TRILLIUM EUROPE

FDL | EUROPE

Φ-Lab Partners

2021 WSF WORLD SPACE FORUM

Adventures on the edge: ML in orbit, hybrid observation and digital twinning planet Earth

TRILLIUM EUROPE

NVIDIA SCAN Google Cloud UNIVERSITY OF OXFORD

FDL | MACHINE LEARNING ON-BOARD

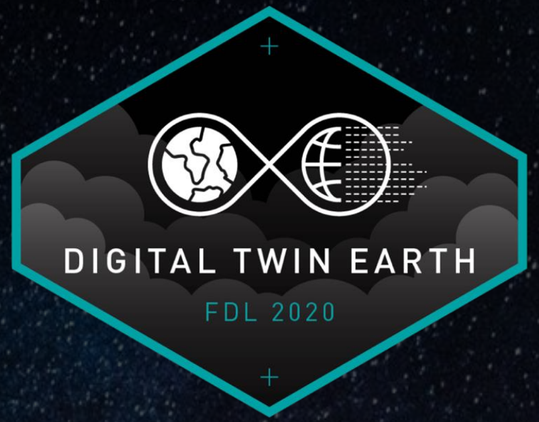
An open question:

How much will our planet change?

(not scientific)

"Earth Operations Centre"

"To successfully manage and coordinate the net- zero efforts on "spaceship Earth", the time has come to build a sort of distributed operations centre to help manage our "spaceship".

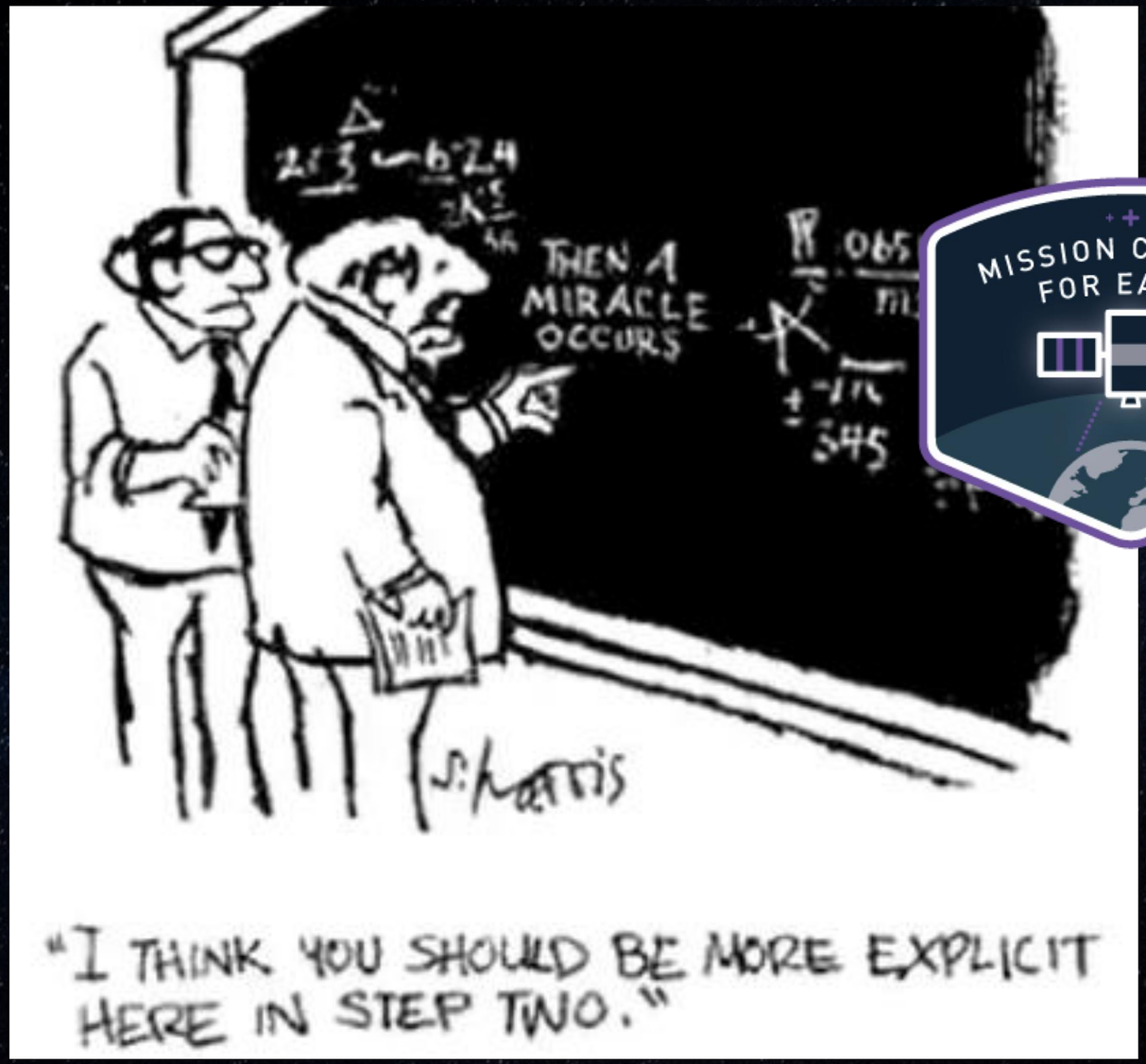


Google Cloud

NVIDIA

SCAN

Easy to say...


THEN A MIRACLE OCCURS
S. Harris
"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

MISSION CONTROL FOR EARTH

Easy to say...

SCIENTIFIC CHALLENGES	TECHNICAL CHALLENGES	PROGRAM CHALLENGES
Computational limits	**Spatial / Temporal Resolution**	**Validation / verification**
Data + model Integration	**Data deluge**	**Use-case definition**
Ameliorating Uncertainty	**Versioning / live data and drift**	**Optimization methodologies**

Adapted from ‘ESA Digital Twin Precursor: Food Systems

Sophisticated meta-learning for monitoring, active learning and optimization. (MLOPs)

SCIENTIFIC CHALLENGES

Computational limits

Data + model Integration

Ameliorating Uncertainty

TECHNICAL CHALLENGES

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USABILITY CHALLENGES

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(*****Technical debt alert********)**

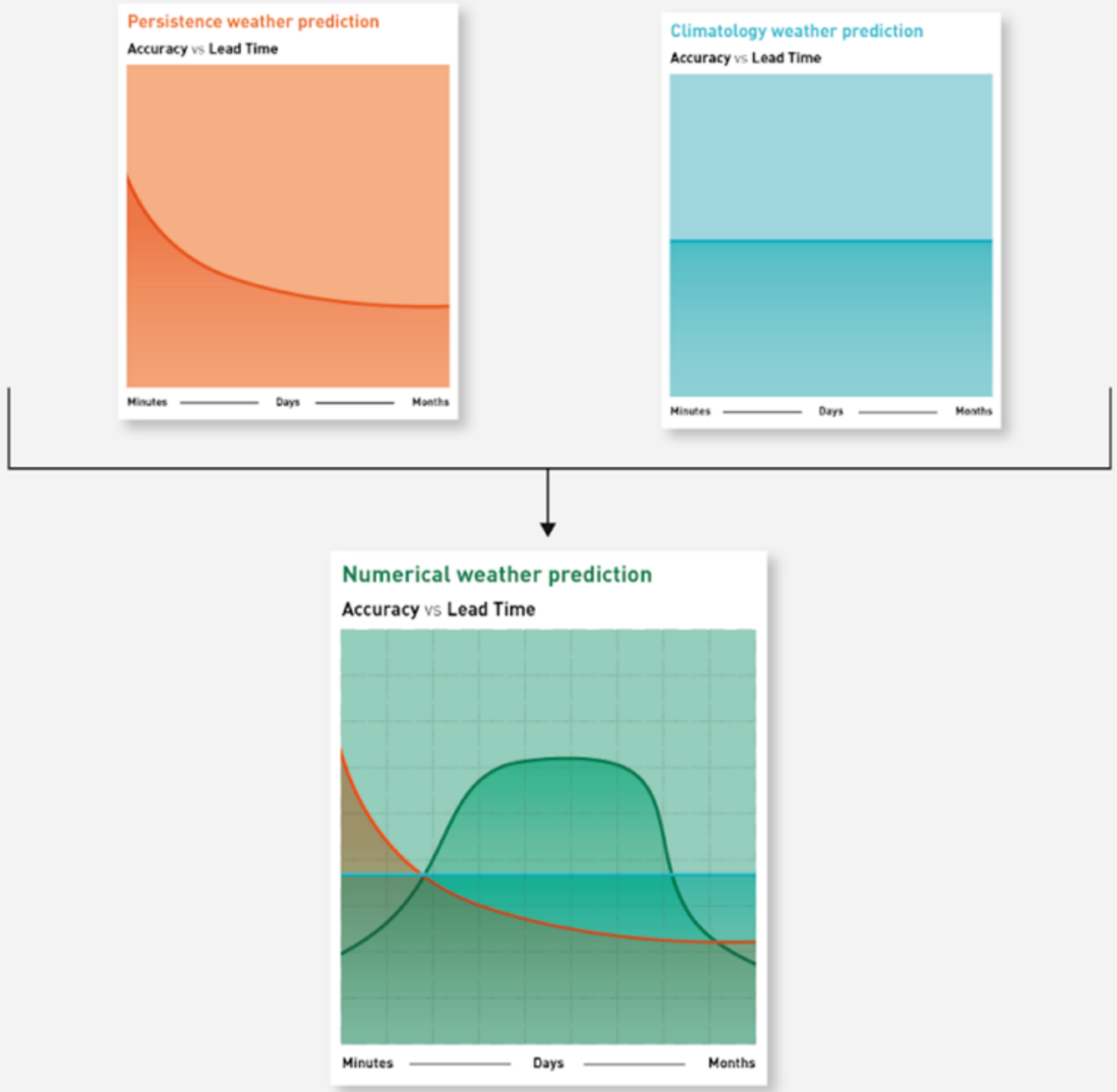
This is probably much harder than we think it’s going to be!

Credit: Associated Press

DIGITAL TWIN EARTH

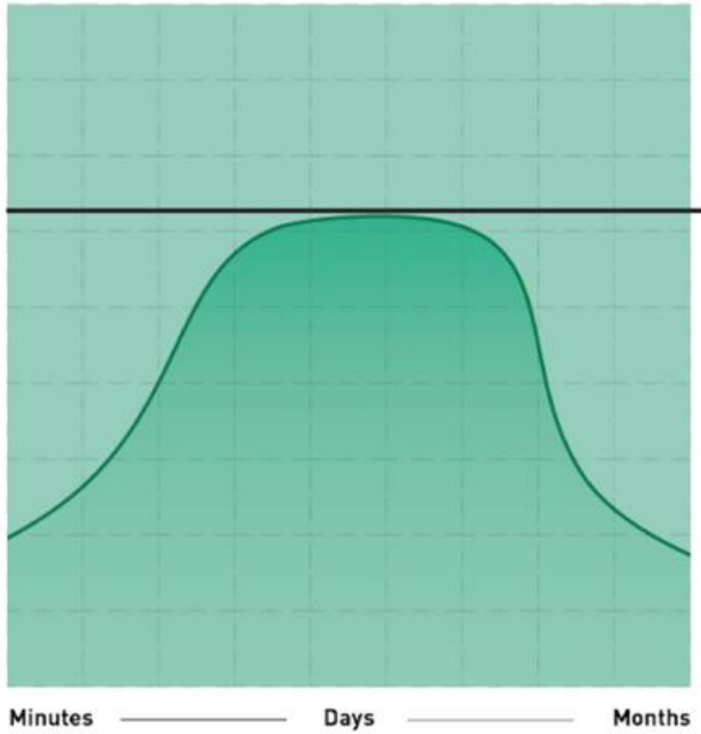
FDL 2020

Can we predict precipitation, globally, using Machine Learning?



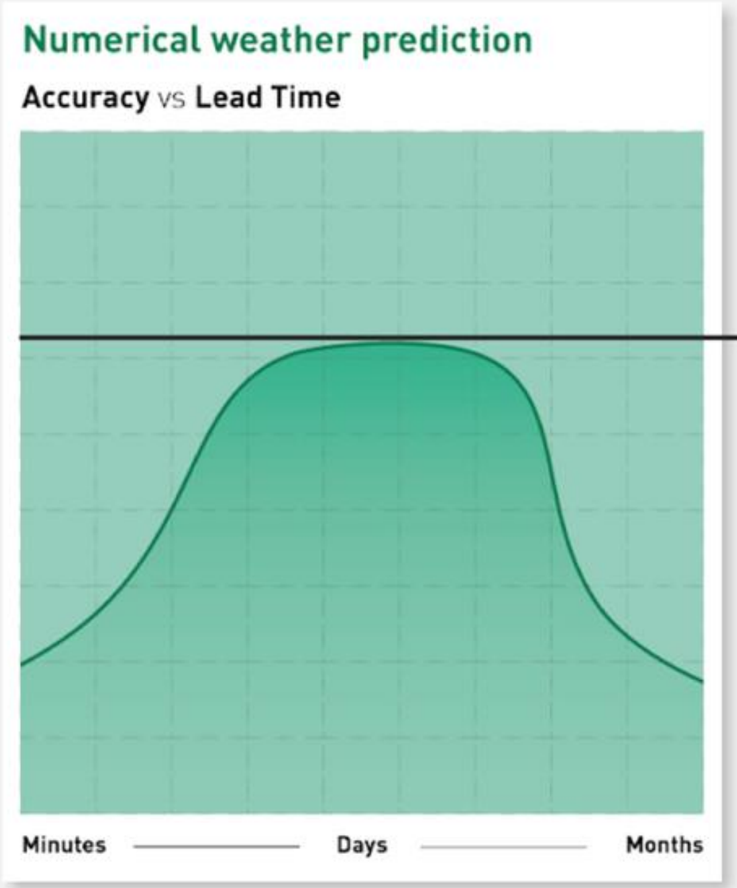
Numerical weather prediction

Accuracy vs **Lead Time**



Increasing grid resolution for improved forecasting hits a **power limit.**

Numerical forecasting is best for the timescale of a couple of days.

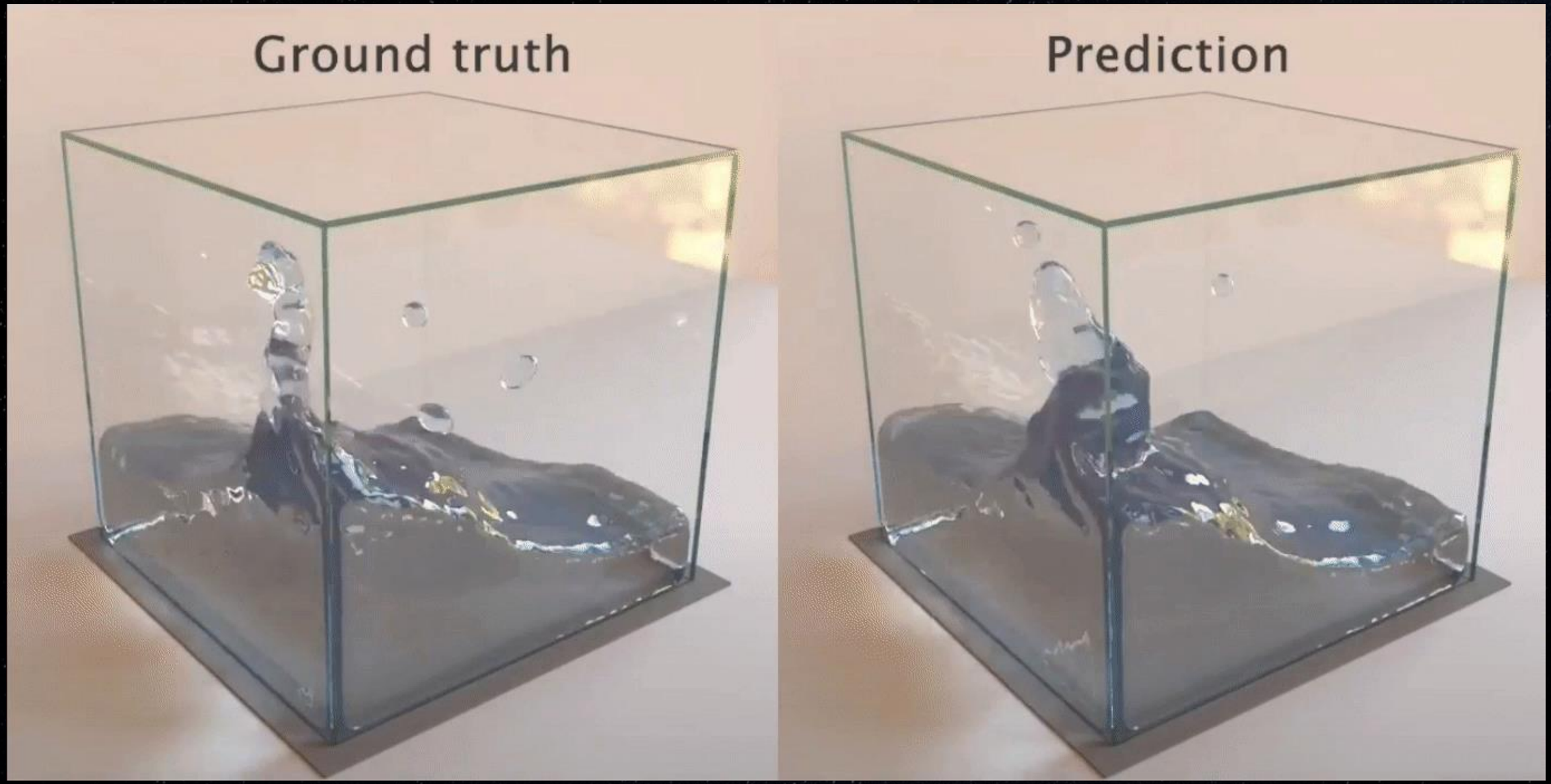


Increasing grid resolution for improved forecasting hits a power limit.

Numerical forecasting is best for the timescale of a couple of days.

Learning to Simulate Complex Physics with Graph Networks

Alvaro Sanchez-Gonzalez [*1] Jonathan Godwin [*1] Tobias Pfaff [*1] Rex Ying [*2] Jure Leskovec [2]
Peter W. Battaglia [1]



Credit: Sanchez-Gonzalez et al

PROJECT

DIGITAL TWIN EARTH

Can we lower the cost of accurate global precipitation forec...

CHALLENGE AREA
EARTH SCIENCE

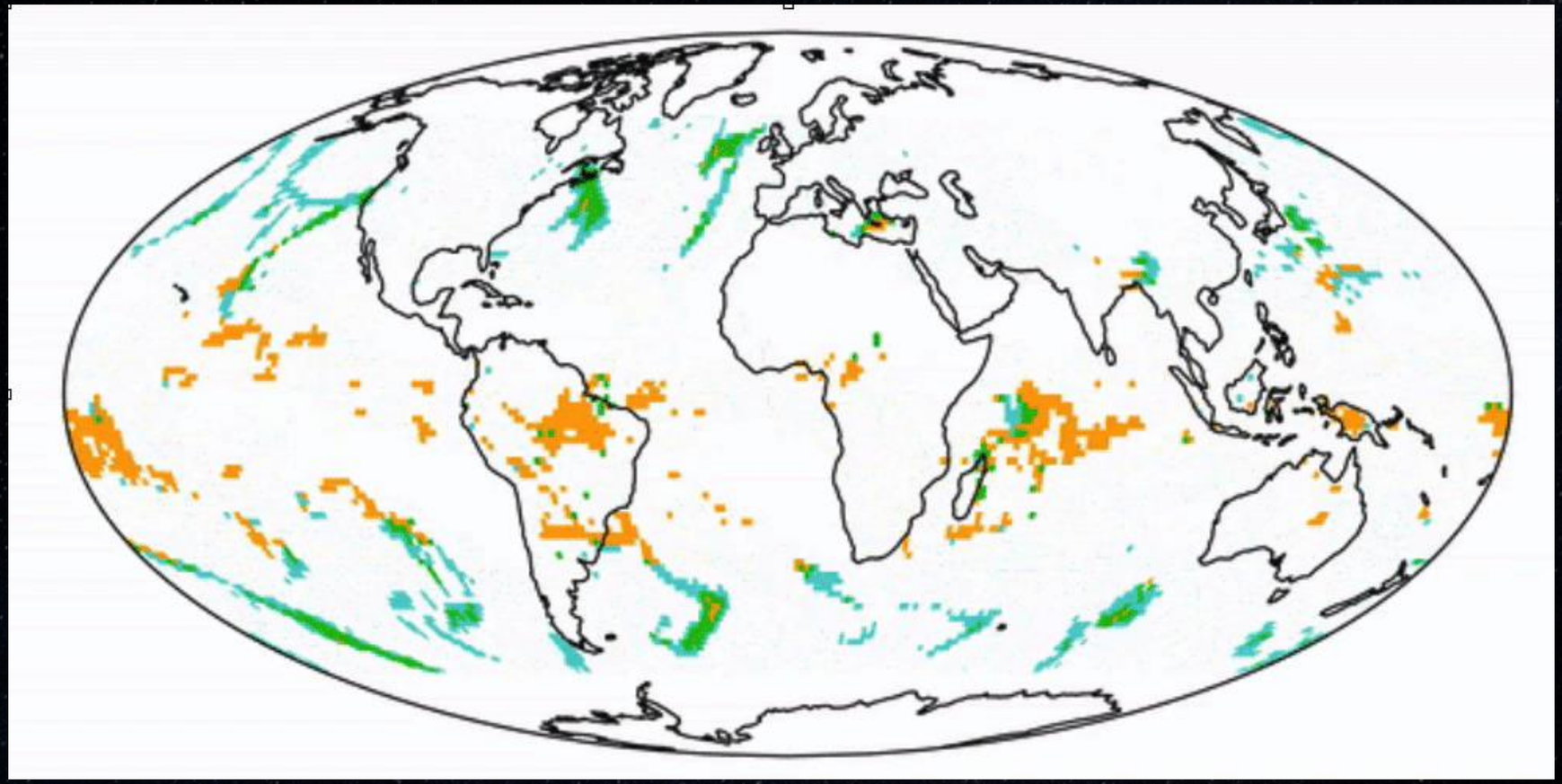
PROGRAM
FDL EUROPE

DATASET

RAINBENCH

Rainbench offers re-gridded data in memmap format sourced from the ERA5, SimSat and IMERG databases.

800GB - 1Tb



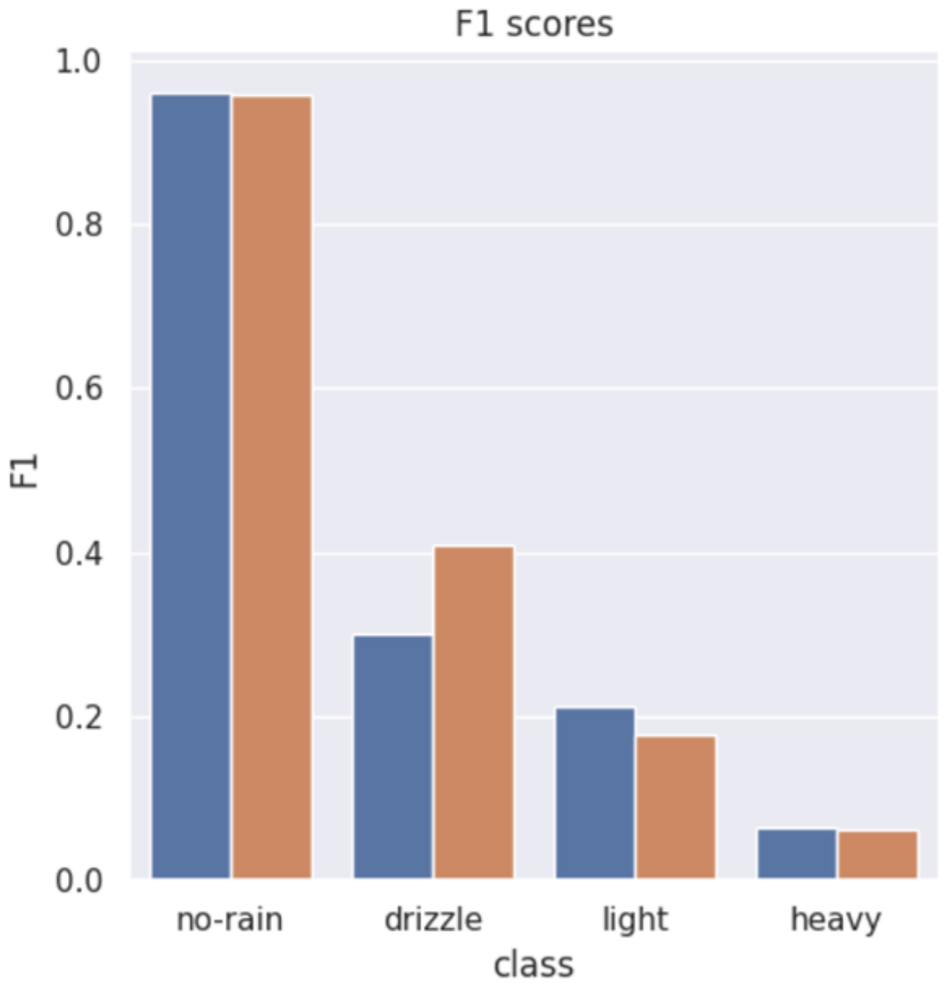
Global Precipitation: 72 hours in advance

DIGITAL TWIN EARTH
FDL 2020

Convolutional Recurrent Neural Network

Stochastic Generative Adversarial Network

Pixel-wise fully connected network



PyRain

ECMWF

https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

What about something at much higher resolution?


Wind
Waves
Land

Coastal Digital Twin

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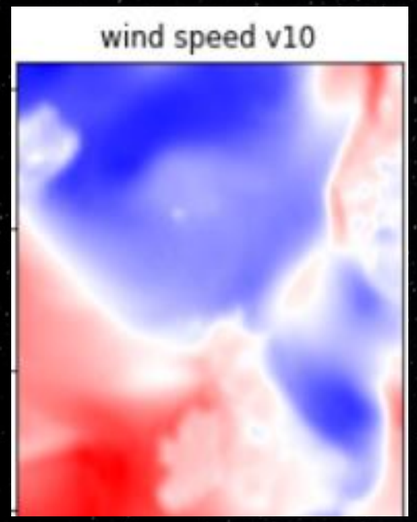
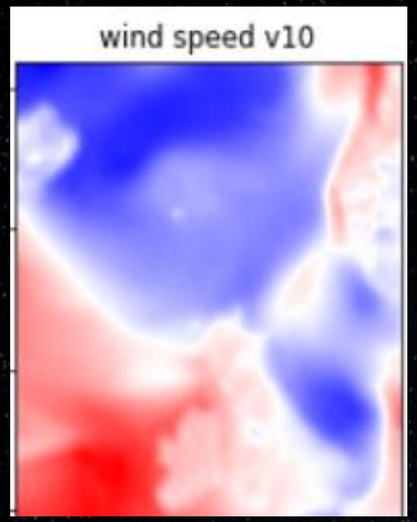
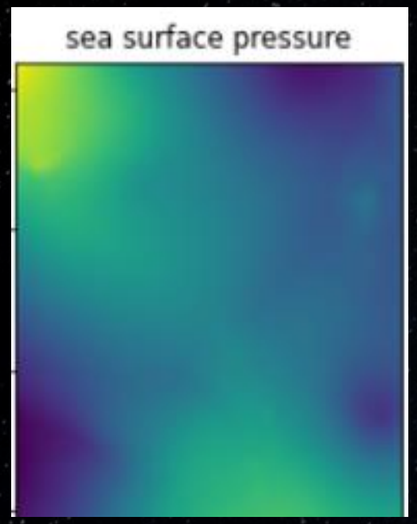
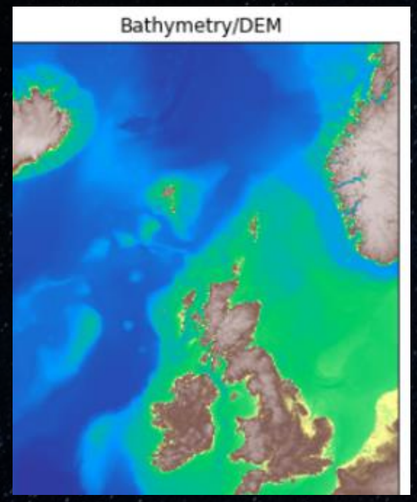




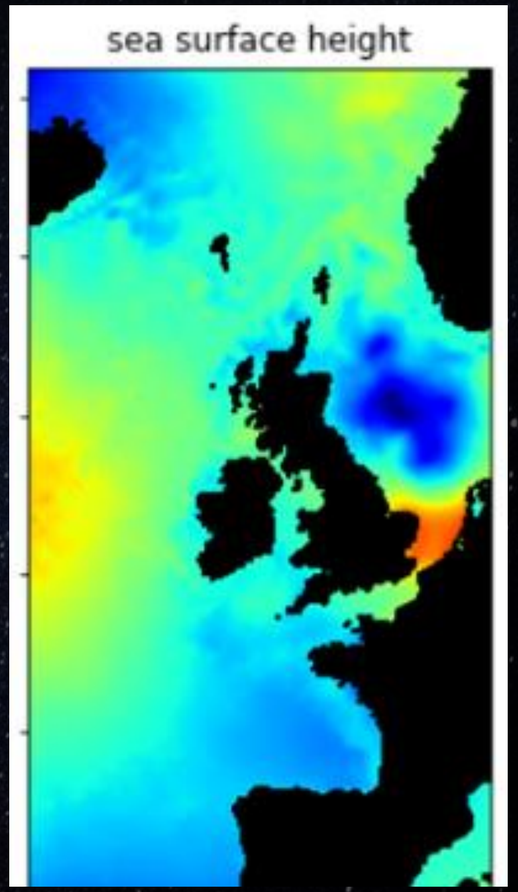


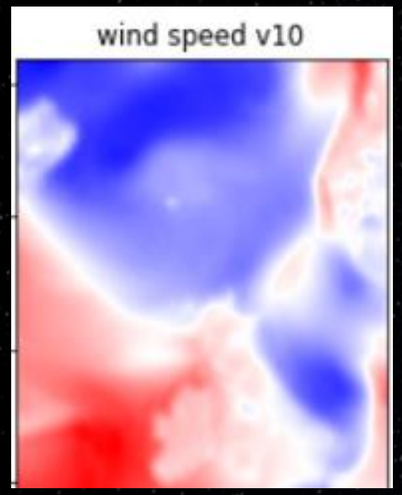


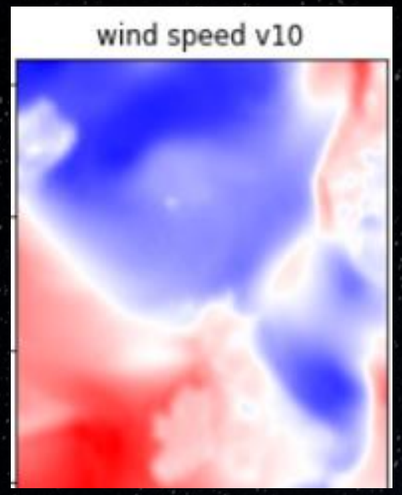
NEMO
Community Ocean Model

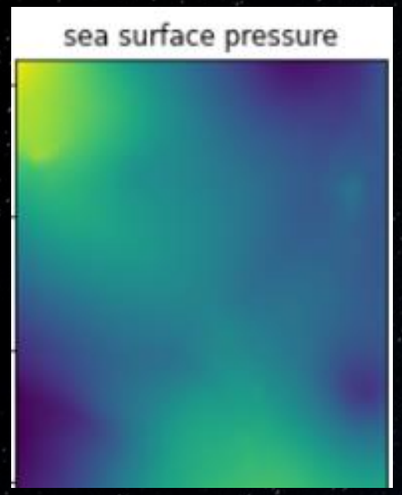
Numerical Models

Physics-based sims are computationally expensive…
No real-time prediction (1.5 Hours)
No uncertainty quantification.



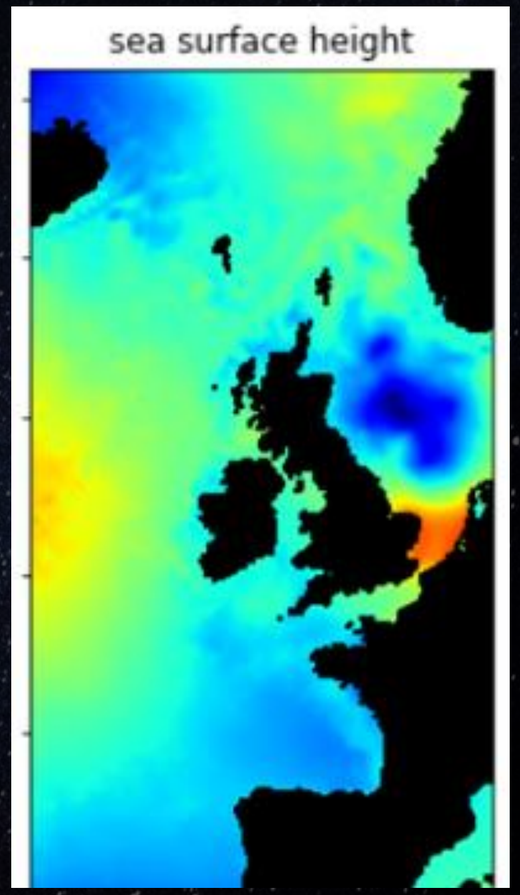






Coastal Digital Twin

60 Minutes in advance



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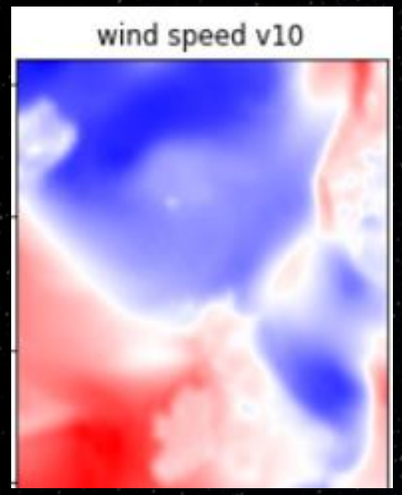
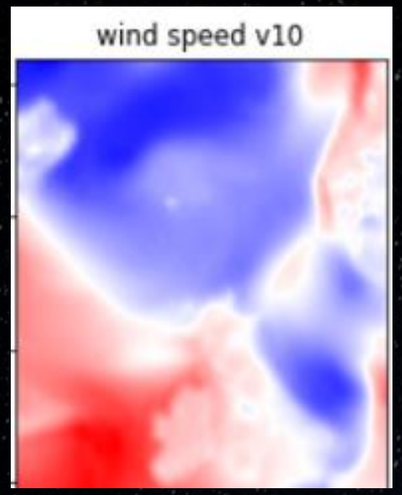
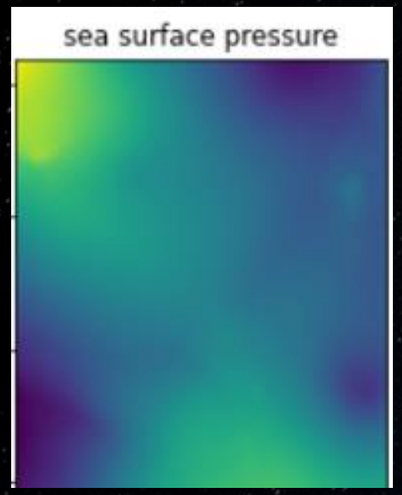


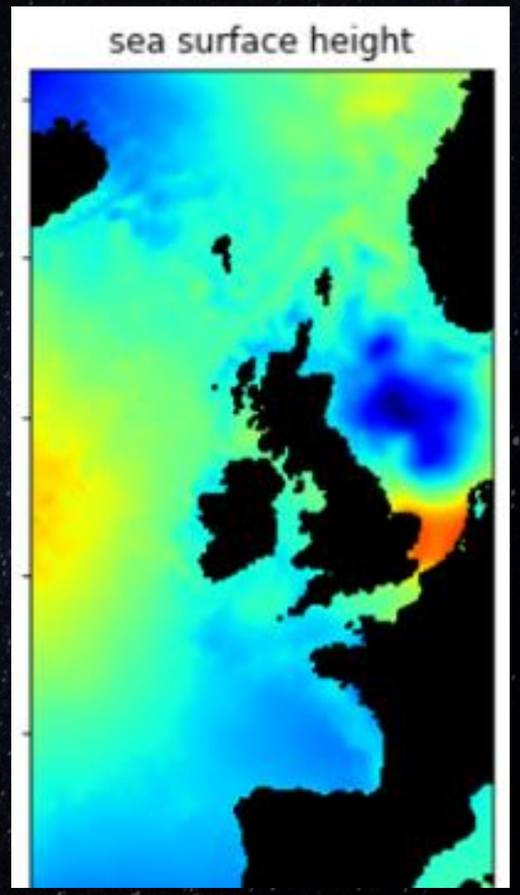




Coastal Digital Twin

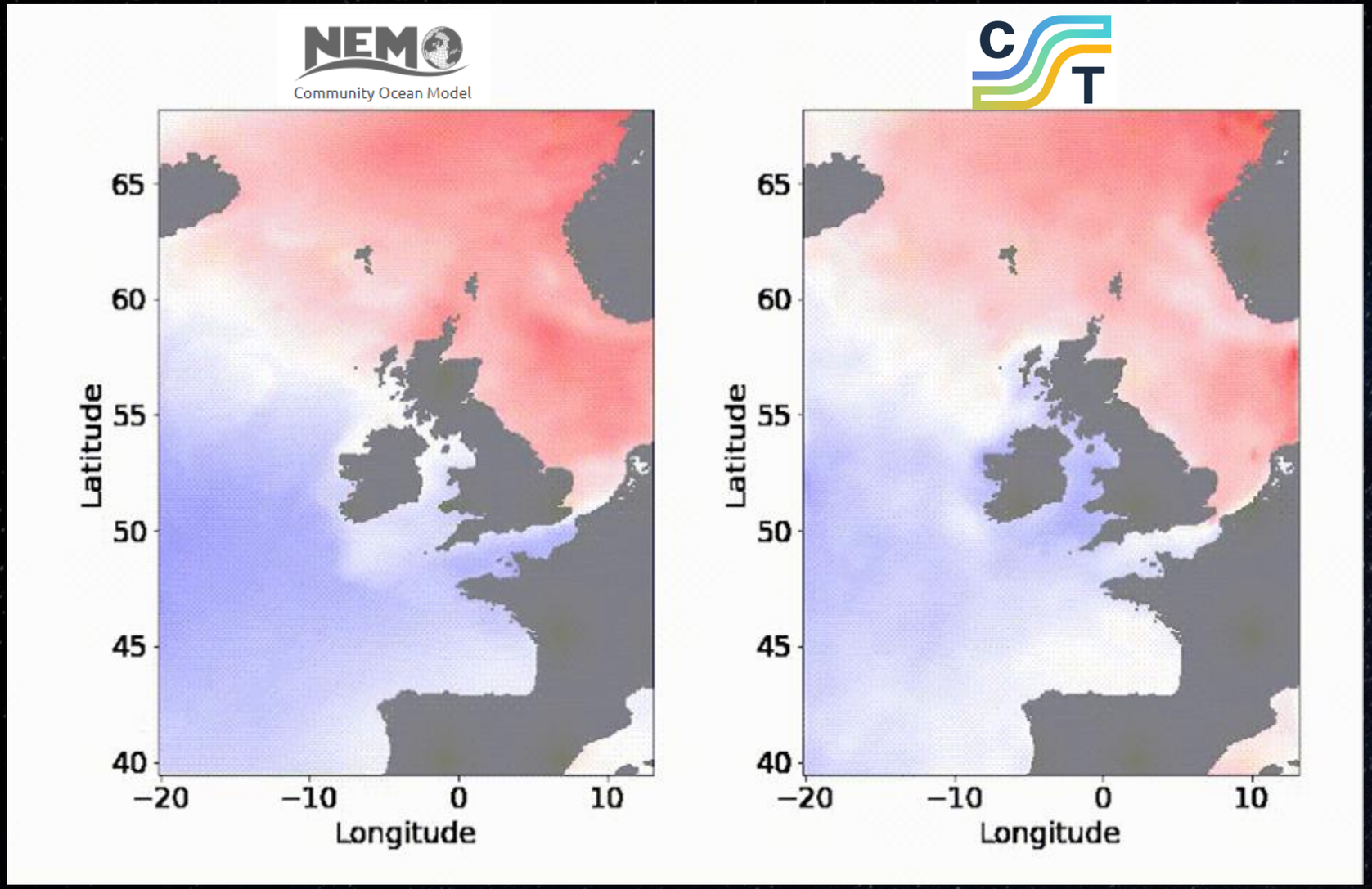
(1000 times faster)

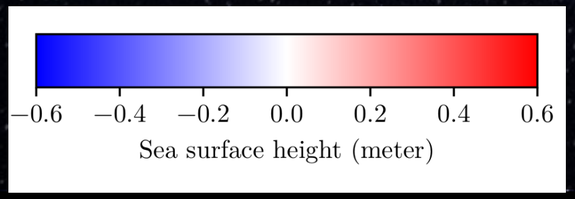
60 Minutes in advance



TRILLIUM EUROPE

FDL | MACHINE LEARNING ON-BOARD





60 Minutes in advance

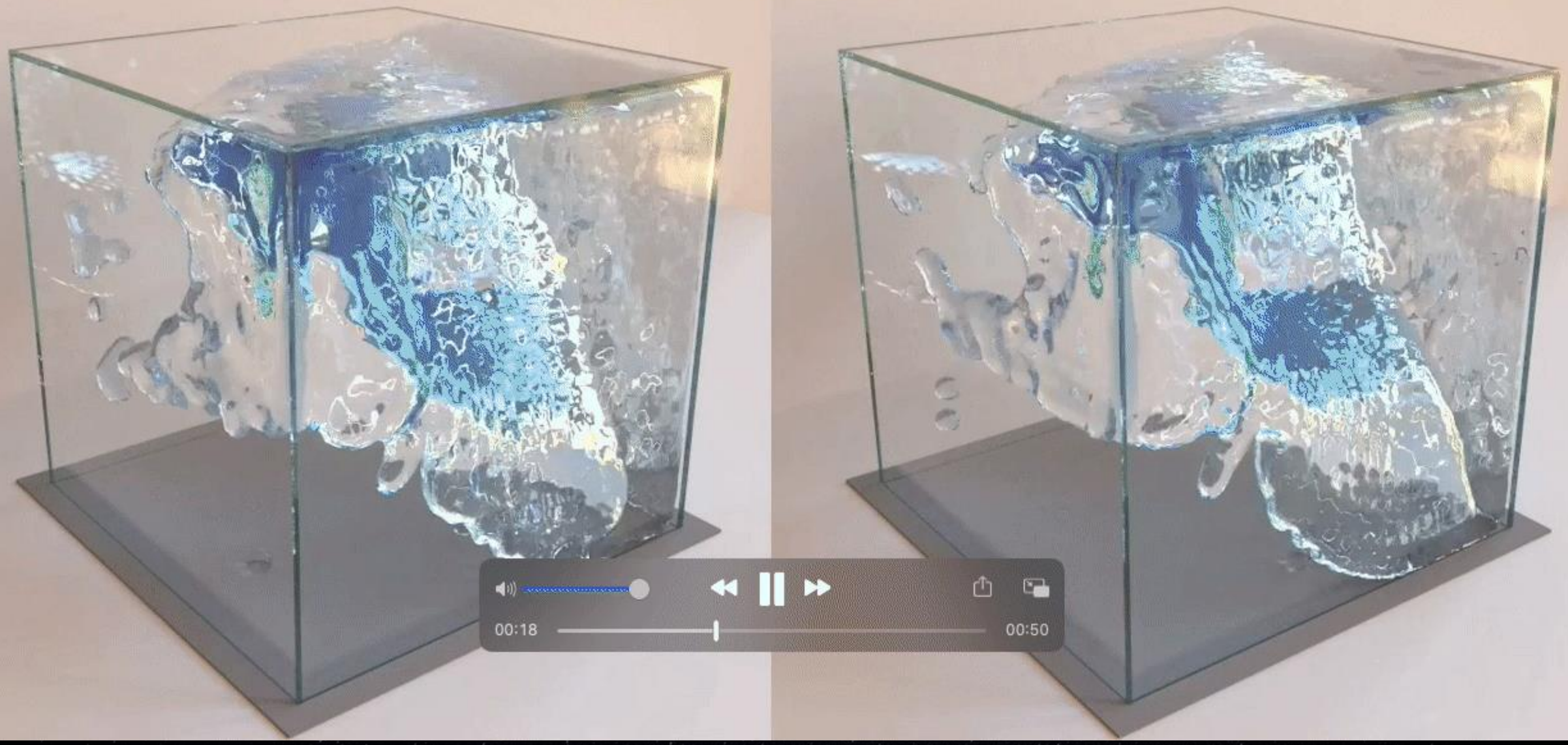
Coastal **T**win emulation:

- ✓ Magnitudes faster
- ✓ Uncertainty-aware
- ✓ High-res simulation

Physics-Informed Neural Net: Fourier Neural Operator (FNO

http://trillium.tech/eie/

Slow motion



Ayutthaya Province, 2011 (NASA EO-1)

ML4FLOODS

ML4CC ∴ SPACEML

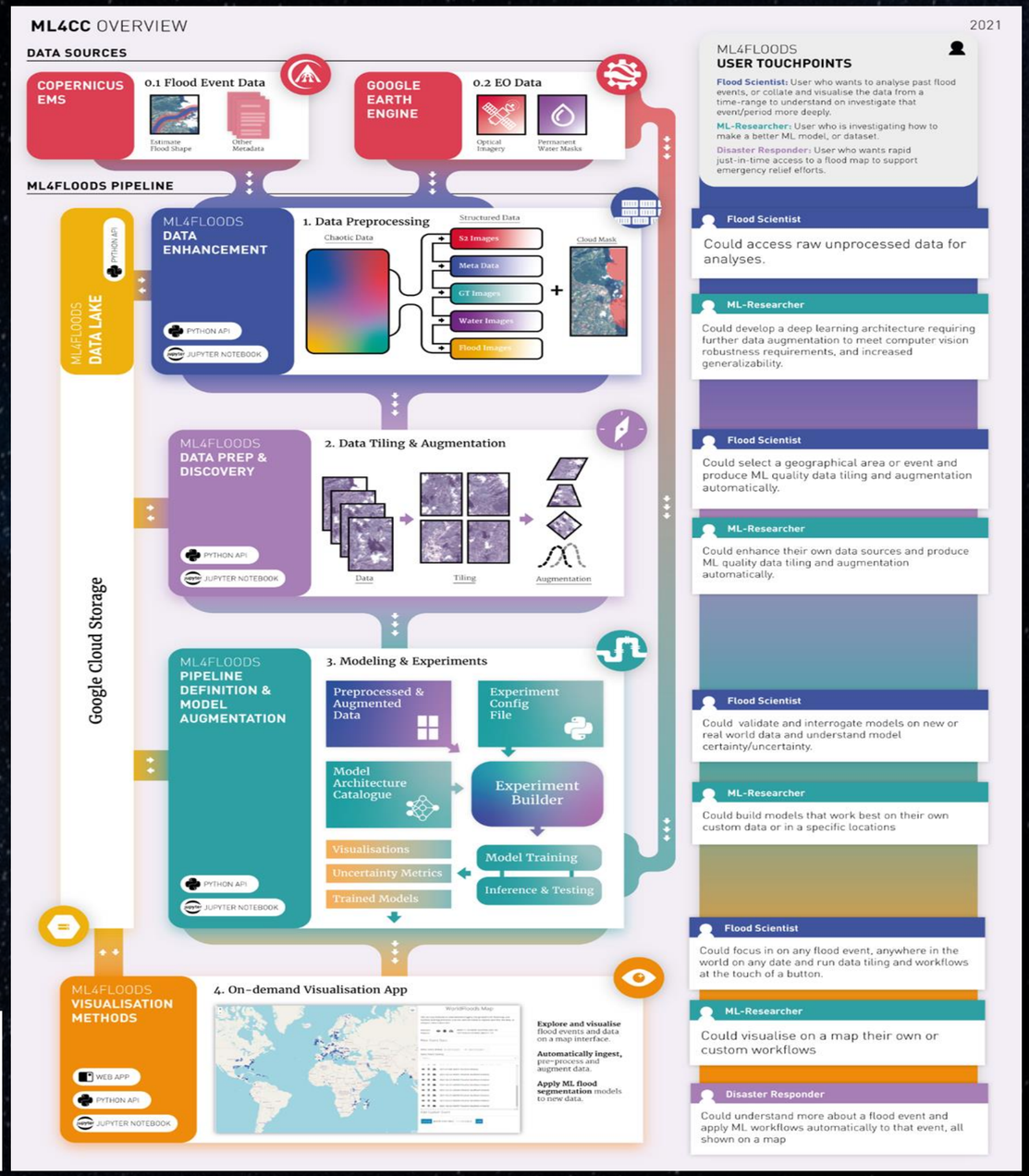
End-to-end open source package for flood extent segmentation

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

EUMETSAT MOOC | Future Learn

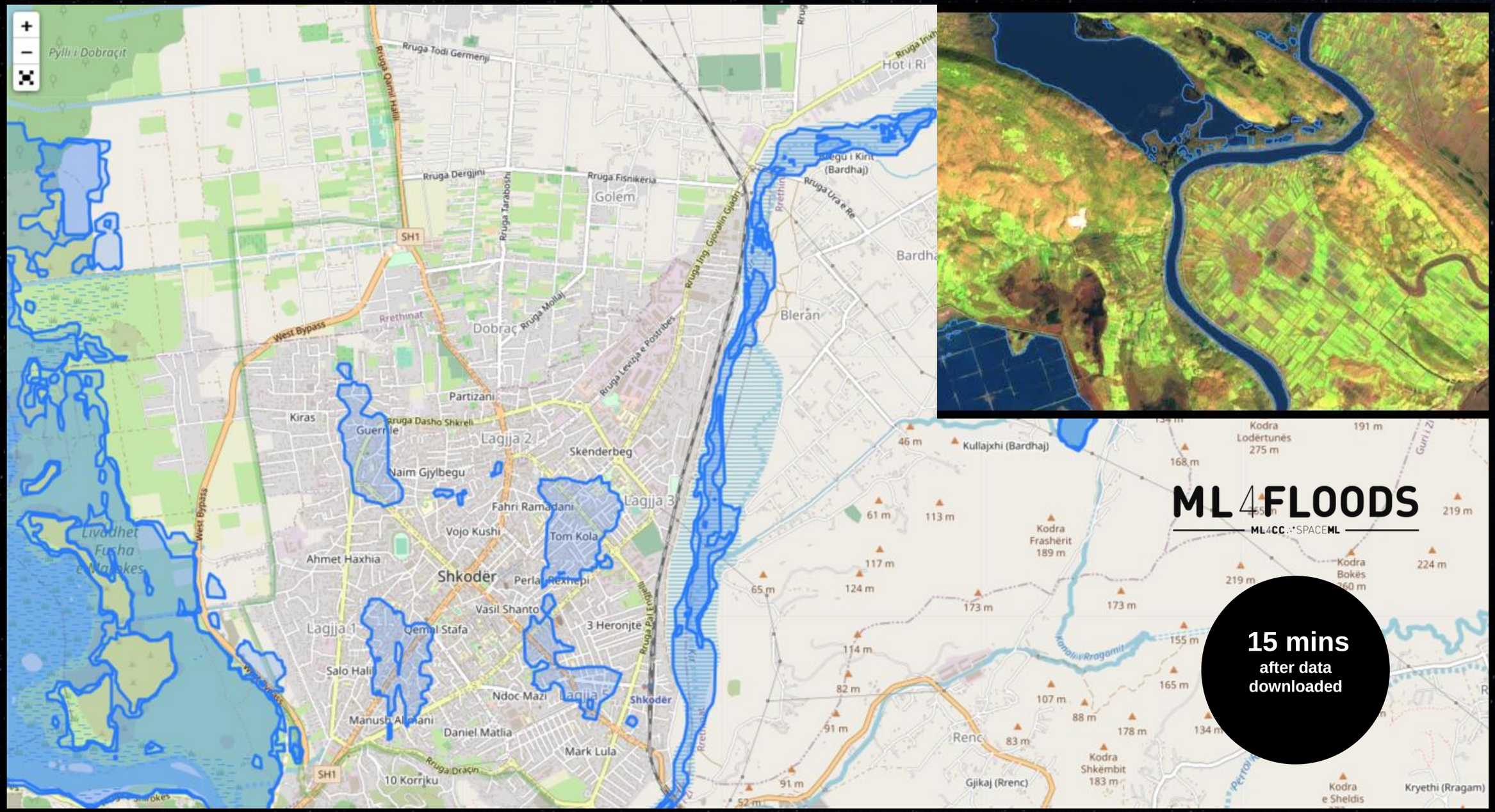
github.com/spaceml/ml4floods

UK SPACE AGENCY



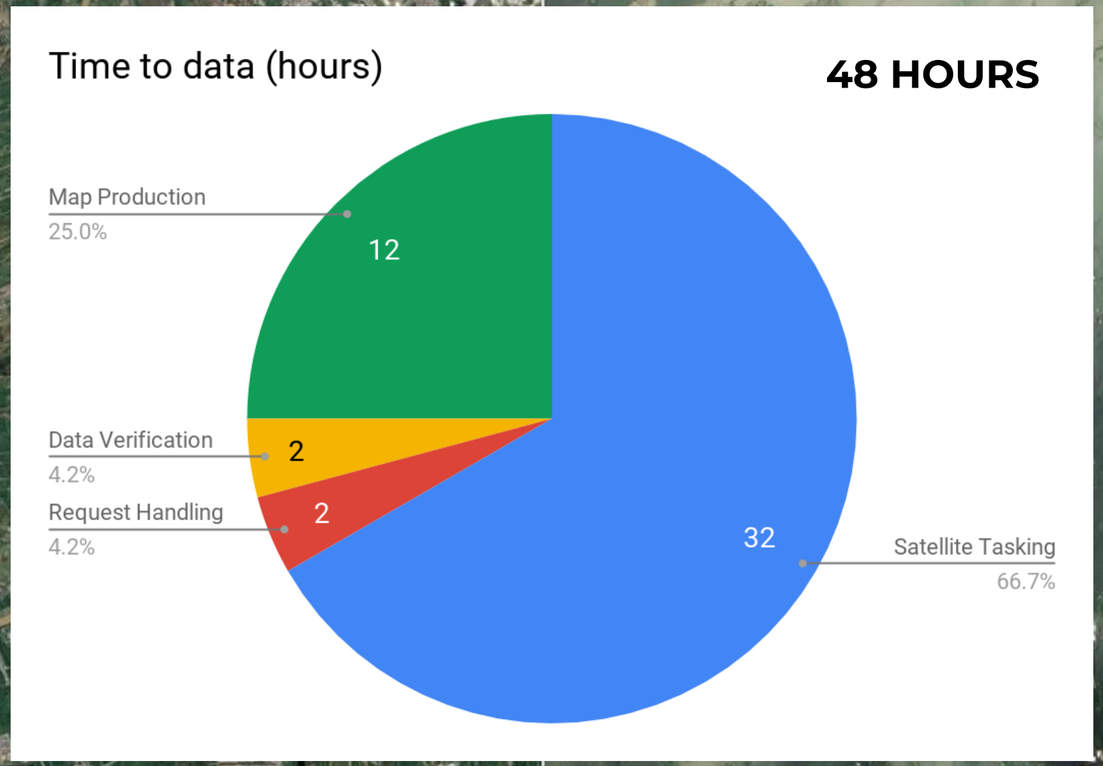
TRILLIUM EUROPE

FDL | MACHINE LEARNING ON-BOARD



TRILLIUM EUROPE

FDL MACHINE LEARNING ON-BOARD



Time for supply of data can be hours, on average 2 days: International “Space and Major Disasters” Charter

What if we could do this in LEO and just send down the vector map?

The *Worldfloods* **In-Orbit** Experiment:

Towards next-generation intelligent constellations

3 Questions:

1. Can a **ML Payload** routinely **analyse large data** in orbit, returning **compressed data products**?

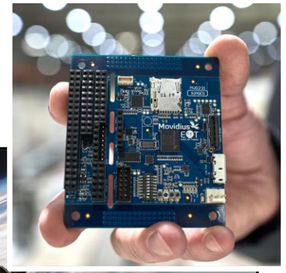
---

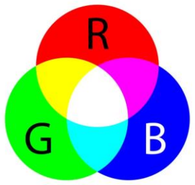
1. Can the same ML Payload be **re-trained** to analyse data from a **very different instrument**?

---

1. Can we demonstrate the **re-trained** ML Payload **successfully operating in orbit**?

Unibap Accelerated Compute Platform

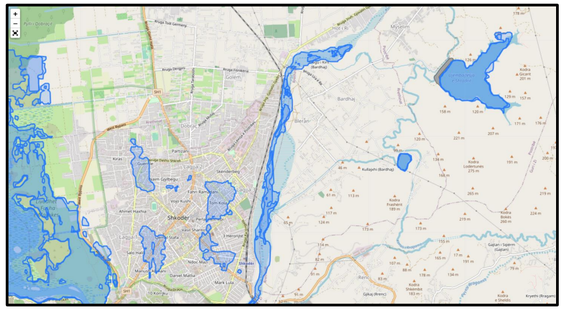




D-Sense Camera

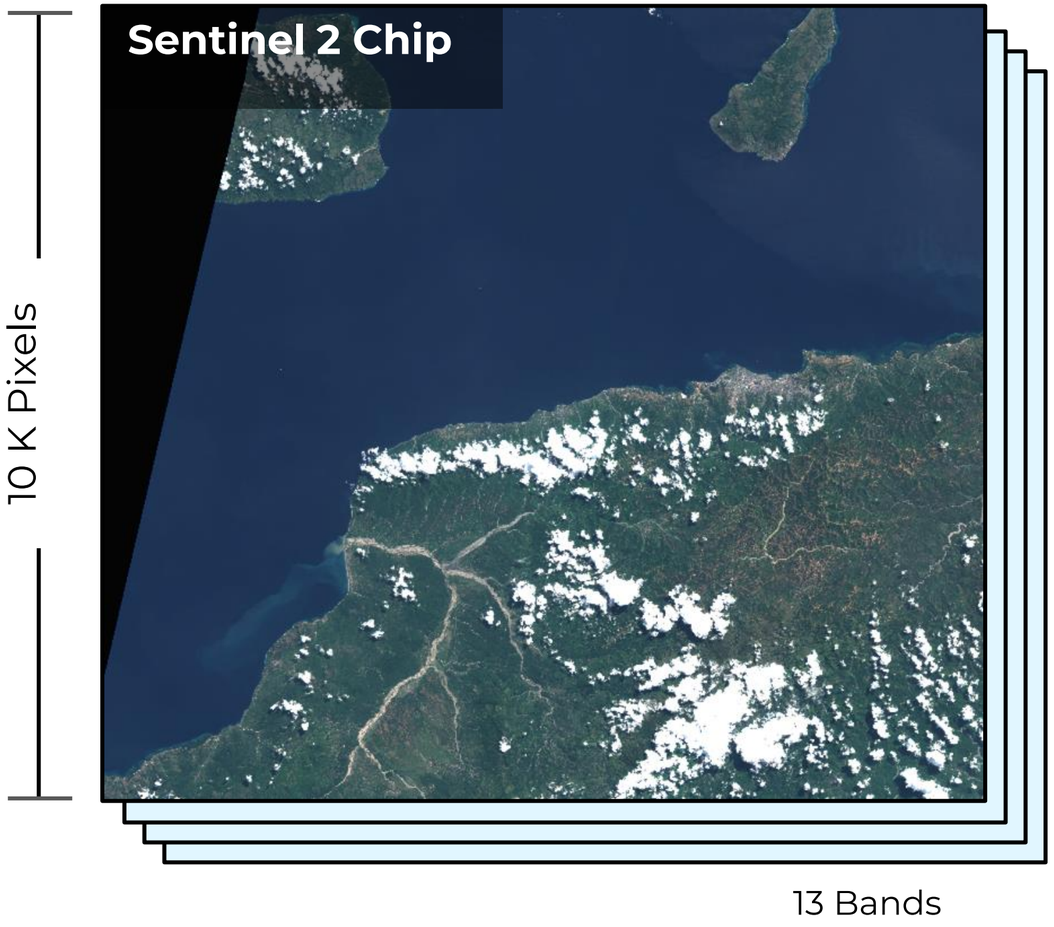
ML

Mateo-Garcia Nature 2020



Worldfloods: Rapid flood-extent maps for first responders

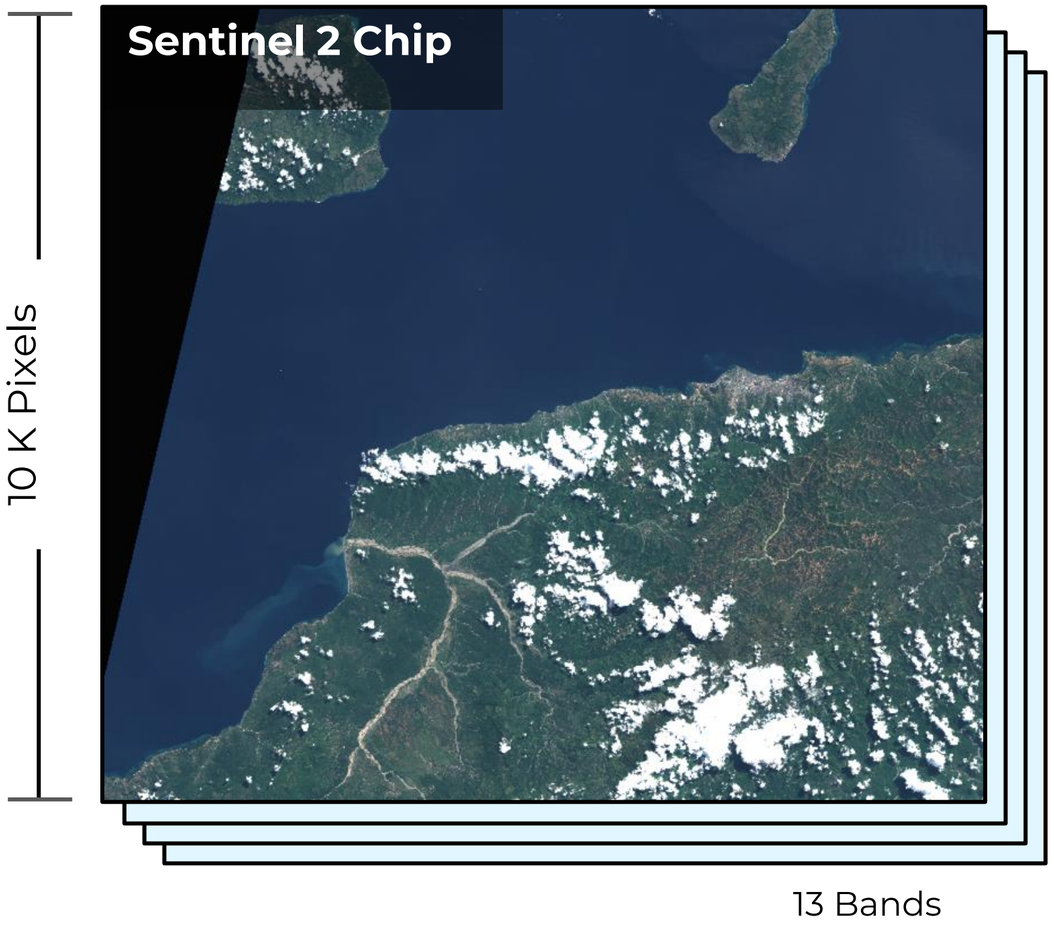
1. Can a **ML Payload** routinely **analyse large data** in orbit, returning **compressed data products**?



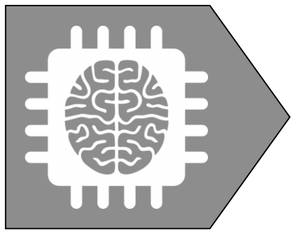
1. Can a **ML Payload** routinely **analyse large data** in orbit, returning **compressed data products**?

Yes

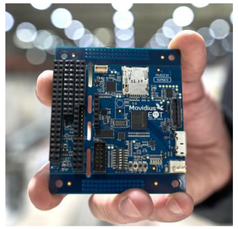
Using the Myriad X processor, the ML Payload can process a full 2.5 GB Sentinel-2 chip in 14 min.

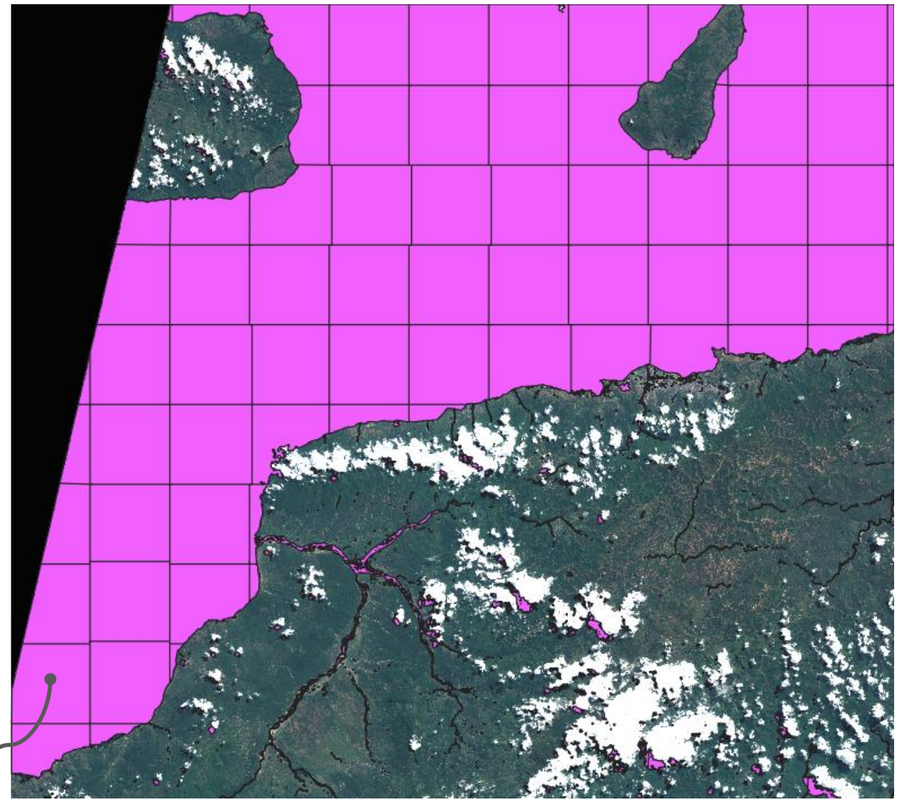


ML Payload



Linear (FC) Neural Network Model





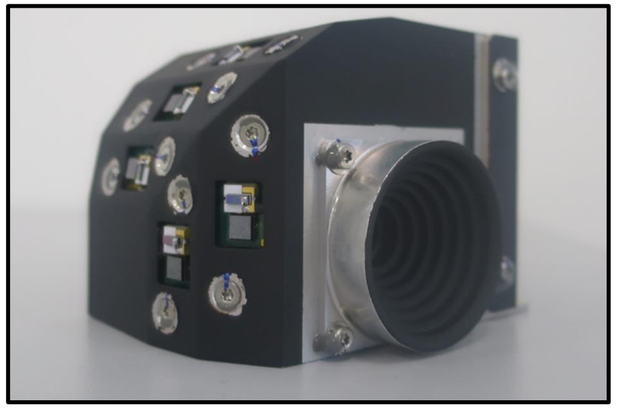
Processing Tiles

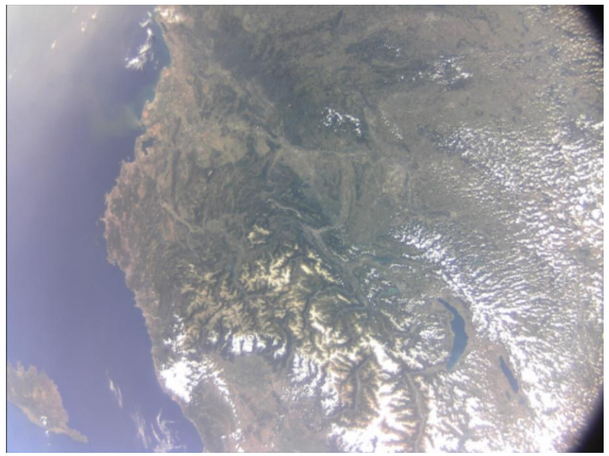
Vector Water Mask (276 KB)

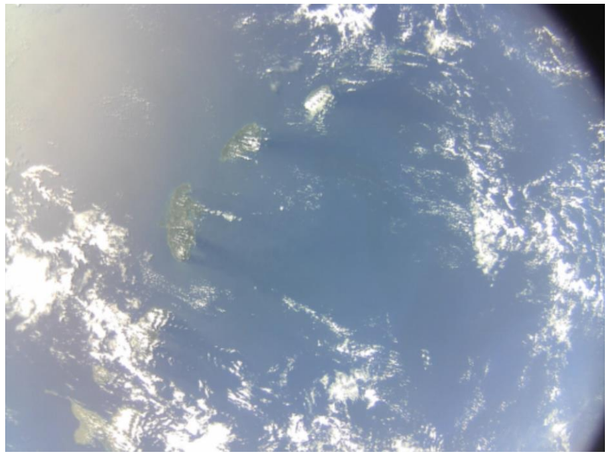
This result demonstrates how ML in orbit can act as a processing node for other EO assets.

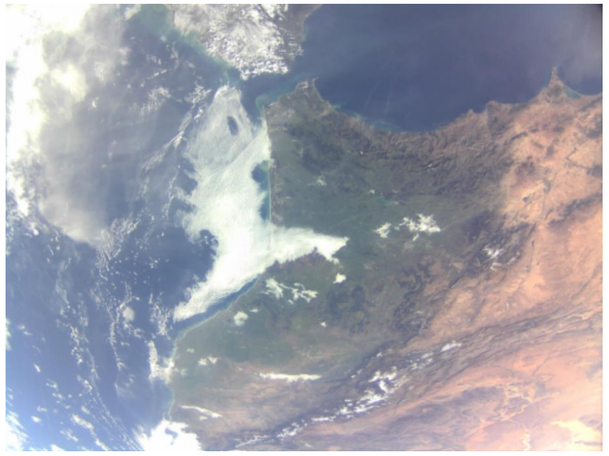
2. Can the same ML Payload be **re-trained** to analyse orbital data from a **very different instrument**?

D-Sense RGB Camera









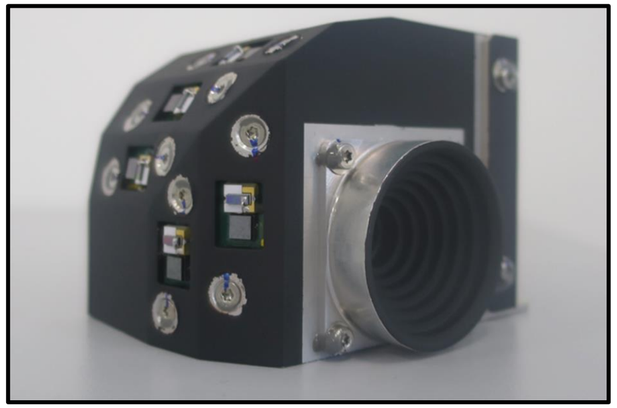
Note: The D-Sense Camera is a **general purpose sensor**, used for star-tracking, attitude control and verifying payload deployment.

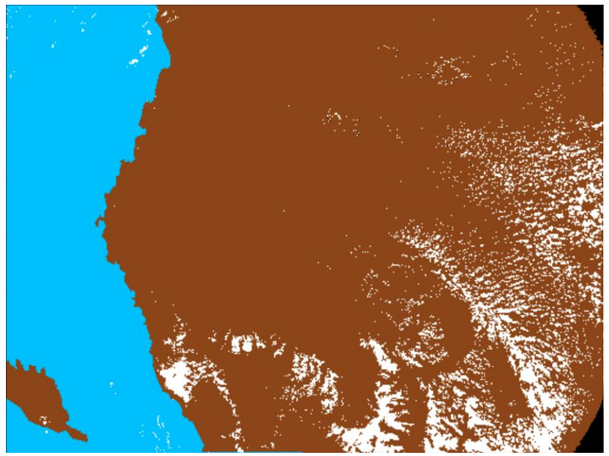
2. Can the same ML Payload be **re-trained** to analyse orbital data from a **very different instrument**?

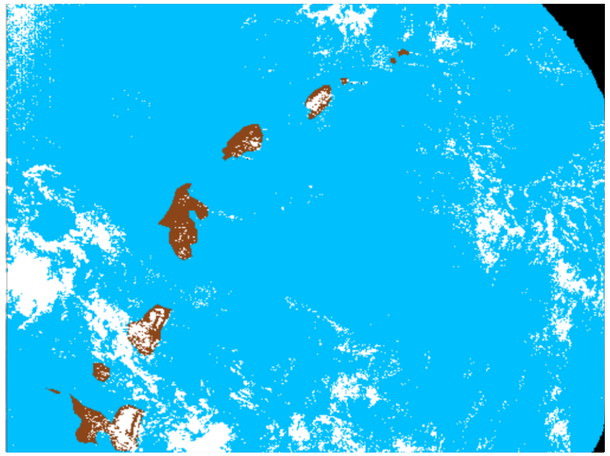
Yes

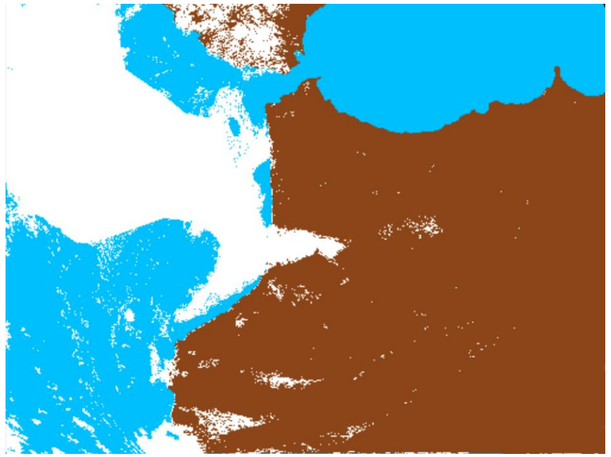
Training on just a few re-labeled examples, we can use already in-orbit ML to get a reasonable result ($t_{processing}$ = 36 seconds)

D-Sense RGB Camera

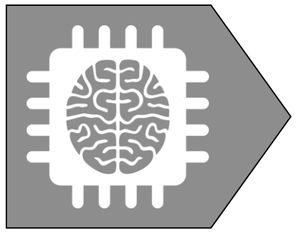




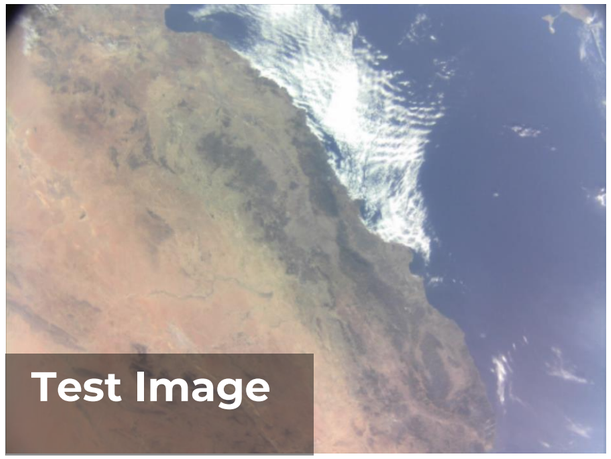




ML Payload



Linear (FC) Neural Network Model

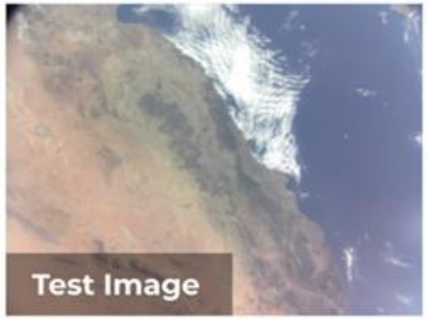


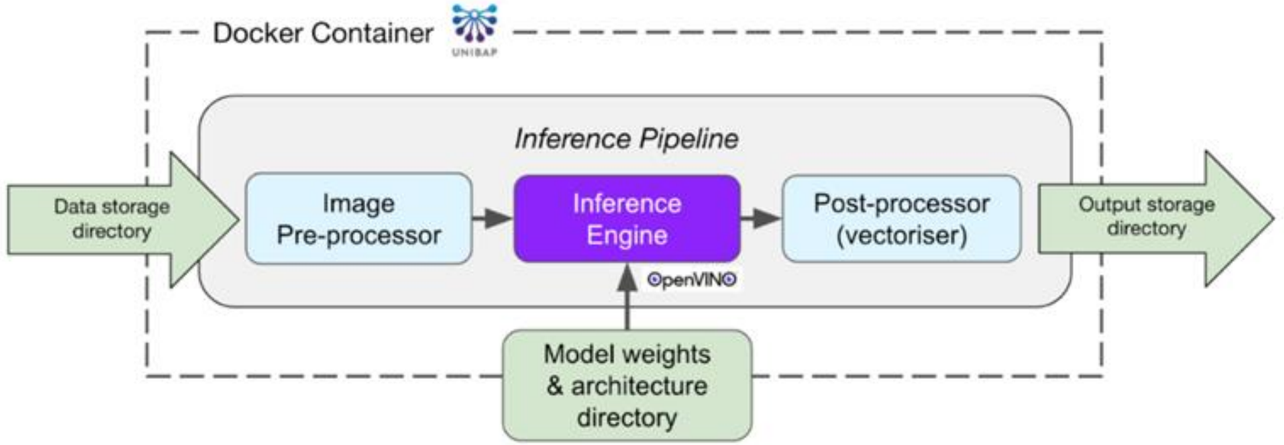
This result demonstrates how ML payloads can be adapted for different instruments on multiple spacecraft.

3. Can we demonstrate the **re-trained** ML Payload **successfully operating in orbit**?

Yes

The in-orbit ML Payload was triggered on December 6th 2021 and the result was downloaded to the ground the next day.





472 KB

New model weights uploaded to spacecraft in orbit

- Only the files defining the weights and, optionally, the model architecture, need be uploaded to the spacecraft.
- The flight-qualified ML Payload software and containerised execution environment can remain untouched.

This result demonstrates how ML payloads in orbit can be retrained and redeployed back to the spacecraft.

DIGITAL TWIN EARTH
FDL 2020

Predictions 60 mins in advance.

- ✓ High-res simulation
- ✓ Magnitudes faster
- ✓ Uncertainty-aware

Insight from orbit 100,000x smaller

- ✓ Multi-instrument
- ✓ Re-trainable (maintainable)
- ✓ 15 minutes to results

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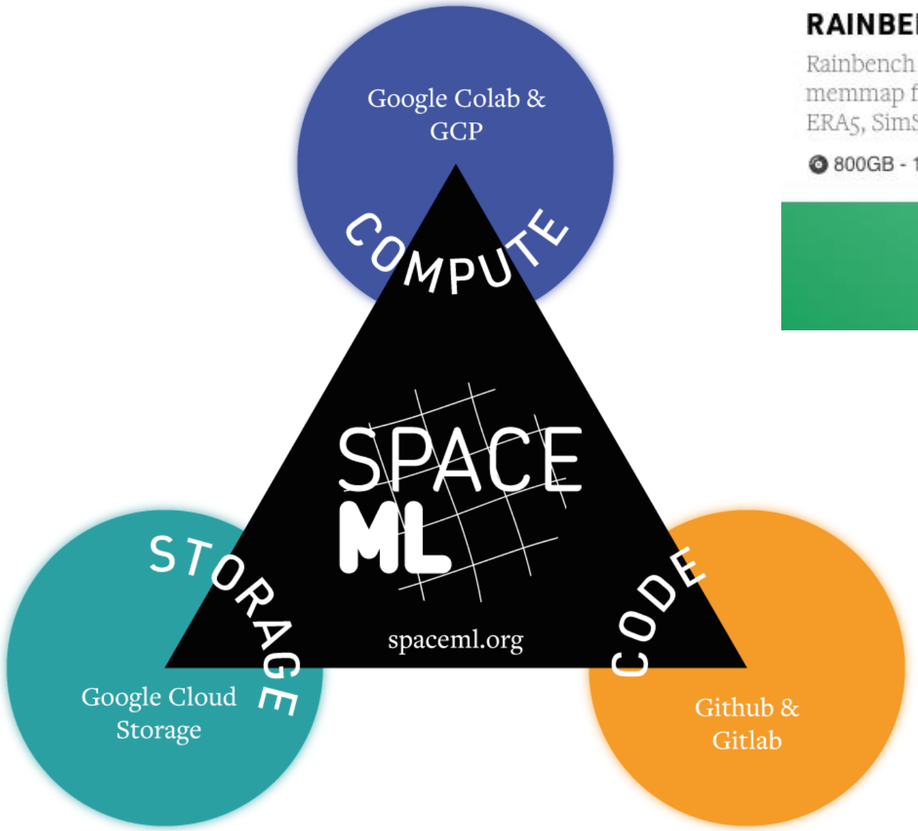
Components of Open Science



DATASET

RAINBENCH

Rainbench offers re-gridded data in memmap format sourced from the ERA5, SimSat and IMERG databases.

800GB - 1Tb

As SpaceML continues to grow, it will help bridge the gap between **data storage**, **code sharing** and **server-side (cloud) analysis.**

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Google Cloud

NVIDIA

SCAN

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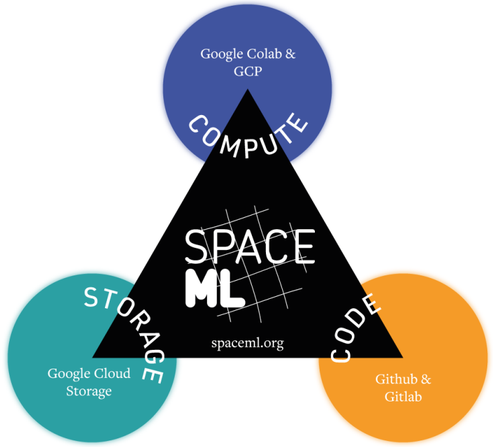
Φ-Lab Partners



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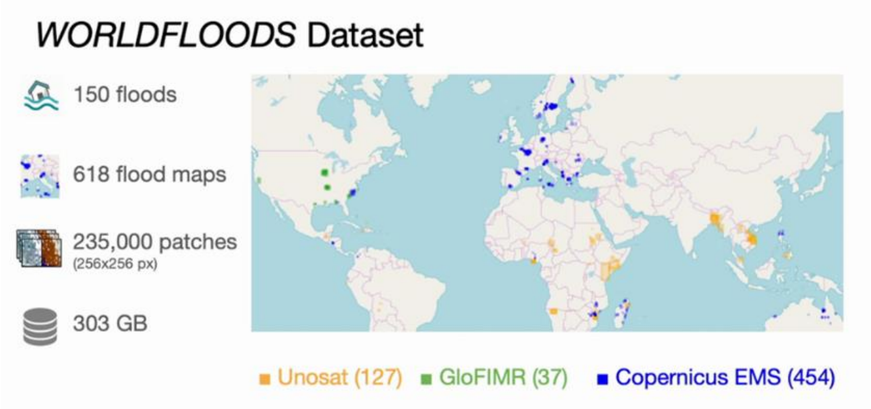

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