AI4space @ISAE-SUPAERO

COMET SIL, Forum UTIAS2

4 et 5 avril 2024

Outline

ISAE-SUPAERO

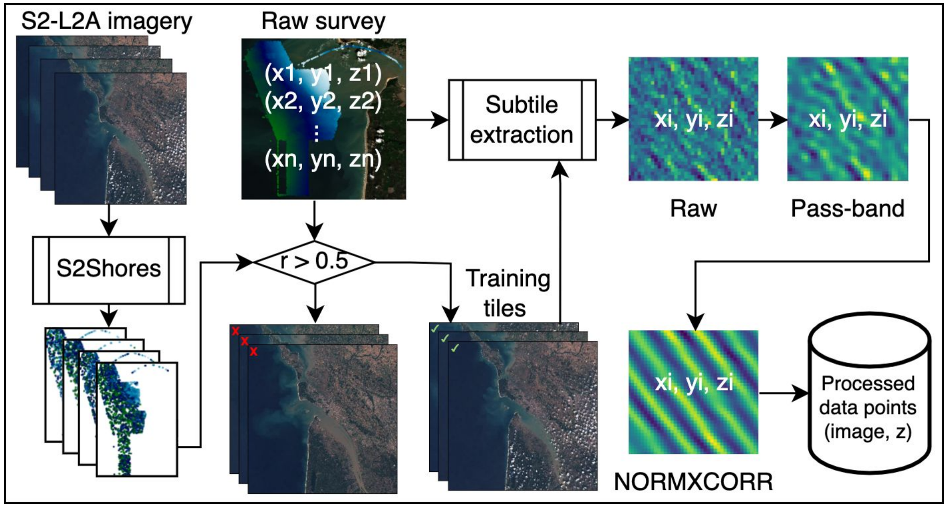
- ISAE-SUPAERO : school of aerospace engineering
  - 1700 students
  - 130 faculty members (professors & researchers)
- Many collaborations with laboratories, companies, space agencies, and universities worldwide

Outline

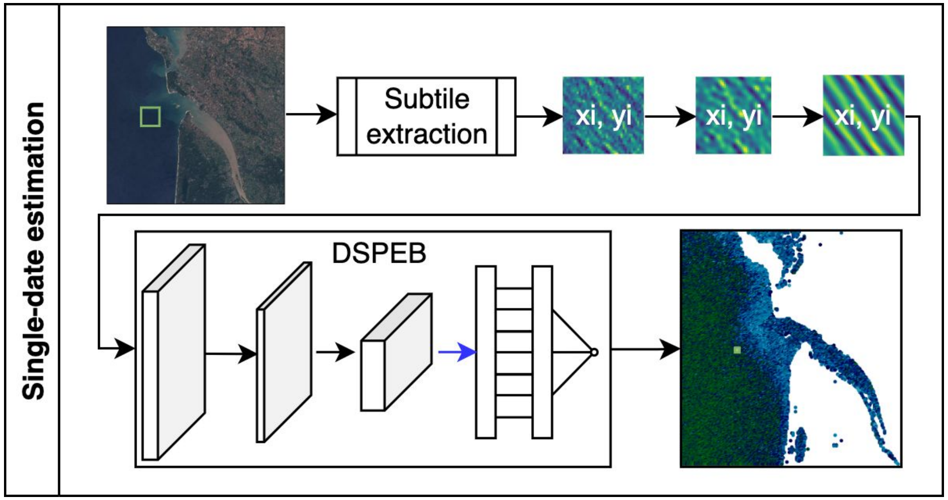
1. AI for Earth observation (Dennis Wilson)
   Deep learning, Machine learning, Remote Sensing
2. AI for satellite image processing (Thomas Oberlin)
   Deep learning, Computer vision, image processing, generative models
3. AI for geoscience and planetology (Alexander Stott, Raphaël Garcia)
   Deep learning, Machine learning, Signal Processing, Multi-modality
4. Satellite operations & scheduling (Emmanuel Rachelson, Alain haït, Laurent Houssin)
   Operations Research, Scheduling, Optimization
5. AI for plant growing in space (Thibault Gateau, Nicolas Drougard)
   Control, Planning, Optimization, Computer Vision, Robotics, Reinforcement Learning
6. AI on chip (Jean-Baptiste Chaudron)
   Deep learning, network quantization and pruning, hardware, FPGA

1. Bathymetry estimation

- Bathymetry estimation from Sentinel 2 using deep learning
- Two main approaches :
  - color
  - wave physics
- Results comparable to current physics-based methods, but more computationally efficient
- Thesis of Mahmoud Al Najar with CNES, OMP



Al Najar, Mahmoud, et al. "Satellite derived bathymetry using deep learning." Machine Learning (2021): 1-24.

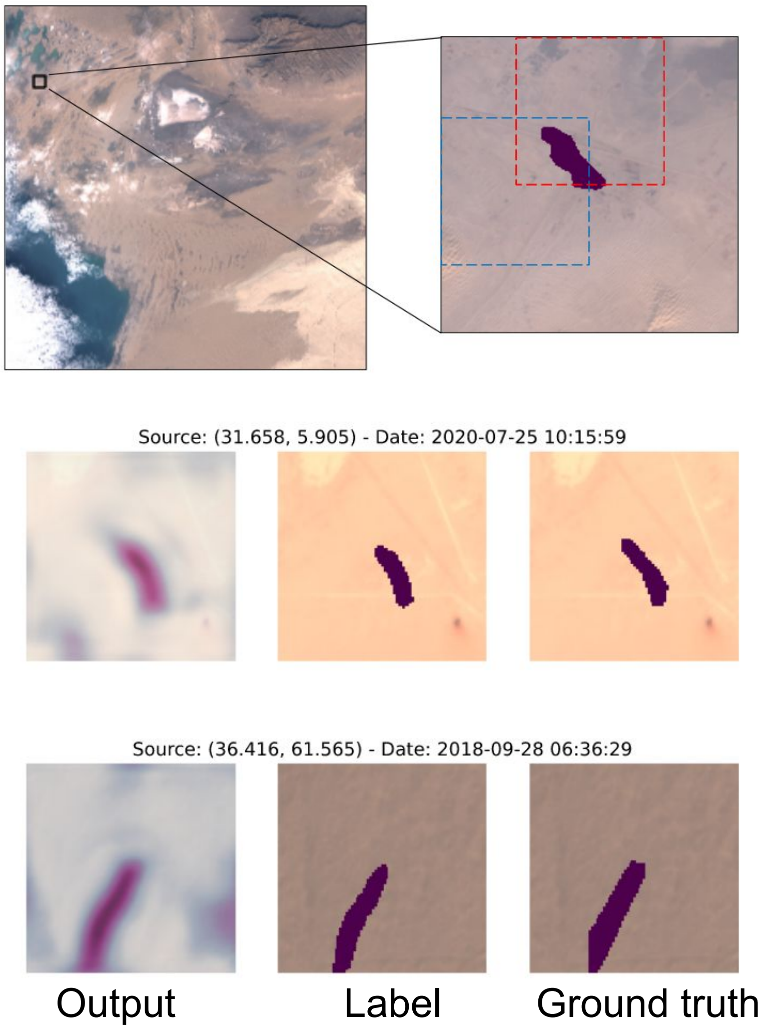


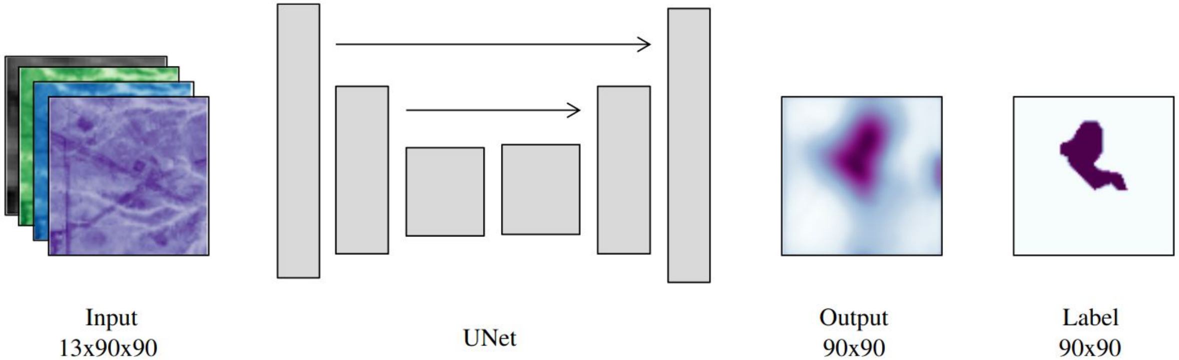
Al Najar, Mahmoud, et al. "Coastal Bathymetry Estimation from Sentinel-2 Satellite Imagery: Comparing Deep Learning and Physics-Based Approaches." Remote Sensing 14.5 (2022): 1196.

1. Methane detection

- Methane detection from Sentinel 2 using deep learning
- Based on recently proposed datasets of detected methane
- Promising initial results, but lack of generalization, general under-detection
- Possibility of integrating data from MERLIN (Methane Remote Sensing Lidar Mission) in 2024
- Student project in 2022-2023, looking for future collaborations

du Baret, Berenice, et al. “Methane Plume Detection with U-Net Segmentation on Sentinel-2 Image Data” NeurIPS 2023 Workshop on Tackling Climate Change with Machine Learning (2023).

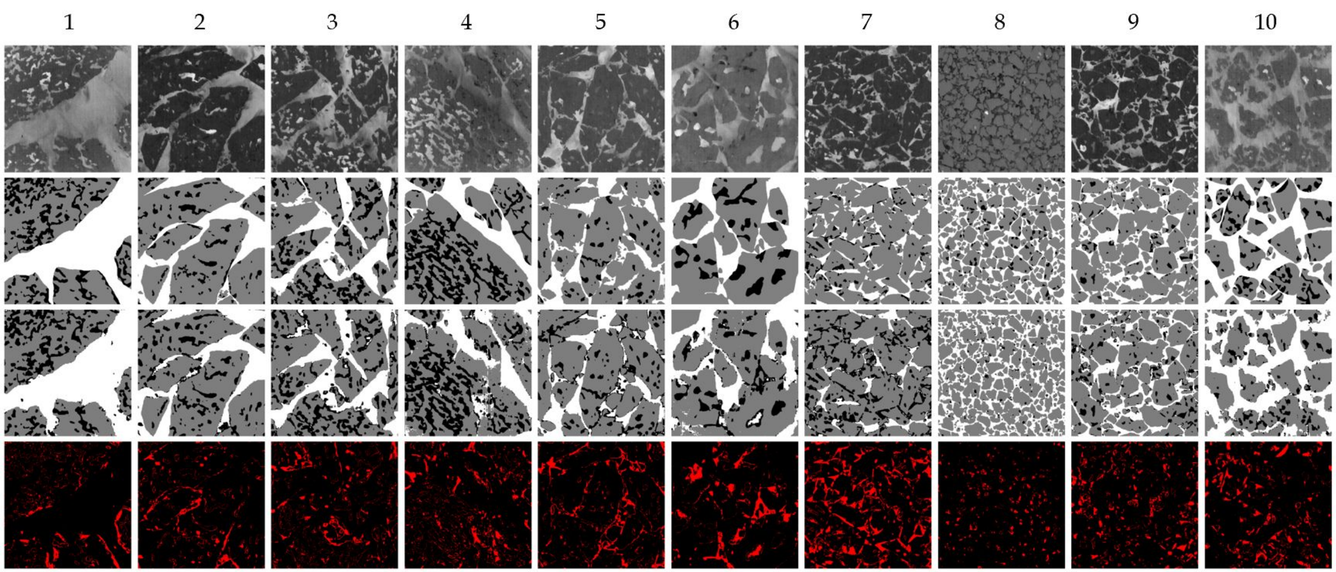




1. Melt pond detection

- Arctic melt ponds are crucial for understanding and predicting changes in the Arctic climate
- Segment thermal infrared (TIR) airborne imagery into melt pond, sea ice, and ocean classes using a data-driven deep learning approach
- Helicopter-borne TIR imagery acquired with an Infratec Vario-CAM HD head 680 camera during the PS131 ATWAICE campaign
  - Schlindwein, Vera Susanne Nicola. "The Expedition PS137 of the Research Vessel POLARSTERN to the Arctic Ocean in 2023." *Berichte zur Polar-und Meeresforschung= Reports on polar and marine research* 781 (2023).
- Adapted and fine-tuned the AutoSAM model
- AutoSAM model achieved a mean IoU of 0.667
- Student project in 2024

Reil, Marlena, et al. "Machine Learning for the Detection of Arctic Melt Ponds from Infrared Imagery" ICLR 2024 Workshop on Tackling Climate Change with Machine Learning (2024).



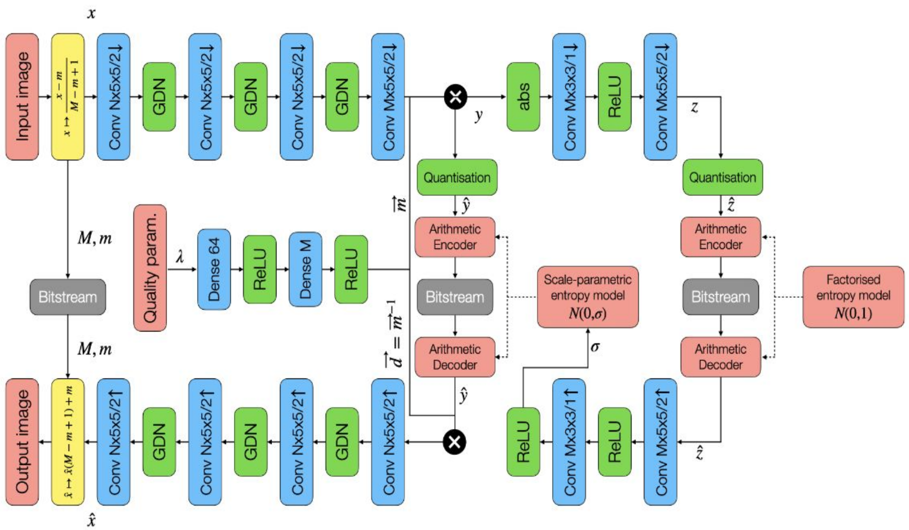
	1	2	3	4	5	6	7	8	9	10
mIoU	0.841	0.782	0.787	0.721	0.692	0.658	0.531	0.592	0.616	0.659
mp IoU	0.69	0.551	0.629	0.69	0.399	0.447	0.227	0.228	0.226	0.351

2. Onboard deep image compression

- Compression by transformation
  - Direct/inverse transforms that simplify image representation (decorrelation, sparsity)
  - Quantization and arithmetic coding in the transformed domain
- On-board deep image compression (with CNES, IRIT, TAS, UAB)
  - Learn a transform by minimizing rate and distortion
  - Popular architectures similar to VAEs
  - Contributions : light models; variable bitrate; fixed-quality compression

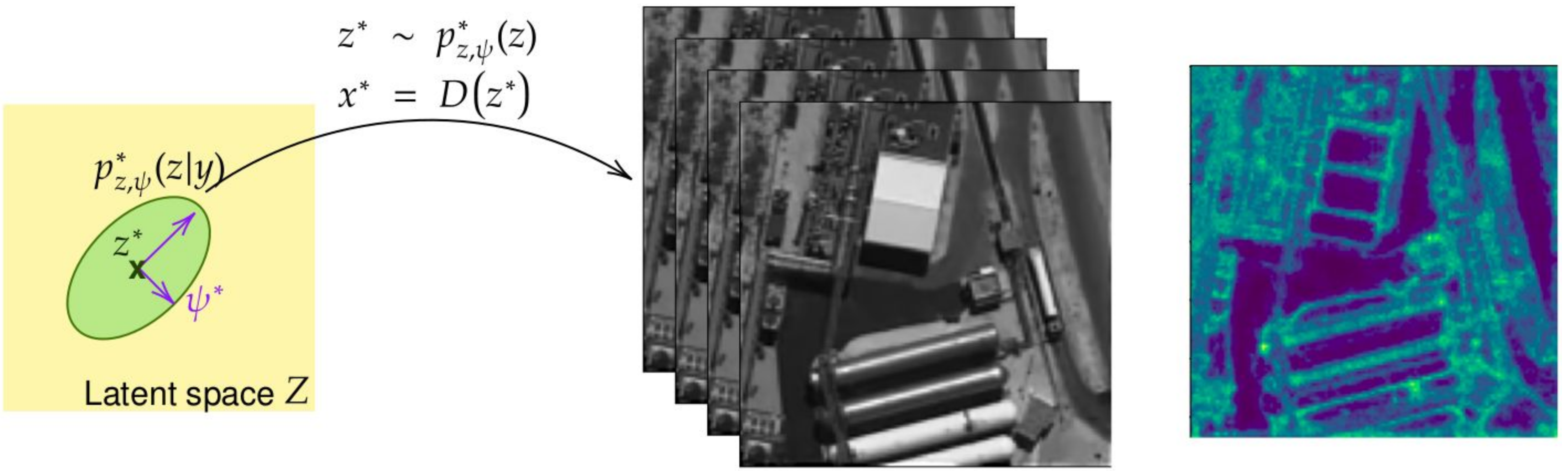
V. A. Oliveira et al. Reduced-complexity end-to-end variational autoencoder for on board satellite image compression, *Remote Sensing*, 2021.

S. M. i Verdú et al. Reduced-complexity multi-rate remote sensing data compression with neural networks. IEEE Geoscience and Remote Sensing Letters, 2024



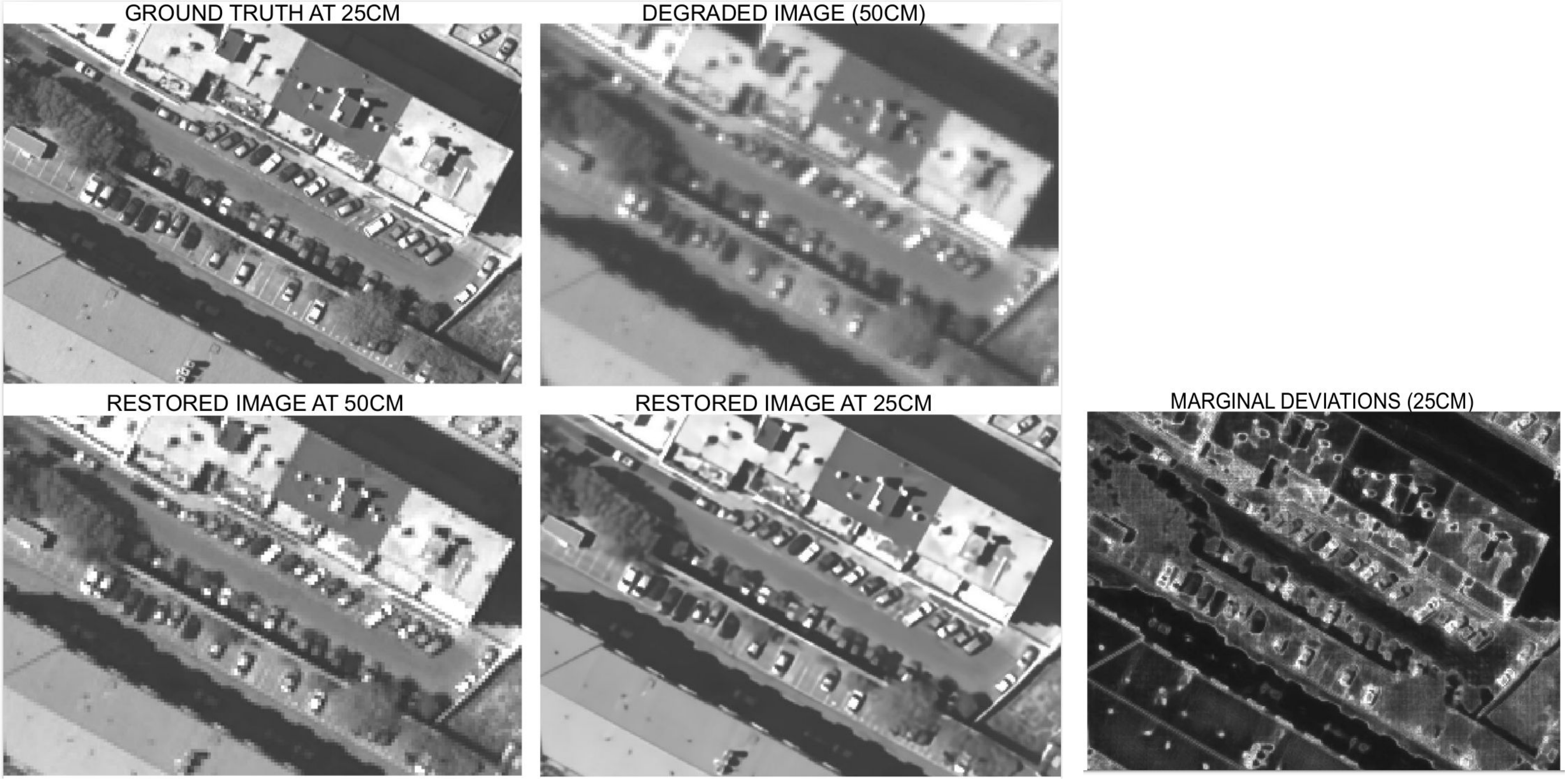
2. Satellite image restoration with AI

- Image restoration and reconstruction (aka inverse problems)
  - De-quantization, deblurring, denoising, super-resolution
  - Multispectral images : demosaicking, pansharpening, image fusion
- Learn the inverse mapping, for instance for super-resolution (ongoing project with Airbus D&S)
- Learn the regularization : ongoing PhD Maud Biquard (with CNES and IRIT). Allows for (approximate) posterior sampling



M. Biquard et al., Variational Bayes image restoration with compressive autoencoders, Arxiv, 2024

2. Application : posterior sampling for super-resolution



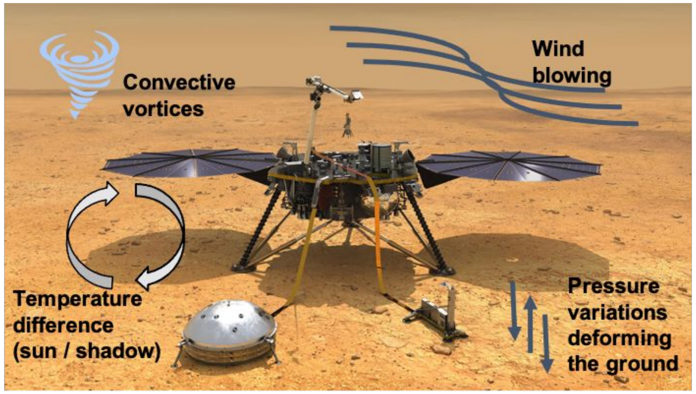
Simulations for Pléiades : deblurring/denoising (left) and SISR x2 (right) © CNES 2024

3. Seismic and atmospheric monitoring on Mars with the NASA InSight and Perseverance missions

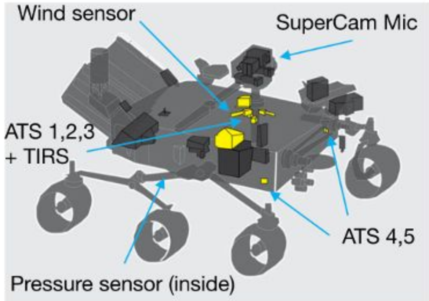
Goal:
Implement machine learning on mission data to extract information on the interior and atmospheric dynamics of Mars

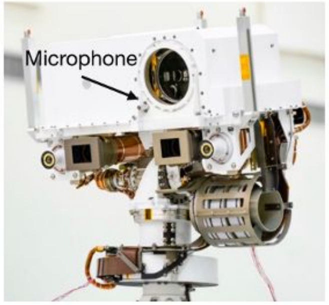
Credit NASA JPL/Caltech

InSight:
- Seismometer, wind, pressure and temperature data
- Neural networks implemented to map between atmospheric and seismic data



Perseverance:
- Microphone instrument developed by ISAE-Supaero
- Meteorology sensor package
- Gaussian process regression to calibrate microphone data to wind speed





Collaborations: CNES (A. Stott CNES postdoc), NASA and mission science teams

Stott, Alexander E., et al. "Machine learning and marsquakes: a tool to predict atmospheric-seismic noise for the NASA InSight mission." GJI (2023)
Stott, Alexander E., et al. "Wind and turbulence observations with the Mars microphone on Perseverance." JGR:Planets (2023).
Stott, Alexander E., et al. ”WindSightNet: the inter-annual variability of Martian winds retrieved from InSight's seismic data with machine learning." in prep (2024).

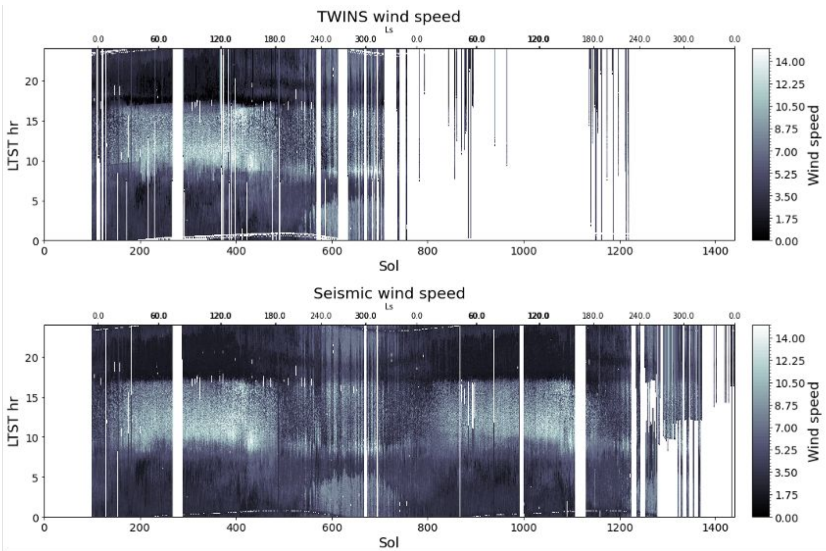
3. Seismic and atmospheric monitoring on Mars with the NASA InSight and Perseverance missions

Catalogue of winds produced from the seismic data

- Covers a longer period when wind sensor was off
- Quantification of year-to-year variability

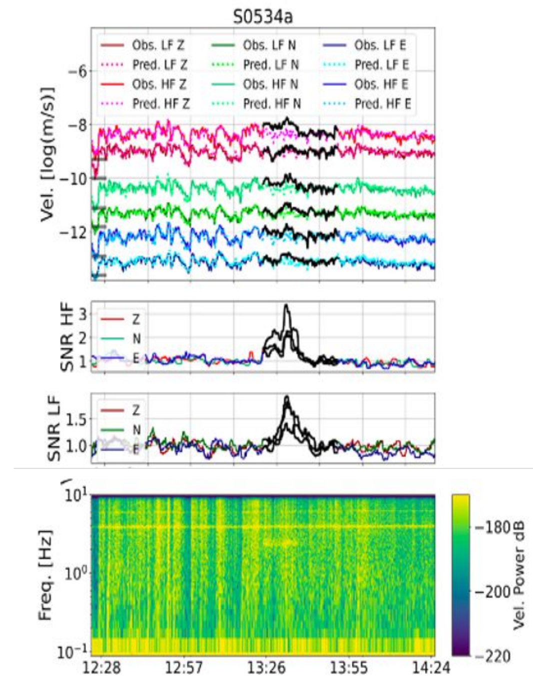
Wind sensor coverage

Machine learning coverage



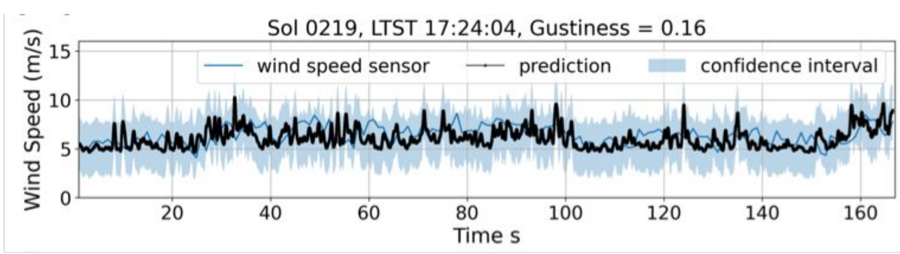
Determined seismic noise due to the atmosphere

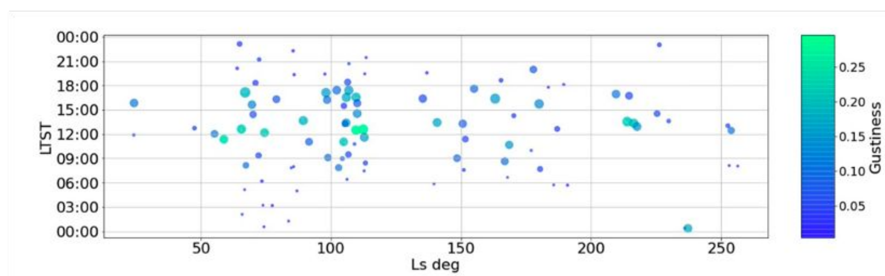
- Discovered new marsquakes
- Discovered new features of seismicity on Mars



Wind speed estimates from microphone are the highest sampling rate available for Mars

- Used to characterise turbulence

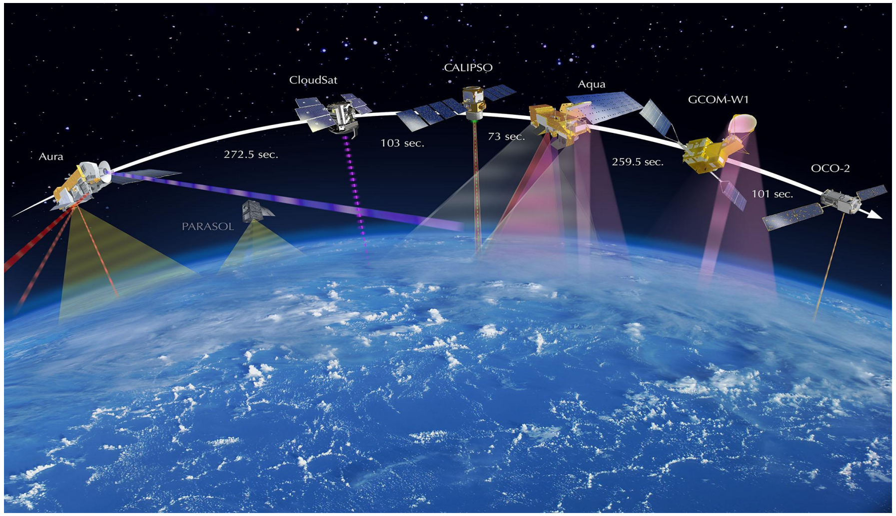




4. Satellite operations & scheduling

Earth observation scheduling for LEO constellations: Who shoots what and when in an heterogeneous constellation?

PhD T. Jammot: multi-agent coordination heuristics, large scale areas acquisition, GLIMPSE demonstrator
PhD M. Zouitine: deep neural networks as heuristics for large scale mathematical programs
Collabs: IRT, A-DS, TAS, IMT, IRIT



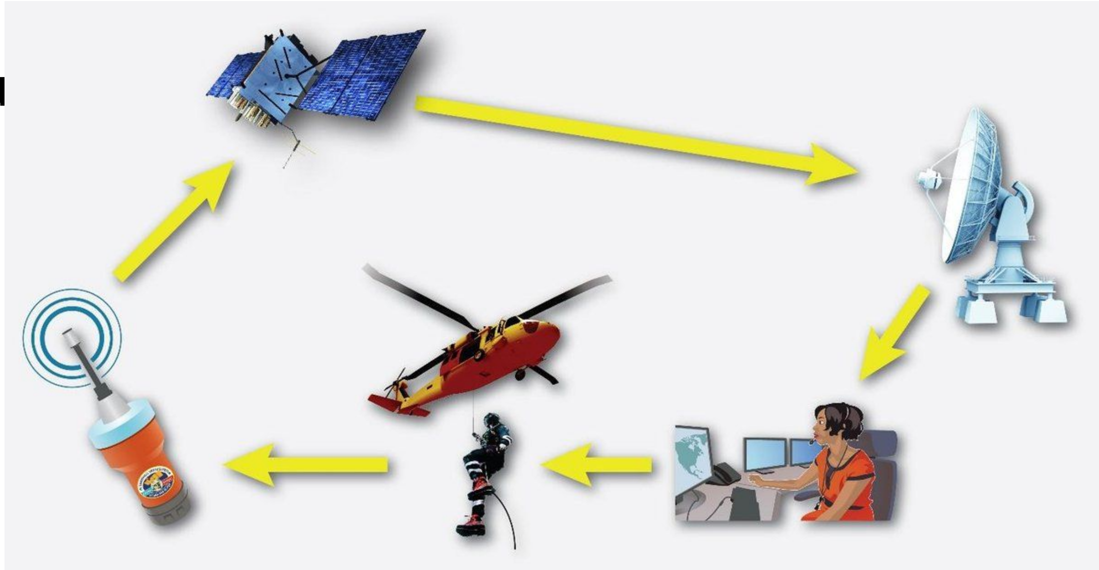
Telecom network routing in a LEO constellation Which path for each telecom packet?

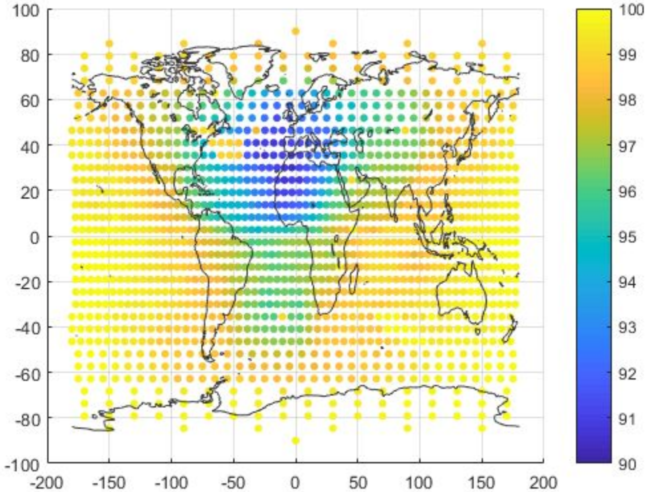
PhD F. Lamothe: discrete optimization algorithms for unsplittable flow problems, real-time optimization of packet routing for large scale problems over several time steps.
Collabs: TAS, CNES

4. Search And Rescue

Search And Rescue: Contact scheduling between Galileo constellation satellites and ground stations.

- Objective : Assign time slots of ground station to satellites.
- Constraints : visibility windows between users and satellites and between satellites and ground stations.
- Matheuristics (based on integer programming) for large scale scheduling problems.
- Collabs: TAS, LAAS-CNRS





Example of coverage by 2 satellites over 10 days.

5. ALICE – AI for Life In spaCE

Context: Life Support Systems and Plant Growth Systems for space exploration with humans

- Limited resources → Precise Agriculture
- Human needs → System Autonomy

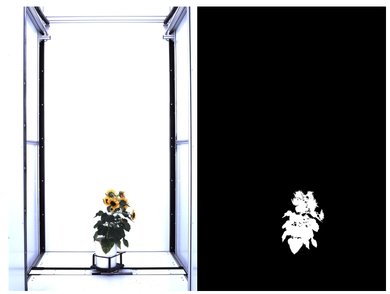
MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

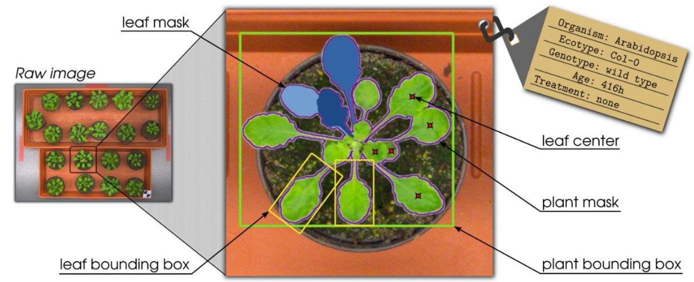
ALICE: student projects aimed at using sensors & robots to monitor & control plant growth using AI tools

Objectives: increase the **autonomy** of plant growth systems & **minimize resource consumption.**

1) **Observe**: Segmentation for growth monitoring

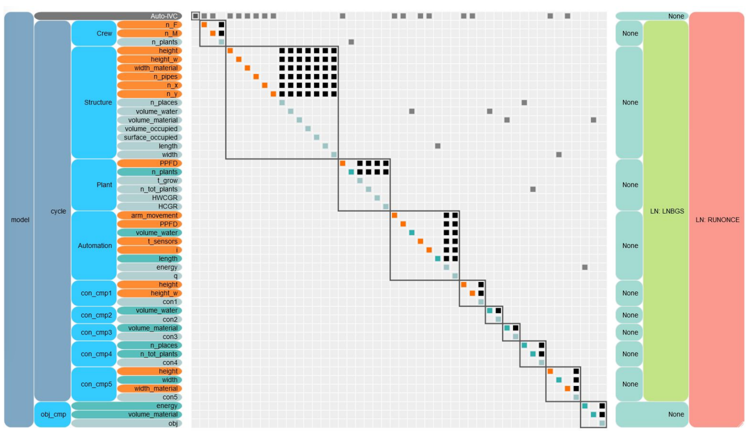
dataset ex:



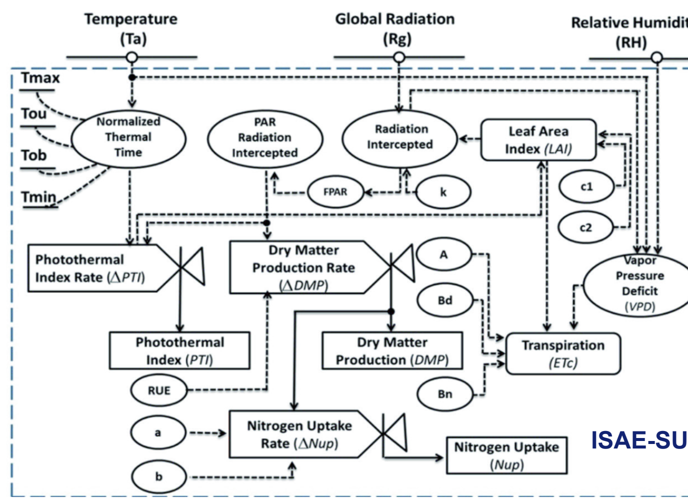


2) **Control**: Planning & Reinforcement Learning *for light, temperature and nutrient optimization.*
3) **Design**: Multi-Disciplinary Analysis & Optimization

openMDAO:



HortSyst:



6. AI Chip IP (Embrya.io)

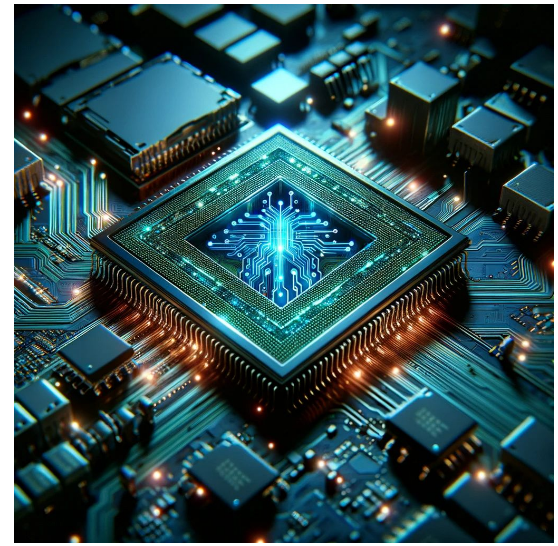
Concept of an innovative AI Chip IP

- Generic and can run all ANNs architectures such as:
    - standard CNN, RNN, combinations such as ConvLSTM,
    - non-standard layers such as STAR or ESN RNN,
    - complex activation functions (SiLU, GeLU, …)
    - Others algorithms (SOM, MDP, POMDP, …)

- Specialized in ANN inference **and** on-line learning (back-propagation) for reinforcement learning algorithm to be integrated on-board.

- Currently implemented on SoC FPGA but concept can be integrated in any ASIC design.

- Can be deployed for several space applications/missions



→ **Innovative concept under patent review**
→ **Technology is being developed per an ISAE-SUPAERO Spin off**

embrya.io

Contacts and posters

1. AI for Earth observation :
   Dennis.Wilson@isae-supaero.fr
   Poster Deep Learning for Addressing Climate Change
2. AI for satellite image processing :
   Thomas.Oberlin@isae-supaero.fr Maud.Biquard@isae-supaero.fr
   Poster Variational Bayes Image restoration
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   Poster *AI for Life In spaCE*
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