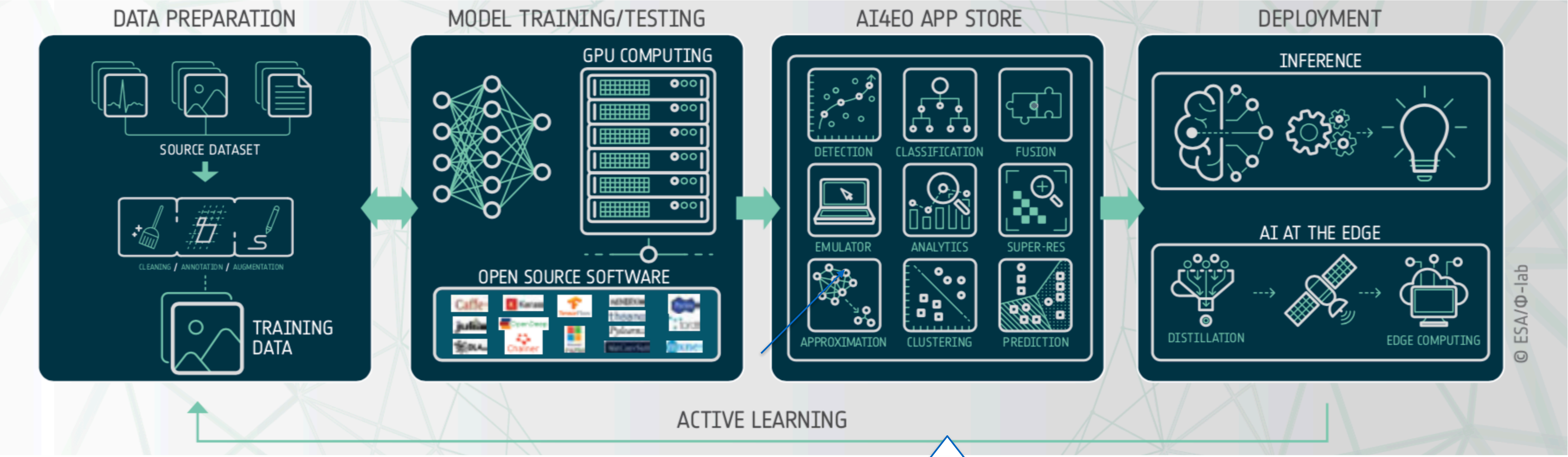
GalaxAI: Machine Learning for Spacecraft Operations

https://spaceandai.ijs.si/2020/Session%201_Matej%20Petkovic.pdf

Courtesy : Jose Martinez-Heras, Alessandro Donati, et al.

AI Workflow Engineering & Management - MLOPS

Towards adaptative AI pipeline

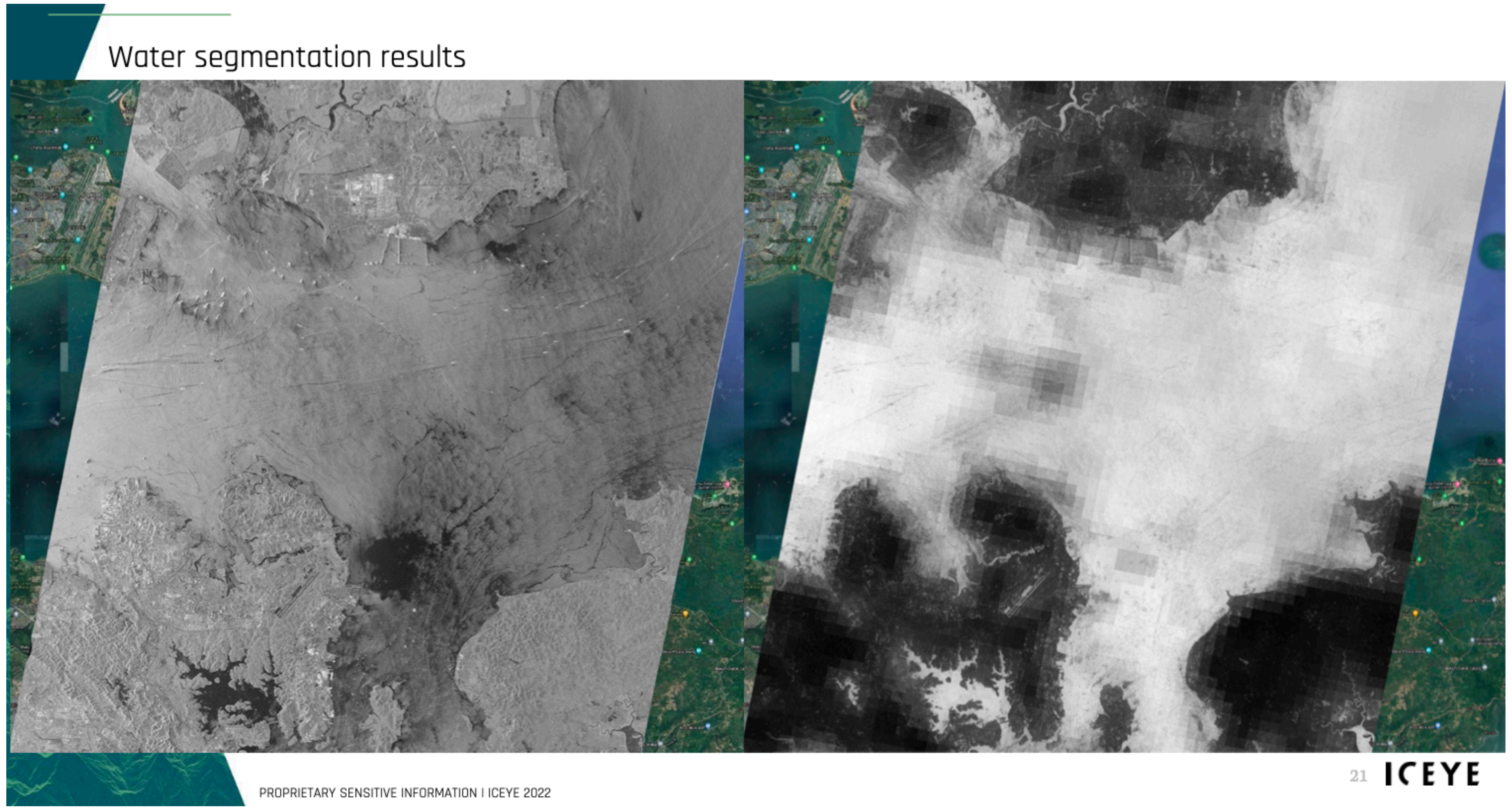


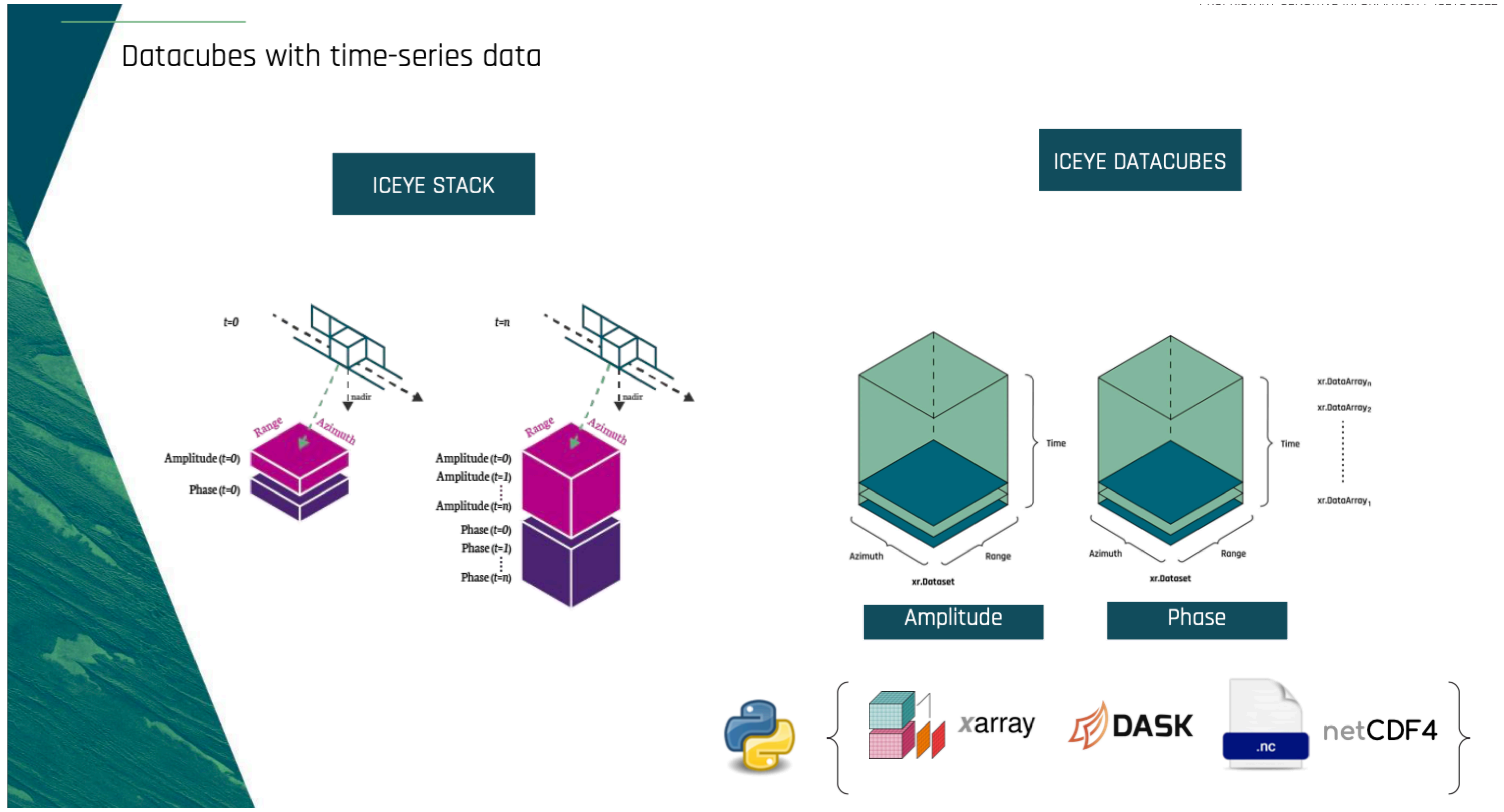
Pre-trained models,
(Foundation Models)

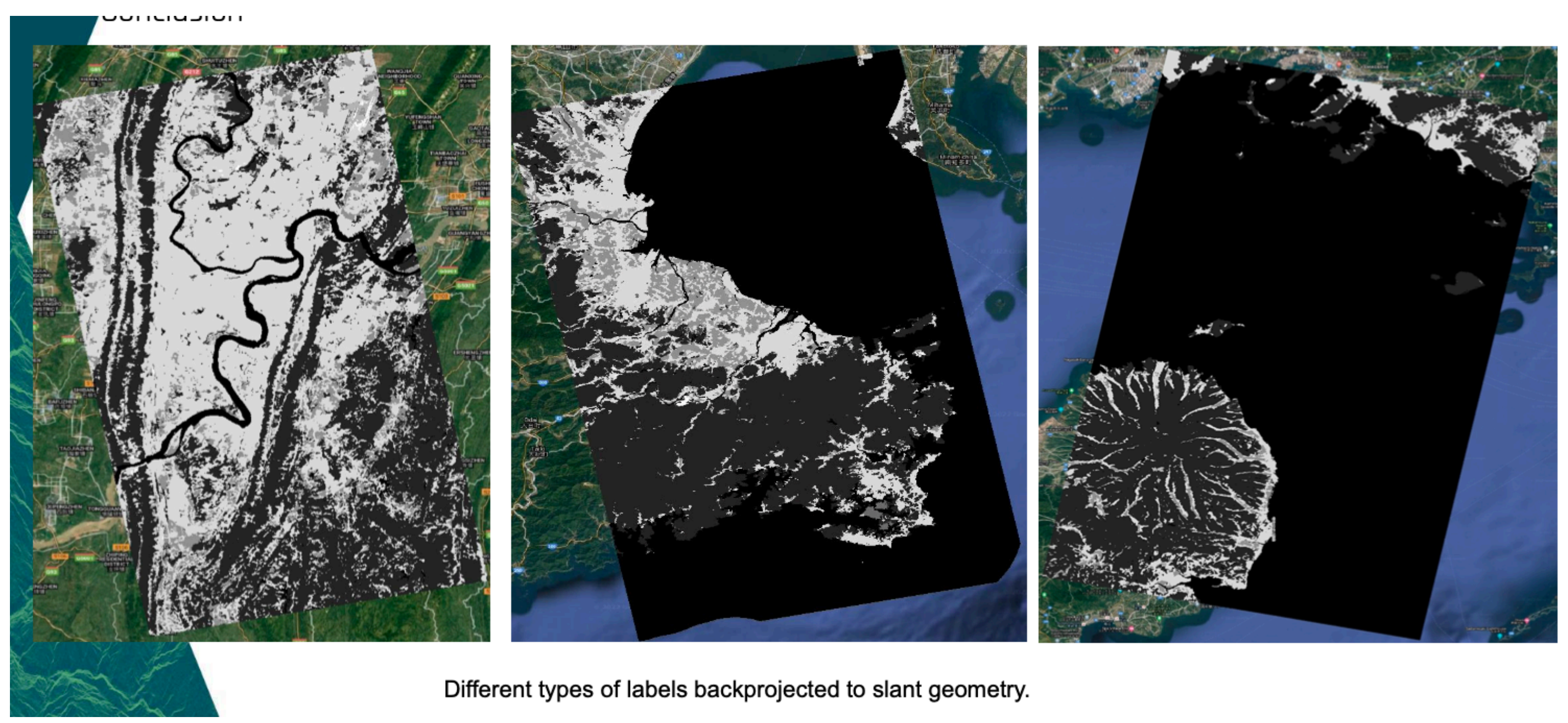
Data Augmentation - Labelling via Gaming

Credit: Blackshore

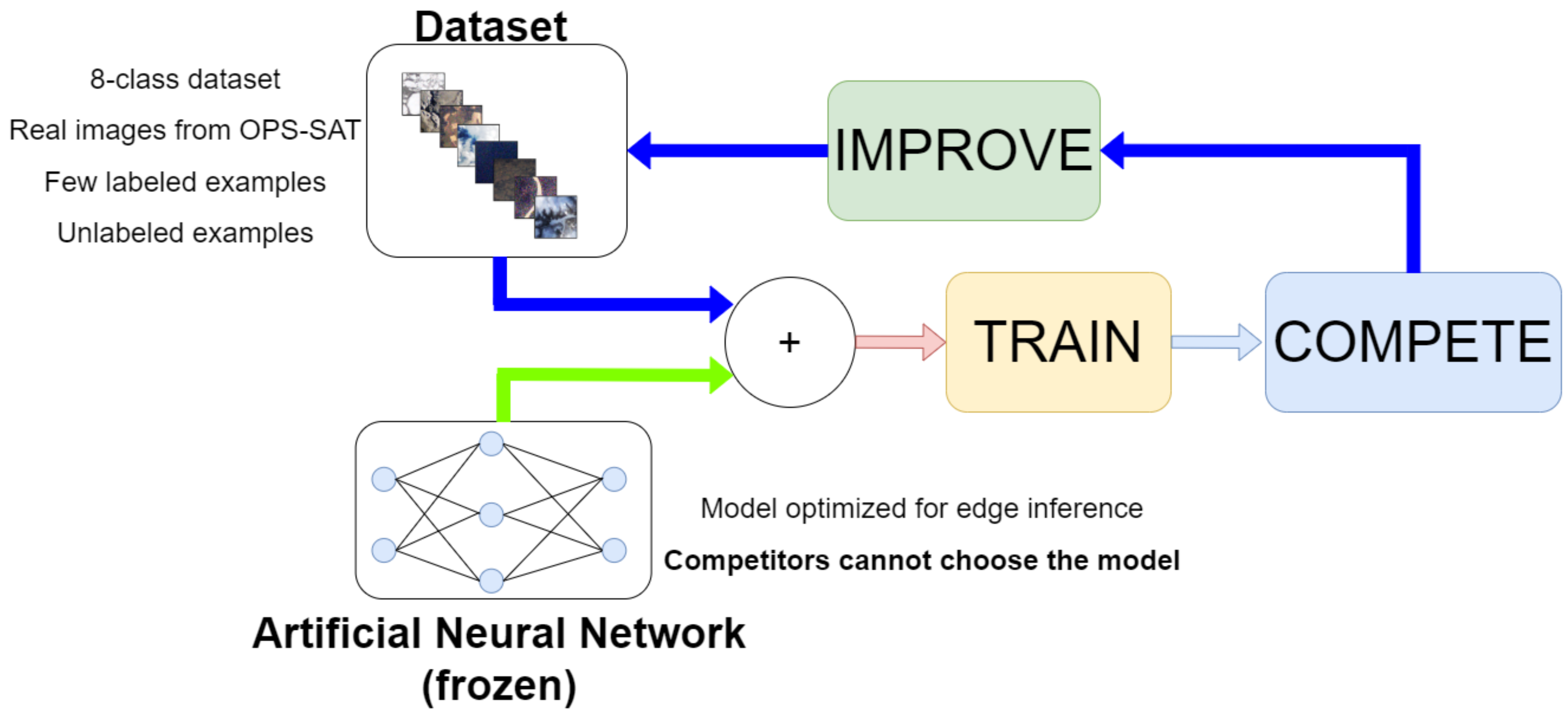
Data Augmentation - SAR (IceCube)







Ops SAT data-centric AI onboard challenge



Data-centric AI Challenge: you are given a (quantized) neural model that has passed all the requirements for inference on-board OPS-SAT.

Can you train its parameters as to predict one of eight classes for some tiles (few shot learning) coming directly from the spacecraft imaging sensor? How to best represent the data

Search by similarity (no labels)

SPACE ML | GIBS DOWNLOADER

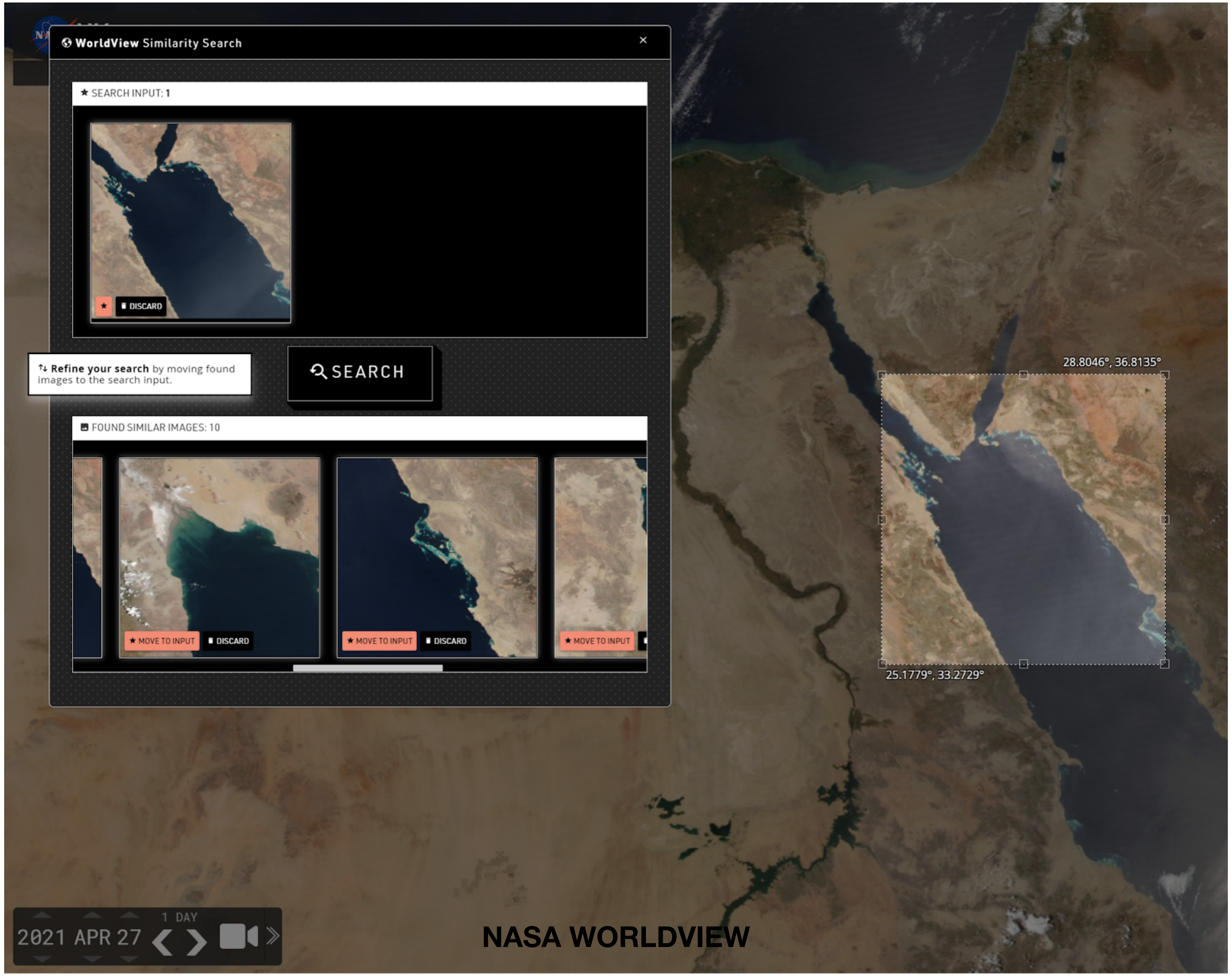
SPACE ML | SWIPE LABELER

SPACE ML | ACTIVE LABELER

SPACE ML | CURATOR SELF-SUPERVISED LEARNER

SPACE ML | IMAGE SIMILARITY SEARCH

SPACE ML | WORLDVIEW SEARCH CHROME EXTENSION



GLOBAL TOP 100

AI solutions for Sustainable Development

FDL FRONTIER DEVELOPMENT LAB

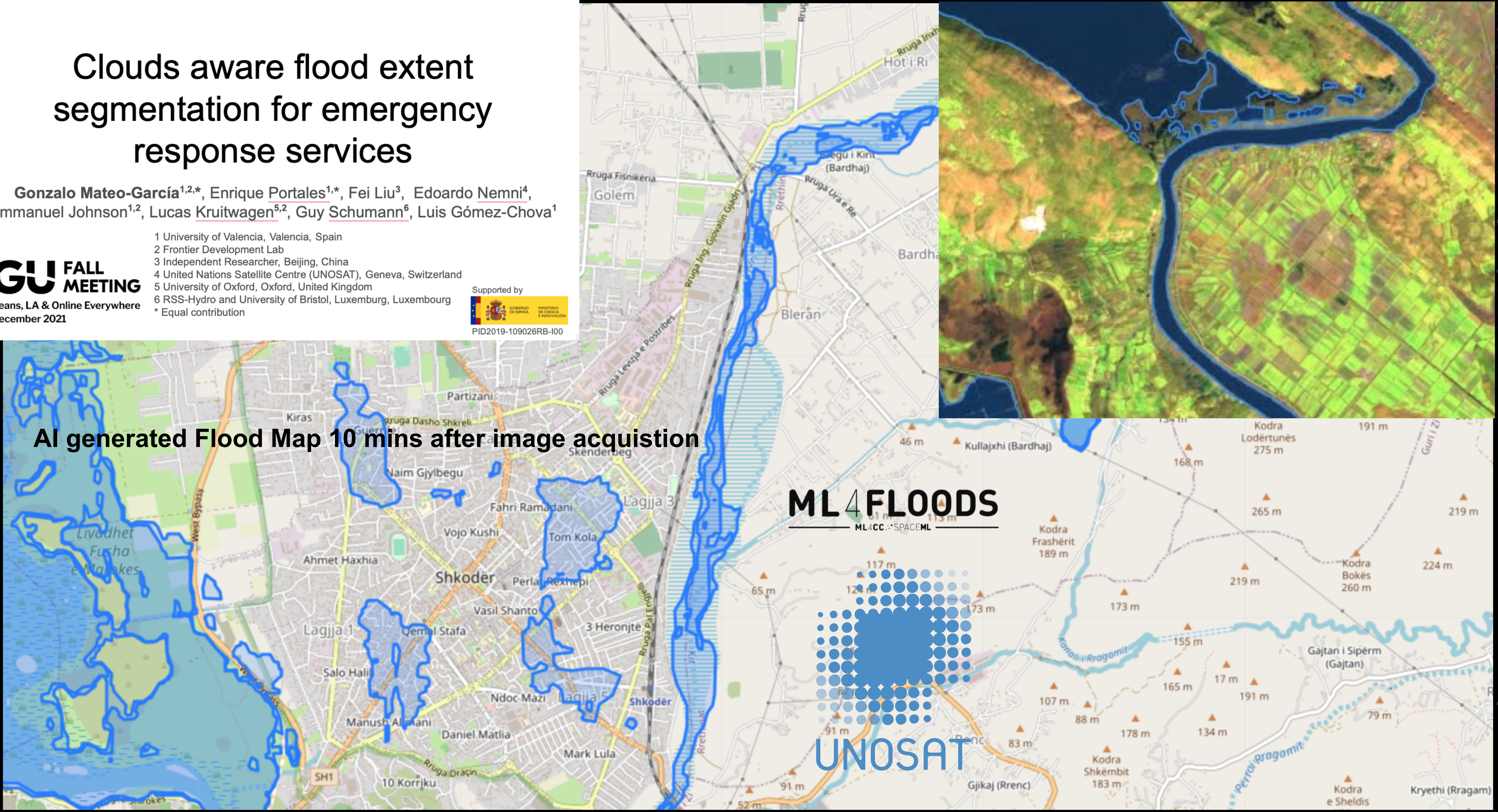
Clouds aware flood extent segmentation for emergency response services

Gonzalo Mateo-García[1,2,*], Enrique Portales[1,*], Fei Liu[3], Edoardo Nemni[4], Emmanuel Johnson[1,2], Lucas Kruitwagen[5,2], Guy Schumann[6], Luis Gómez-Chova[1]

1 University of Valencia, Valencia, Spain
2 Frontier Development Lab
3 Independent Researcher, Beijing, China
4 United Nations Satellite Centre (UNOSAT), Geneva, Switzerland
5 University of Oxford, Oxford, United Kingdom
6 RSS-Hydro and University of Bristol, Luxemburg, Luxembourg
* Equal contribution

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

Supported by
GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN
PID2019-109026RB-I00

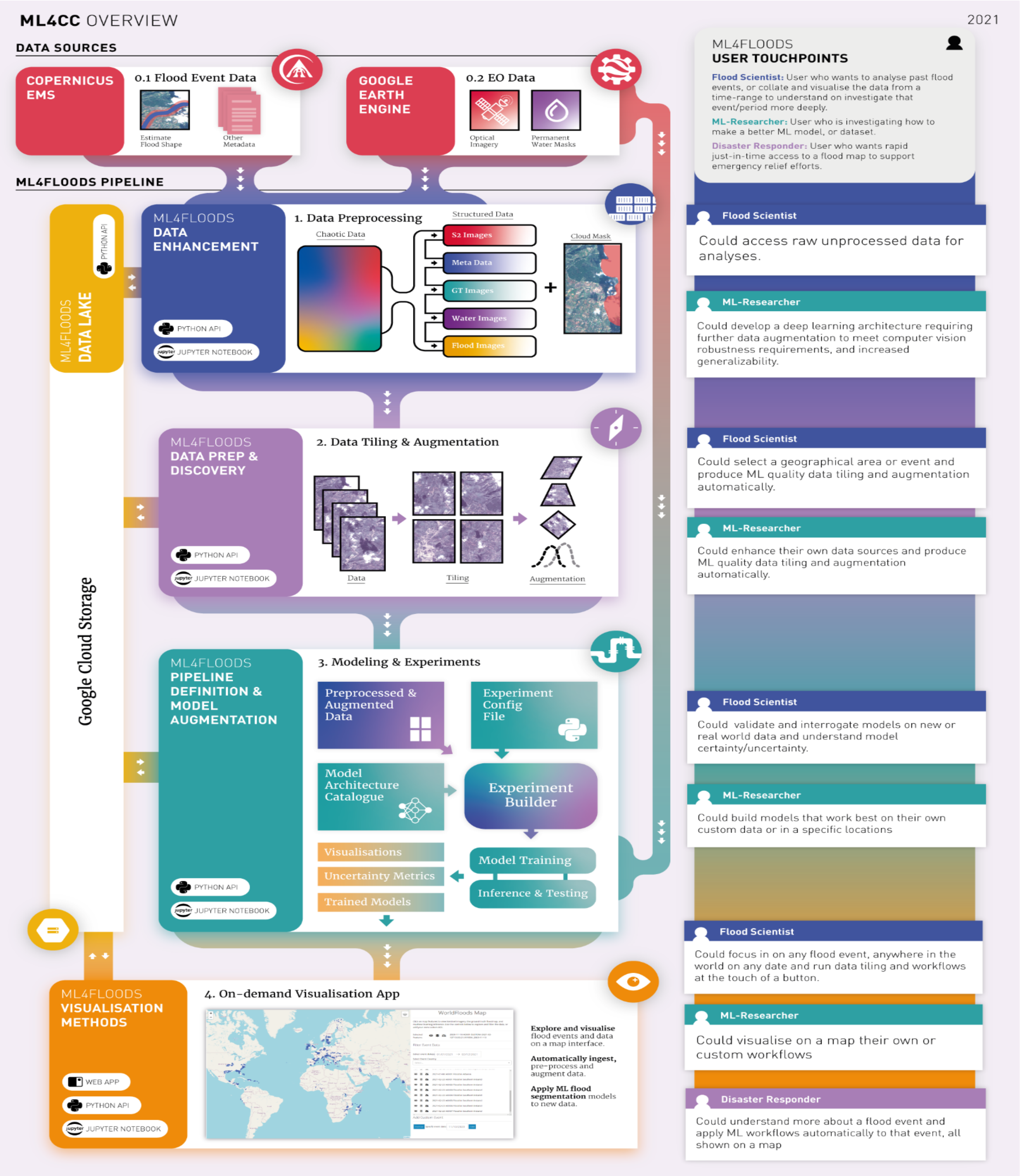


https://docs.google.com/presentation/d/13ANb-jPD7oCAkprPTbPekbvRRDjxwXeEpfGCs-WkY-M/edit#slide=id.p

ML4Floods

ML4FLOODS
ML4CC SPACEML

esa



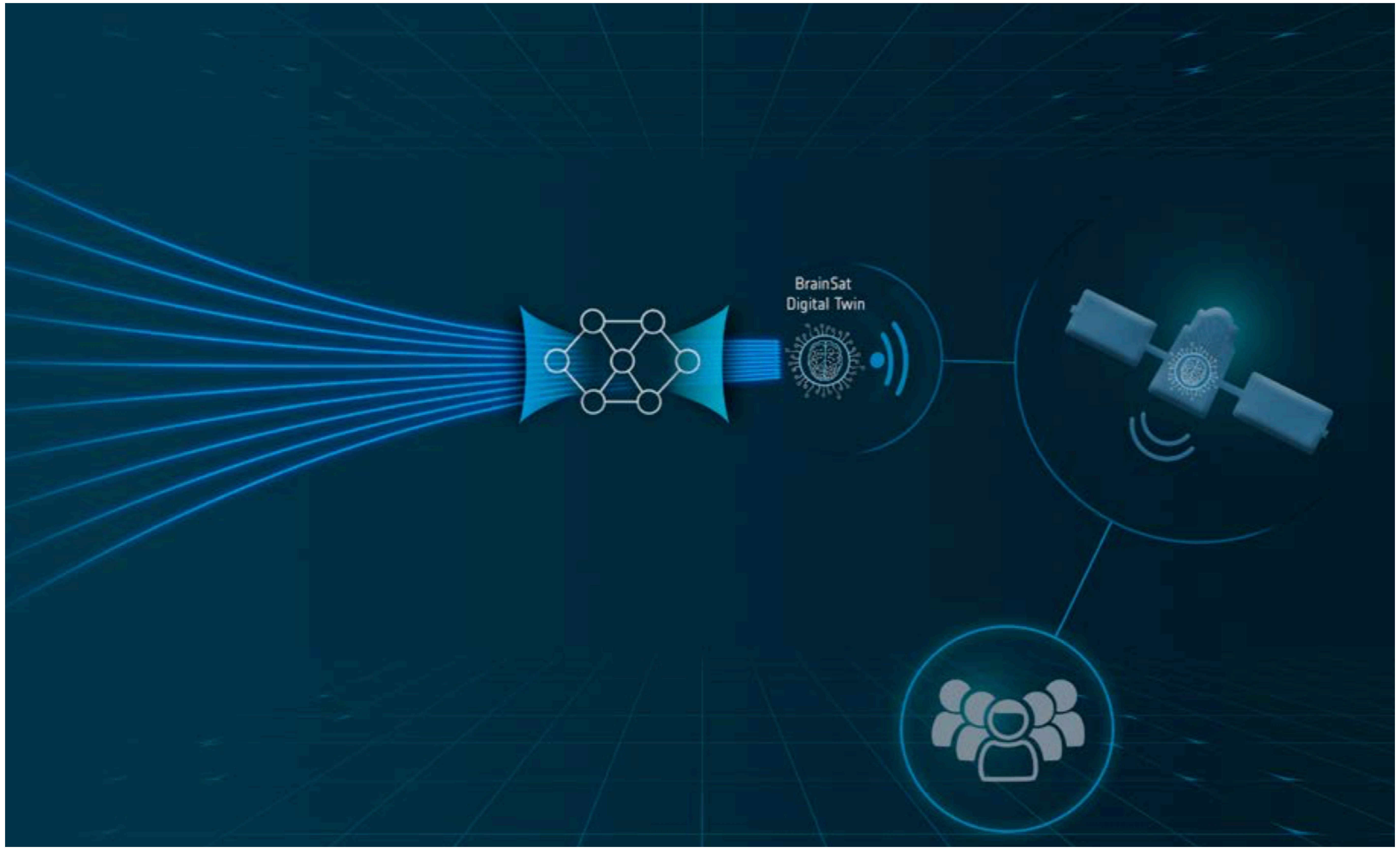
end-to-end open source package for flood extent segmentation

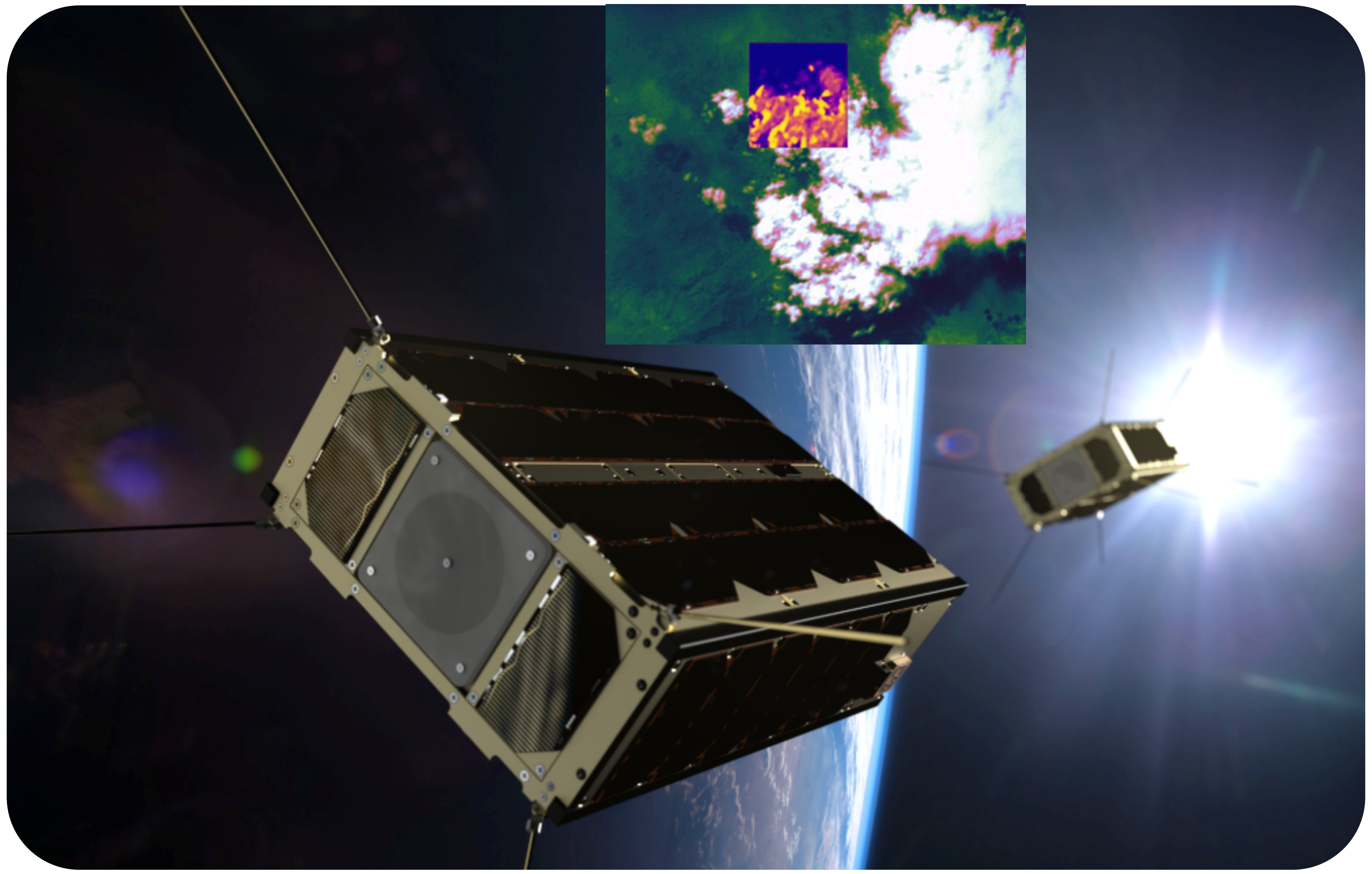
Data acquisition from different sources
Preprocessing
Training of DL models
Inference on new images
Metrics
Dashboards

EUMETSAT MOOC | Future Learn

Network Intelligence in Orbit

Edge Computing

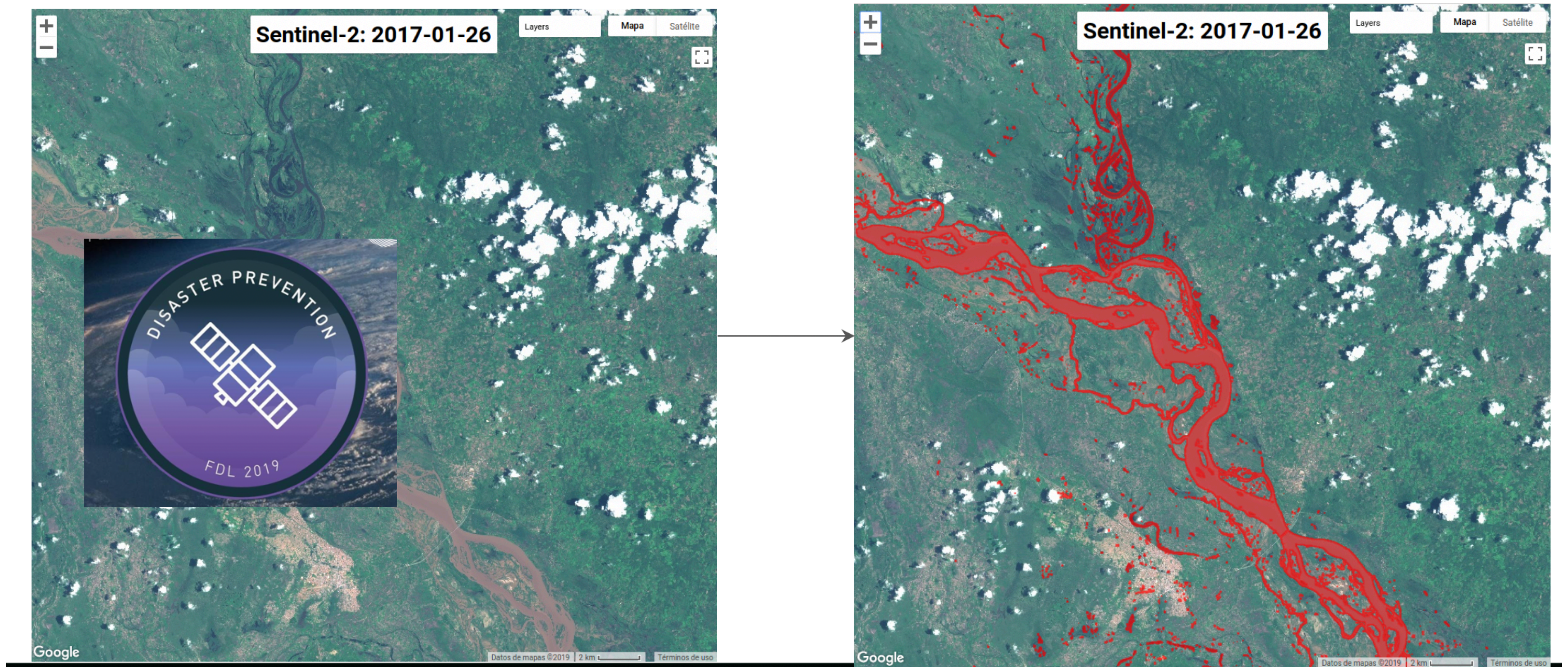




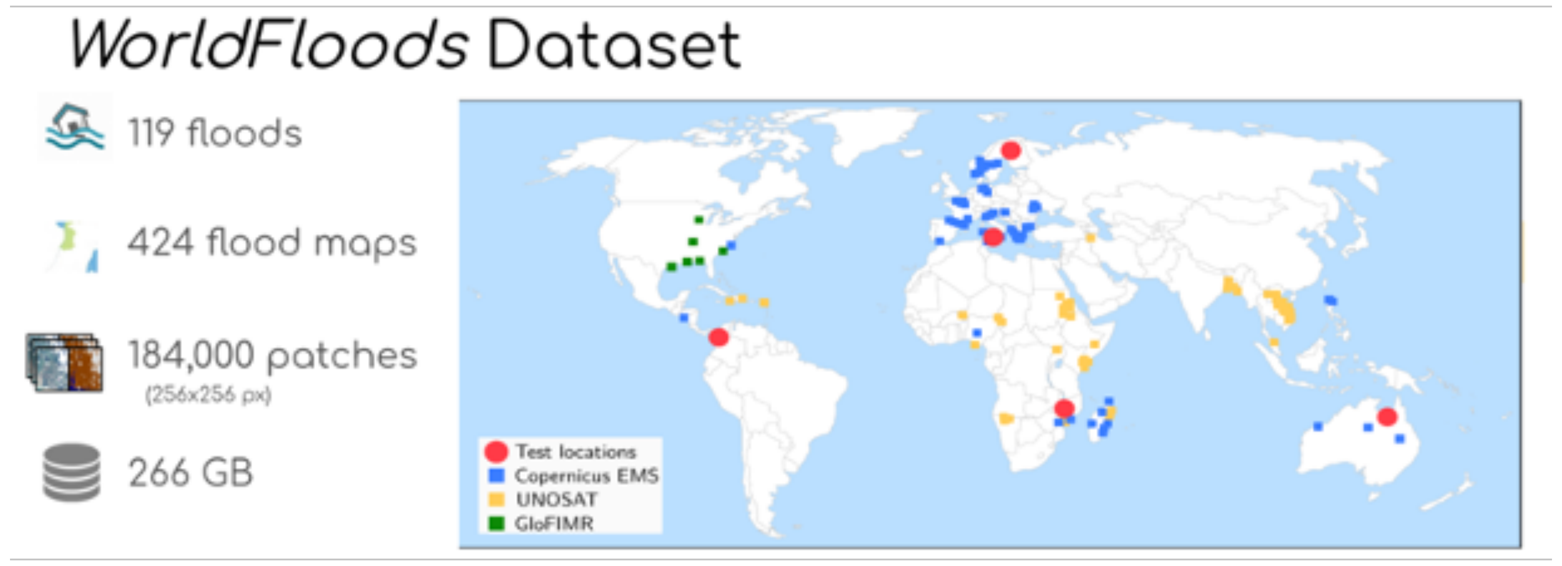
> *The value of satellite-based EO no longer grows with the ability to collect and transmit data back to Earth, it increasingly lies with the ability to transmit customer-relevant insight in real-time.*
>
> **Peter Platzer,**
> *Spire, Φ-week 2019*

Ultra-low Power,
High peed, Cheap

Flood extent/Water segmentation (optical)



Check Video https://bit.ly/2PTSjgB




www.nature.com/scientificreports

scientific reports

OPEN Towards global flood mapping onboard low cost satellites with machine learning

Gonzalo Mateo-Garcia[1,9], Joshua Veitch-Michaelis[2,9], Lewis Smith[3,9], Silviu Vlad Oprea[4], Guy Schumann[5,6], Yarin Gal[3], Atılım Güneş Baydin[3] & Dietmar Backes[7,8]

D-Orbit

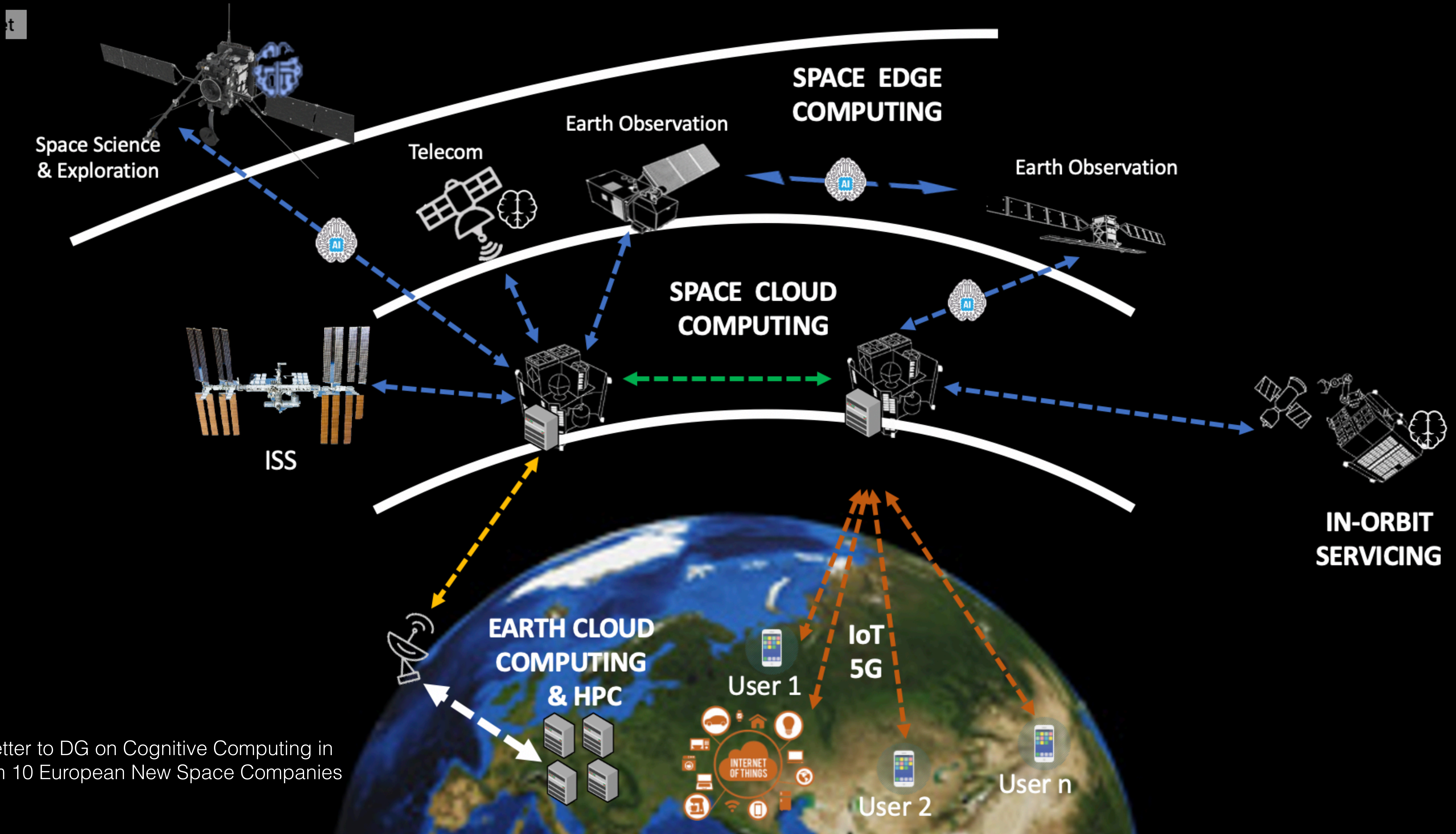
Wild Ride Mission, June 2021

ION Platform with 6 cubesats, 20+Machine Learning Apps on SpaceCloud

Dashing through the stars, Jan 2022

Re-training of ML

Cognitive Cloud Computing in Space



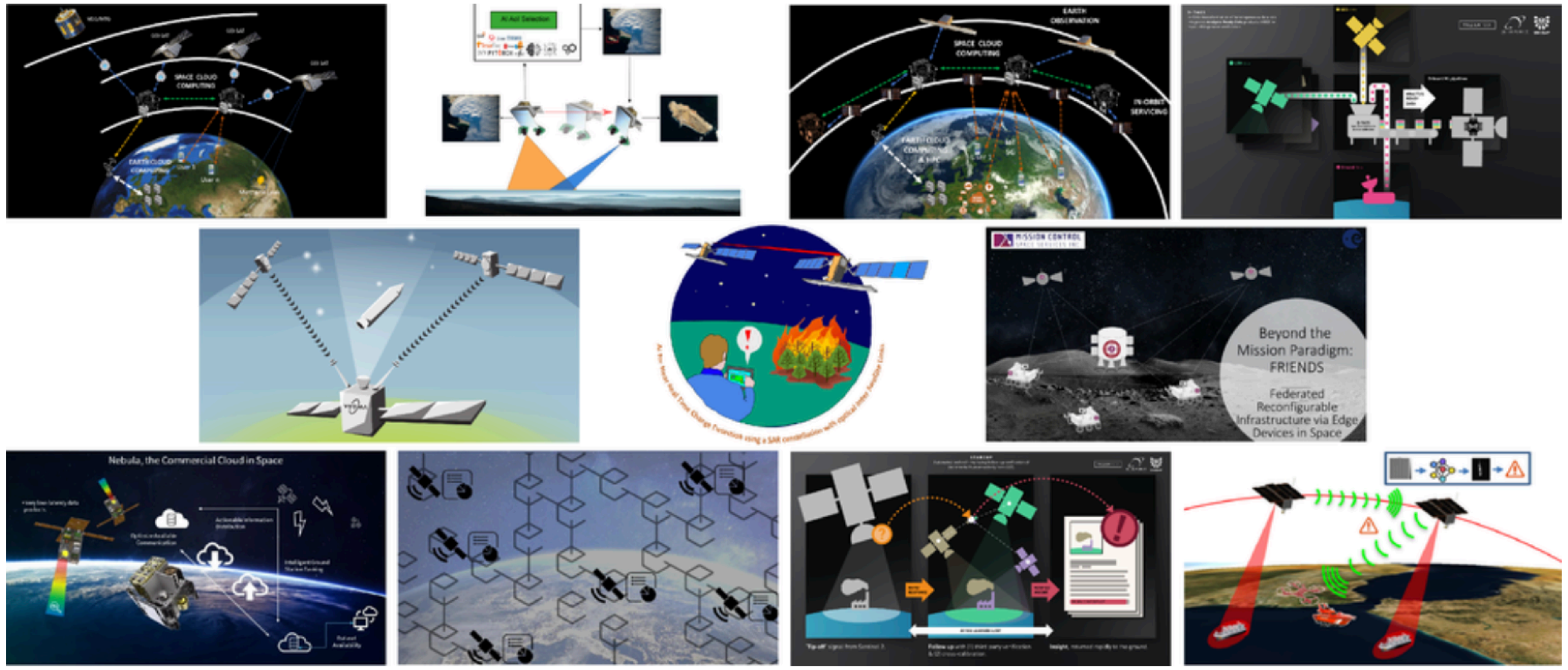
Source: Letter to DG on Cognitive Computing in Space, from 10 European New Space Companies

Key announcement – the age of AI and edge computing in space has come

DG Josef Aschbacher announced a new 1,000,000 € challenge (10 x 100 k€), driven by the vision of ESA Agenda 2025, to explore how the use of cloud computing and artificial intelligence in space could help transform the way we develop space missions and applications.

With this campaign, ESA is soliciting new mission concepts that can cover any space domain while complementing or augmenting existing and planned space-based systems. Ideas could address new ways to accelerate Earth and space sciences, new methods for extracting information on the fly, or new applications and services creating new markets.

Cognitive Cloud Computing - Discovery Call



- AI data centres
- Blockchain
- Tip&Cue LEO-GEO for Methane
- Space traffic management
- Neuromorphic computing
- Lunar rover autonomy
- Federated Learning for constellations
- Auto-calibration in orbit
- Optimised sampling dual camera
- ….

https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/The_Discovery_Campaign_on_cognitive_cloud_computing

Concluding Remarks

Enabling AI-research assistant?

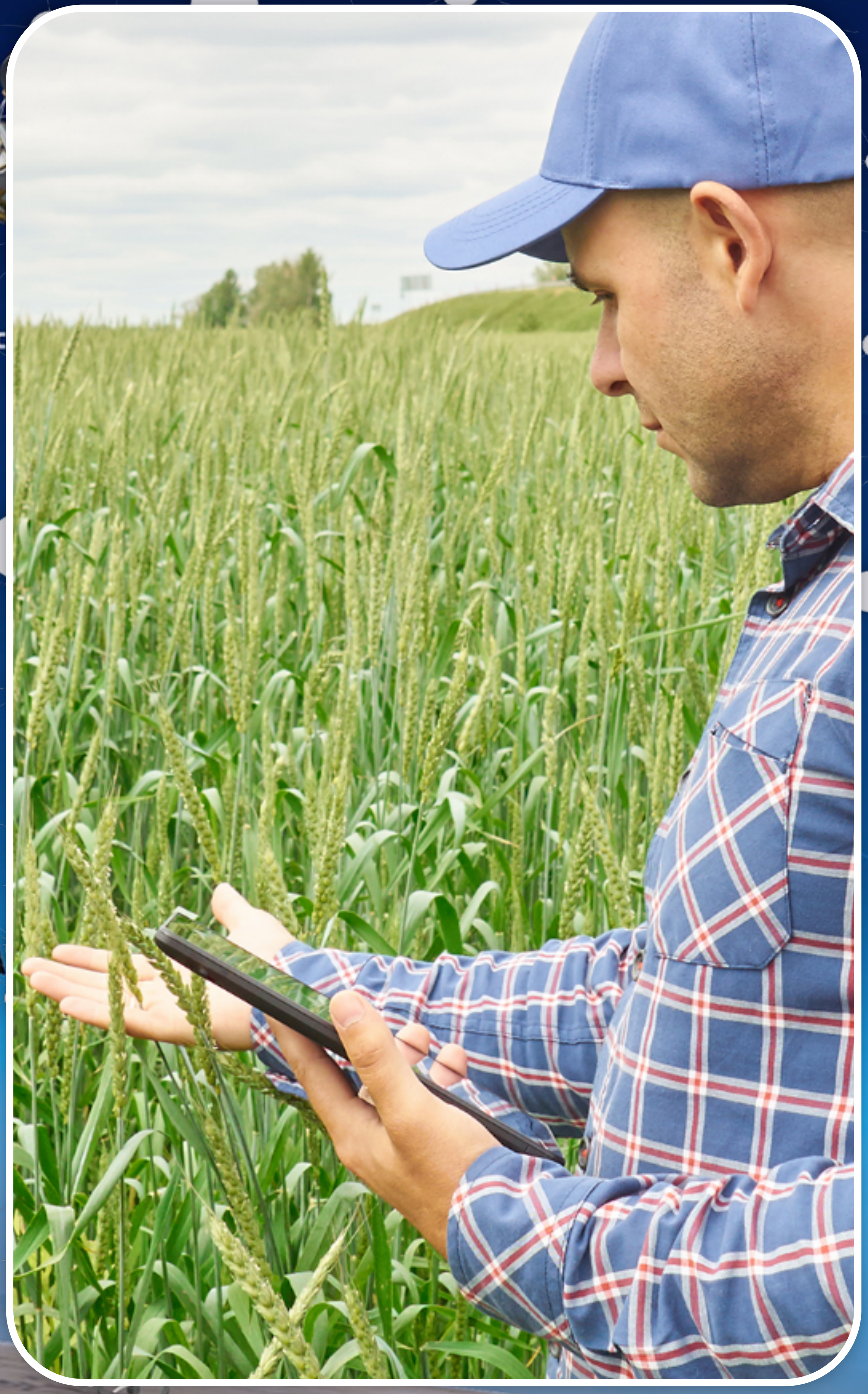
Opportunities

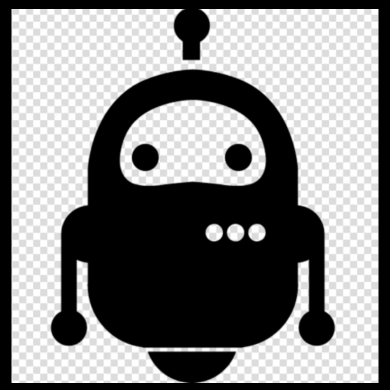
- AI feeds on **Big data** & **learn** the underlying **Structure** of data
- AI **accelerates Time to Insight** for EO
- Big complex problems can be split into small problems
- Reshape **software-defined sensing**
- Enable **transfer learning**

Challenges

- Whitening the black box & Interpretability (xAI)
- Quantifying **Uncertainty**
- Issue of **generalisation +** depends on **data quality**

System of Systems





AI co-pilot

Apollo 17, 1972

MAKE SPACE FOR EUROPE

#SpaceAmbition

philab.phi.esa.int

linkedin.com/in/ppmathieu

www.esa.int