ThalesAlenia Space
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CHIME Onboard Processing: Cloud detection and selective compression

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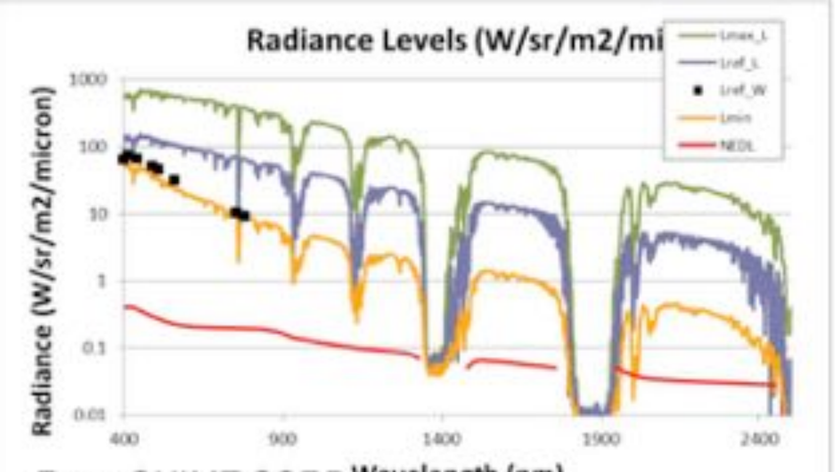
→ THE EUROPEAN SPACE AGENCY

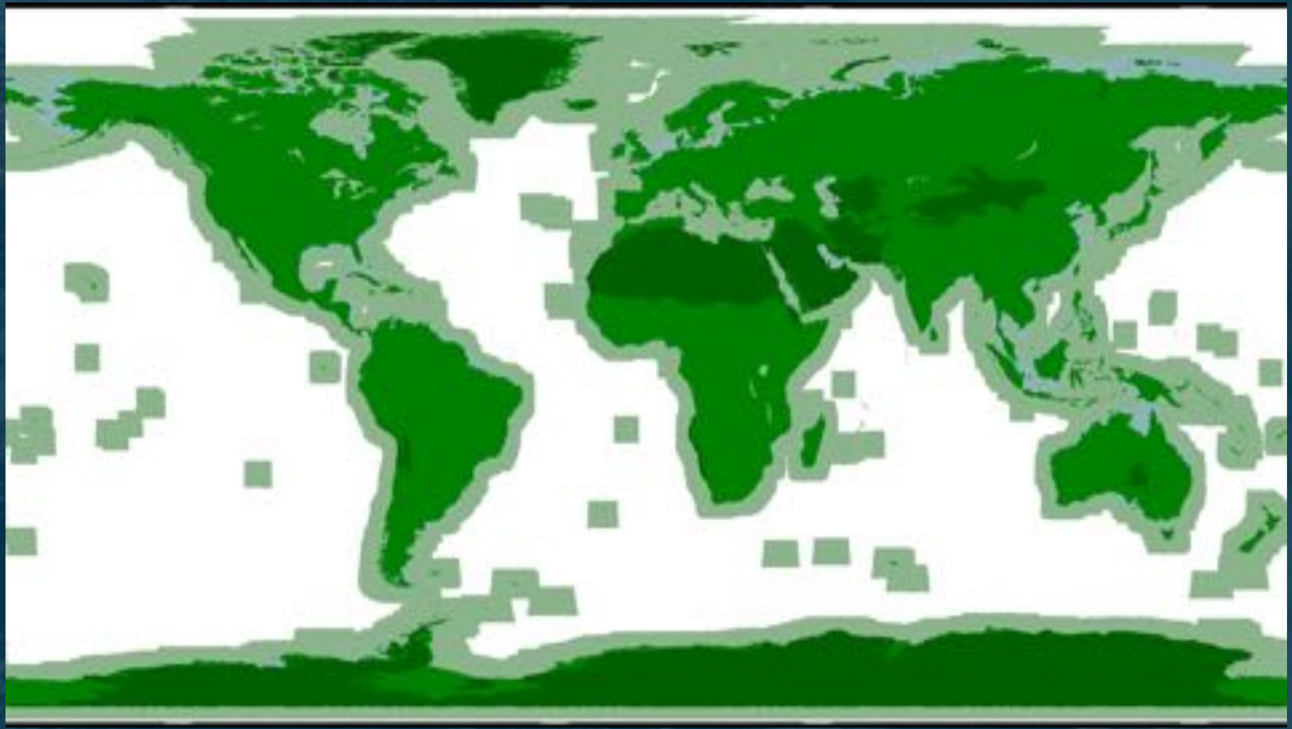
CHIME mission

Continuous acquisition of all emerged and coastal areas

- More than 200 bands - Spectral range 400-2500nm
- High spectral resolution – 10nm
- High spatial resolution – 30m
- Wide swath – 130km
- Tremendous data volumes (>100 Tbits/day raw)
- Very high throughput (>4Gbps).



From CHIME SSRD



Context and rationale

CHIME constraints on data reduction:

- High data acquisition **volumes** and **rates**.
- High **radiometric requirements**.
- Limited **HW resources**.
- Limited **transmission capacity**.
- **Costly** space-to-ground **data delivery**.
- **Standard** solutions preferred.

Opportunities:

- Latest CCSDS standard aiming at hyperspectral image compression (**CCSDS 123.0-B-2**)
- Precise knowledge of imaging system: **near-lossless compression possible**.
- **Cloud pixels** “unsuitable” for mission needs.
- **Cloud cover** > 54% Earth land surface (68% of the oceans).
- **Selective compression** to improve efficiency (not standardized).

CCSDS 123.0-B-2 compression standard

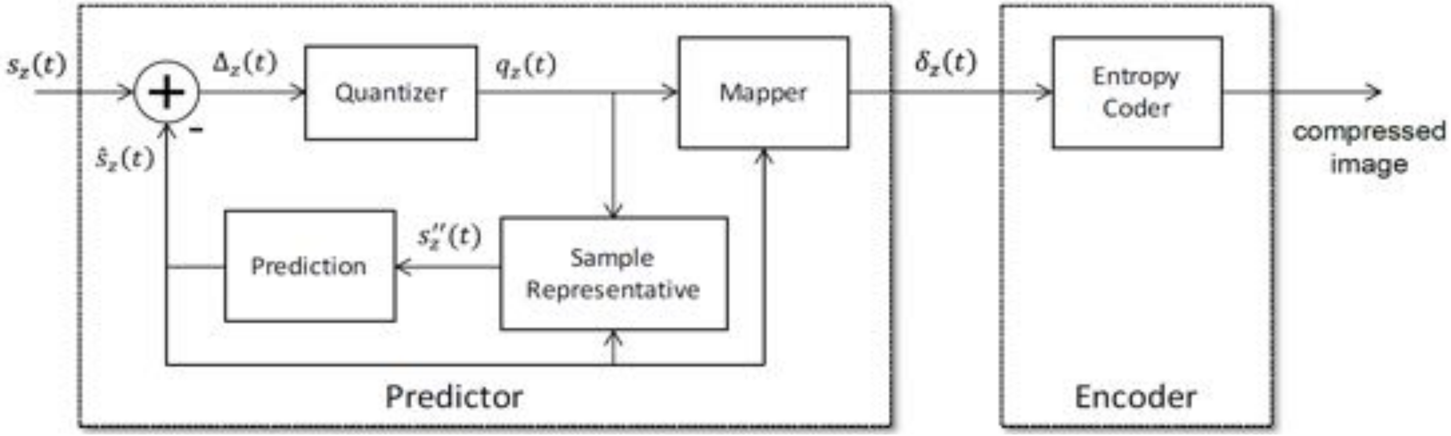
A **low-complexity highly flexible** standard for **lossless and near-lossless** hyperspectral data compression.

Based on previous lossless standard using an adaptive linear predictor based on the values of nearby samples in a small three-dimensional neighbourhood.

Loss is controlled for each band and guaranteed for each pixel (absolute error limit).

For CHIME, the quantizer step size is kept for each band below the **noise floor** (NEDL @ Lmin) or **lossless**, to satisfy all **radiometric requirements**.

Selective compression not natively supported



Onboard cloud detection

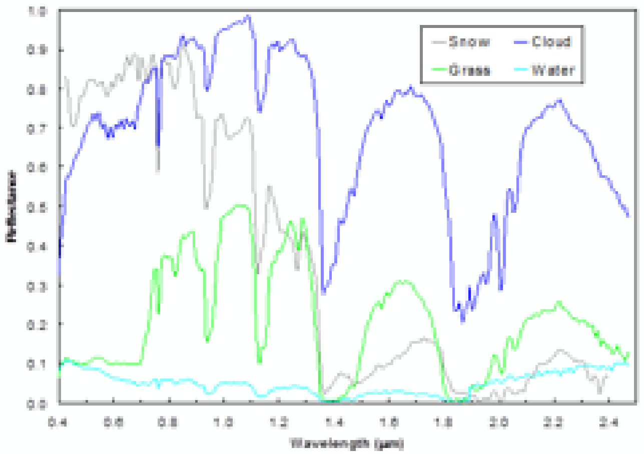
Objective: To define a simple cloud detection algorithm for further onboard data reduction

Top of Atmosphere Reflectance is needed for the 2 approaches in order to be free of solar illumination

On-board conversion limited to the bands used for cloud detection

Physical approach (also called Threshold approach)

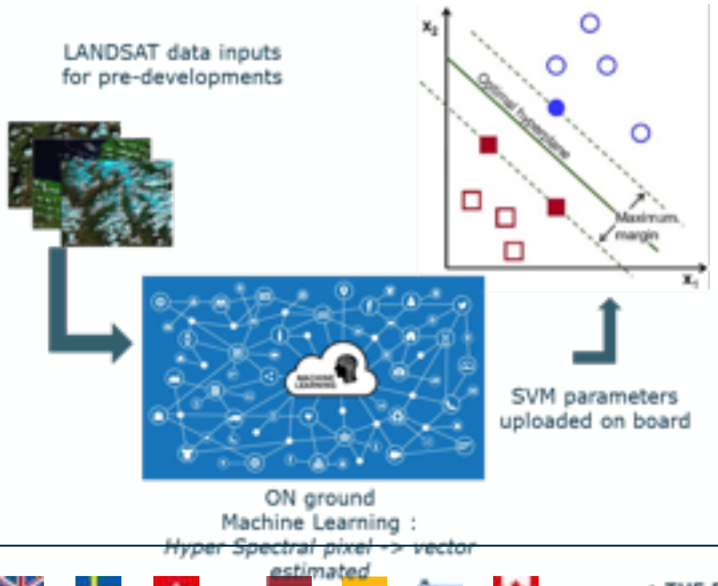
- Discriminate clouds from ground features in the scene
- Threshold tests to image spectral properties based on a few useful bands and on specific indexes (i.e. band combinations) to help high reflective rejection (vegetation, sand, snow)
- Classical approach used for (on-ground) cloud classification (Landsat, Sentinel-2 , EO-1 Hyperion …)



Extract from M. K. Griffin & all - "Cloud Cover Detection Algorithm for EO-1 Hyperion Imagery" - 17th SPIE AeroSense 2003

Support Vector Machine approach

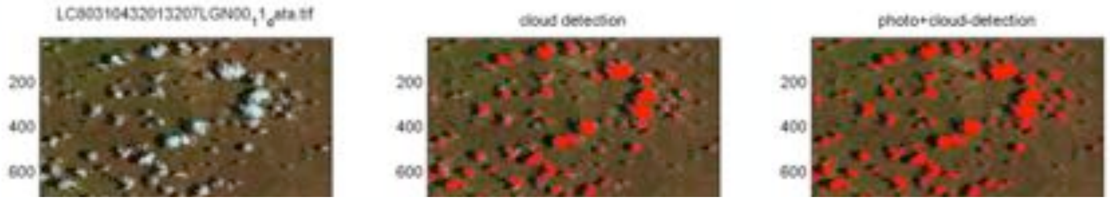
- Separate pixels in **2 classes** in N-dimension space
- Learning stage with cloud data base to find the optimal hyperplane between the 2 classes
- Already used for on-ground cloud classification on multispectral sensors (French and Thales Alenia Space export program)
- N limited to useful bands and indexes from threshold approach
- Learning stage on-ground

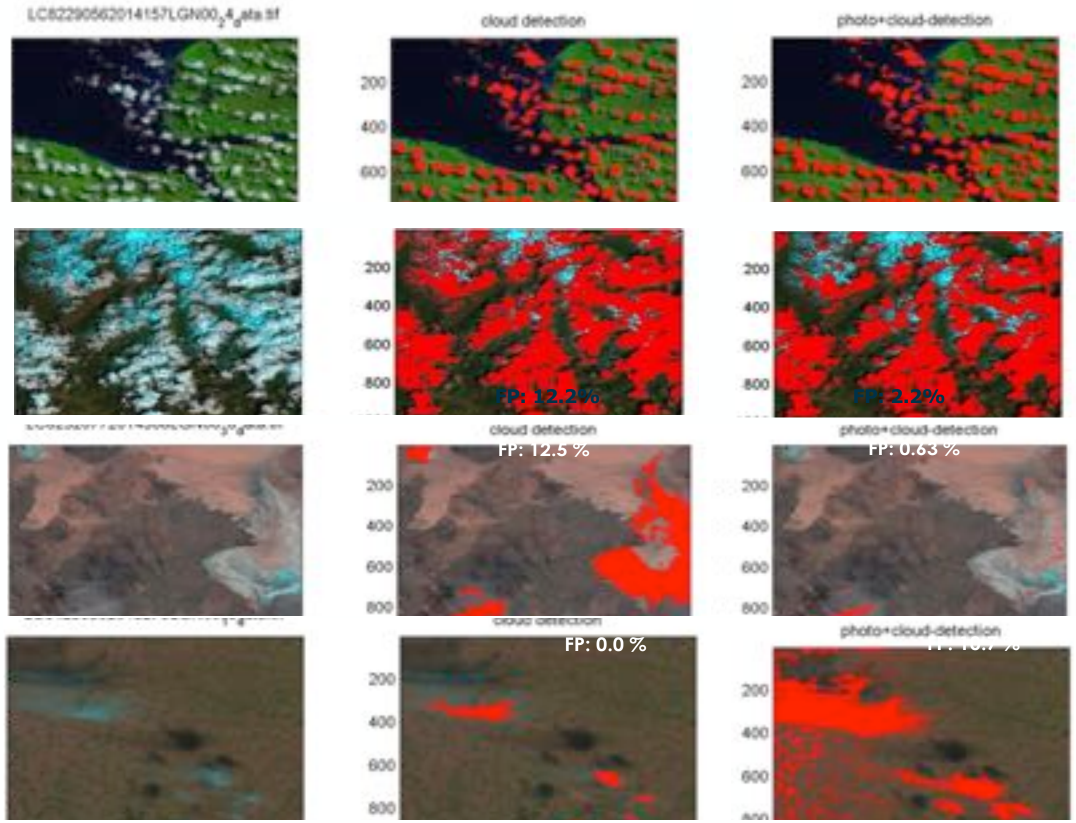


Onboard cloud detection

Results on 42 reference cloud data base images

Threshold approach SVM approach





GLOBALLY GOOD DETECTION BUT WITH SOME CRITICAL CASES (FALSE POSITIVE*>10%)

2 CASES WITH THRESHOLD APPROACH

- Old/melted/Snow
- Salt area

1 CASE WITH SVM APPROACH

- Desert area (similar samples not included in training set)

Quantitative results

False Positive (%)	Threshold	SVM
Mean	0.93	0.60
Standard deviation	2.76	1.73

→ SVM APPROACH SELECTED

Data reduction strategy

Several options considered

Method	Pros	Cons
Deletion of cloud contaminated samples	Low complexity High data reduction Compliant with standard	Loss of (potentially useful) data Lack of flexibility*
Selective compression Removal of prediction residuals on clouds (***RtZ*** *"Residual to Zero" method*)	Low-Medium complexity High compression efficiency Standard decompressor	Lack of quality control on clouds Lack of flexibility* 
Selective compression Two-class quantizer (***DAE*** *"Different Absolute Error" method*)	Very high flexibility* Competitive compression efficiency 	Slightly higher complexity Not compliant with standard

*Image quality needed on clouds still unclear (straylight correction)

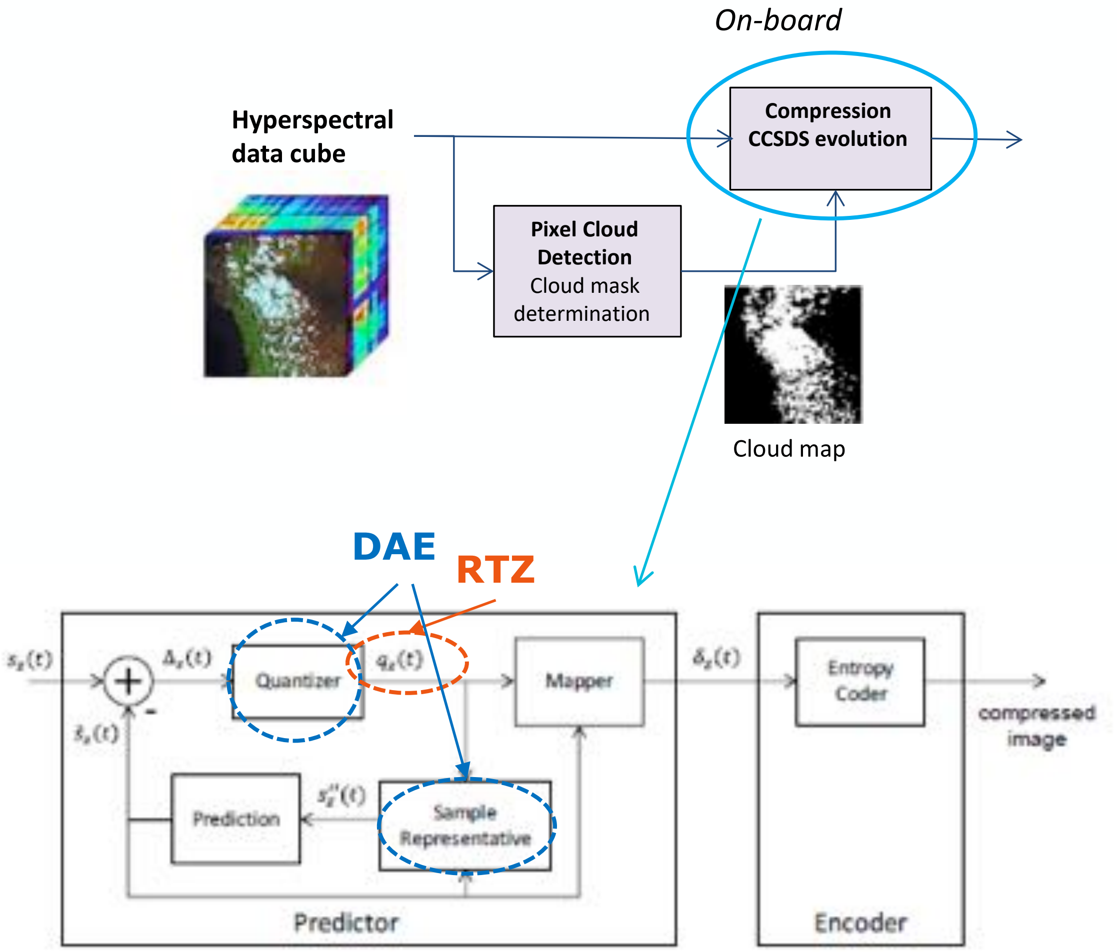
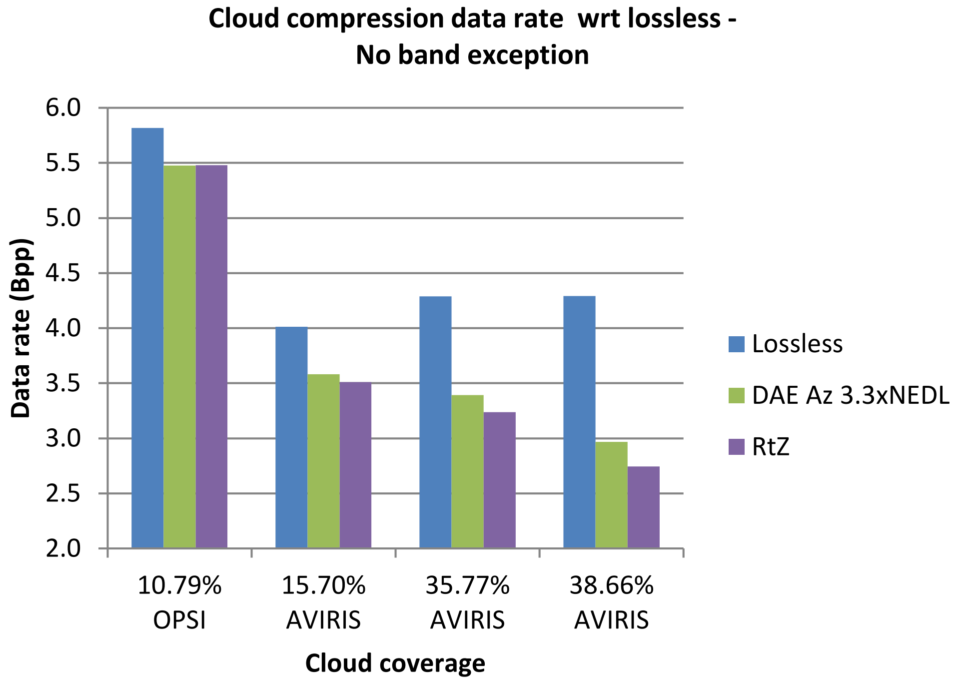


Figure 2-1: Compressor Schematic

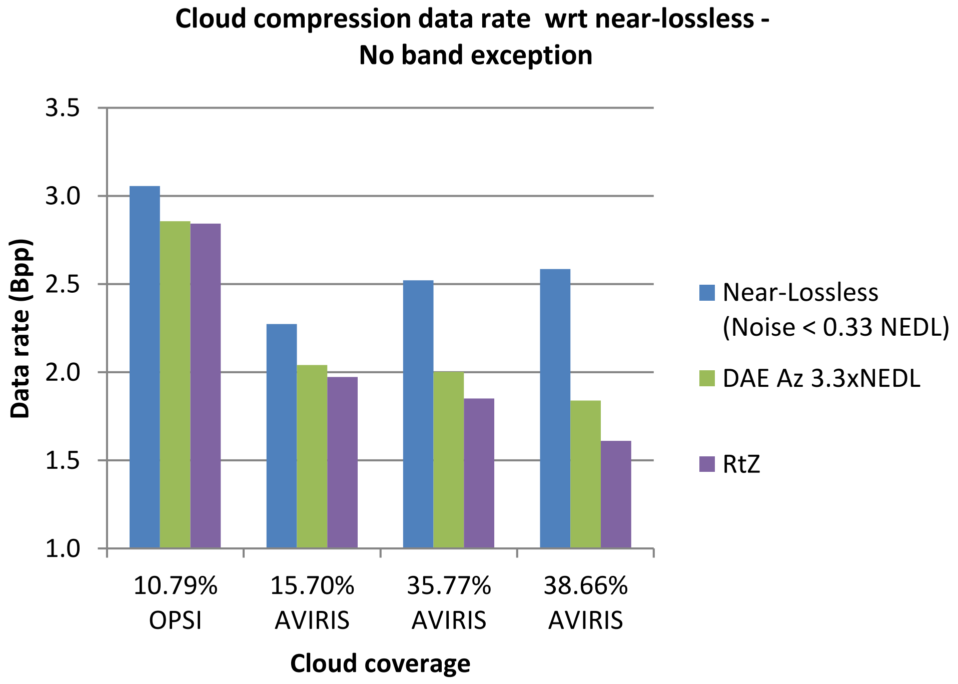
Selective compression efficiency

Cloud compression: Data rate lossless & near-lossless mode - all bands

Clear pixels = Lossless mode



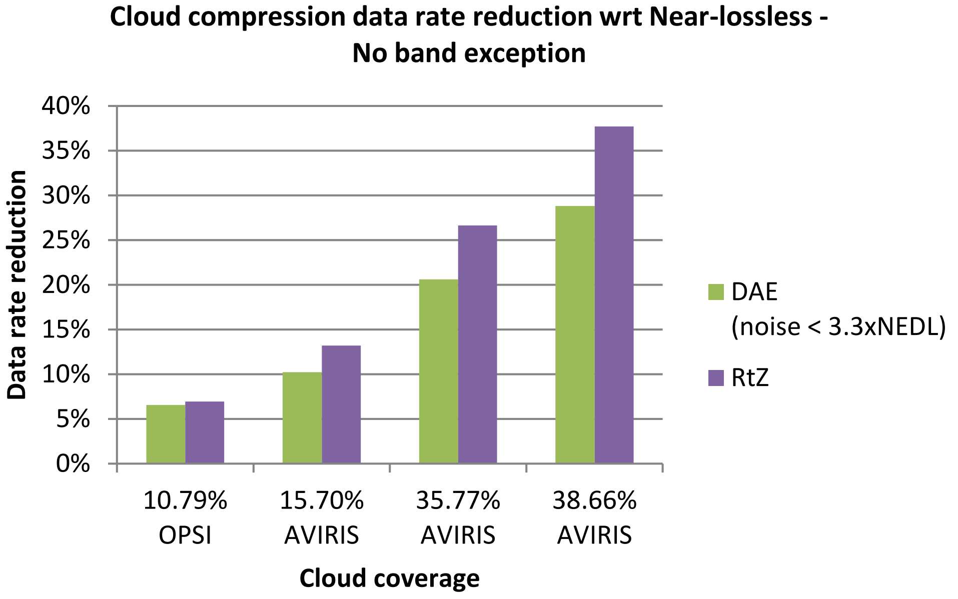
Clear pixels = Near-lossless mode



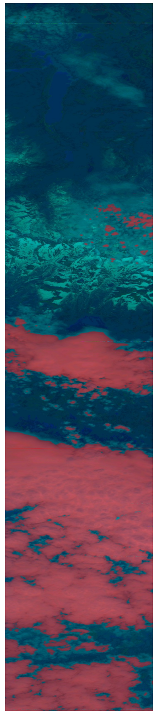
Selective compression efficiency

Cloud compression: Data rate reduction / all bands

Clear pixels = Near-lossless mode



35.77 %



38.66 %

Cloud compression performance scales almost linearly with cloud coverage

→ depends also on cloud distribution (lower efficiency on scattered clouds)

$$Cloud\ compression\ data\ rate\ reduction\ (\%) = 100\times\frac{DataRate_{Standard\_Compression} - DataRate_{Cloud\_Compression}}{DataRate_{Standard\_Compression}}$$

Conclusion

Improved data reduction for an overall mission cost reduction

Latest CCSDS standard provides an excellent flexible solution for CHIME

Near-lossless compression satisfying all requirements thanks to precise knowledge of imaging system (**NEDL**).

→ Significant compression efficiency improvement

CR<3 (lossless) vs. CR>4 (TBC - near-lossless).

Cloud detection and selective compression to provide enhanced data reduction

Data reduction depends on cloud cover and cloud distribution

(between 20 and 35% for images with around 40% of clouds)

Selected method provides **highly flexible low complexity solution with limited risk**

(can comply with any image quality requirement both on ground and on cloudy pixels).