



FAPEC-based compression results on satellite imaging data

Jordi Portell (IEEC/DAPCOM/UB)

Gabriel Artigues (ICE/IEEC)

Enrique García-Berro (IEEC/UPC)

Hamed Ahmadloo (IEEC)

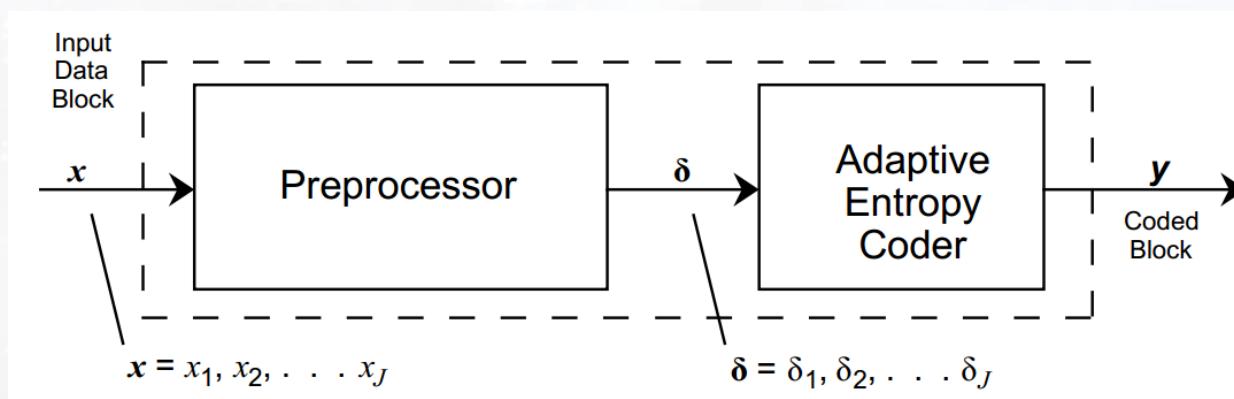
Presented by Jordi Portell

Image Data Compression in space

- ▶ Limitations in satellite data compression:
 - ▶ On-board processing power
→ low complexity
 - ▶ Communications channel reliability
→ (relatively) small and independent data blocks
- ▶ The case of image data:
 - ▶ Images generally contain a significant amount of redundancy
 - ▶ Often high ratios required
 - ▶ Typically lossy compression is preferable
 - ▶ Quality (PSNR, artefacts) vs. ratio
 - ▶ Fixed-quality vs. fixed-rate
 - ▶ Greyscale (2D) vs. multi/many band (3D)

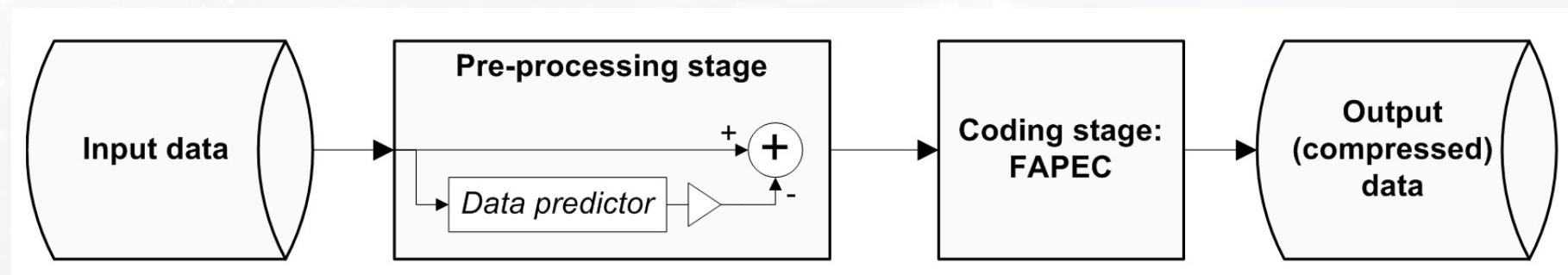
CCSDS 121.0 recommendation

- ▶ Current space standard for lossless data compression
- ▶ Blocks of 8 or 16 samples
- ▶ Reasonable compression ratios
- ▶ Low processing requirements
- ▶ Software and hardware implementations
- ▶ Efficiency abruptly decreases when noise is introduced



FAPEC entropy coder

- ▶ FAPEC: Fully Adaptive Prediction Error Coder
- ▶ Quick entropy coding with excellent coding efficiency
- ▶ Adequate for data with unusual statistical distributions and/or affected by outliers
- ▶ Better resiliency to such cases than CCSDS 121.0
- ▶ Very good for large sample sizes
 - ▶ Current implementation: up to 28-bit samples
- ▶ Software and hardware (FPGA) implementations
 - ▶ ~35mW at 32 Mbps (16-bit samples), ACTEL PROASIC 3L



The FAPEC core: PEC

- ▶ PEC: Prediction Error Coder
- ▶ Very quick semi-adaptive entropy coder
- ▶ 3 coding options, 4 coding parameters (segments)
- ▶ FAPEC adds an adaptive layer to PEC
 - ▶ Selection of adequate parameters based on a quick statistical analysis of each coding block (typ. 100-1000 samples)
- ▶ Software implementation tested on Maxwell SCS750
 - ▶ 8% (600MHz) at 5 Mbps (including complex pre-proc. stage)

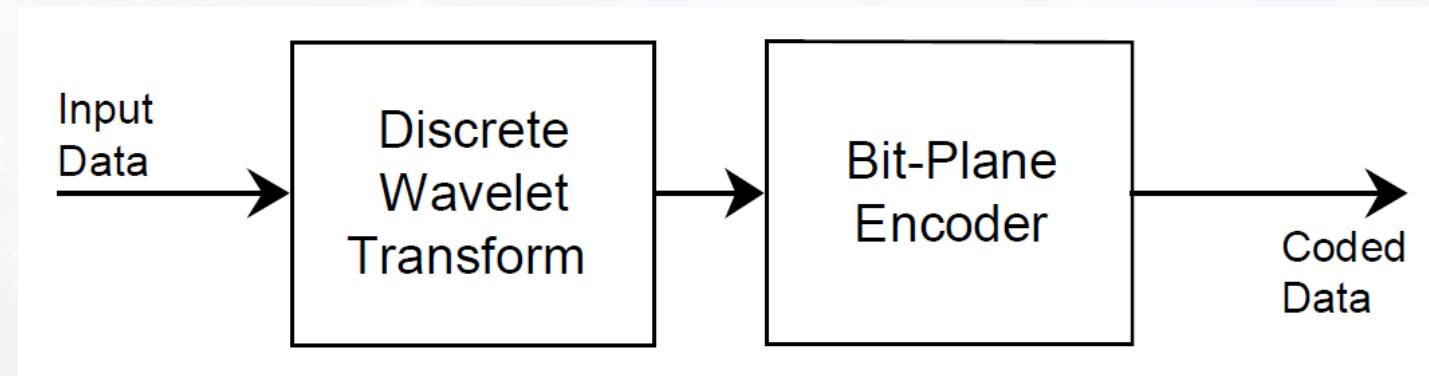
Low Entropy				
1 st range:	$\pm X[h]$			
2 nd range:	-	$0[h]$	$\pm (X-2^h)[i]$	
3 rd range:	-	$0[h]$	$\pm 1[i]$	$0 (X-2^h-2^i+1)[j]$
4 th range:	-	$0[h]$	$\pm 1[i]$	$1 (X-2^h-2^i-2^j+1)[k]$

Double-Smoothed				
	$\pm X[h]$			
	$\pm 1[h]$	$(X-2^h+1)[i]$		
-	$0[h]$	± 0	$(X-2^h-2^i+1)[j]$	
-	$0[h]$	± 1	$(X-2^h-2^i-2^j+1)[k]$	

Large Coding				
0	$X[h]$	\pm	(sign only if $X \neq 0$)	
10	$(X-2^h)[i]$	\pm		
110	$(X-2^h-2^i)[j]$	\pm		
111	$(X-2^h-2^i-2^j)[k]$	\pm		

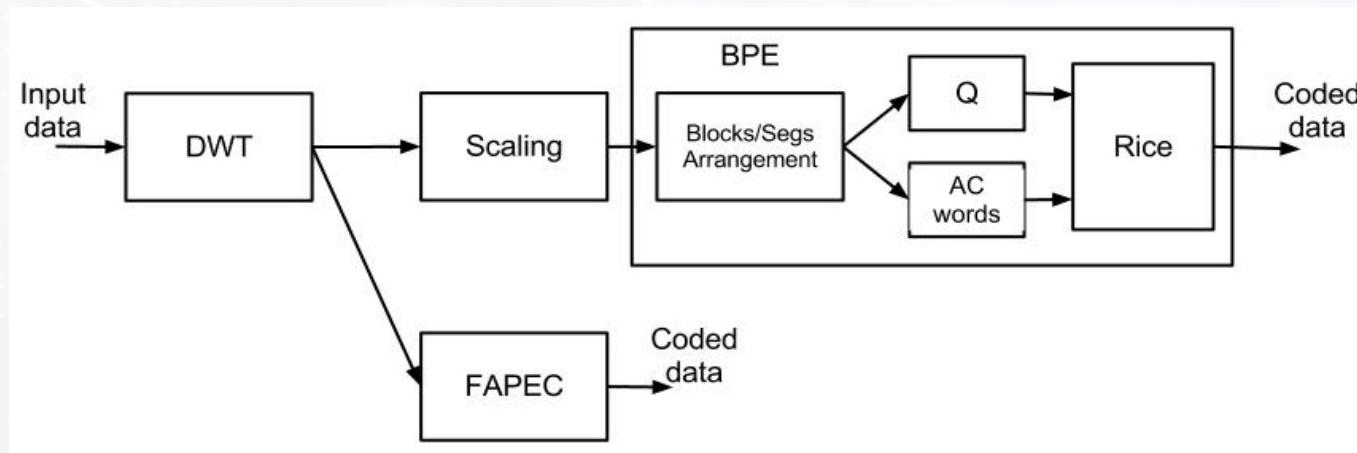
CCSDS 122.0 recommendation

- ▶ Current standard for satellite image data compression
- ▶ Lossless + lossy operation
- ▶ Up to 16-bit, grayscale images
- ▶ Discrete Wavelet Transform + Bit Plane Encoder
- ▶ DWT: 3-level 2-dimensional transform
- ▶ BPE uses Rice-based coding for wavelet coeffs. in 'blocks' of 64 coeffs. each

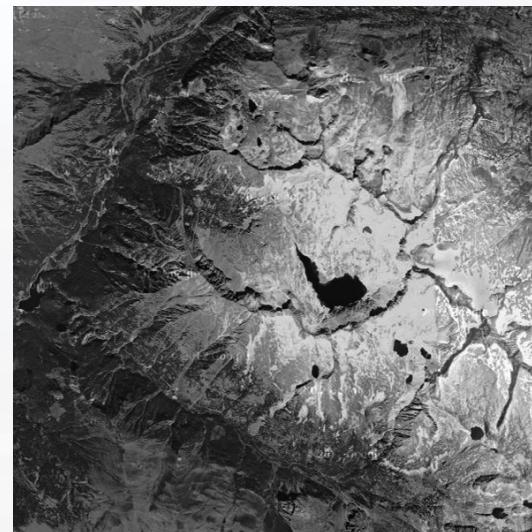
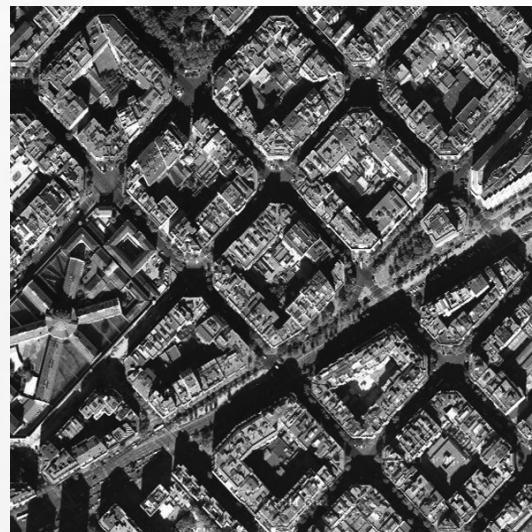
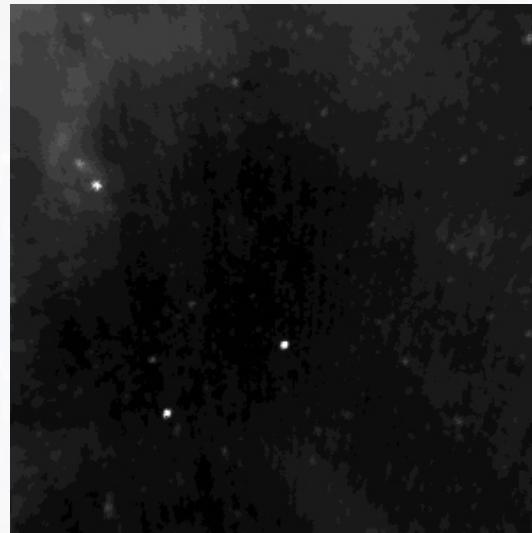


DWTFAPEC

- ▶ Started from 'Nebraska' C implementation of 122.0
- ▶ Optimal integration option found:
 - ▶ FAPEC on non-scaled coefficients (direct DWT output)
 - ▶ Smaller header than original 122.0
- ▶ Recent improvements
 - ▶ Differential coding for the DC coefficients
 - ▶ Stream partitioning to work with color images (RGB):
 - 3 sub-streams each with a single band or color



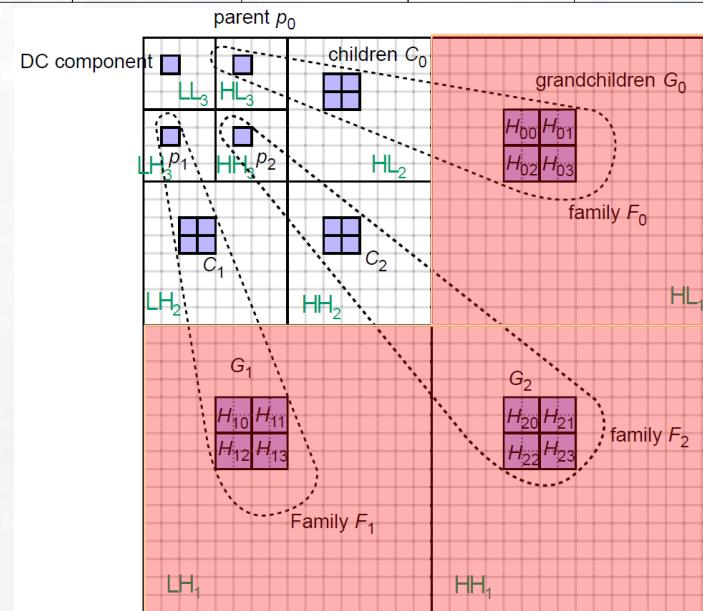
Some testing images



Improved DWTFAPEC test results

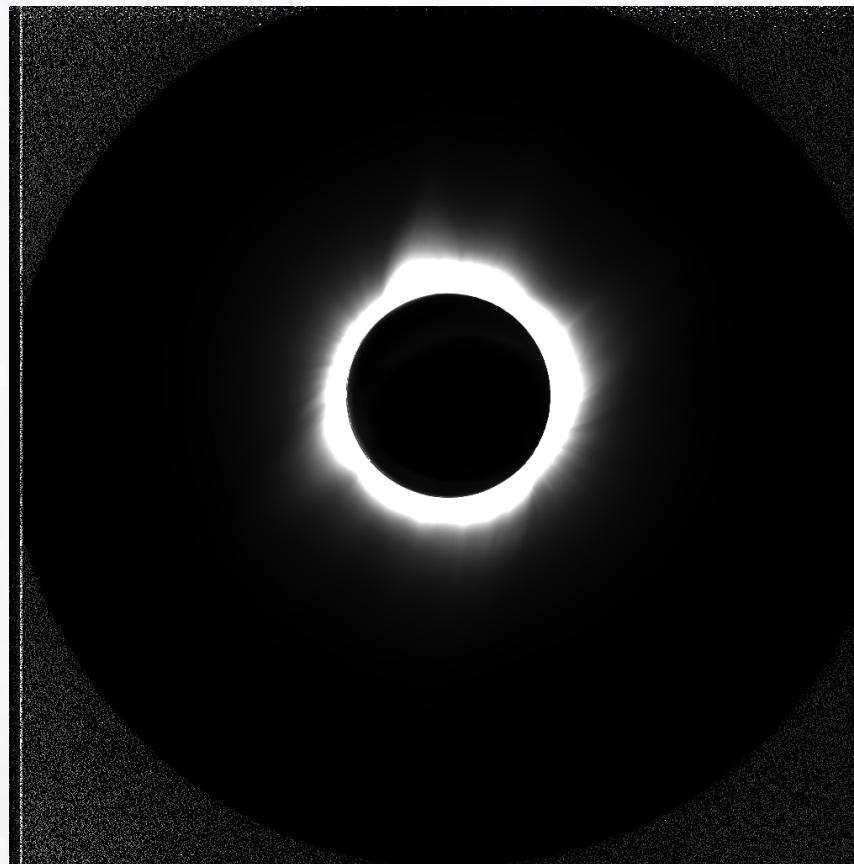
- Small improvement in lossless, but significant in lossy

Image	Lossless ratios		Lossy ratios L2		PSNR (dB)
	Abs DC	Diff DC	Abs DC	Diff DC	
com0001.fits	2.03	2.06	7.69	8.10	11.53
for0001.fits	3.21	3.24	8.97	9.28	17.98
galaxy.fits	1.90	1.92	6.59	6.80	19.63
banyoles.raw	1.40	1.41	4.37	4.45	16.49
eixample.raw	1.20	1.20	3.80	3.85	12.54
pirineus.raw	1.41	1.41	4.31	4.41	16.37



Solar observation: example image

- ▶ Image provided by the Solar Orbiter team
(1024x1024 pixels, 16-bit greyscale)



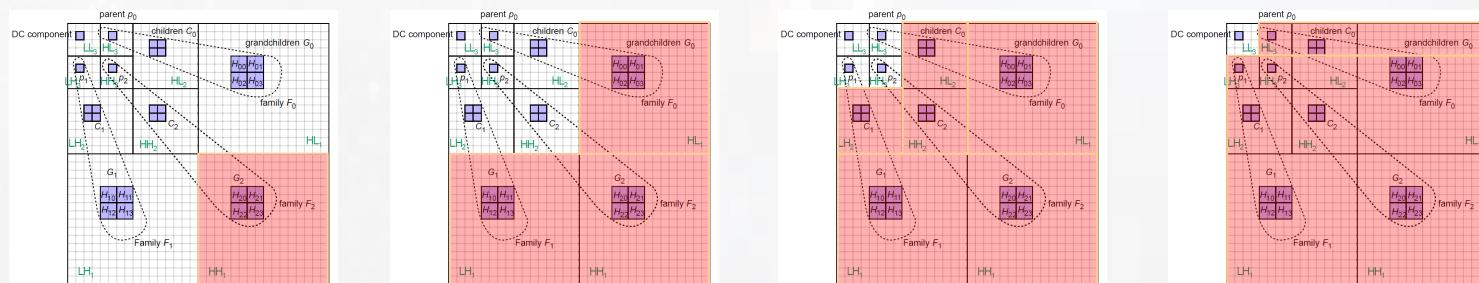
Solar observation test results

► Lossless compression

Image	FAPEC		DWTFAPEC		CCSDS 121.0		CCSDS 122.0	
	Ratio	CPU time (ms)	Ratio	CPU time (ms)	Ratio	CPU time (ms)	Ratio	CPU time (ms)
Mosaic10	2.51	120	2.47	540	2.51	128	2.55	693

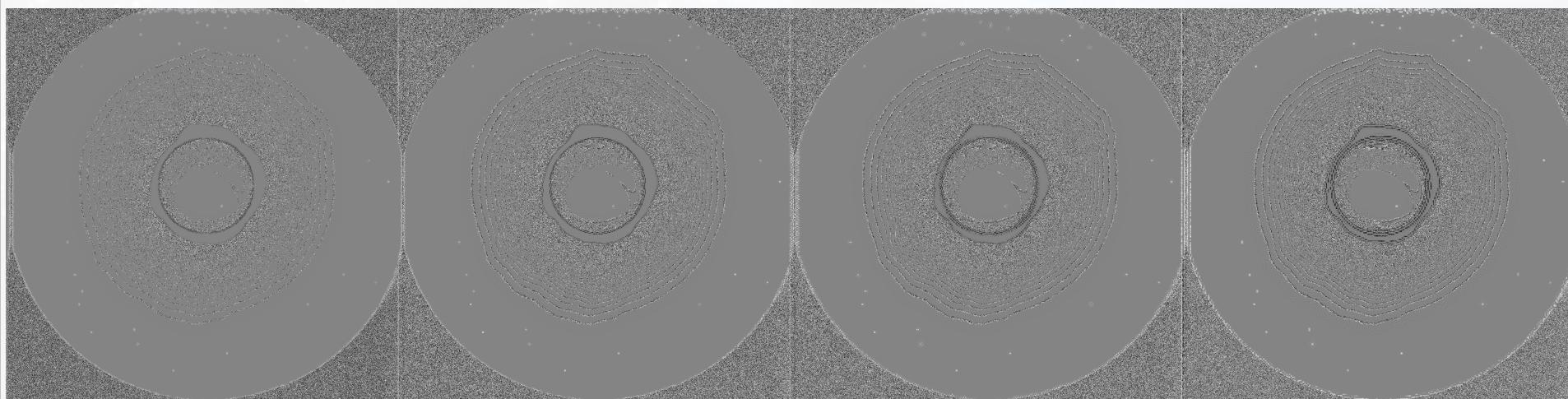
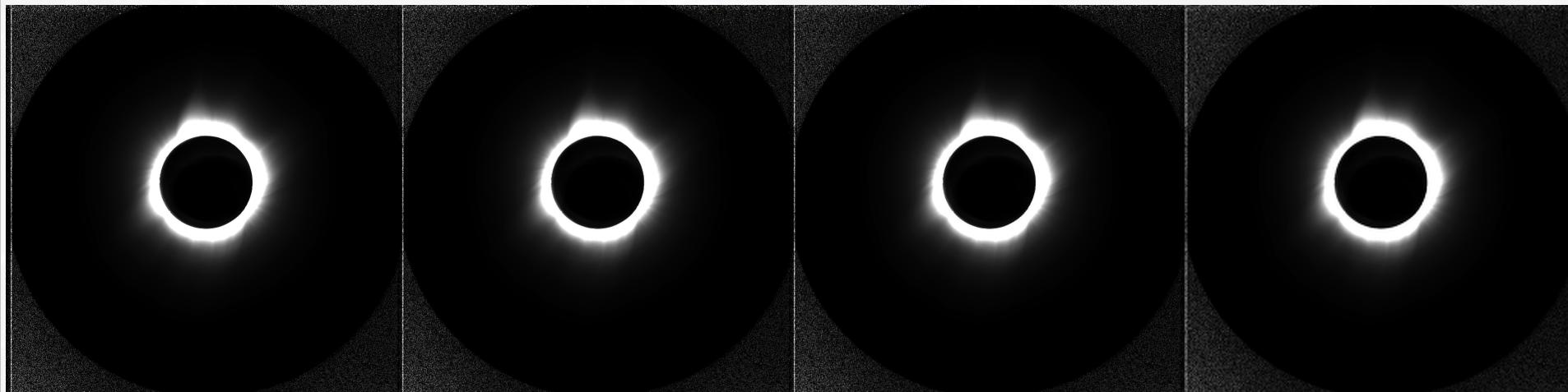
► Lossy compression

Image (Mosaic10)	Level 1		Level 2		Level 3		Level 4	
	Ratio	CPU time (ms)						
DWTFAPEC	3.19	440	8.31	260	10.63	430	25.28	330
CCSDS 122.0	3.24	740	7.94	470	9.94	410	23.28	301
PSNR (dB)	30.44		25.24		24.88		23.83	



Solar observation test results

r3.19, 30.44dB r8.31, 25.24dB r10.63, 24.88dB r25.28,
23.83dB

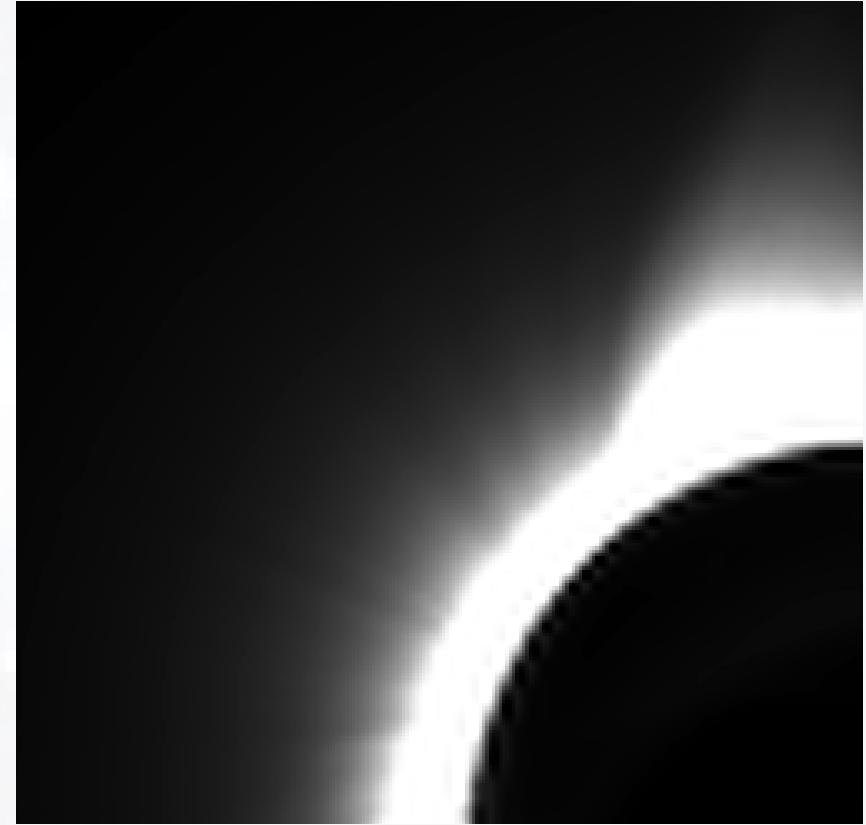


Solar observation test results

r3.19, 30.44dB (level 1)



r25.28, 23.83dB (level 4)



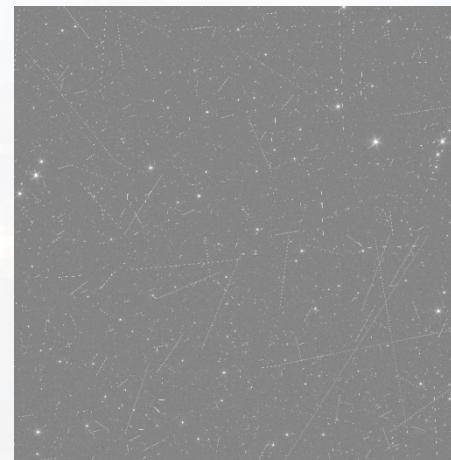
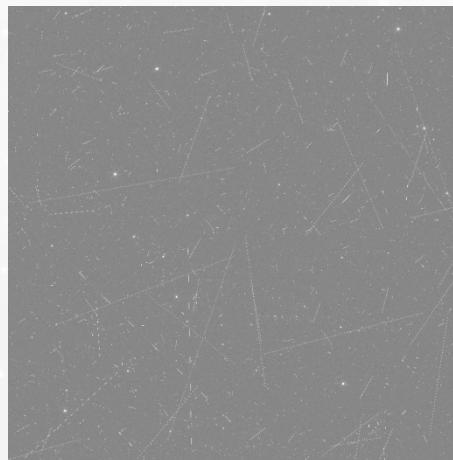
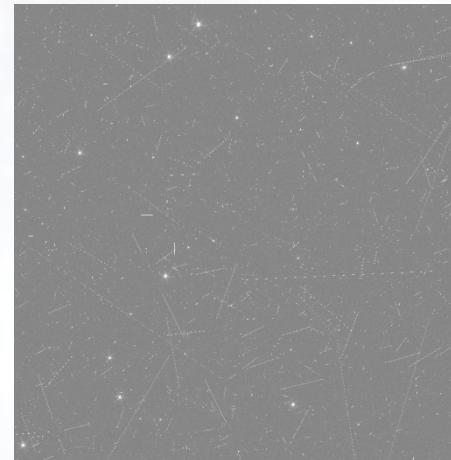
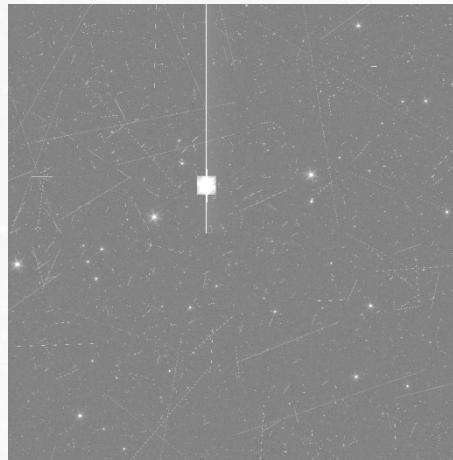
Quality level 2 (r8.31, 25.24dB) is probably the best compromise

Euclid: simulated images

examples

- ▶ Images provided by the Euclid team

- ▶ Left to right, top to bottom: 30deg, 60deg, 90deg, VISCCD



Euclid test results

► Lossless compression

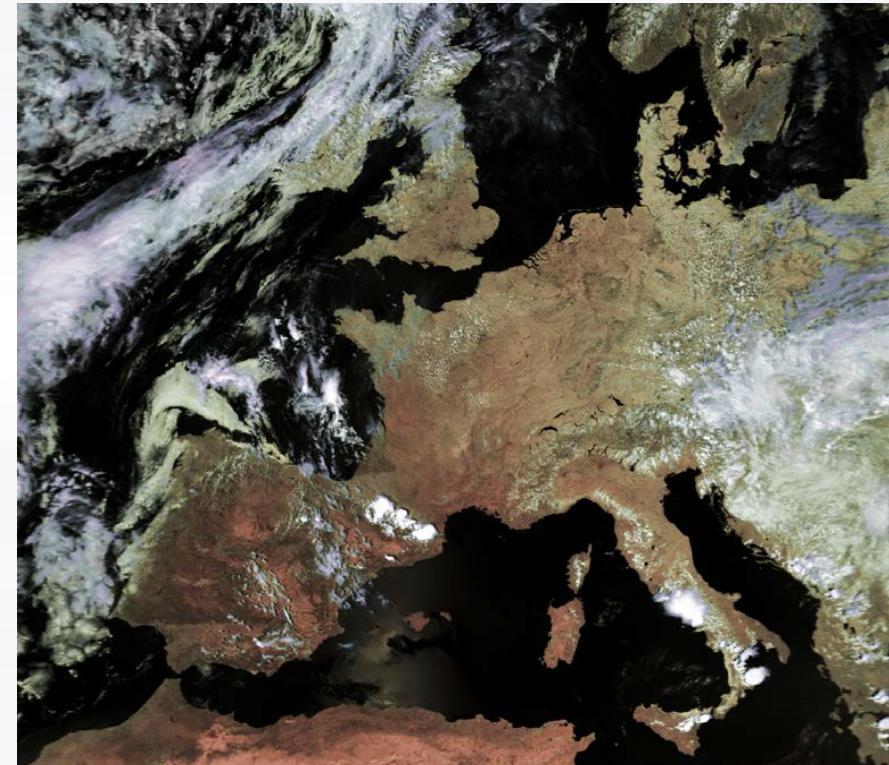
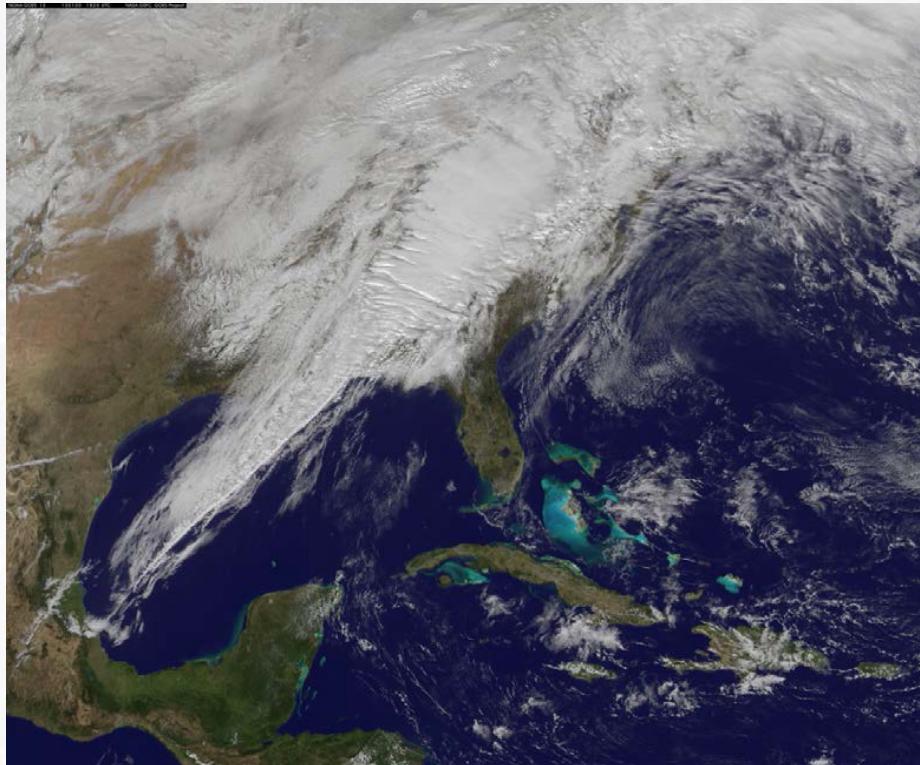
Image	FAPEC		DWTFAPEC		CCSDS 121.0		CCSDS 122.0	
	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)
30deg	3.63	1.51	3.45	9.07	3.26	2.22	3.43	10.44
60deg	3.69	1.47	3.49	8.92	3.30	2.25	3.47	10.56
90deg	3.68	1.47	3.49	8.96	3.29	2.21	3.47	10.57
VISCCD	3.61	1.47	3.45	9.05	3.26	2.22	3.43	10.72

(lossy compression is not considered in the Euclid mission requirements)

- FAPEC seems to be definitely the best solution
 - Pending to repeat tests with more realistic simulations

Earth Observation example

► Images obtained from NOAA (left) and EUMETSAT (right)



► Stream partitioning scheme → 3 sub-bands (colors)

Meteorological test results

► Lossless compression

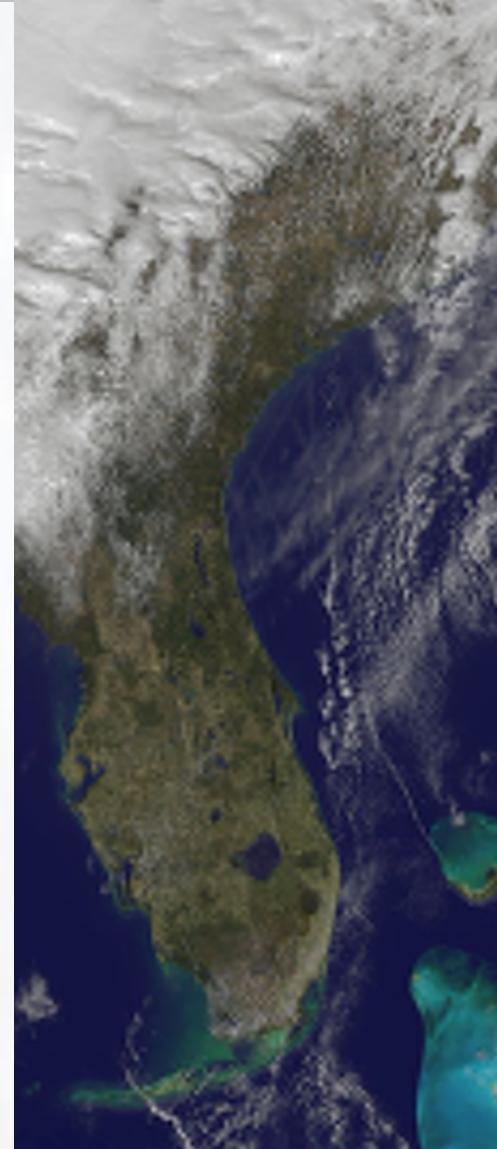
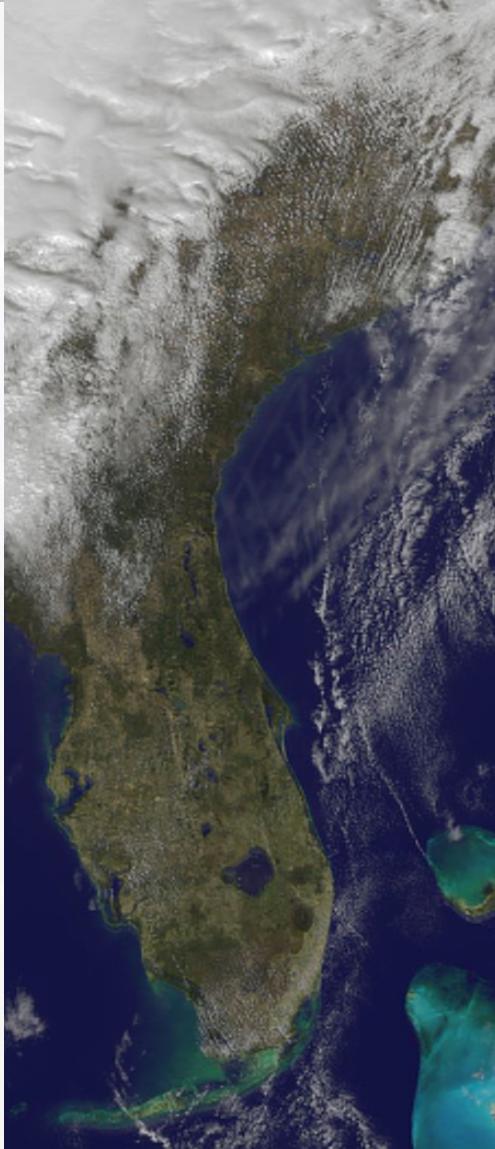
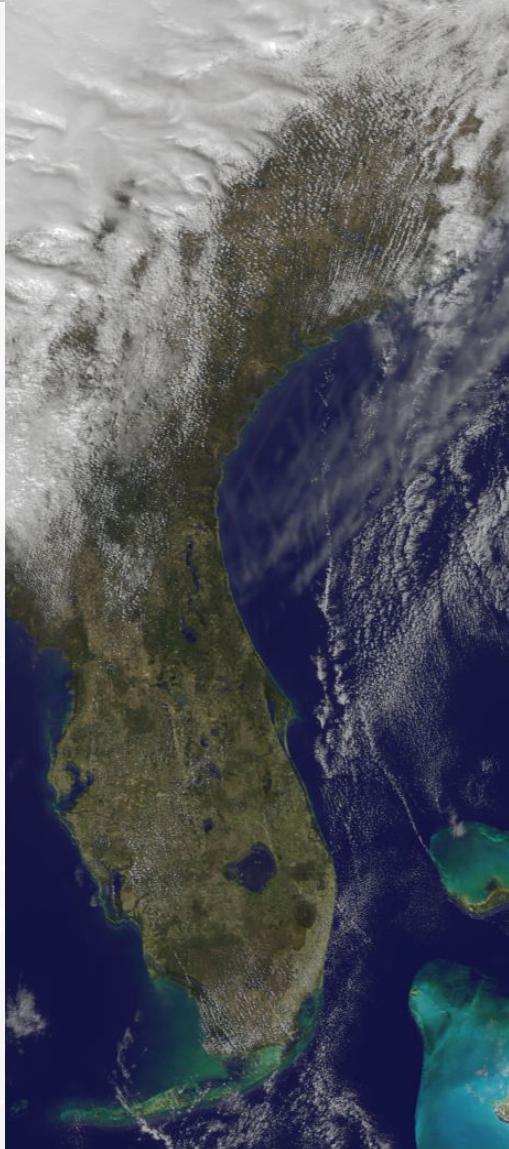
Image	FAPEC		DWTFAPEC		CCSDS 121.0		CCSDS 122.0	
	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)
pyrenees	1.61	0.5	1.80	4.12	1.72	0.84	1.93	3.81
723585main	1.87	3.46	2.07	23.81	2.00	6.16	2.26	27.00

► Lossy compression

Image	Level 1		Level 2		Level 3		Level 4	
	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)	Ratio	CPU time (s)
pyrenees	DWTFAPEC	2.08	2.72	5.03	1.27	6.37	1.14	16.12
	122.0	2.25	3.39	4.82	1.83	5.87	1.73	13.78
723585main	DWTFAPEC	2.41	12.72	5.76	7.90	7.29	7.71	18.32
	122.0	2.62	16.07	5.54	10.57	6.73	10.09	15.72

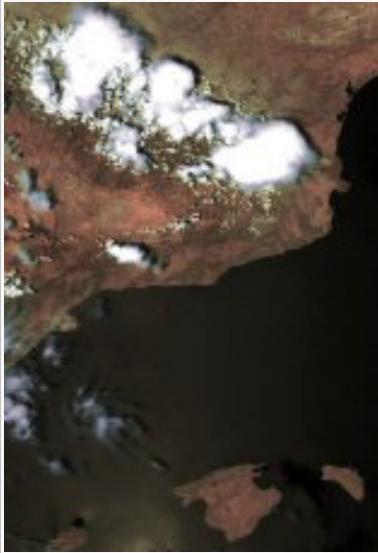
Image	Level 1 PSNR (dB)	Level 2 PSNR (dB)	Level 3 PSNR (dB)	Level 4 PSNR (dB)
pyrenees	21.85	16.26	15.69	14.02
723585main	26.69	20.18	18.00	17.01

Meteorological test results

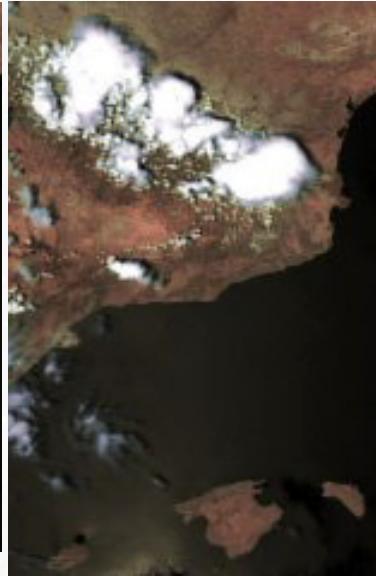


Meteorological test results

r1.80



r2.08, 21.85dB



r5.03, 16.26dB



r6.37, 15.69dB



r16.12, 14.02dB



- ▶ Level 4 should really be avoided
- ▶ Levels 2 and 3 look like a good compromise

Meteorological test results

- ▶ Bonus track: lossless colour compression using plain FAPEC with an adequate pre-processing stage (still being prototyped)

Ratios:	FAPEC	DWTFAPEC	CCSDS 121.0	CCSDS 122.0	FAPEC-RGB
<i>pyrenees</i>	1.61	1.80	1.72	1.93	2.21
<i>723585main</i>	1.87	2.07	2.00	2.26	2.62

- ▶ “Green” and “Blue” use spatial + inter-band prediction
- ▶ Ratios similar to those obtained with a Level-1 lossy compression
- ▶ Almost the same performance as plain (delta) FAPEC

Conclusions and forthcoming work

- ▶ FAPEC can be used as the coding stage of complex compressors
 - ▶ Available on software (PEC core tested on Gaia VPUs) and hardware
- ▶ DWTFAPEC:
 - ▶ Good ratios for lossy, good compression times
 - ▶ Still requiring some improvement in the lossless option
- ▶ Solar Orbiter: best results with lossy DWTFAPEC (level 2)
- ▶ Euclid: FAPEC definitely offers the best solution (so far)
- ▶ Meteorological images:
 - ▶ Stream partitioning → Support color images (DWTFAPEC+122.0)
 - ▶ Good DWTFAPEC compression ratios and timing, specially with lossy
 - ▶ Preliminary results with FAPEC-RGB look excellent
- ▶ Future work:
 - ▶ Optimized DWT pre-processor for FAPEC
 - ▶ Multi-band (color and hyperspectral) compression
 - ▶ Revise lossy option
 - ▶ Extend to >16 bit samples
 - ▶ Implement fixed-rate option



FAPEC-based compression results on satellite imaging data

Jordi Portell (IEEC/DAPCOM/UB) – *jordi.portell@dapcom.es*

Gabriel Artigues (ICE/IEEC)

Enrique García-Berro (IEEC/UPC)

Hamed Ahmadloo (IEEC)

Presented by Jordi Portell