Seismic Imaging with Remote Sensing for Energy Applications

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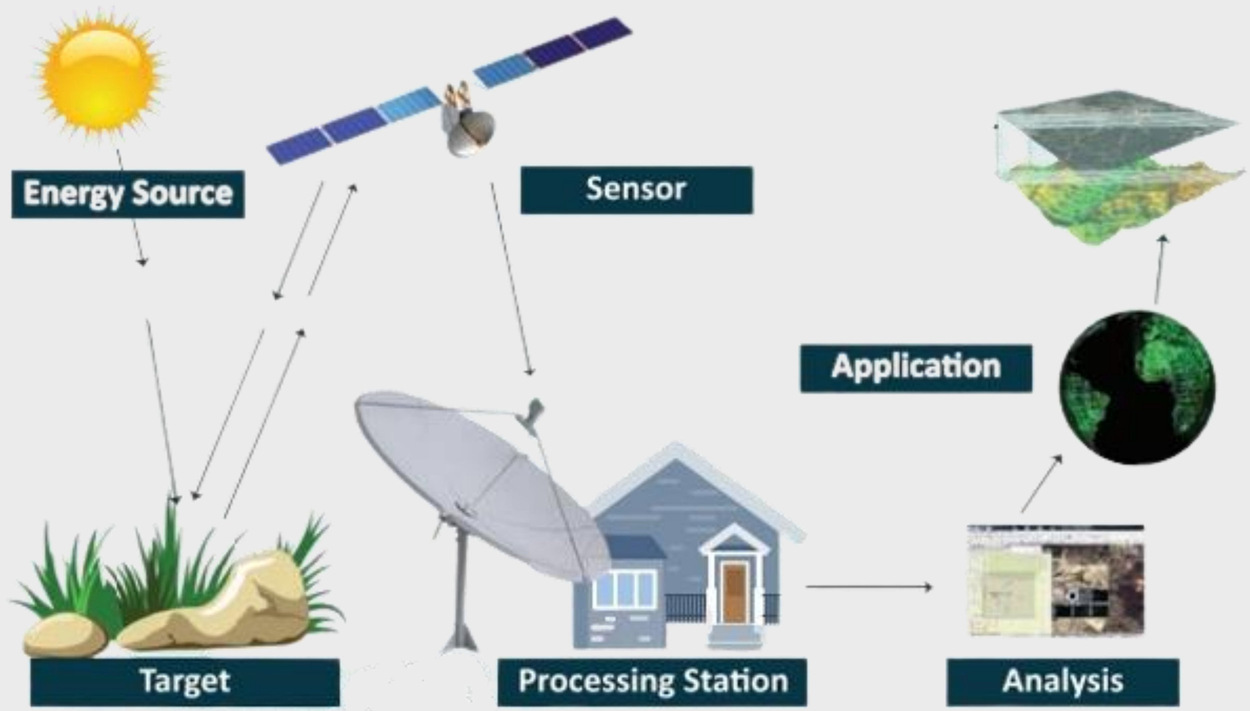
Task 4.2

Contents

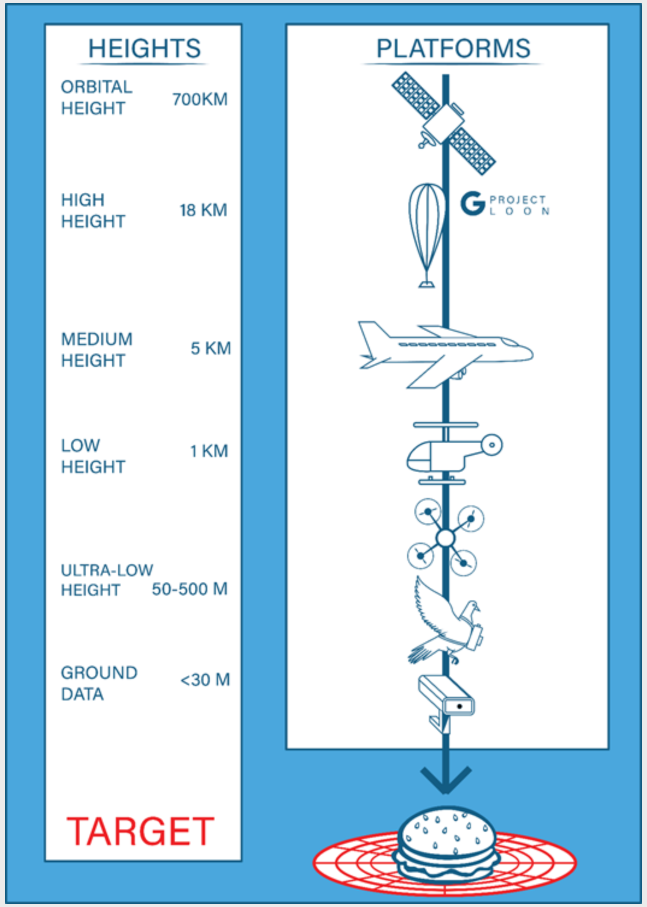
- Remote sensing principles; production of land cover maps
- Seismic imaging principles; 2D seismic imaging
- Integration of remote sensing to constrain seismic imaging: near surface
- Future works

Remote (without physical contact)
Sensing (measurement of information)

- Measure radiation of different wavelengths reflected or emitted from distant objects

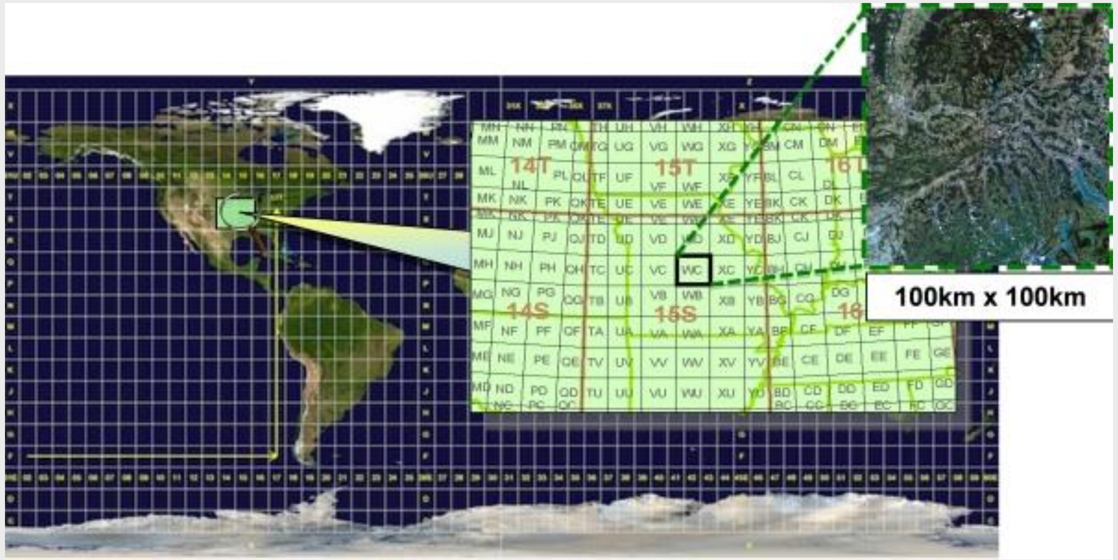


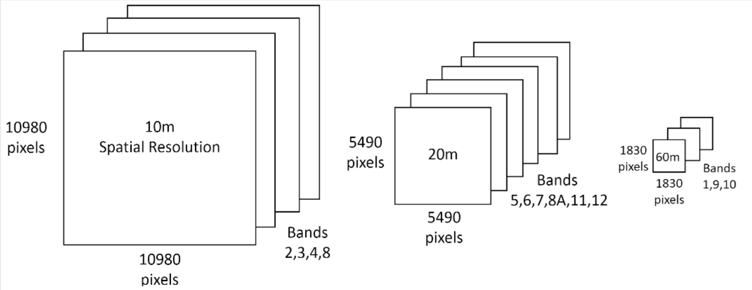
Elements of Remote Sensing, https://www.brainkart.com/article/Elements-of-Remote-Sensing_41124/



Earth Observation Mission: Copernicus Sentinel-2

- Twin polar-orbiting satellites with temporal resolution of 5 days
- Open data policy





Copernicus Europe's eyes on Earth

https://sentinels.copernicus.eu/

Workflow in Earth Observation

EO data → Data Retrieval → Preprocessing → Data Analysis → Prediction → Validation and Evaluation → Output

DEEP CPU

JURECA GPU

DEEP supercomputer

JURECA supercomputer

Workflow management with Apache Airflow

- Features of Apache Airflow
  - Open-source platform
  - Python based
  - Scheduling capabilities
  - Monitoring
  - Scalability

Workflow management with Apache Airflow

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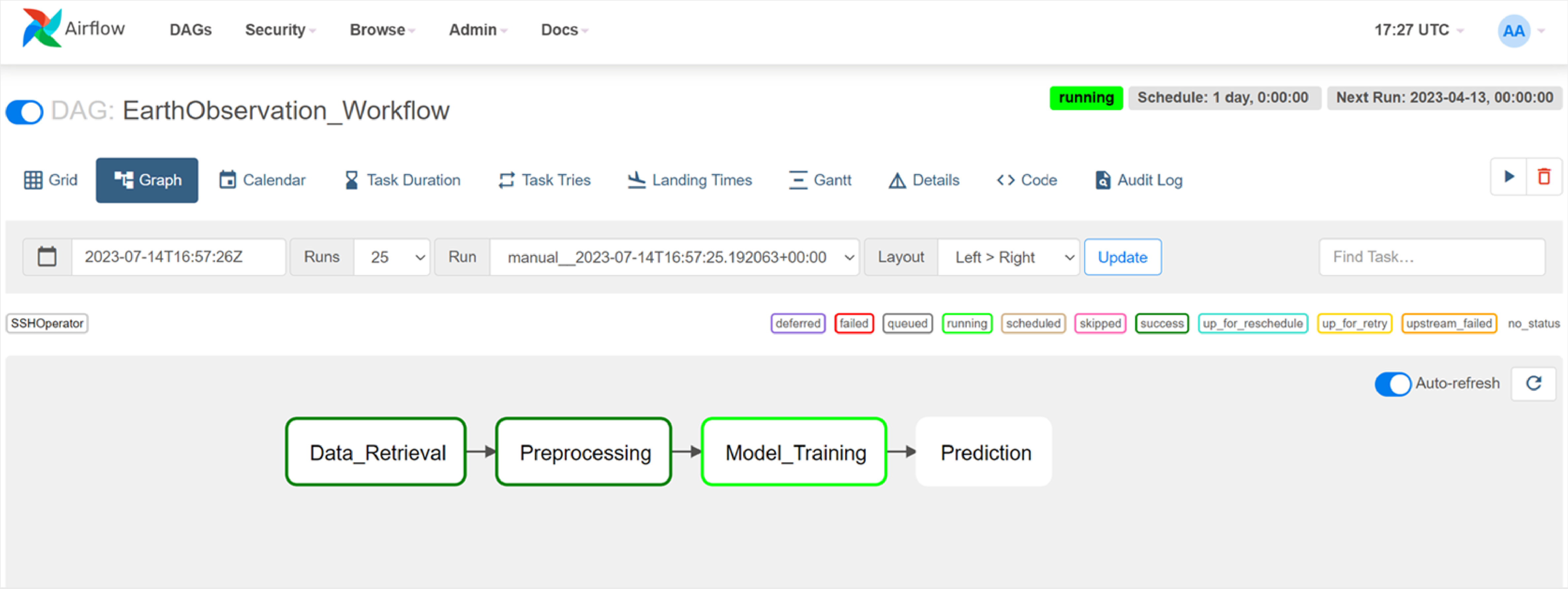
- Check the dependency of subtasks



Workflow management with Airflow

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- Monitor the process

DAGs

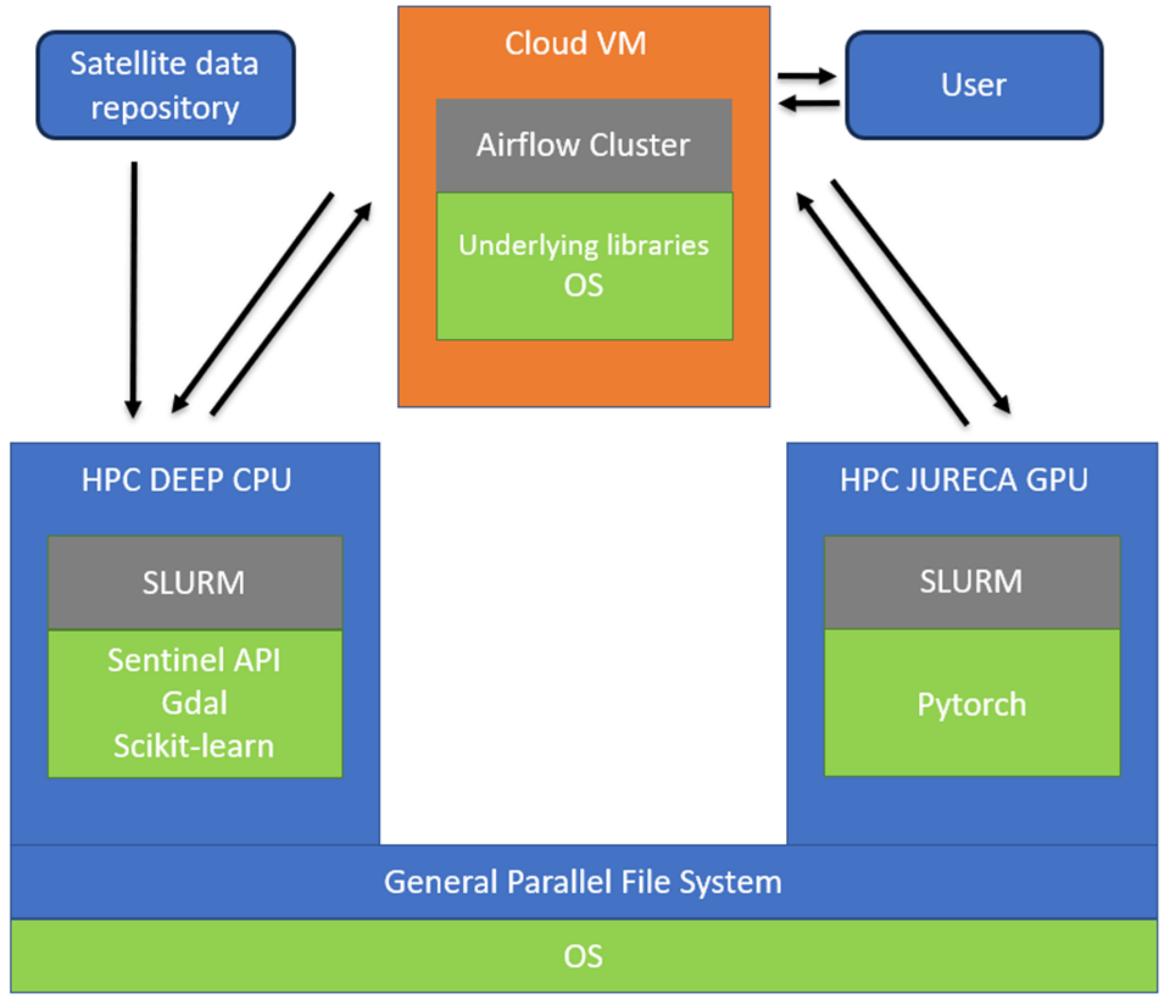
All 9 | Active 7 | Paused 2

Filter DAGs by tag

Search DAGs

DAG	Owner	Runs	Schedule	Last Run	Next Run	Recent Tasks	Actions	Links
steps	liang		1 day, 0:00:00		2023-03-30, 00:00:00			...
study_tutorial_1			1 day, 0:00:00					...
test1	enxhi		1 day, 0:00:00		2023-03-24, 00:00:00			...
test_date_23	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...
test_date_24	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...
test_date_25	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...
test_date_hourly	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...
test_date_none	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...
test_date_once	enxhi		1 day, 0:00:00		2023-03-30, 00:00:00			...

Scalable Workflow with Airflow



Airflow integrated with HPC systems

L. Tian, R. Sedona, A. Mozaffari, E. Kreshpa, C. Paris, M. Riedel, M. G. Schultz, G. Cavallaro,"End-to-End Process Orchestration of Earth Observation Data Workflows with Apache Airflow on High Performance Computing, " in Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2023 (press)

Production of Land Cover Maps

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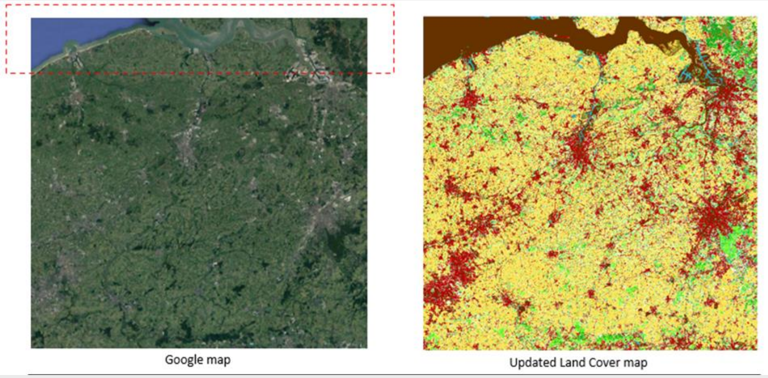
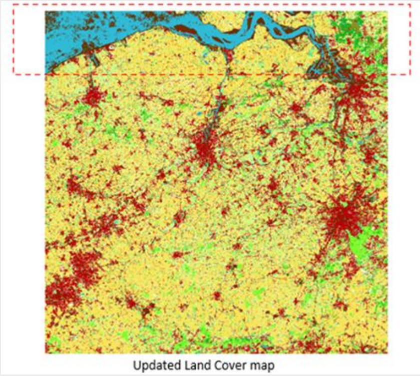


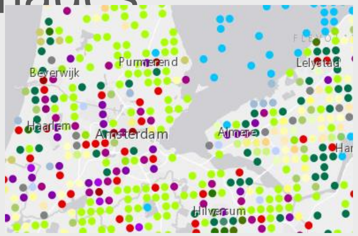


Legend

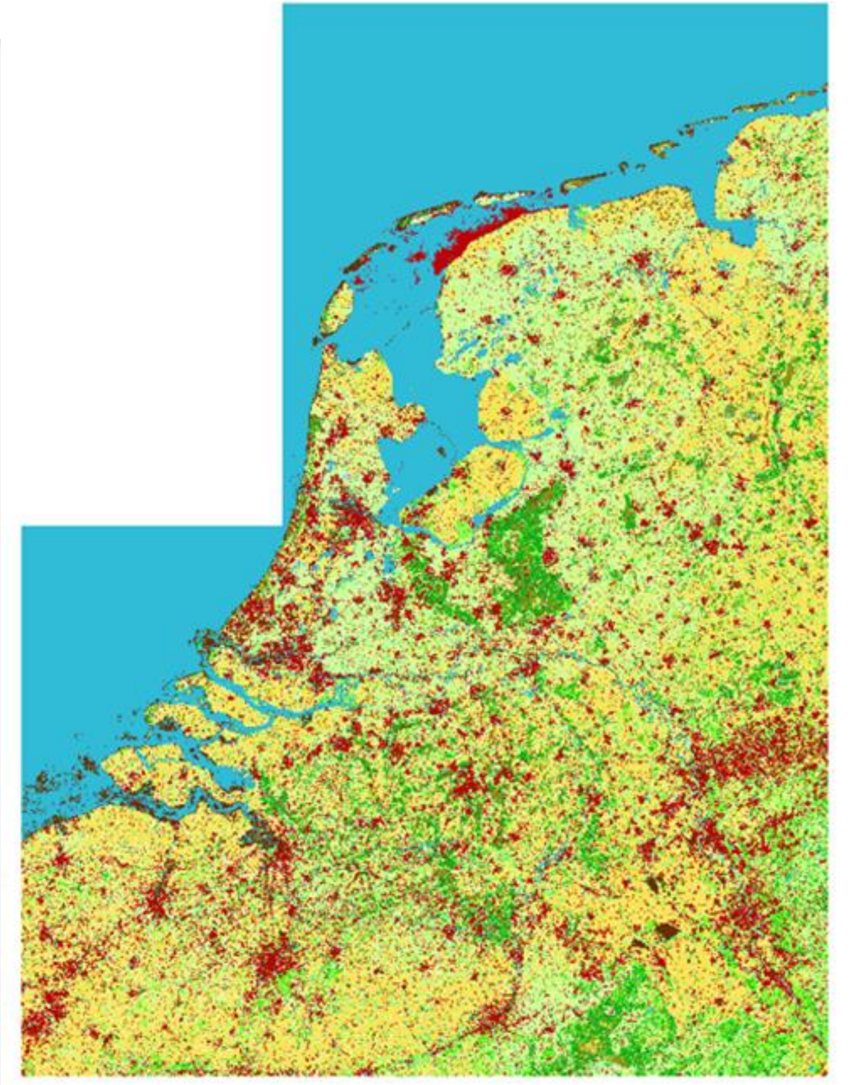
Artificial Land	Rice fields	Conifers	Lake
Grassland	Bareland	Shrubland	Snow
Cropland	Broadleaves	Lagoon	

Production time
1.5 h vs. 14 h (without HPC)

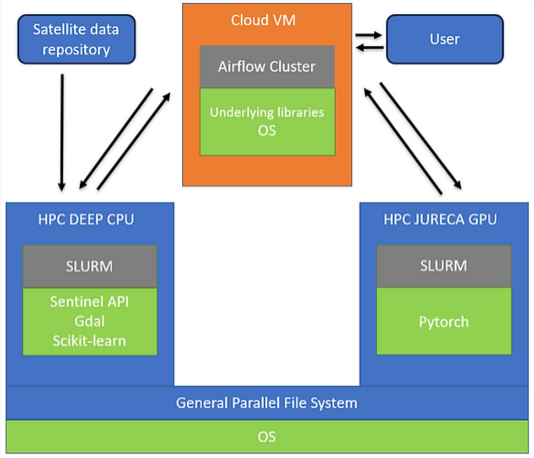
- Validation with street-level crowdsourcing geo-tagged images



https://land.copernicus.eu/imagery-in-situ/lucas/lucas-2018



Code Repository

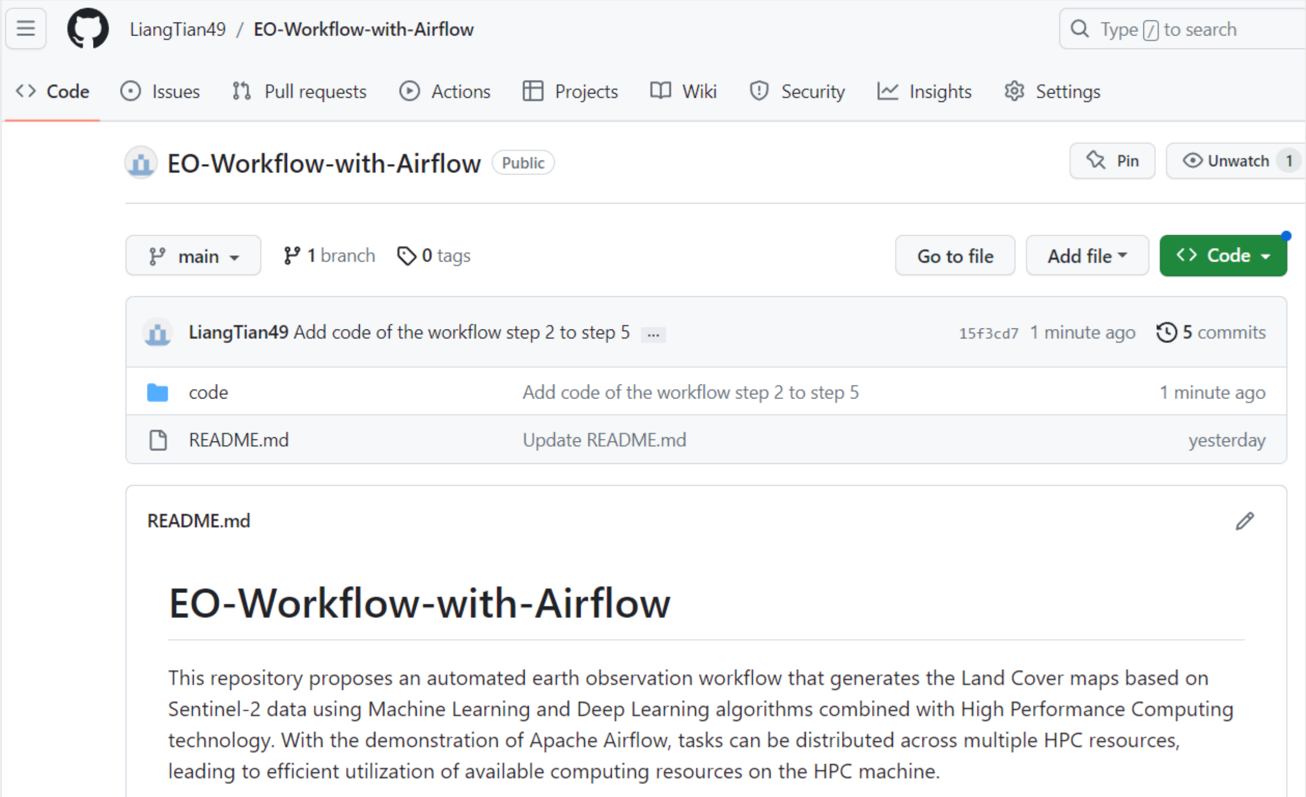


Earth Observation Data Workflows with Apache Airflow

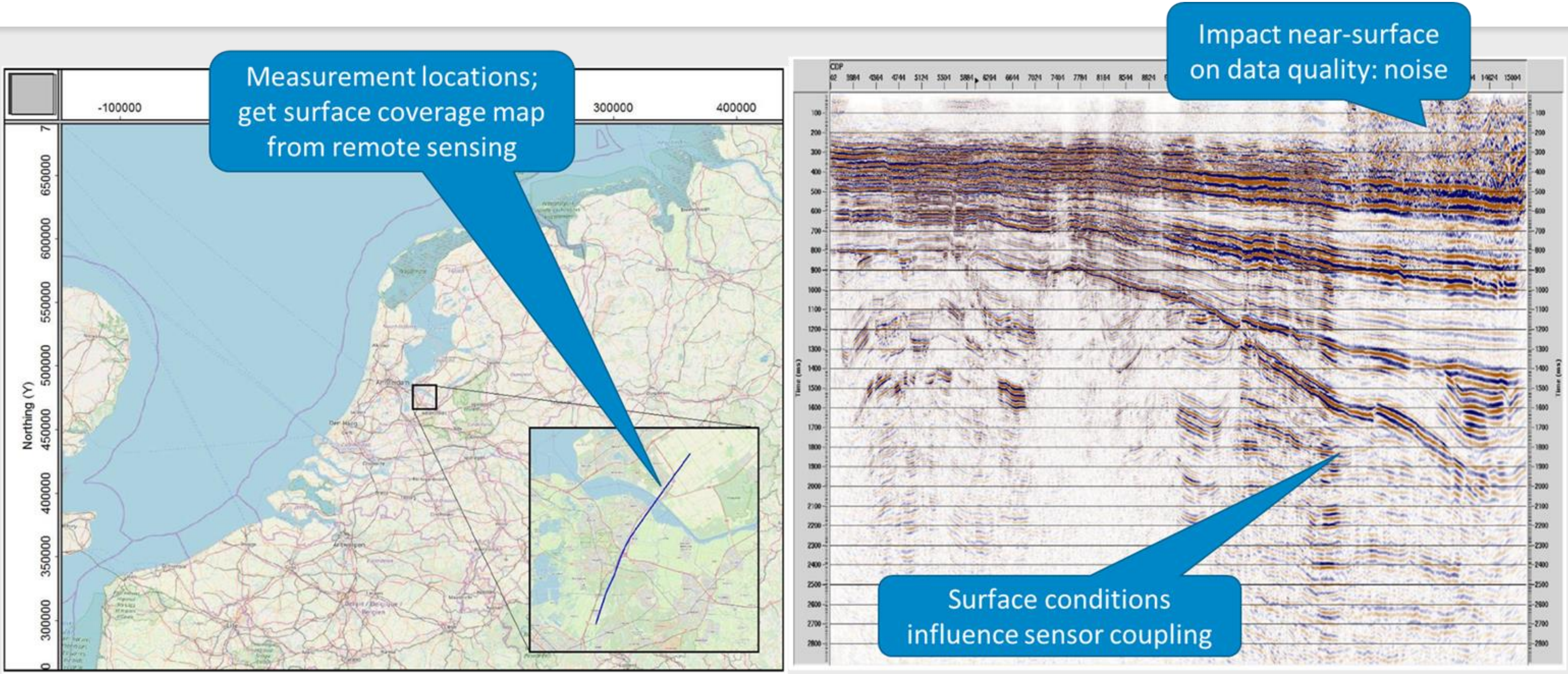
This repository presents a scalable and parallelizable workflow using Apache Airflow, capable of integrating Machine Learning (ML) and Deep Learning (DL) models with Modular Supercomputing Architecture (MSA) systems [6]. To test the workflow, we considered the production of large-scale Land-Cover (LC) maps as a case study. It can generate LC maps based on Sentinel-2 data using ML and DL algorithms combined with High-Performance Computing (HPC) technology.

The workflow manager, Airflow, offers scalability, extensibility, and programmable task definition in Python. It allows us to execute different steps of the workflow in different HPC systems, leading to efficient utilization of available computing resources on the HPC machine. The workflow is demonstrated on the Dynamical Exascale Entry Platform (DEEP) and Jülich Research on Exascale Cluster Architectures (JURECA) hosted at the Jülich Supercomputing Centre (JSC), a platform that incorporates heterogeneous JSC systems.

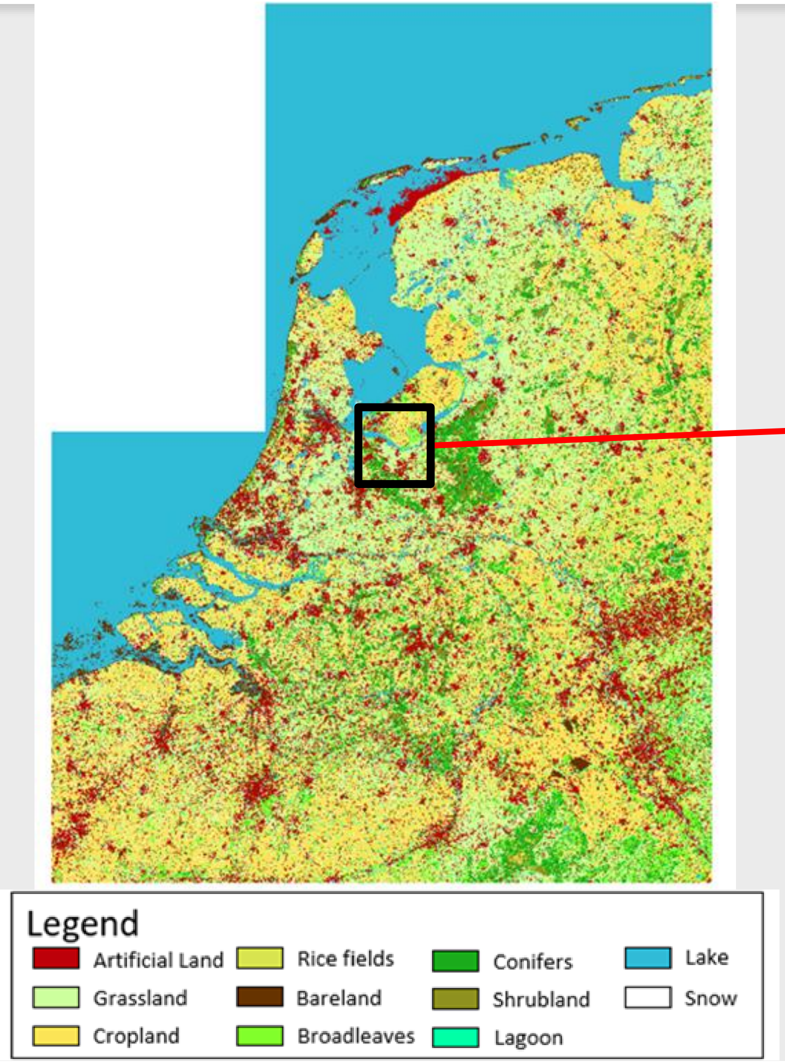
GIT Repository



Working on: Linking Remote Sensing with Seismic imaging



Working on: Linking Remote Sensing with Seismic imaging



- Extract LC information along the seismic record line
- Data of 2018 as a start
- Accurate validation

Multi-temporal Land Cover Maps

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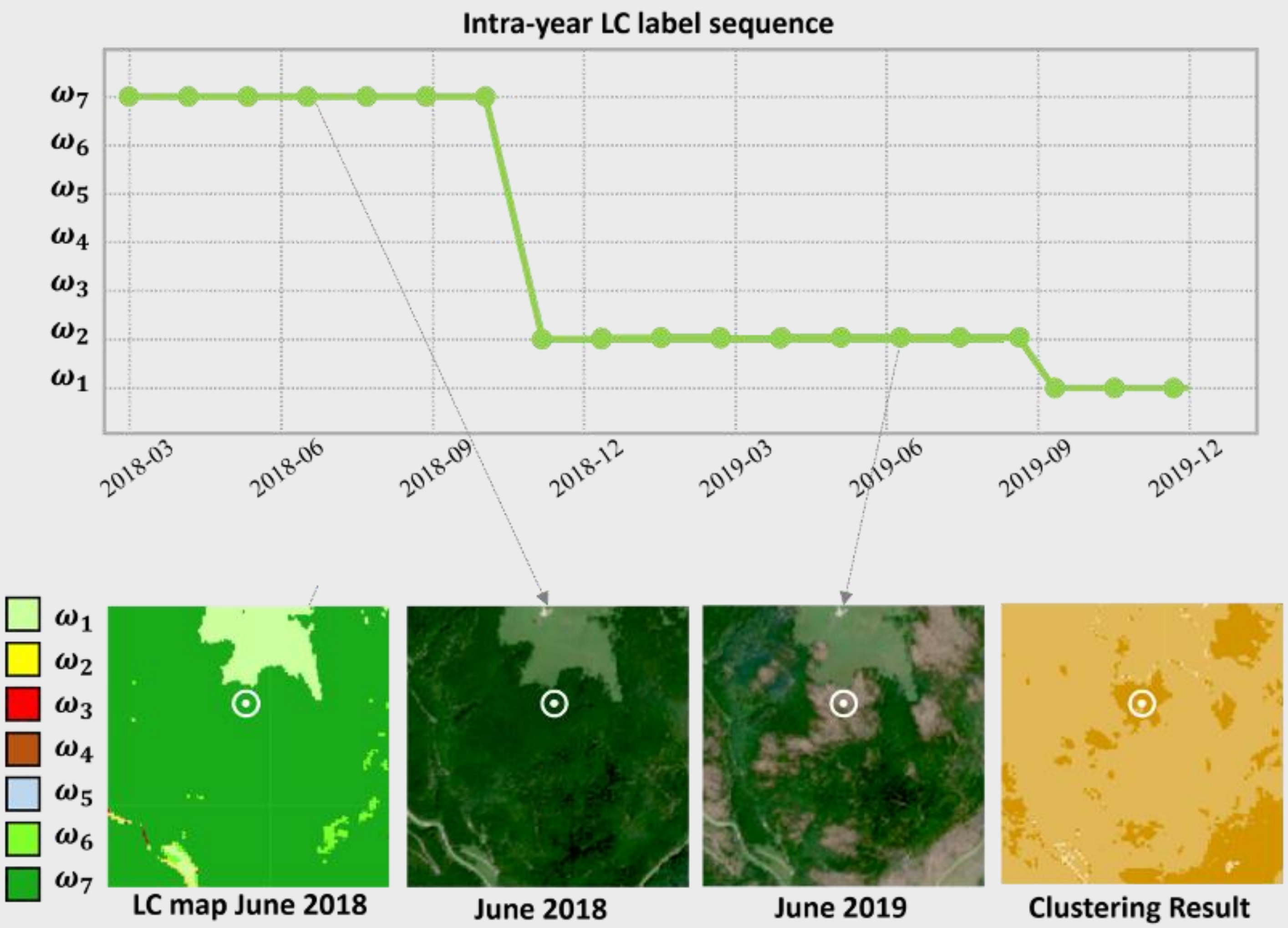
- Transformer with local attention mask can detect changes throughout time
- Inference: mask with sliding window
  - stride of 1 acquisition



Multi-temporal Land Cover Maps

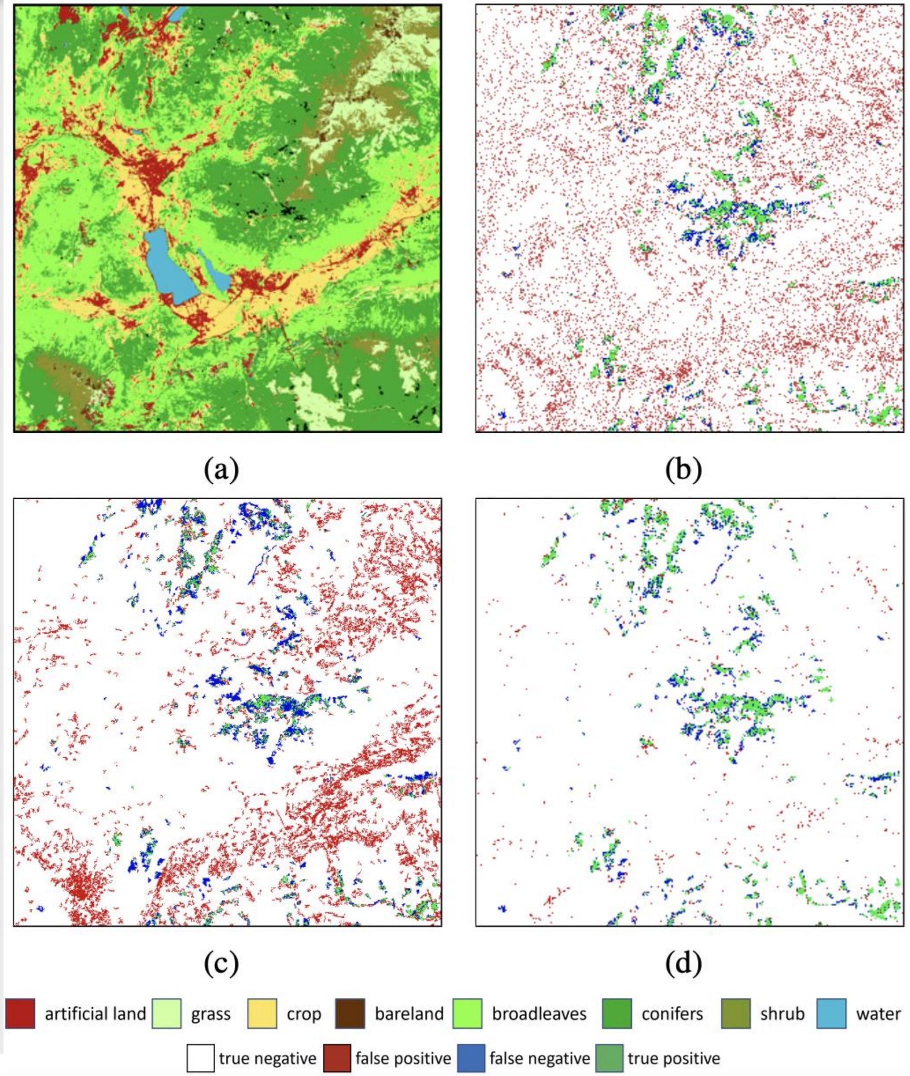
- Rule based approach to disentangle:
  - Stable component
  - Seasonal component
  - Abrupt changes
- Estimated date of change can be extracted

(a) Predicted land cover map
(b) RF: detected change
(c) Transformer: detected change
(d) PM: detected change

Detected abrupt change

	precision	recall	F1 score	IoU
RF	0.20	0.67	0.30	0.18
Transformer	0.13	0.75	0.22	0.13
PM	0.72	0.59	0.65	0.48

RF: Random forest
PM: Proposed method (ours)



Multi-temporal Land Cover Maps

- Use a solid baseline land cover map
- Add change
- Increased consistency
- Better detection of abrupt changes (validation with reference ground truth)

RF: Random forest
PM: Proposed method (ours)

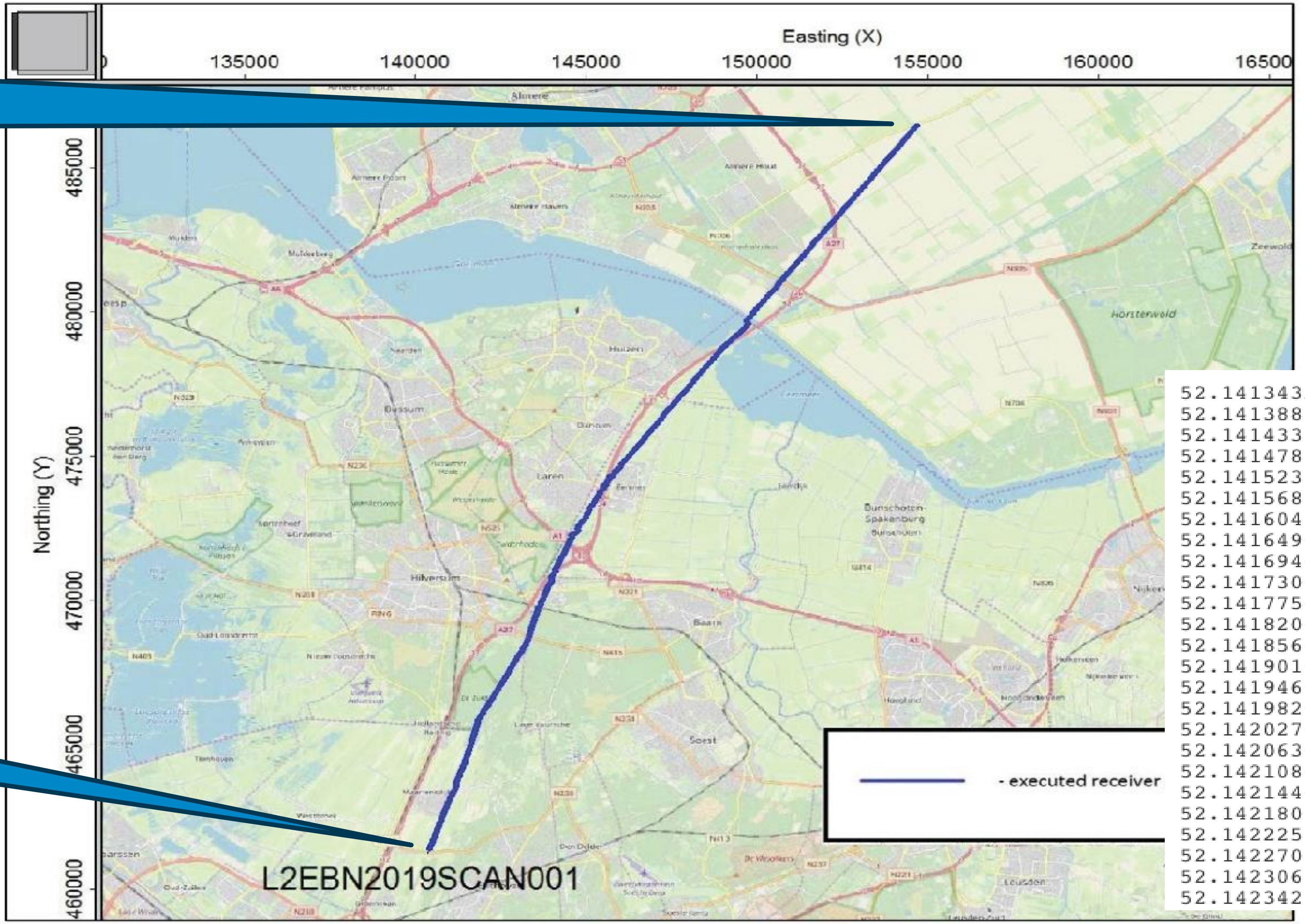
Multi-year agreement

	RF			Transformer			PM		
Class	2018-2019	2019-2020	2018-2020	2018-2019	2019-2020	2018-2020	2018-2019	2019-2020	2018-2020
Artificial land	85.4	83.1	80.3	79.3	88.0	84.4	100	100	100
Grass	87.5	79.6	79.6	84.7	52.7	62.6	100	100	100
Crop	88.0	85.1	81.2	79.3	77.8	74.2	99.9	99.9	99.9
Bareland	70.5	73.4	58.3	72.7	46.4	46.4	99.8	98.8	98.7
Broadleaves	88.1	90.5	82.8	79.6	88.1	87.3	99.9	99.8	99.7
Conifers	87.0	86.9	79.0	88.3	83.0	84.6	97.5	95.5	93.1
Shrub	74.3	81.8	66.7	45.0	62.8	64.6	99.9	99.9	99.9
Water	97.2	97.7	96.4	93.4	78.1	80.1	99.9	99.9	99.9
Overall	86.6	86.7	79.9	80.4	80.3	81.2	99.1	98.5	97.7

Linking Remote Sensing with Seismic Imaging

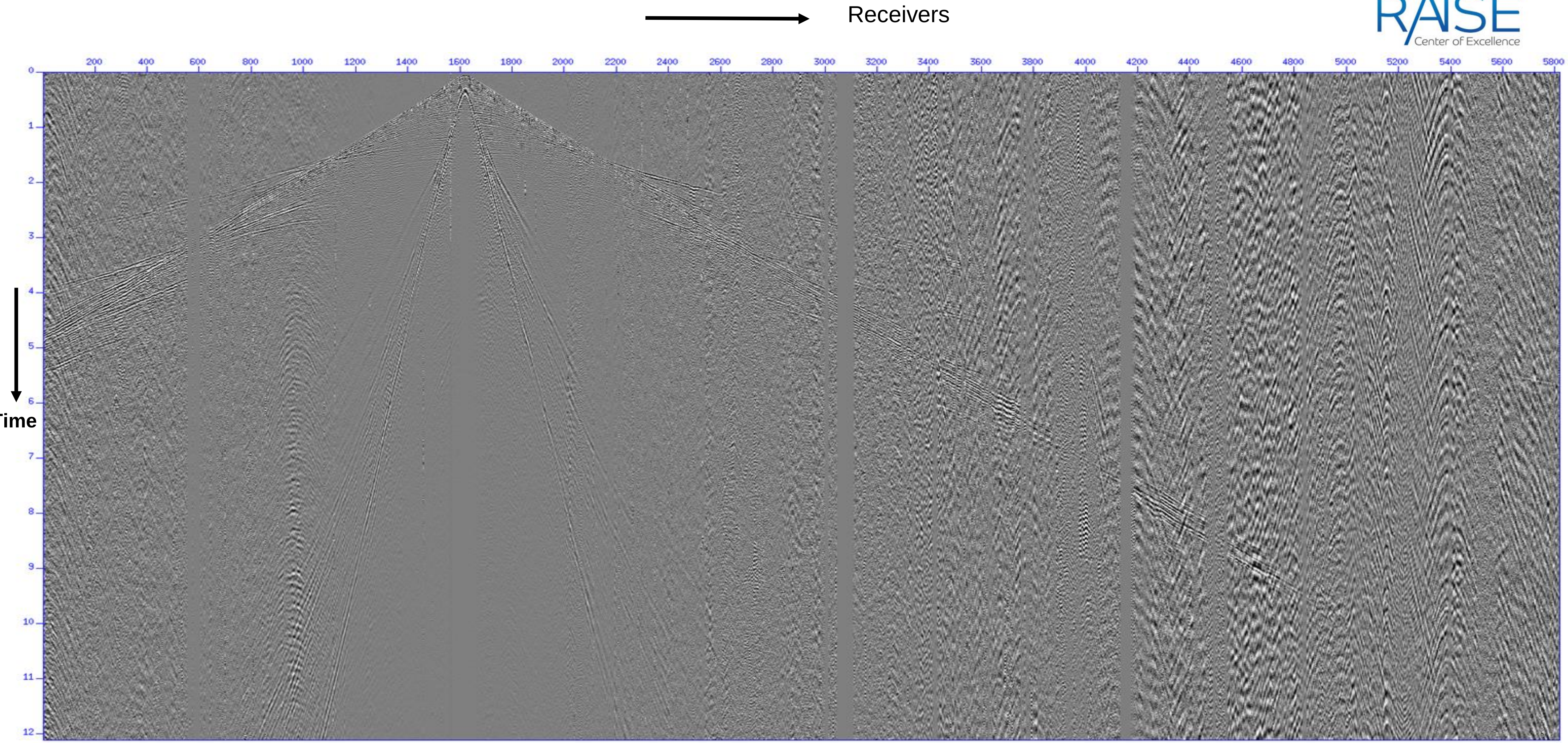
Last receiver number=7617, total 5817 receivers per shot record
Total shots= 1355

First receiver number = 1800



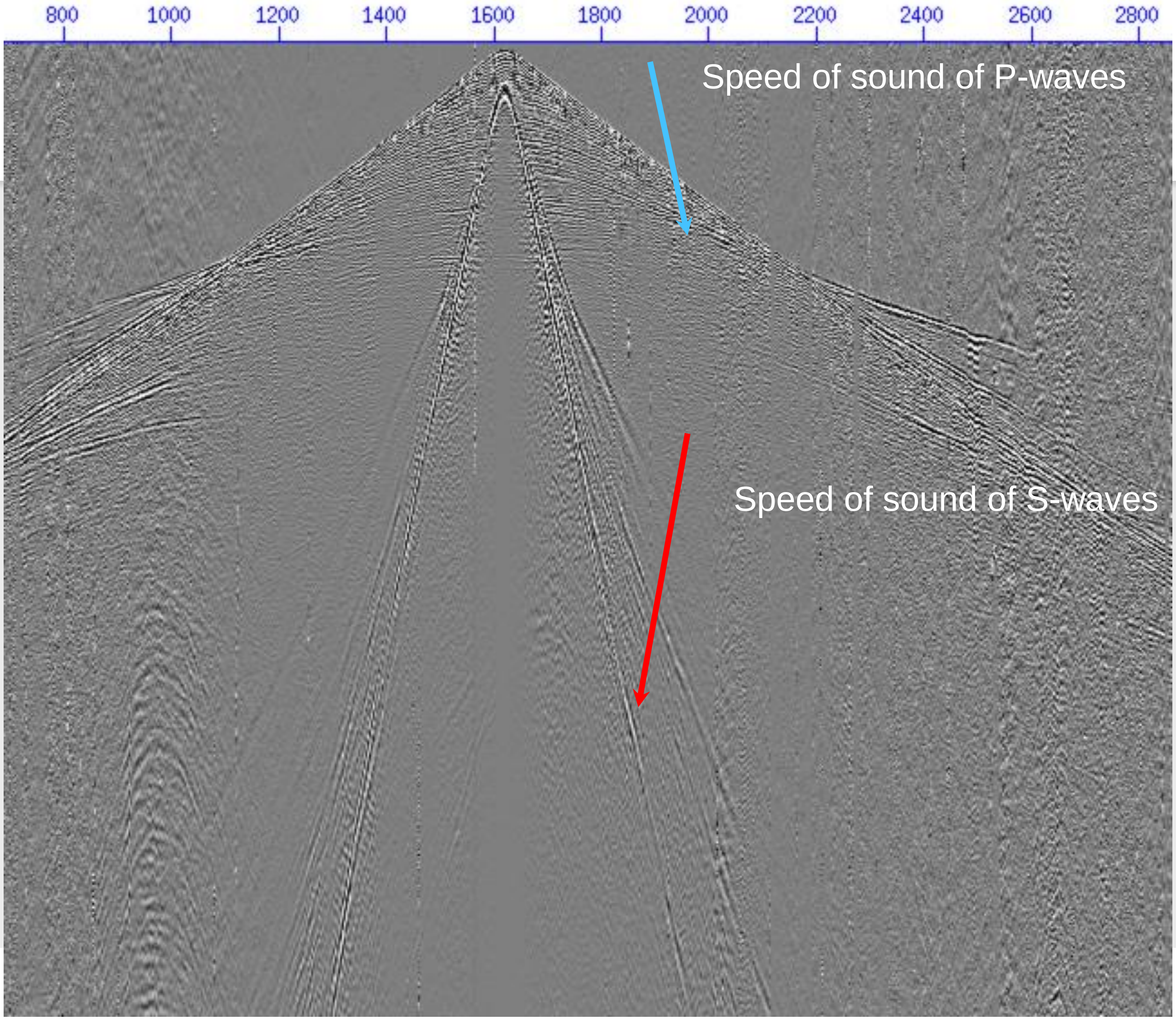
Coordinate conversion:
seismic coordinate system to global coordinate system
Line length: 29 km
R/S interval: 5/20 m

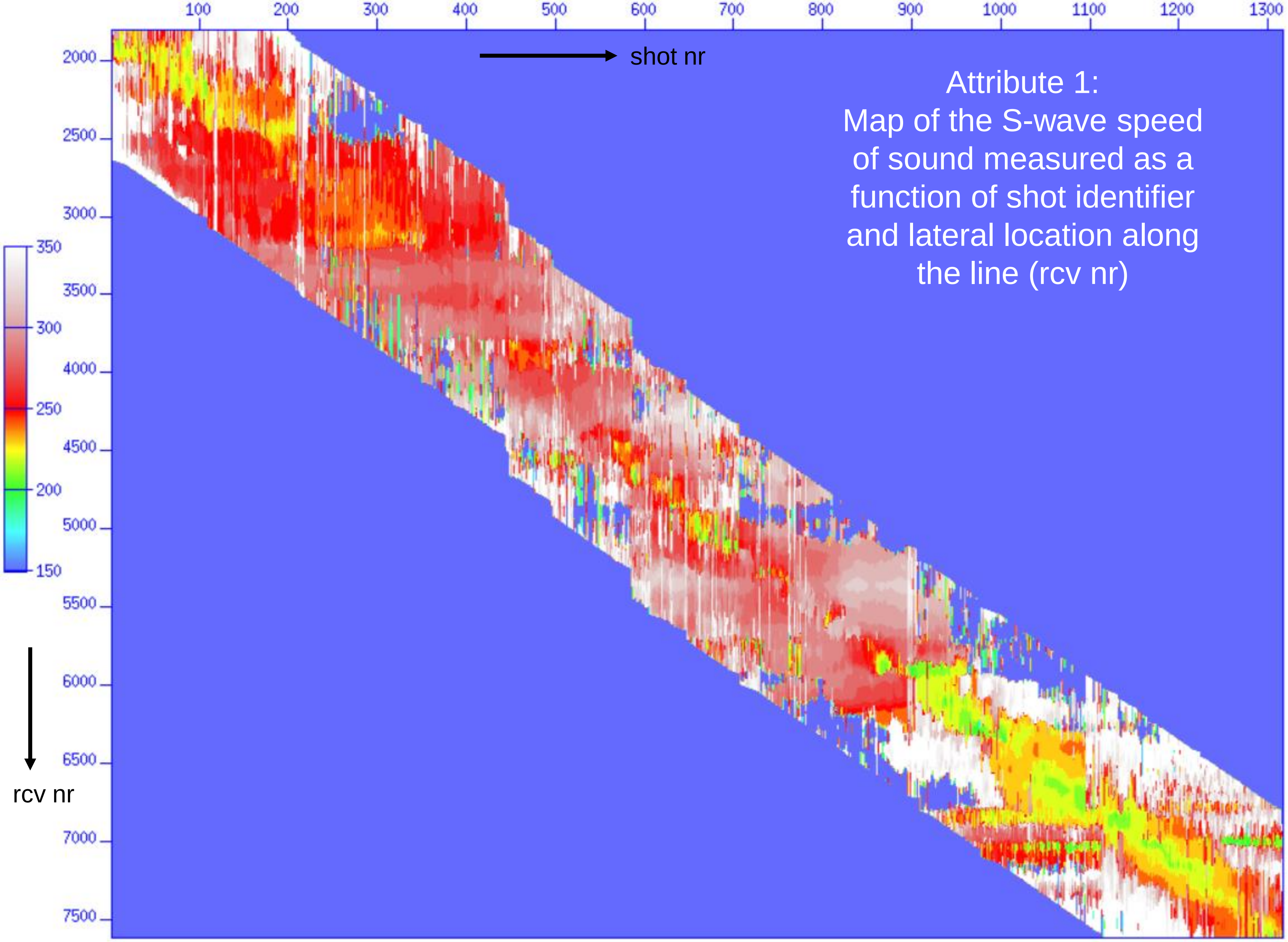
52.1413432031	5.1746851781	1.0000000000
52.1413881743	5.1746995735	1.0000000000
52.1414331454	5.1747139690	1.0000000000
52.1414781429	5.1747429742	1.0000000000
52.1415231141	5.1747573698	1.0000000000
52.1415681116	5.1747863751	1.0000000000
52.1416041201	5.1748154234	1.0000000000
52.1416490912	5.1748298191	1.0000000000
52.1416940887	5.1748588246	1.0000000000
52.1417300709	5.1748732631	1.0000000000
52.1417750420	5.1748876589	1.0000000000
52.1418200395	5.1749166645	1.0000000000
52.1418560480	5.1749457131	1.0000000000
52.1419010191	5.1749601089	1.0000000000
52.1419460166	5.1749891148	1.0000000000
52.1419820250	5.1750181635	1.0000000000
52.1420270488	5.1750617794	1.0000000000
52.1420630573	5.1750908283	1.0000000000
52.1421080810	5.1751344444	1.0000000000
52.1421440895	5.1751634933	1.0000000000
52.1421801243	5.1752071523	1.0000000000
52.1422251216	5.1752361586	1.0000000000
52.1422701453	5.1752797750	1.0000000000
52.1423061801	5.1753234342	1.0000000000
52.1423421885	5.1753524834	1.0000000000



Example seismic shot

Zoom on example seismic shot





Attribute 1:
Map of the S-wave speed of sound measured as a function of shot identifier and lateral location along the line (rcv nr)

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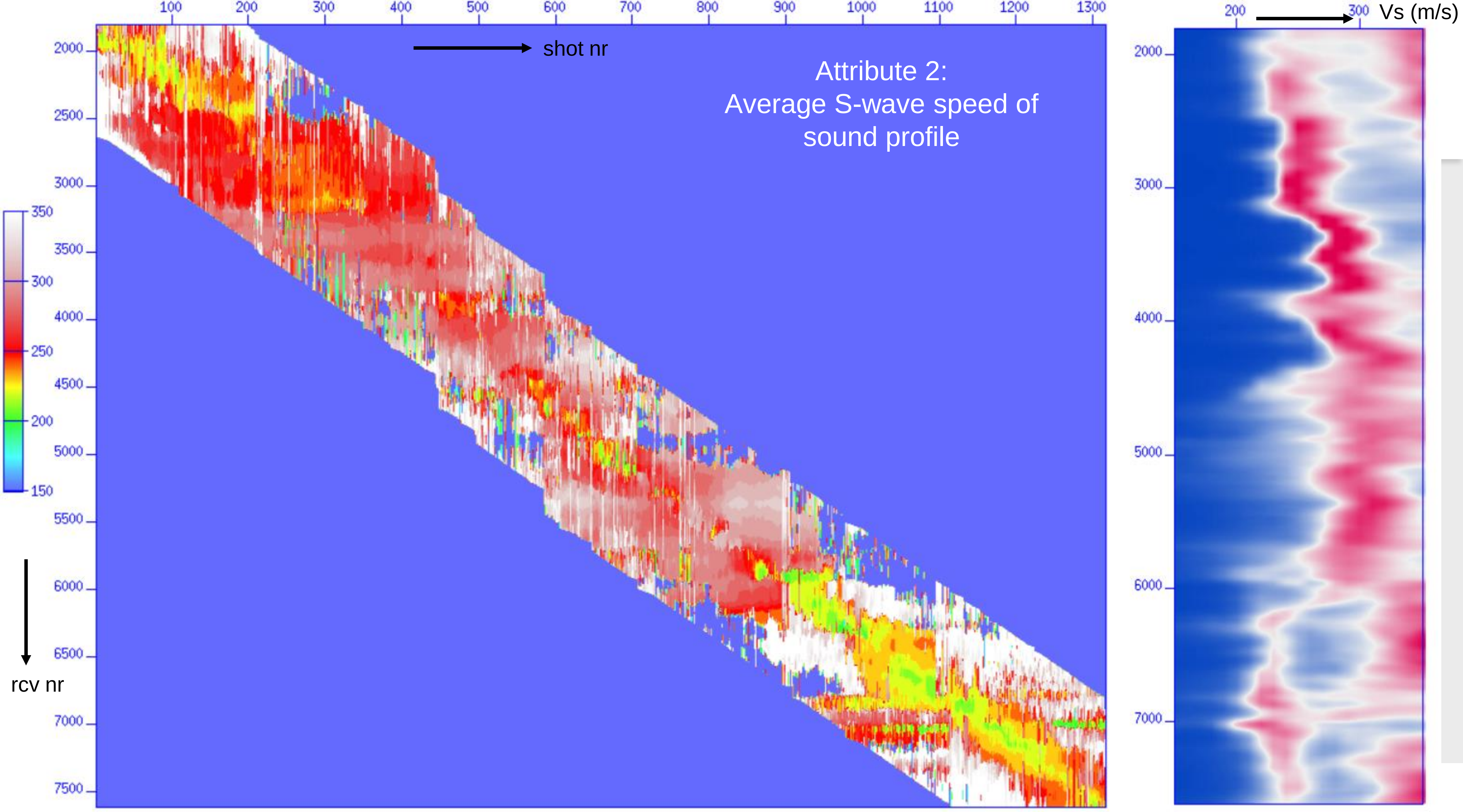
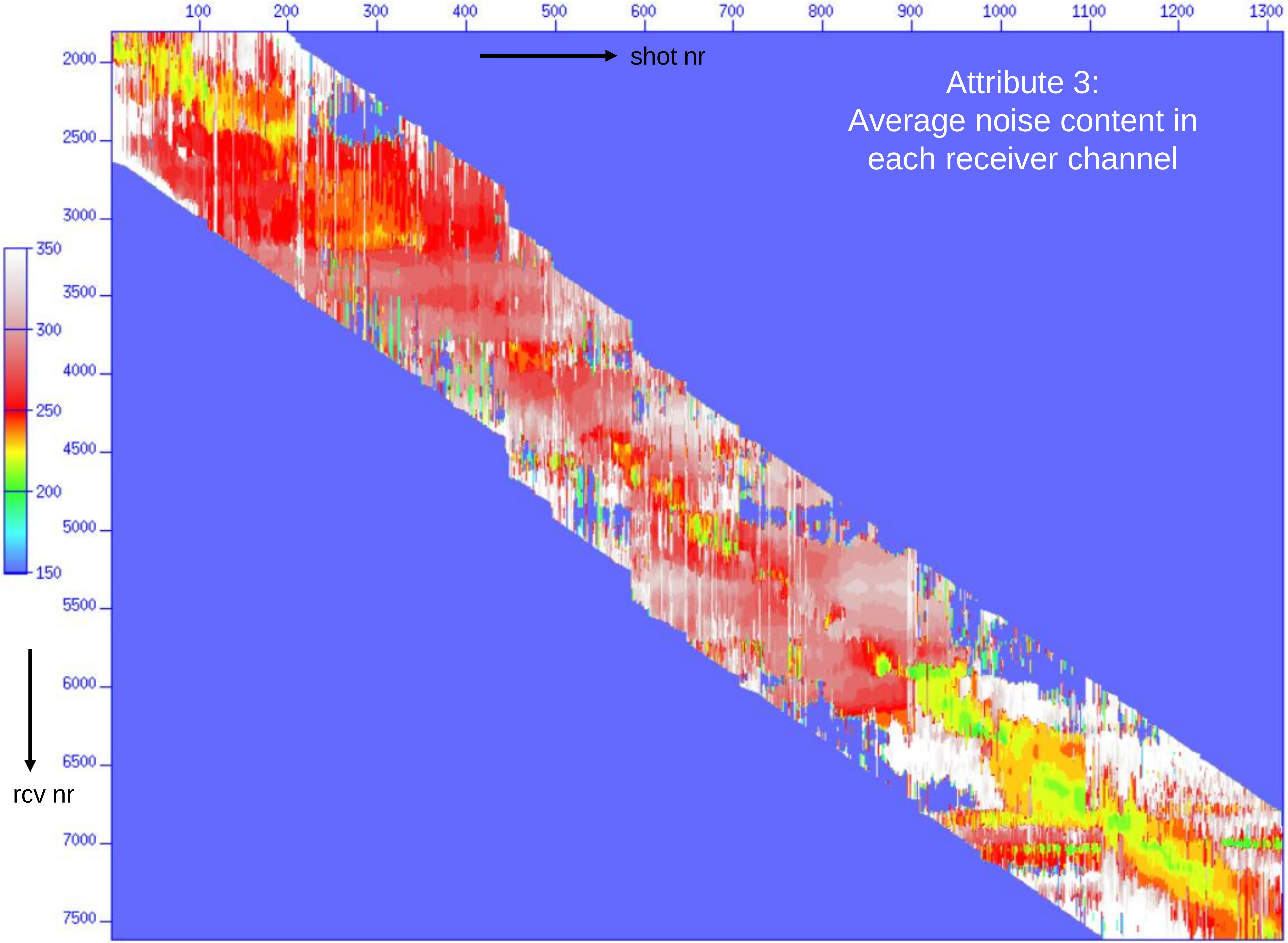
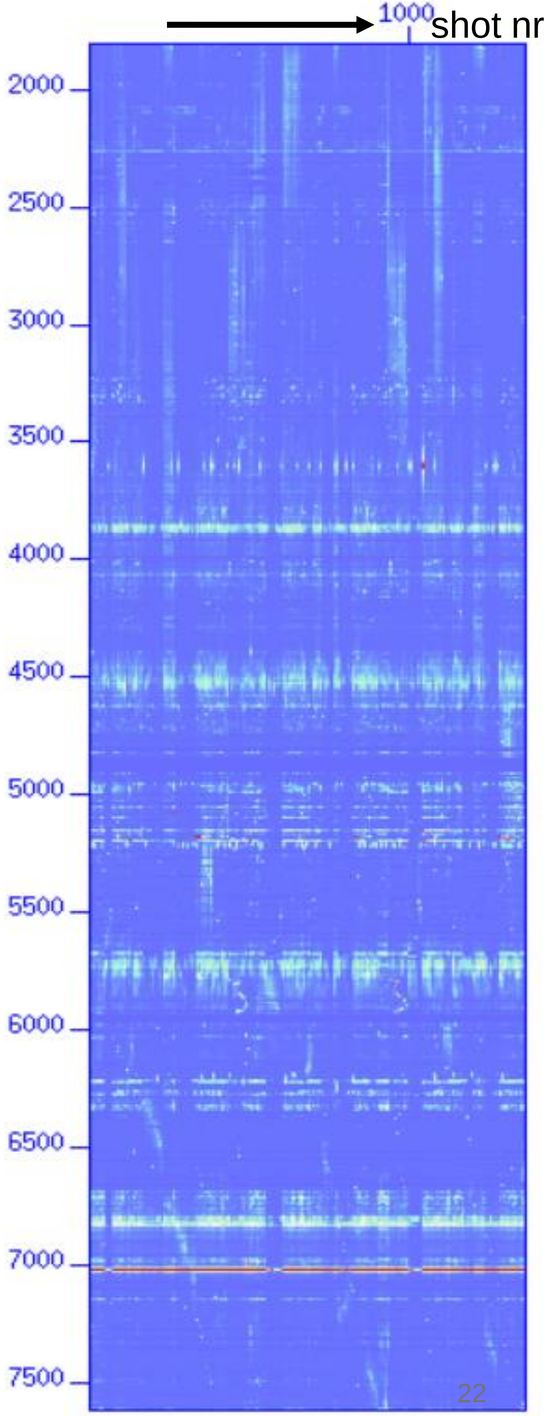
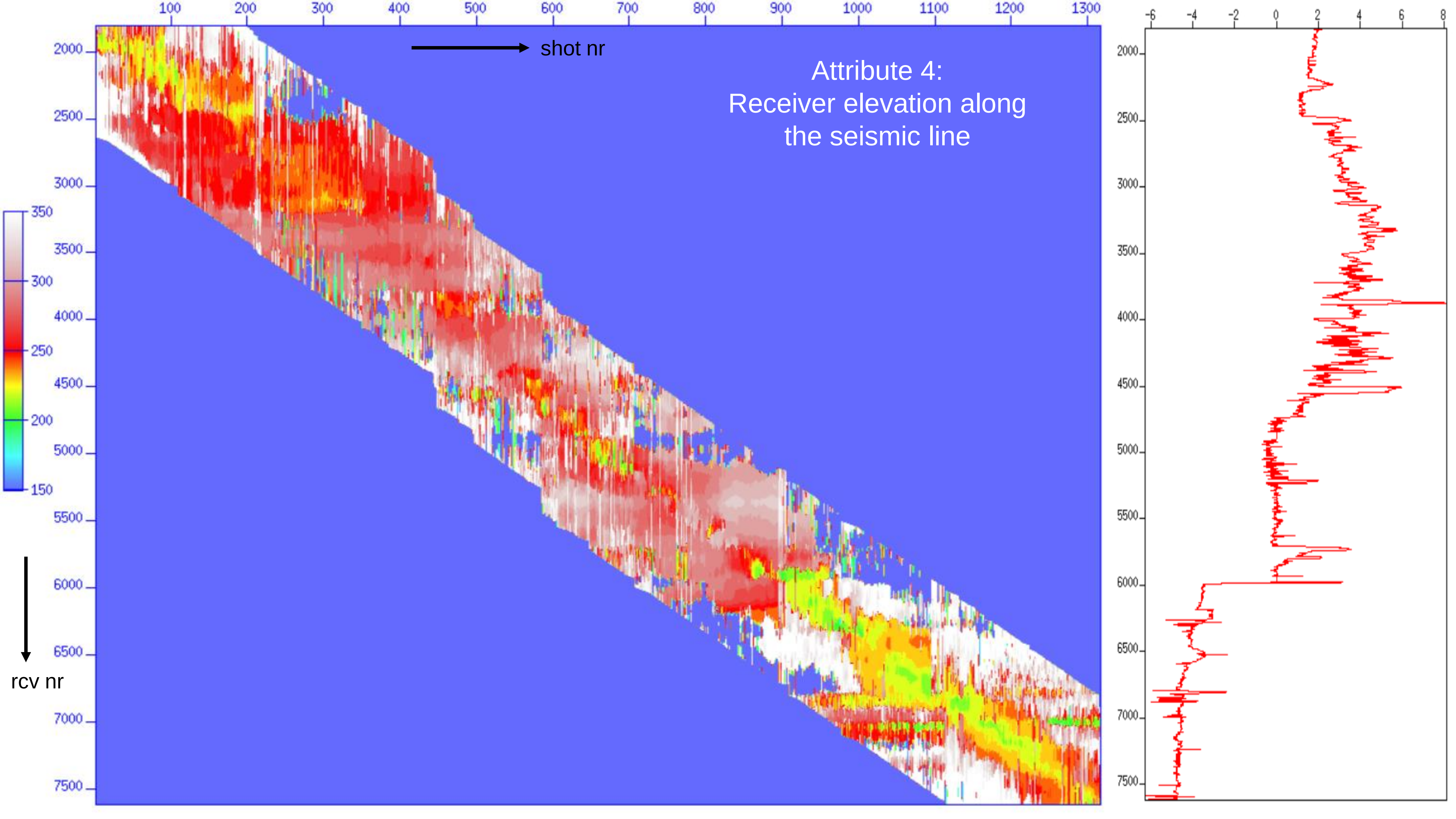

shot nr
Attribute 2:
Average S-wave speed of sound profile
rcv nr
Vs (m/s)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
350
300
250
200
150

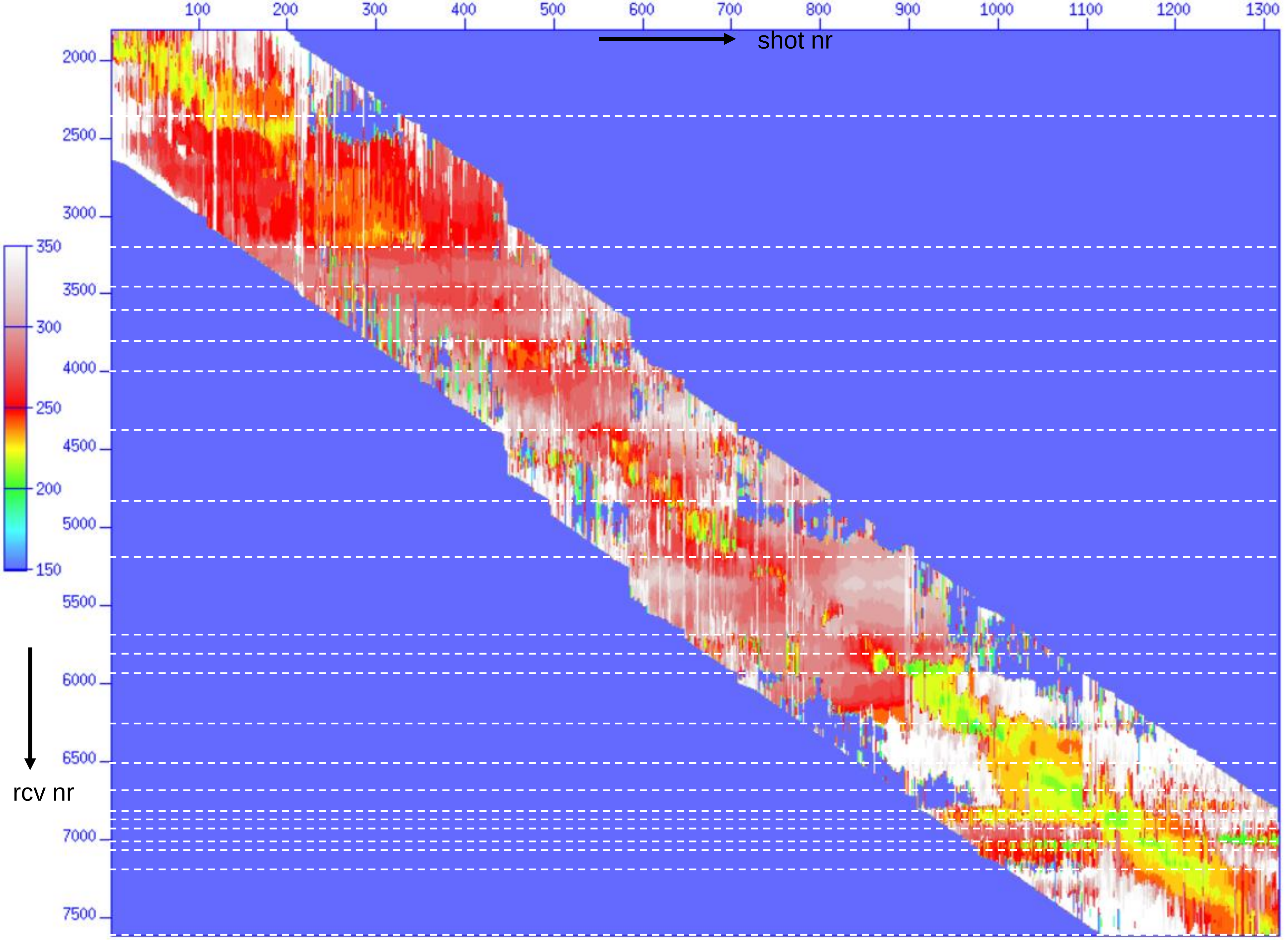
Attribute 3: Average noise content in each receiver channel





Attribute 4:
Receiver elevation along the seismic line





Identified regions using all attributes

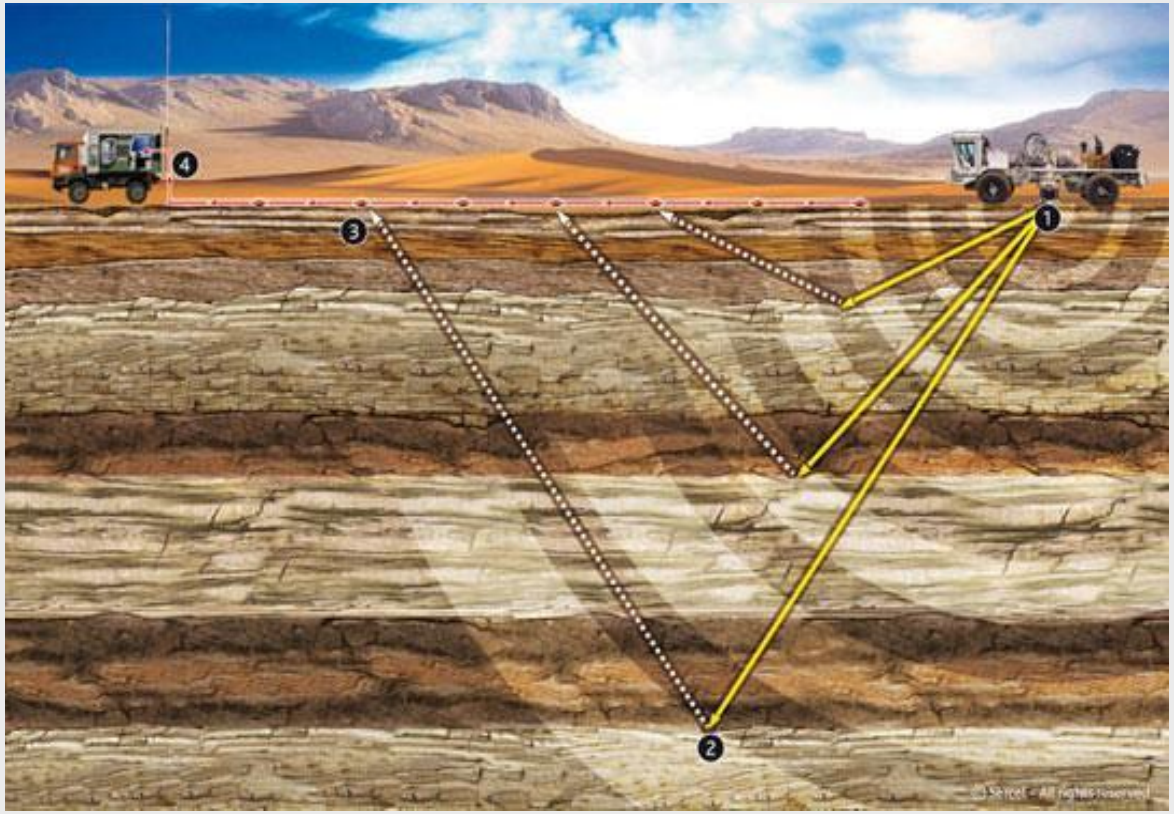
Seismic Imaging: Revealing Earth's Subsurface

- Sub-field of Geophysics, broadly speaking Geosciences

- Seismic waves that pass through Earth's subsurface layers and recorded back on the surface by receivers called geophones.

- Recorded signals turn into subsurface images aiming to discover hidden treasures of the Earth.

Land seismic survey design

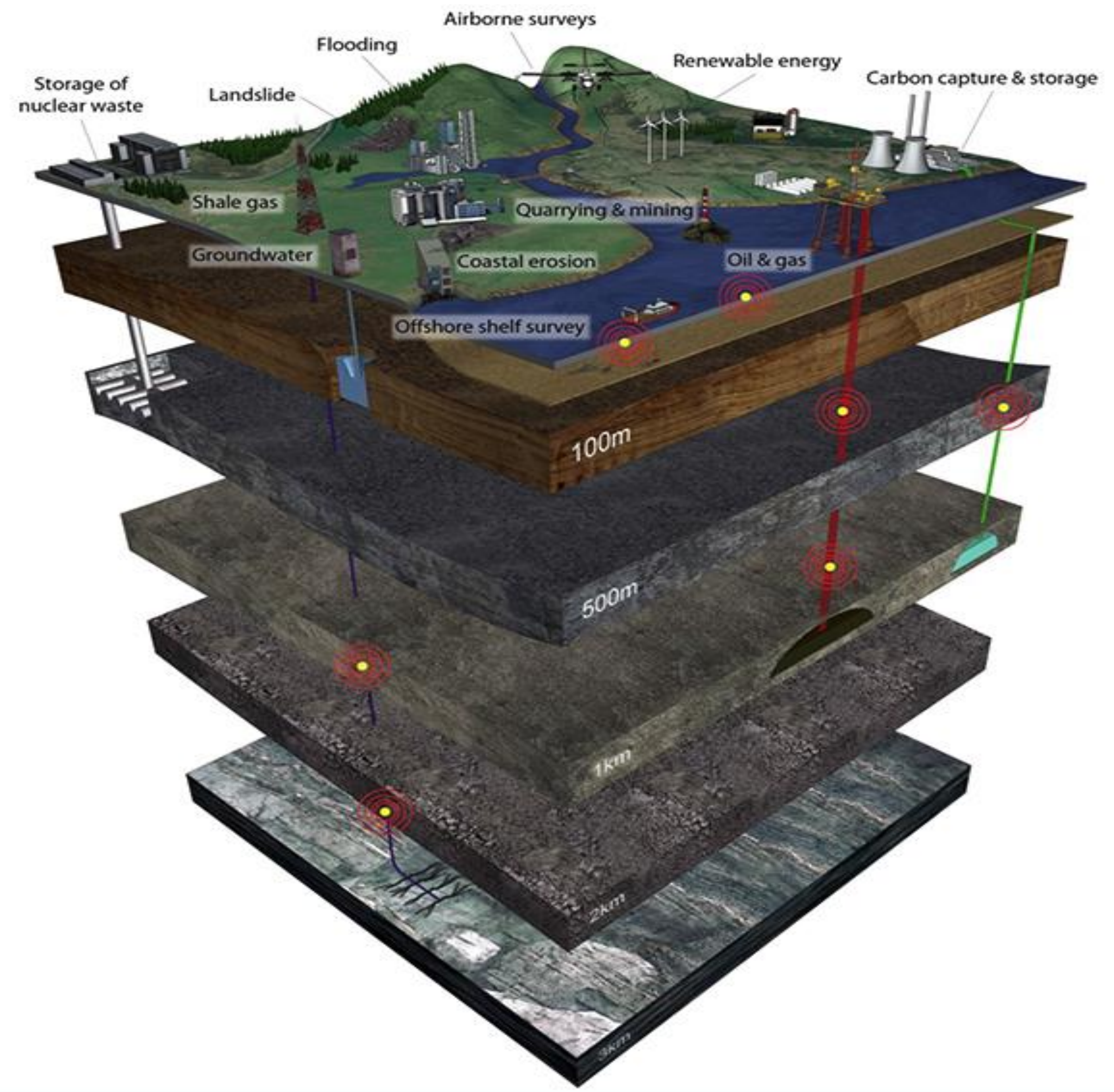


Seismic Imaging: Significant Applications

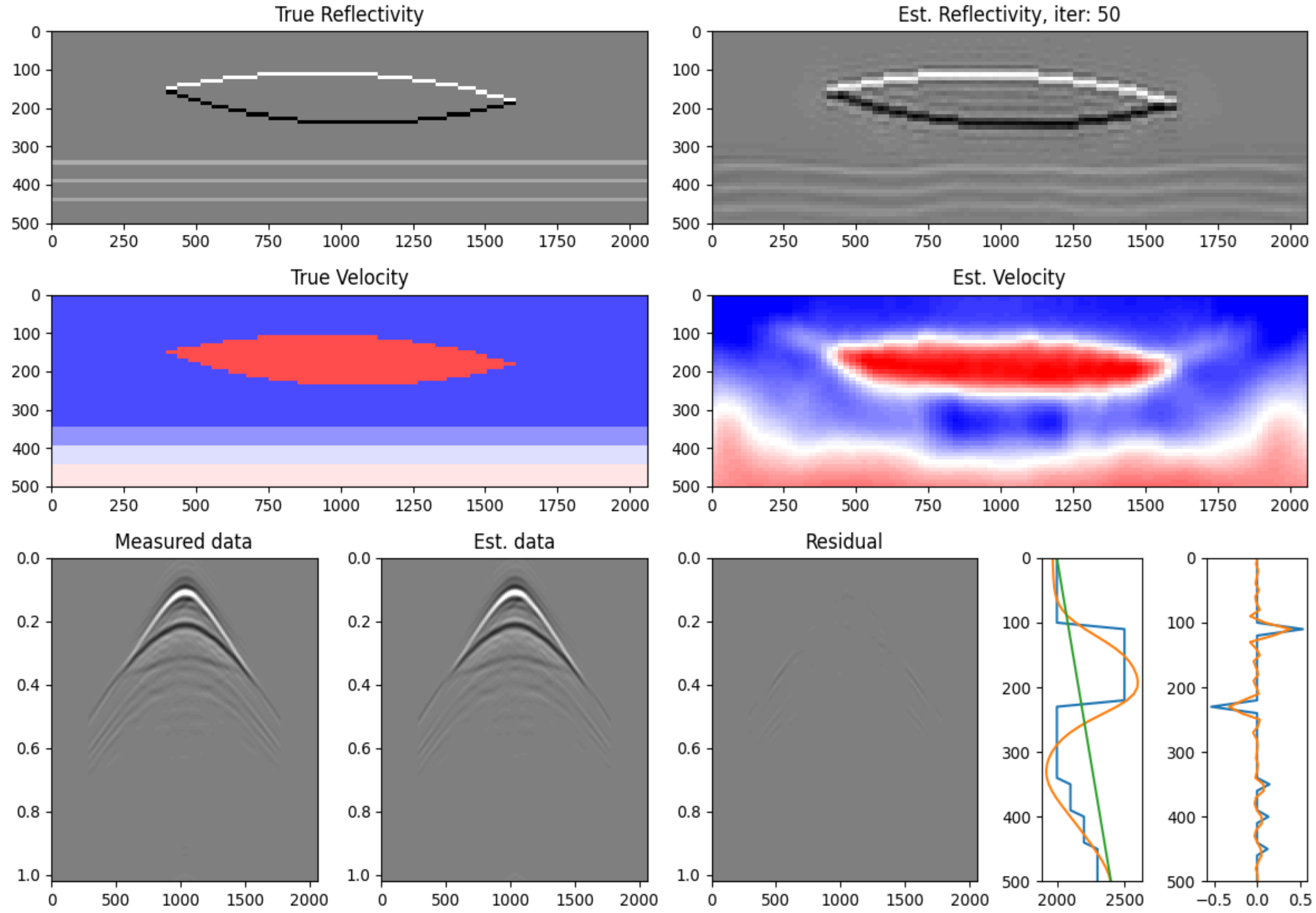
- Subsurface characterization and monitor
- Natural hazards studies

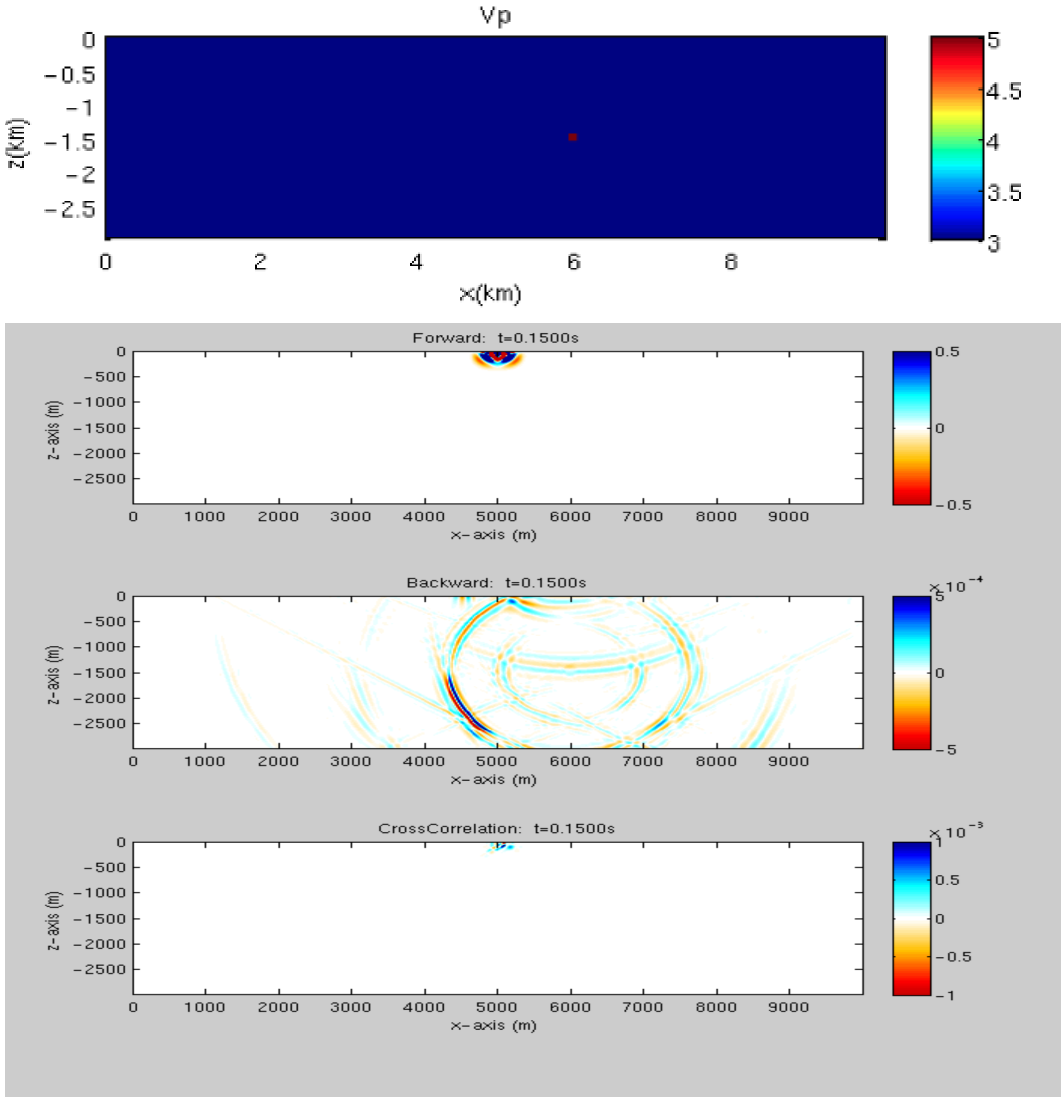
  (Earthquakes, Tsunami, volcano)

- Geo-technical industry (civil engineering)
- Green hydrogen storage (salt caverns)
- Geothermal Energy



Seismic waves modeling
Joint Migration Inversion(JMI)





Huge seismic data volumes

- Seismic datasets are huge in size, involving 1000’s of source locations, each source ‘shooting’ into a receiver spread of also 10,000’s of sensors.

- With a basic sampling of 12.5m to 50m in both spatial directions, and covering areas spanning 25 x 25 km, the data volumes contain 10’s or 100’s of Tbytes, or even reaching the Pbyte.

- Explored ML methods aiming to at least partly replace computationally expensive part for wave modeling process.

Machine Learning: Seismic Wavefield Reconstruction

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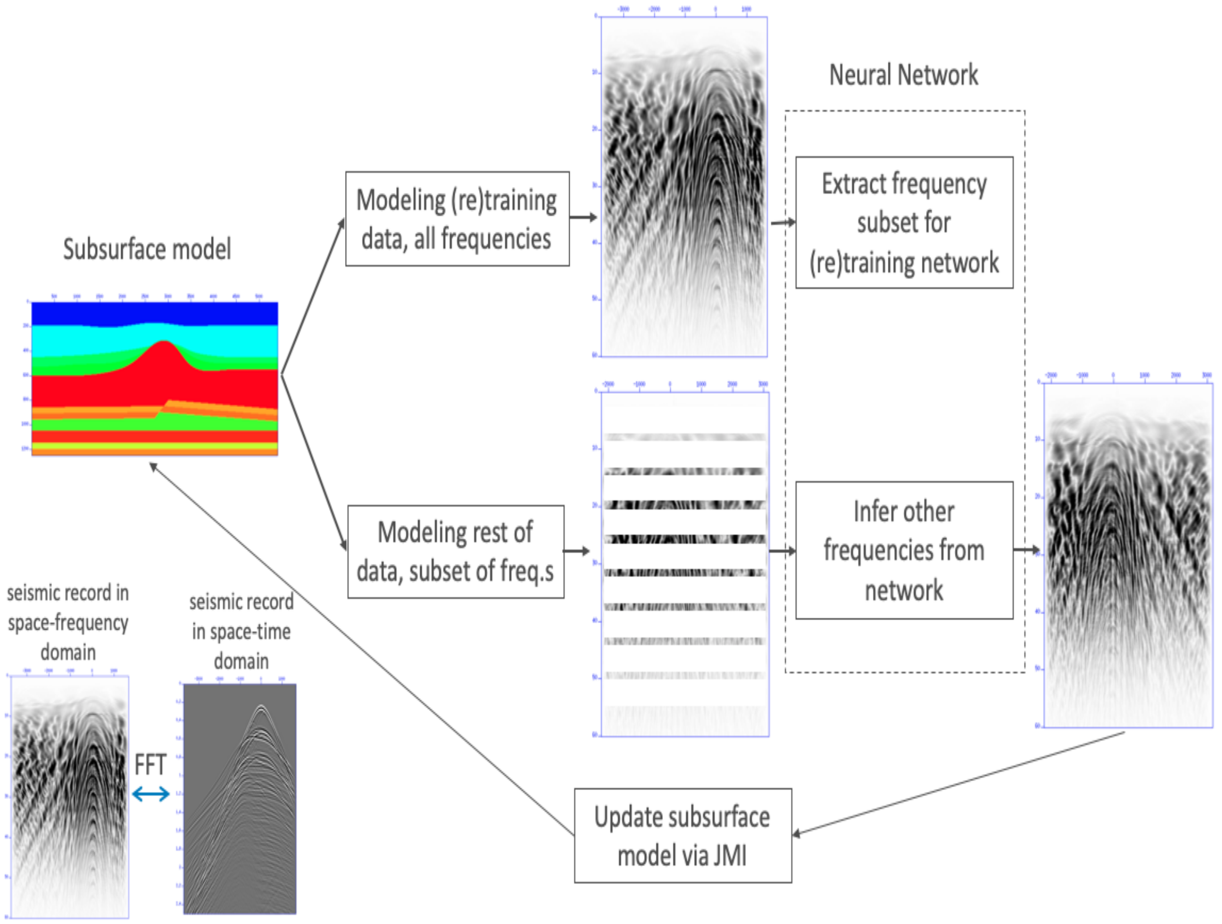
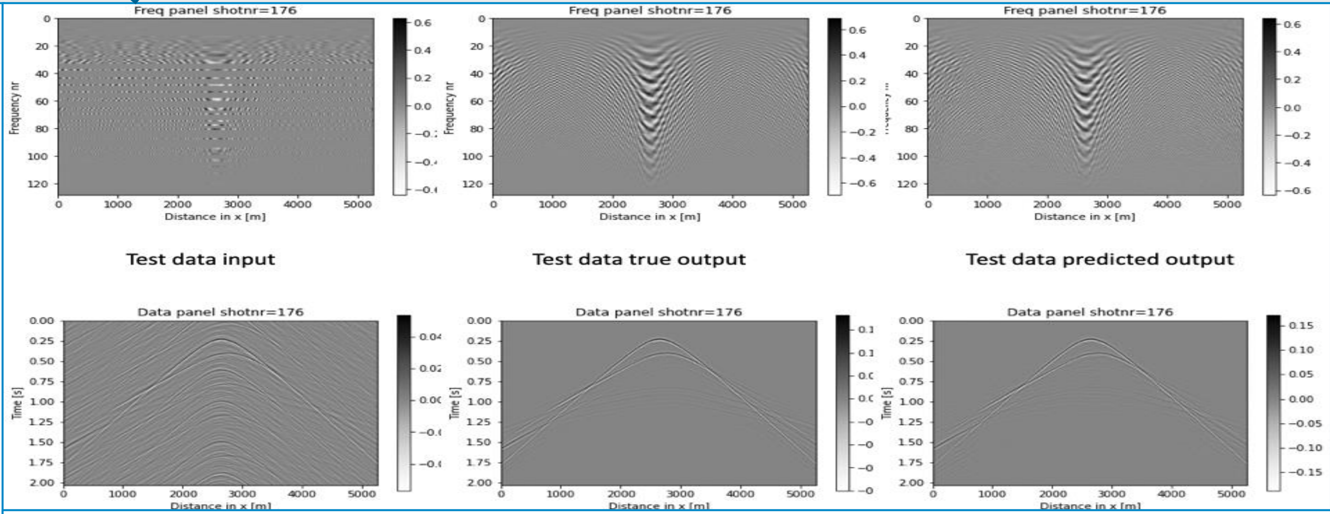
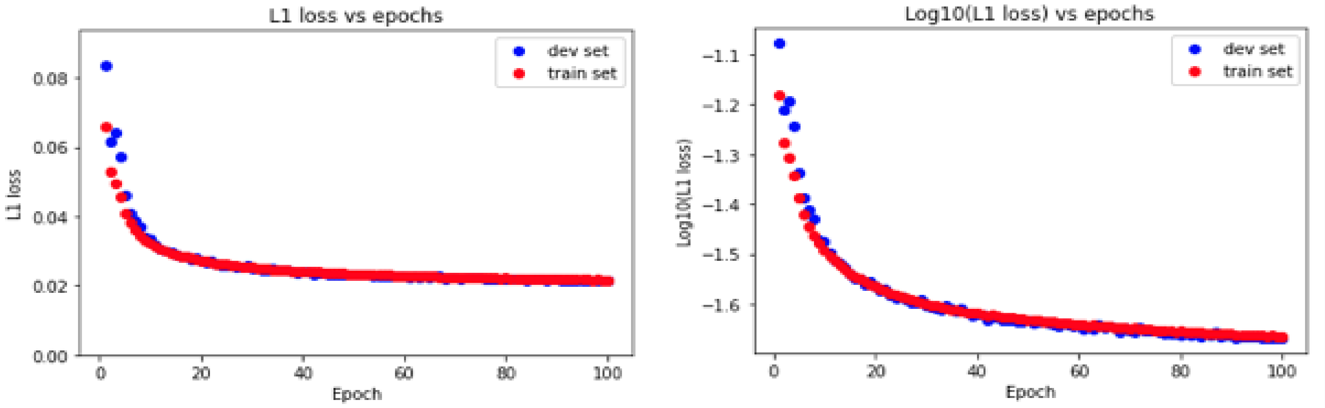
Workflow



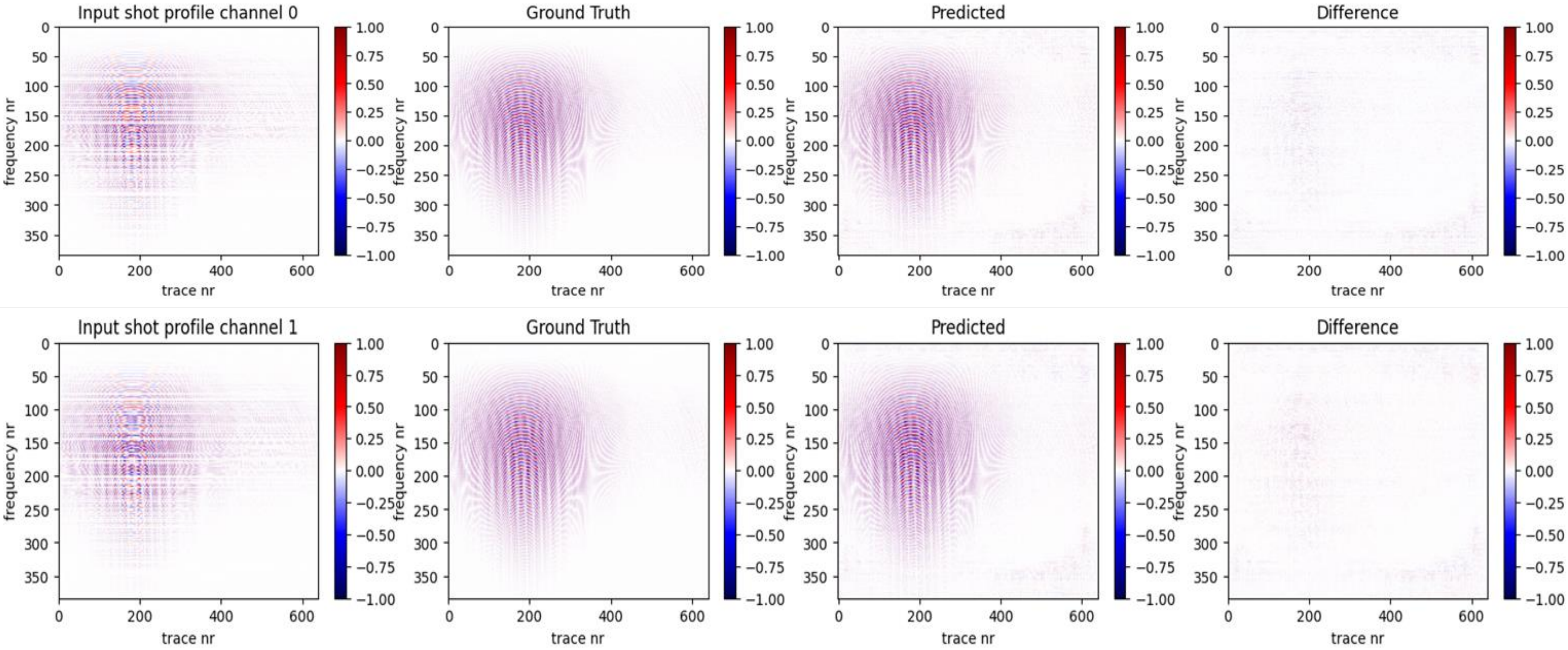
Results



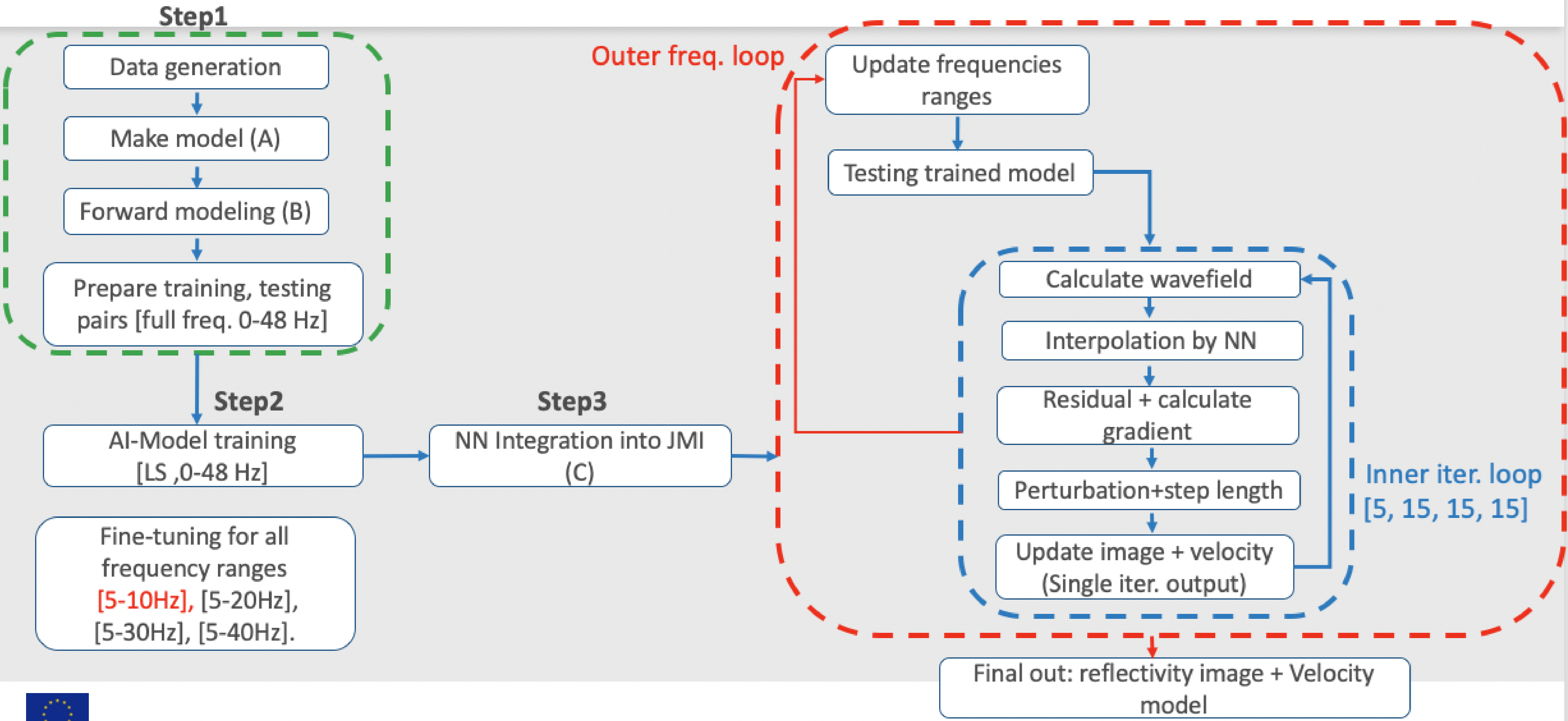
Structure of the U-Net and loss function



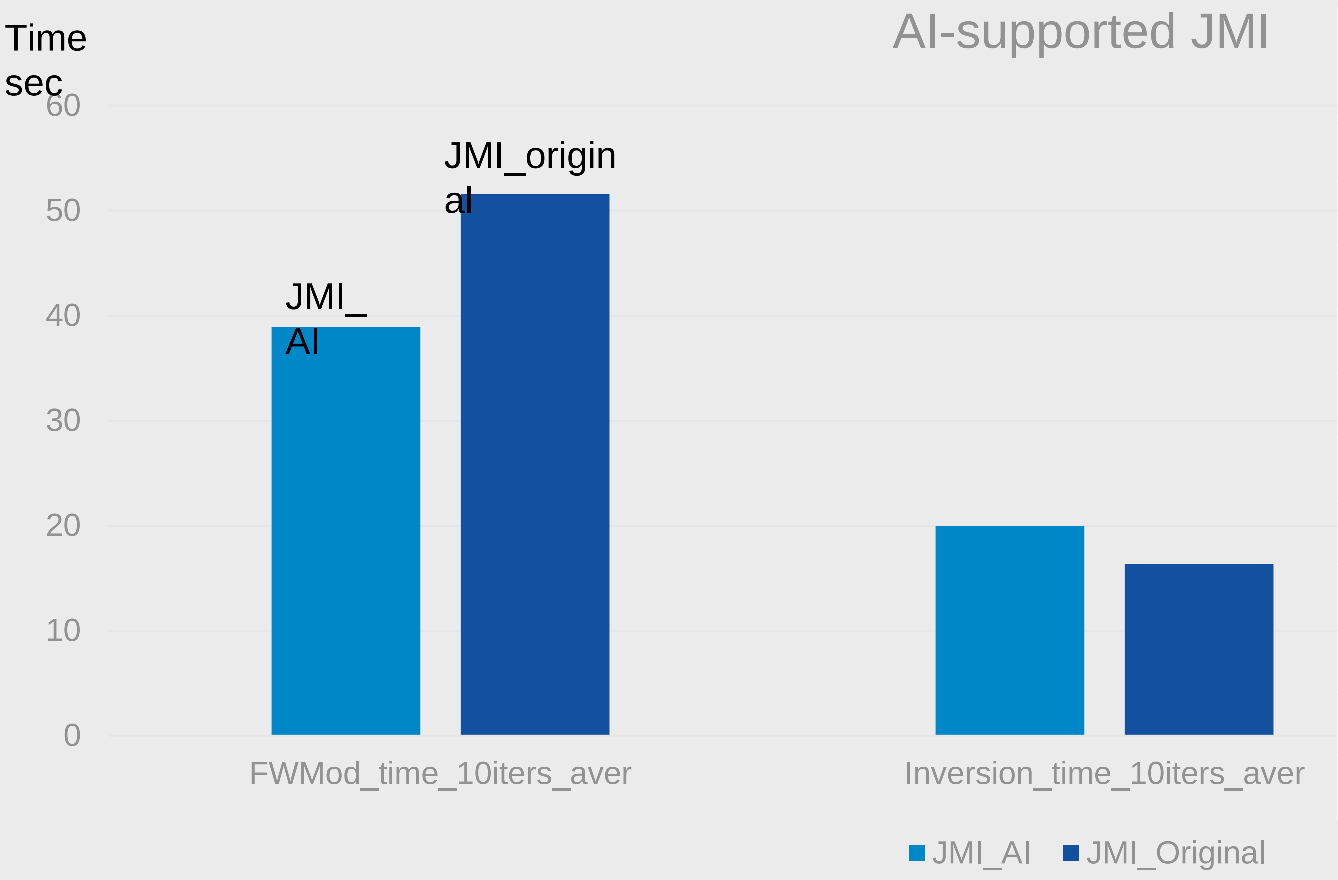
Results: Pix2pix (cGAN) for SEAM industry standard model



Workflow: AI integration into regular JMI



'AI' is faster than original JMI software



Iterations	JMI_AI Mod step	JMI_orig Mod step	JMI_AI Inversion	JMI_orig Inversion
1	7.54	5.38	1.99	1.65
2	3.43	5.38	1.97	1.63
3	3.54	5.13	1.96	1.63
4	3.48	5.35	2.0	1.64
5	3.46	4.68	2.02	1.62
6	3.5	5.36	2.0	1.64
7	3.49	5.14	2.01	1.62
8	3.47	5.26	2.03	1.64
9	3.52	5.17	2	1.64
10	3.48	4.71	1.98	1.63
TOTAL	**38.91**	**51.56**	**19.96**	**16.34**

Next Steps: Task 4.2

- Envisioned integration of remote sensing (RS) and seismic imaging tools.Objective: The information from the land-cover map directly defines the seismic processing parameters.

- Integrate ML trained models into regular JMI software particularly for seismic inversion calculations.

- Facilitate to update the design and workflow for seismic data acquisition and processing.

drive. enable. innovate.

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The CoE RAISE project have received funding from
the European Union's Horizon 2020 –
Research and Innovation Framework Programme
H2020-INFRAEDI-2019-1 under grant agreement no. 951733

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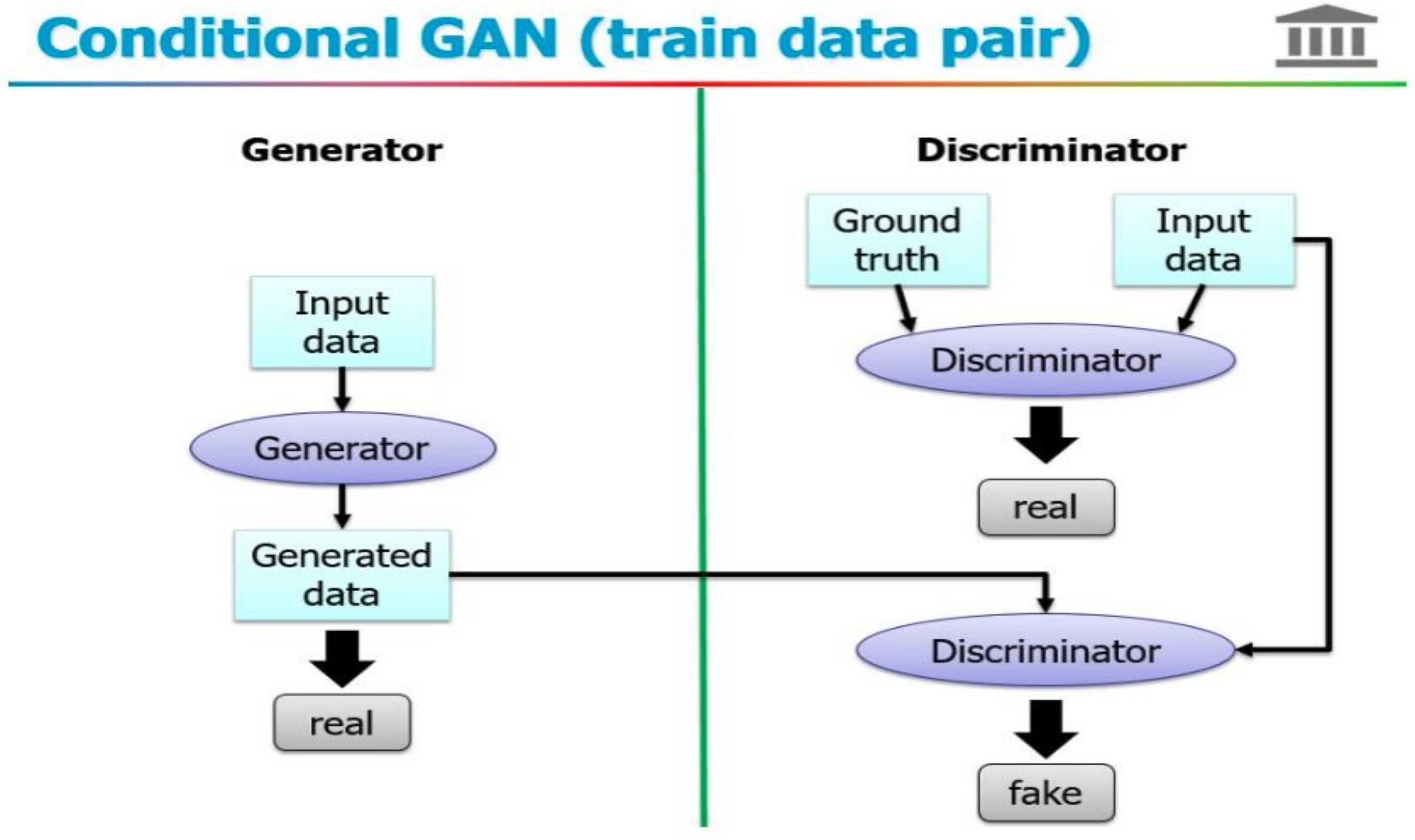
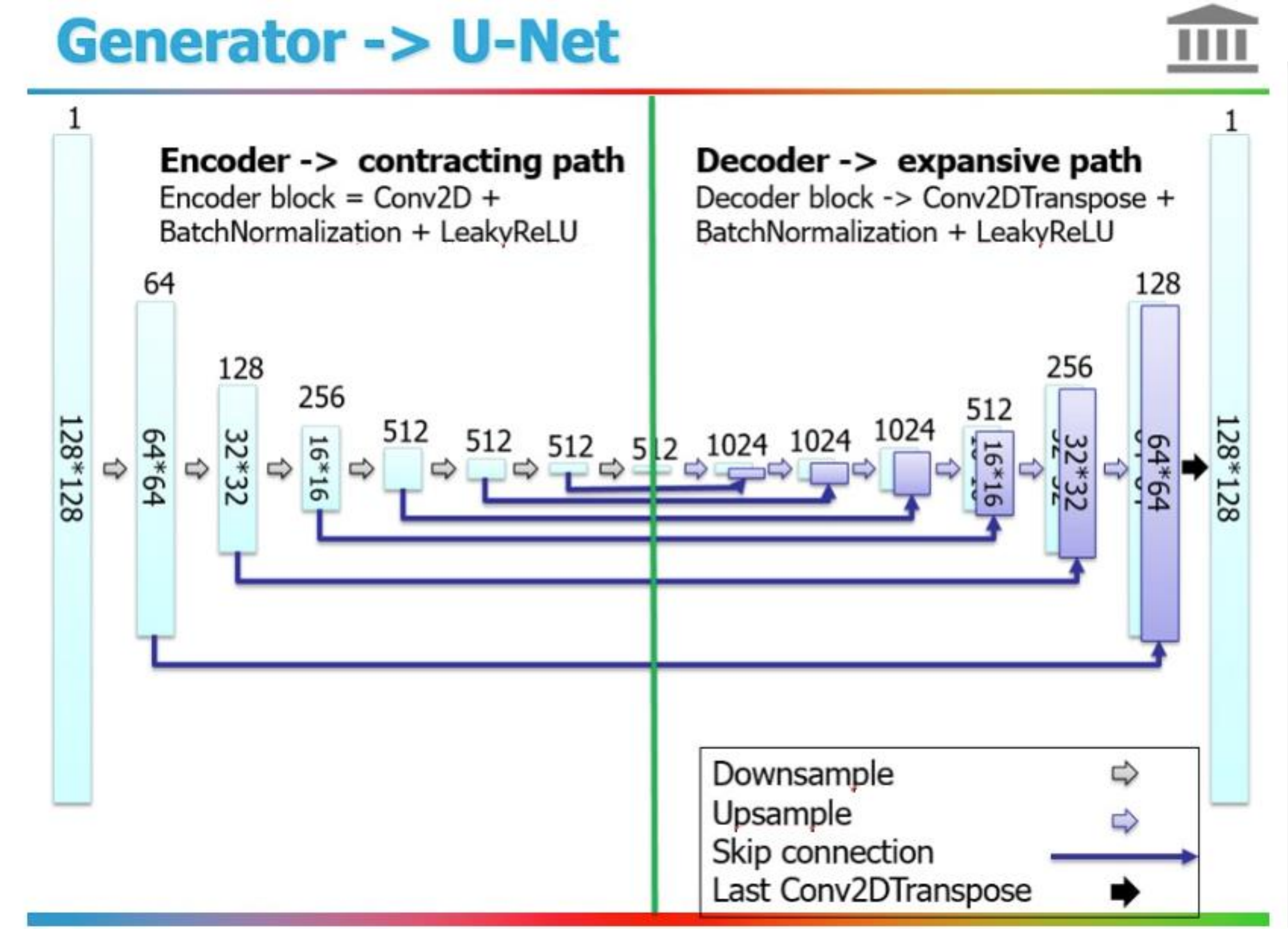
Neural Network Architecture



Generator Building:



Discriminator Building