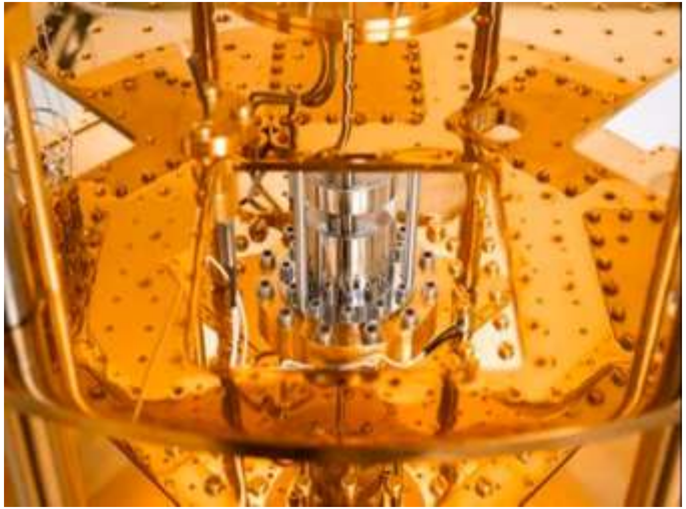


QUANTUM COMPUTING FOR EARTH OBSERVATION (QC4EO) STUDY

HPCQC 2023 - AMER DELILBASIC

JÜLICH Forschungszentrum

ThalesAlenia Space

INFN

IQM

Will Quantum Computing (QC) bring an advantage in Earth Observation (EO) applications within the next 15 years? How?

- QC promises to revolutionize several industrial sectors that will benefit from a substantial computational complexity reduction, increased solution quality, lower mass and energy consumption
- EO is rich in computationally hard problems both in space and on ground

The **objective** of QC4EO is to **identify a set of potentially relevant EO use cases** (UC) that can be enhanced by QC and estimate when this will be feasible for applications in production

HOW TO ANSWER THE QUESTION

A consortium capable to fully cover the set of interdisciplinary expertise required during the project

supported by: esa

A study methodology providing practical and actionable insights for the next 15 years

- Use cases definition
- Quantum solution definition
- Quantum machines roadmap assessment
- Use cases timeline

USE CASES DEFINITION

Preliminary UC list

12

- **Computational problems in EO applications**
- **Research areas of the consortium partners**

Refined UC list

6

- **Number and quality of the publications**
- **Time horizon of this study: 15 years**

Highly impacting UCs

4

- **Evaluation and methodology based on KPIs**
- **Applicability on NISQ devices**

USE CASES DEFINITION

MISSION PLANNING FOR EO ACQUISITIONS

MISSION DESIGN OPTIMIZATION

SAR DIGITAL BEAM FORMING

ANTENNA DESIGN OPTIMIZATION

SAR RAW DATA PROCESSING

IN-SAR PHASE UNWRAPPING

IN-SAR COREGISTRATION

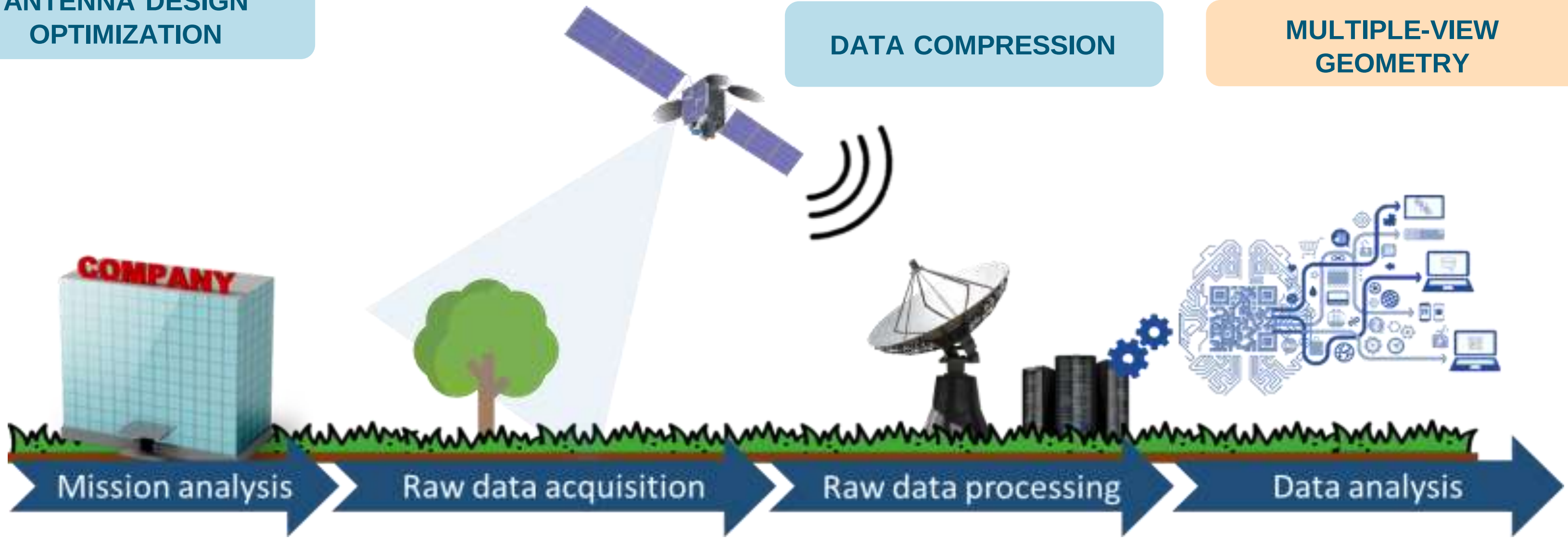
DATA COMPRESSION

OPTICAL-RADAR DATA FUSION

SAR IMAGE SEGMENTATION

OPTICAL SATELLITE DATA ANALYSIS

MULTIPLE-VIEW GEOMETRY

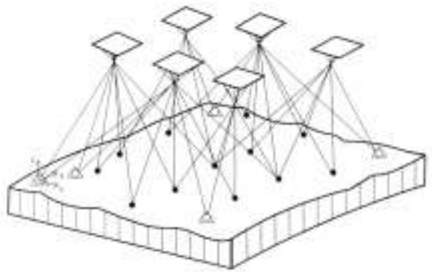


HIGH-IMPACT USE CASES (1/2)

1) Mission Planning for EO Acquisitions

DESCRIPTION	Optimal scheduling of satellite observations for a given list of user requests
MOTIVATIONS	Trend of large constellations, useful for both optical and radar images
CLASSICAL SOLUTIONS	Combinatorial optimization: genetic algorithms, simulated annealing
BOTTLENECKS	Exponential problem complexity. Quality of the solution for large constellations and time horizons > few days
EXAMPLE PROBLEM INSTANCES	Minimum size: 2 satellites, 2000 requests Full size: 10-100 satellites, 10-100K requests
PROPOSED QUANTUM SOLUTION	2 formulations: QUBO (quantum optimization), QNN (quantum neural network)

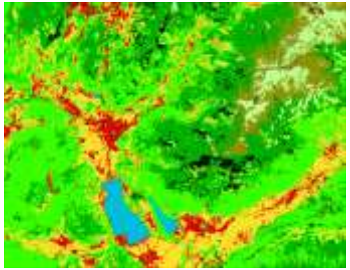
2) Multiple-view Geometry on Optical Images



DESCRIPTION	Acquisition of different views of same the area of interest: images may be rotated or translated, the illumination or scale may differ from one acquisition to another
MOTIVATIONS	Change analysis, terrain reconstruction, enhancing applications like target detection
CLASSICAL SOLUTIONS	Computer vision algorithms for keypoint extraction and alignment
BOTTLENECKS	Exponential problem complexity. Not solvable as one large optimization problem
EXAMPLE PROBLEM INSTANCES	Minimum size: 10 keypoints, 8*8 patches Full size: up to 30K*30K pixels
PROPOSED QUANTUM SOLUTION	QUBO (quantum optimization) + quantum kernel evaluation

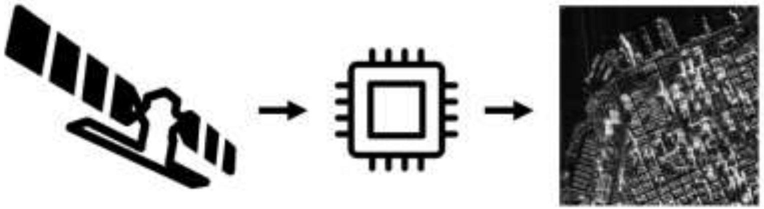
HIGH-IMPACT USE CASES (2/2)

3) Optical Satellite Data Analysis



DESCRIPTION	Generate classification maps from satellite data, thereby providing an invaluable resource for understanding and managing land resources effectively
MOTIVATIONS	Importance of information extraction from large amount of data for end users
CLASSICAL SOLUTIONS	Machine learning: random forest, SVM, neural networks
BOTTLENECKS	Tradeoff between model performance and computational cost. Kernel methods: computation of kernel matrix expensive for large datasets.
EXAMPLE PROBLEM INSTANCES	Minimum size: 1000 training samples (pixels) Full size: a few million samples (pixels)
PROPOSED QUANTUM SOLUTION	Quantum kernels

4) SAR Raw Data Processing



DESCRIPTION	Generating an intensity image that gives a visual description of the physical properties of the analyzed area, starting from the acquired raw signal
MOTIVATIONS	Crucial role of SAR in EO, unexplored solution
CLASSICAL SOLUTIONS	Frequency-domain, time-domain focusing algorithms
BOTTLENECKS	Heavy computational burden for large images for FFT
EXAMPLE PROBLEM INSTANCES	Minimum size: 16*16 patch (specific object) Full size:10000*10000 patch (Sentinel-1 acquisition)
PROPOSED QUANTUM SOLUTION	Quantum Range Doppler based on Quantum Fourier Transform (QFT)

USE CASES TIMELINE

2025 — 2030 — 2035 — 2040

Mission planning (QUBO)

Minimum size problem on NISQ device (quantum annealer, neutral atoms)

Mission planning (QNN)

Minimum size problem on NISQ device (superconducting, ion-trap)

Multiple-view geometry

Minimum size problem on NISQ device (superconducting, ion-trap)

Mission planning (QUBO)

Minimum size problem on NISQ device (superconducting, ion-trap)

Multiple-view geometry

Medium size problem on NISQ device (superconducting, ion-trap)

Mission planning (QNN)

Full size problem on NISQ device (superconducting)

SAR raw data processing

Minimum size problem on NISQ device (ion-trap)

Mission planning (QUBO)
Multiple-view geometry
SAR raw data processing

Full size problem requires fully scalable error corrected QC (superconducting)

Optical satellite data analysis

Full size problem requires very low gate times (superconducting)

CONCLUSIONS

- The study proved the existence of EO use cases where **quantum computing can have an impact** in the next 15 years
- Trends are **hard to predict**: fundings and opportunities can affect the forecasts for different technologies accordingly
- An **efficient problem formulation** is important, as it determines the required computing resources
- Additional studies on the formulation of the selected algorithms can **speed up implementation** on real hardware
- This is a preliminary study: the focus is on **selecting use cases** and solutions
- An **in-depth study** with a workforce of multidisciplinary expertise could unlock new insights on QC4EO

THANK YOU FOR YOUR ATTENTION

JÜLICH Forschungszentrum

Gabriele Cavallaro
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Madita Willsch

INFN

Ilaria Siloi
Simone Montangero
Marco Tesoro
Marco Ballarin

IQM

Björn Pötter
Markus Weber
Jay Nath
Jiri Guth Jarkovsky
Frank Deppe

ThalesAlenia Space
a Thales / Leonardo company

Mattia Verducci (IT)
Tommaso Catuogno (IT)
Benjamin Marchand (FR)
Serge Rainjonneau (FR)

THALES

Frederic Barbaresco
Noe Olivier
Michel Novak