MACHINE LEARNING-BASED ON-BOARD REAL-TIME CLOUD DETECTION FOR THE CHIME MISSION

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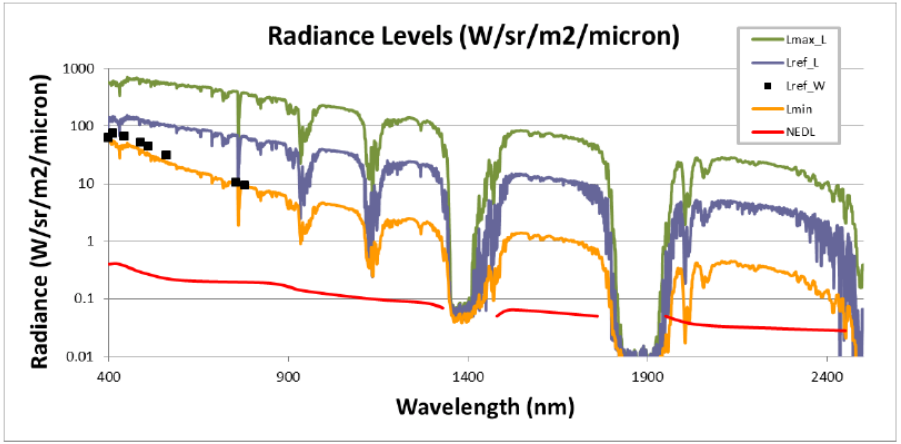
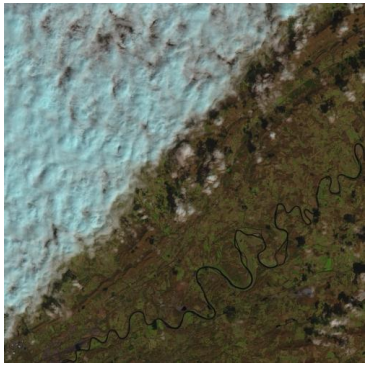
COPERNICUS HYPERSPECTRAL IMAGING MISSION FOR THE ENVIRONMENT (CHIME)

/// Future Space mission To complement COPERNICUS "Sentinels"

- Hyperspectral instrument with 220 spectral bands in VNIR and SWIR (400 – 2500nm) domains
- Spatial sampling of 30 m - SWATH > 100 km
- Continuous acquisitions over the land and coastal areas

HIGH VOLUME OF DATA => ON-BOARD COMPRESSION APPEARS MANDATORY



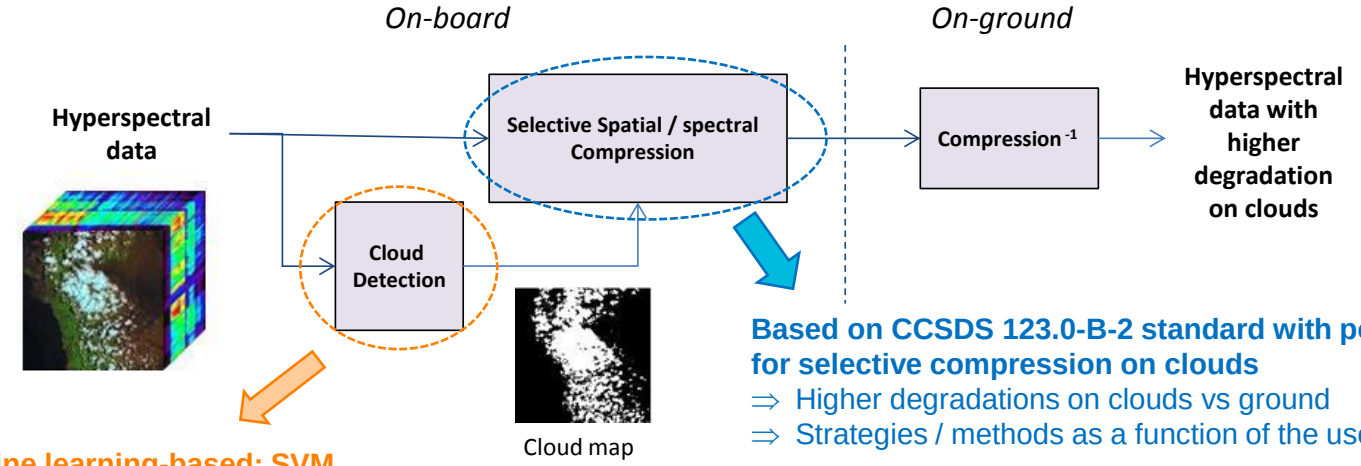


/// Clouds statistically cover more than 50% of the Earth surface

=> POSSIBILITY TO REDUCE ON-BOARD DATA VOLUME AND DOWNLINK DATA RATE WITH A SELECTIVE COMPRESSION APPLIED ON OPAQUE CLOUDS

SELECTIVE CLOUD COMPRESSION

/// General compression scheme



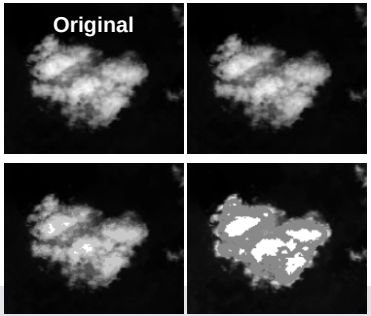
Machine learning-based: SVM

Based on CCSDS 123.0-B-2 standard with potential adaptations for selective compression on clouds

⇒ Higher degradations on clouds vs ground

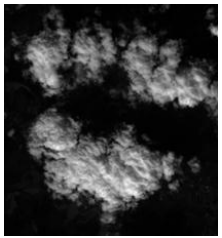
⇒ Strategies / methods as a function of the user needs

Pre-quantization

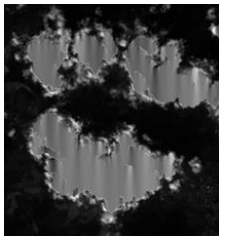


Adaptation of CCSDS standard

Selective error settings



Residual to Zero



See OBPDC paper 2020 :
***On-board cloud detection and selective spatial/spectral compression based on CCSDS 123.0-B-2 for hyperspectral missions**, Lebedeff et al for more details*

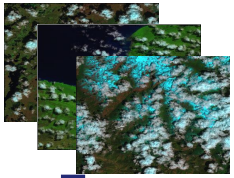
ON-BOARD CLOUD DETECTION

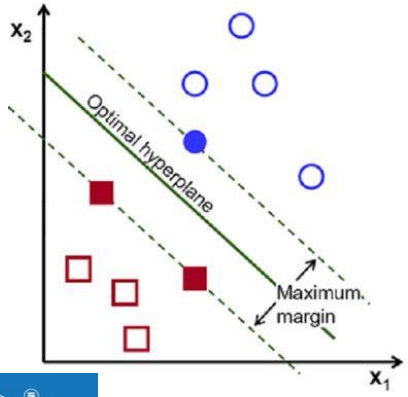
/// Machine learning based cloud detection - Support Vector Machine approach has been selected

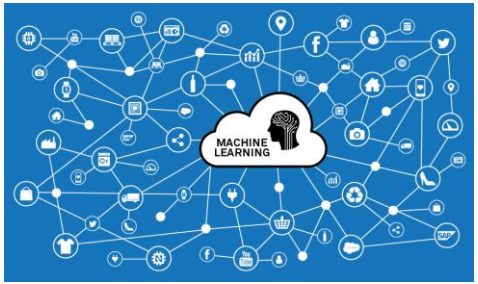
- **SEPARATE PIXELS IN 2 CLASSES (CLOUD OR CLEAR) IN N-DIMENSION SPACE**
  - Learning stage with cloud data base to find the optimal hyperplane between the 2 classes

- **MACHINE LEARNING FOR SVM PARAMETERS DETERMINATION FROM TAS EXISTING TOOL**
  - Machine learning inputs :
    - Useful bands for features discrimination
    - Specific indexes (i.e. band combinations) to help high reflective rejection (e.g. snow)
    - Worked on existing Cloud multi spectral Data Base (LandSat)
  - Machine learning Outputs
    - Generic parameters are considered (no distinction on type of ground)
  - Existing tool in the framework French sensor / Thales Alenia Space Export Programs

LANDSAT data inputs
for pre-developments







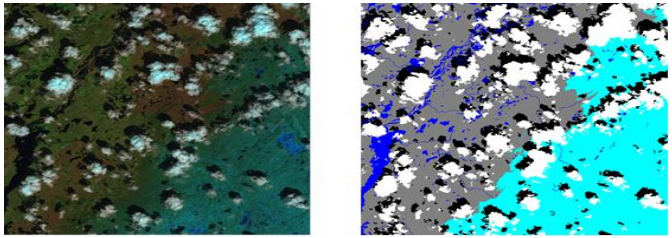
ON ground
Machine Learning :
Hyper Spectral pixel -> vector estimated

SVM parameters
uploaded on board

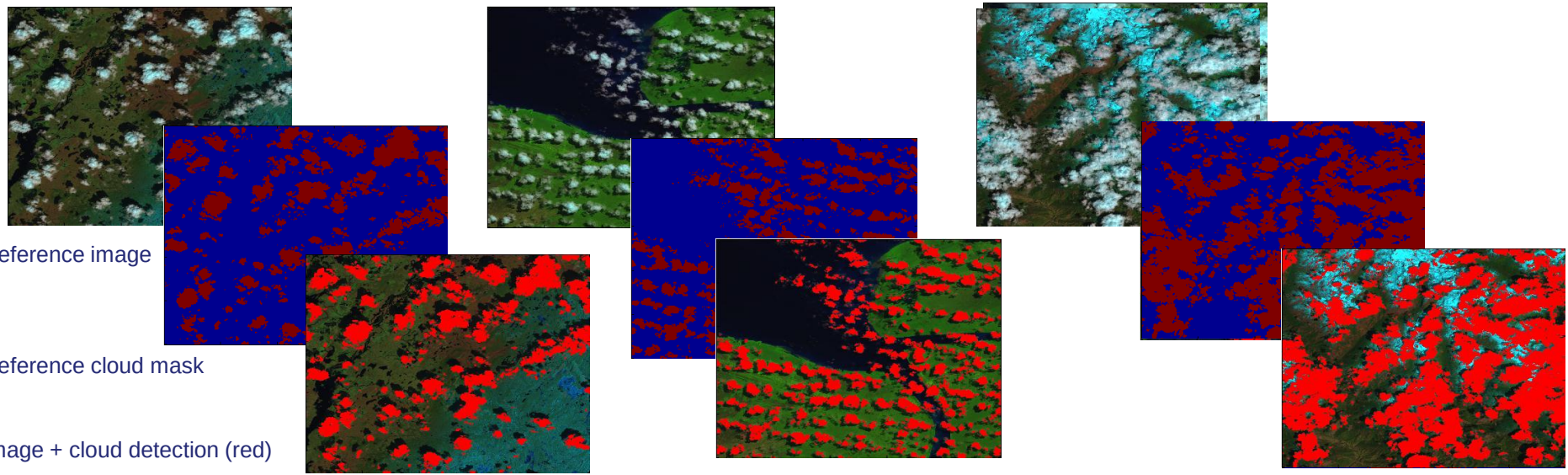
ON-BOARD CLOUD DETECTION

/// Performances assessed on SPARCS Landsat 8 data base
https://landsat.usgs.gov/cloud-validation/sparcs/l8cloudmasks.zip

- **80 SCENES, SIZE 1000 X 1000 X 10 SPECTRAL BANDS WITH CLOUD MASK**
- **HALF OF SCENES FOR TRAINING / HALF FOR PERFORMANCE ASSESSMENT**



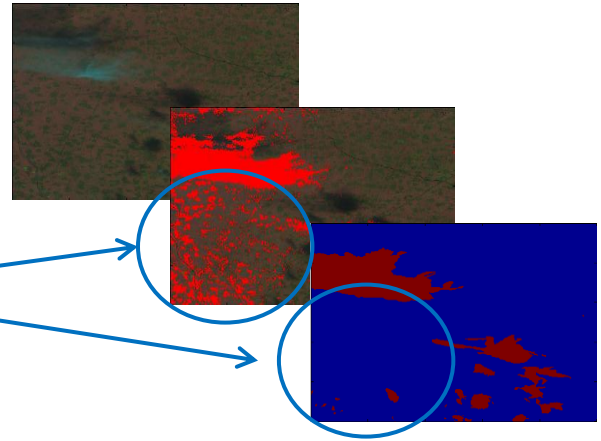
Example of Landsat data base with mask (right)



ON-BOARD CLOUD DETECTION

/// Globally good detection for all type of landscapes

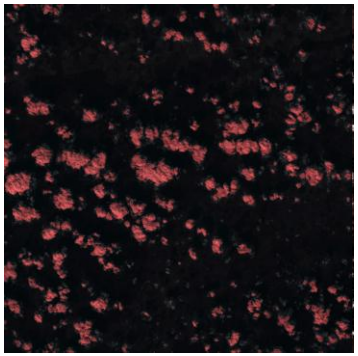
- **FALSE POSITIVE*: 0.60% IN AVERAGE**
- **ONE CRITICAL CASE (FALSE POSITIVE>10%) OVER DESERT AREA**
  - Such landscape was not part of the limited training set (< 40 images)
    => should be removed with complete training set



/// On hyperspectral images with SVM trained on Landsat data base

- **VISUALLY GOOD DETECTION, FALSE POSITIVE SEEMS LOW**
- **NO DETECTION ON IMAGE WITHOUT CLOUD**
  => ROBUST SOLUTION

- **POTENTIAL IMPROVEMENT WITH ADDITIONAL BANDS AND HYPERSPECTRAL IMAGES TO BE COLLECTED DURING THE PROGRAM**



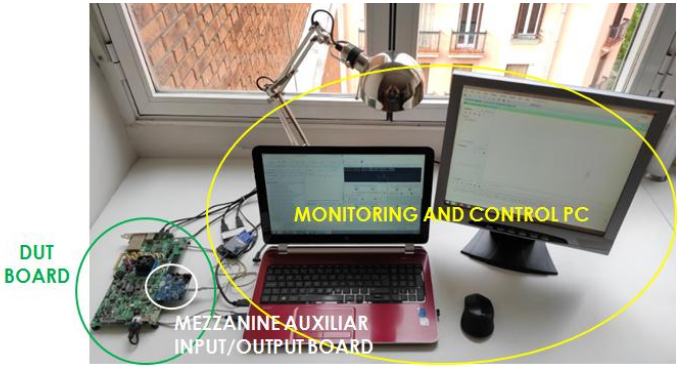
CHIME simulation
1536 x 1536
220 bands [400-2500nm]
Clouds 10.8%

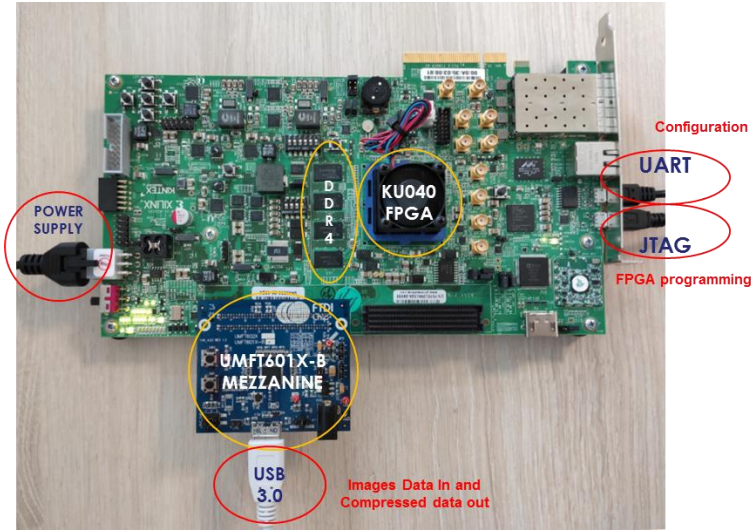
AVIRIS
677 x 1800
224 bands [365-2500nm]
Clouds 35.7%

AVIRIS
710 x 5501
224 bands
[365-2500nm]
Clouds 38.6%

**False Positive: Proportion of clear pixels incorrectly detected as cloud*

DEMONSTRATOR PHYSICAL IMPLEMENTATION





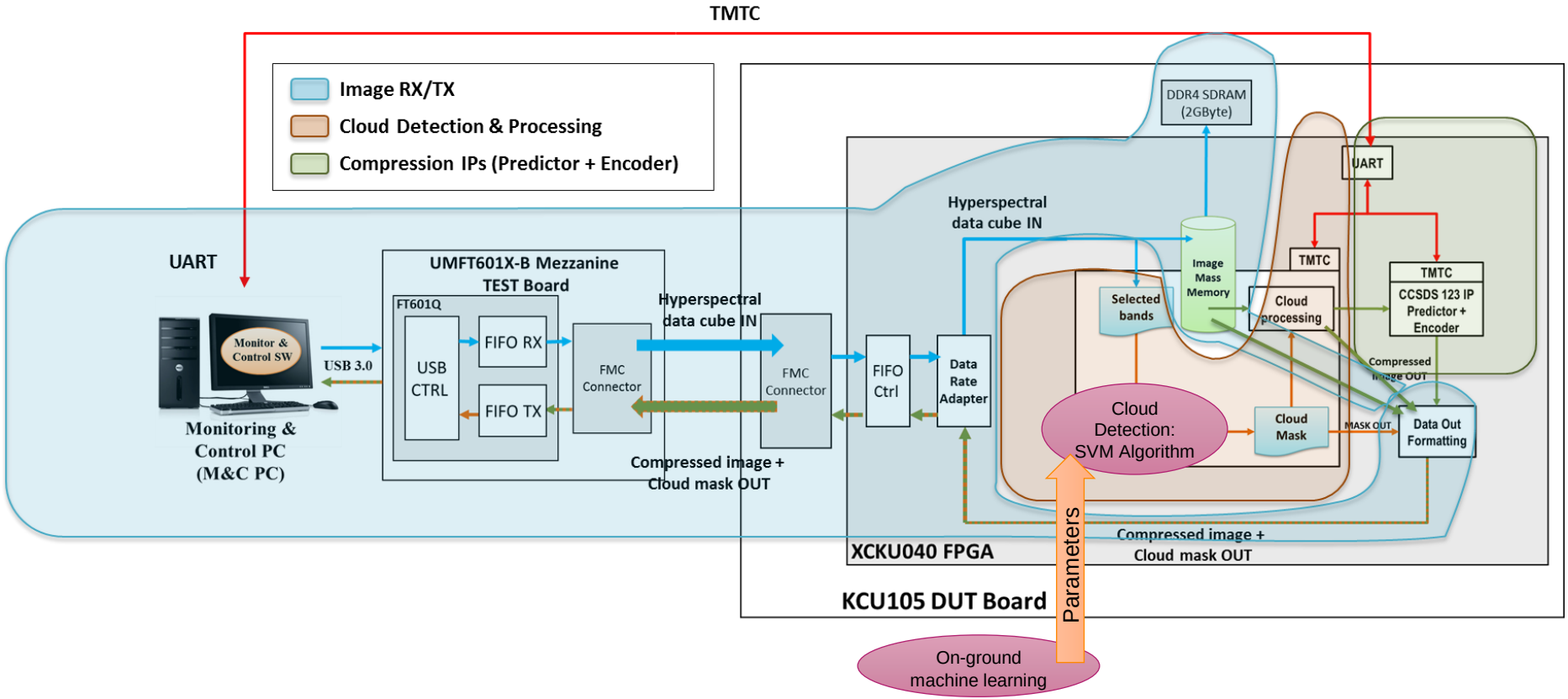
/// FTDI UMFT601X-B mezzanine

- USB 3.0 to FIFO interface bridge
- Max 2,13344Gbps

/// Xilinx KCU105 board

- FPGA: Xilinx Kintex Ultrascale, XCKU040
- External Memory: 16 Gb DDR4
- Monitoring & Control interface: UART
- Data Input and output interfaces: FMC connector with mezzanine
- USB JTAG to program the FPGA

DEMONSTRATOR TEST SET-UP

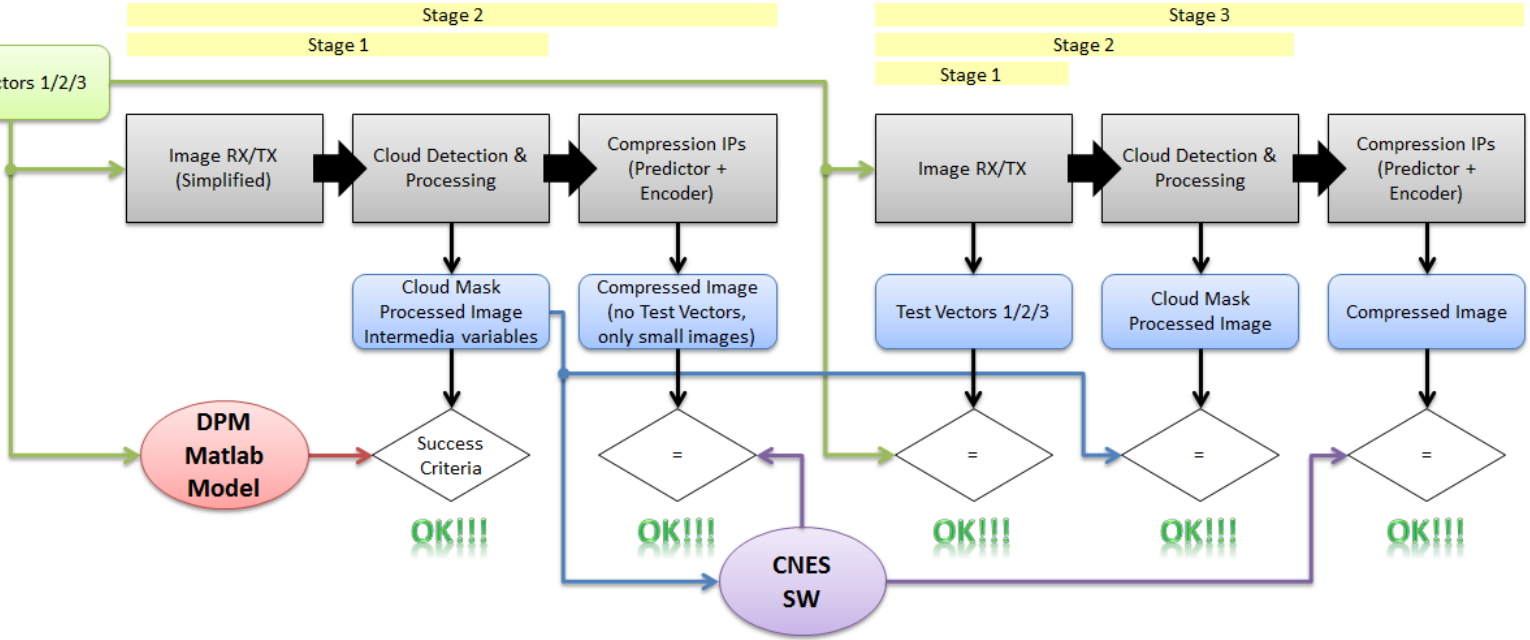


VALIDATION PLAN

AVIRIS hyperspectral data inputs for validation on representative image

Conformity Tests
Compliance with the models: DPM and CCSDS 123 B2 standard
By VHDL simulations in workstation (Mentor Graphics Questa Sim tool)
Outputs: text files coming from the simulations

Demonstrator tests
On hardware validation
VHDL code synthesized, place&route performed into Xilinx FPGA
Outputs: text files generated by the Tester SW in the M&C PC



TESTS RESULTS: SUCCESS CRITERIA MET

/// **SUCCESS CRITERION 1:** Limited quantization error between VHDL and DPM Matlab model (maximum 2%).

OK!!!

/// **SUCCESS CRITERION 2:** For the Cloud Mask a maximum of 1% of False Positives admitted between implementation and model.

OK!!! With threshold adaptation

/// **SUCCESS CRITERION 3:** The CCSDS 123.0-B2 compressed image bit to bit comparable to the data obtained from the CNES software.

OK!!!

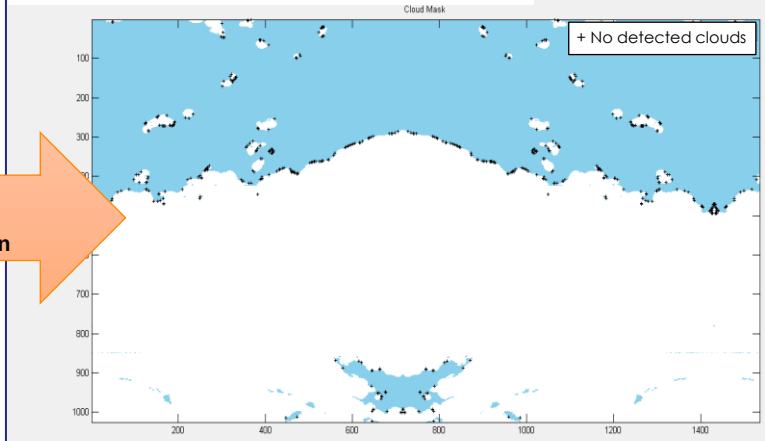
/// **SUCCESS CRITERION 4:** Data rate comparable with real data rate in Chime (up to 2 Gbps, 16 bits sample at 125MHz).

OK!!! For Cloud Algorithms

```
-------------------------------------------------------------------------------
Cloud Mask Validation: Threshold adapted for 0 False Positives
Threshold =  -81.066528000000005
-------------------------------------------------------------------------------
Number of Total Errors:          560  |  0.058%  (100% =  965941)
Number of False Positives:         0  |  0.000%  (100% =  965941)
Number of No Detected Clouds:    560  |  0.058%  (100% =  965941)
-------------------------------------------------------------------------------
```

Cloud detection algorithms: Cloud mask generation

Cloud Mask threshold adapted for 0 False Positives



CONCLUSION

/// Pre-development Demonstration has been established into a Xilinx KU040 FPGA including:

- The Cloud Detection and Processing algorithms
- The CCSDS 123.0-B-2 compression modules (Predictor and Encoder)

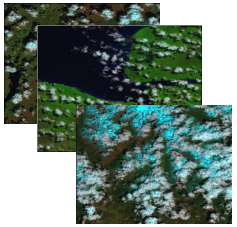
/// Cloud compression scheme has been defined for on-board implementation

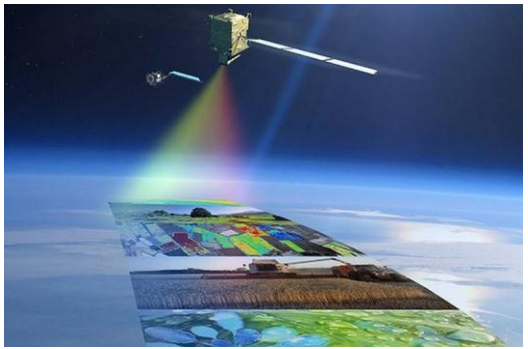
- Support vector machine for on-board cloud detection
- Spatial / spectral selective compression scheme based on CCSDS standard with potential evolutions
- Data rate reduction between 20 and 35% for images with around 40% of clouds

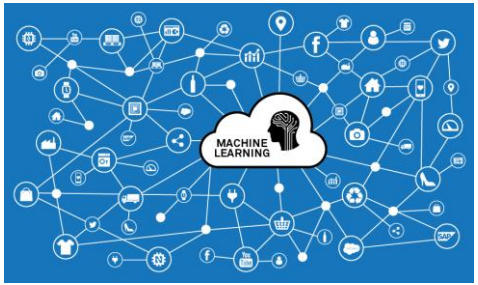
/// Machine learning allows Potential improvement with additional bands And hyperspectral images to be collected during the mission

- Cloud data base can be built / consolidated during commissioning phase
- SVM parameters can be updated and uploaded on-board

LANDSAT data inputs
for pre-developments
Hyperspectral real data collected
during the CHIME program







Parameters uploaded
on board to DPU

ON ground
Machine Learning :
Hyper Spectral pixel -> vector estimated