An Efficient Approach to Lossy Compression with Pointwise Relative Error Bound

Sheng Di, Dingwen Tao, Franck Cappello
Argonne National Laboratory

Nov. 2017

Outline

- Background
- Problem Formulation
- Point-wise relative error lossy compression in SZ
- Evaluation of Compression Quality
- Conclusion and Future Work

Background

- Extreme large volumes of scientific data
  - Climate Simulation : 260TB every 16s
  - HACC : 60PB for simulating 3.5 trillion particles
- Error control
  - ***Absolute error bound (AEB)***: a positive constant such as 1E-5
  - ***Precision (PRE)***: the number of bits to reserve in binary representation, such as 20 bits
  - ***Value-range based relative error bound (VR_REB)***: a positive constant ratio such as 1%, compared with value range)
  - ***Peak signal-to-noise ratio (PSNR)***: 20log10(VR/MSE)
  - ***Point-wise relative error bound (PW_REB)***: a positive constant ratio such as 1%, compare with the individual data values.

Problem Formulation

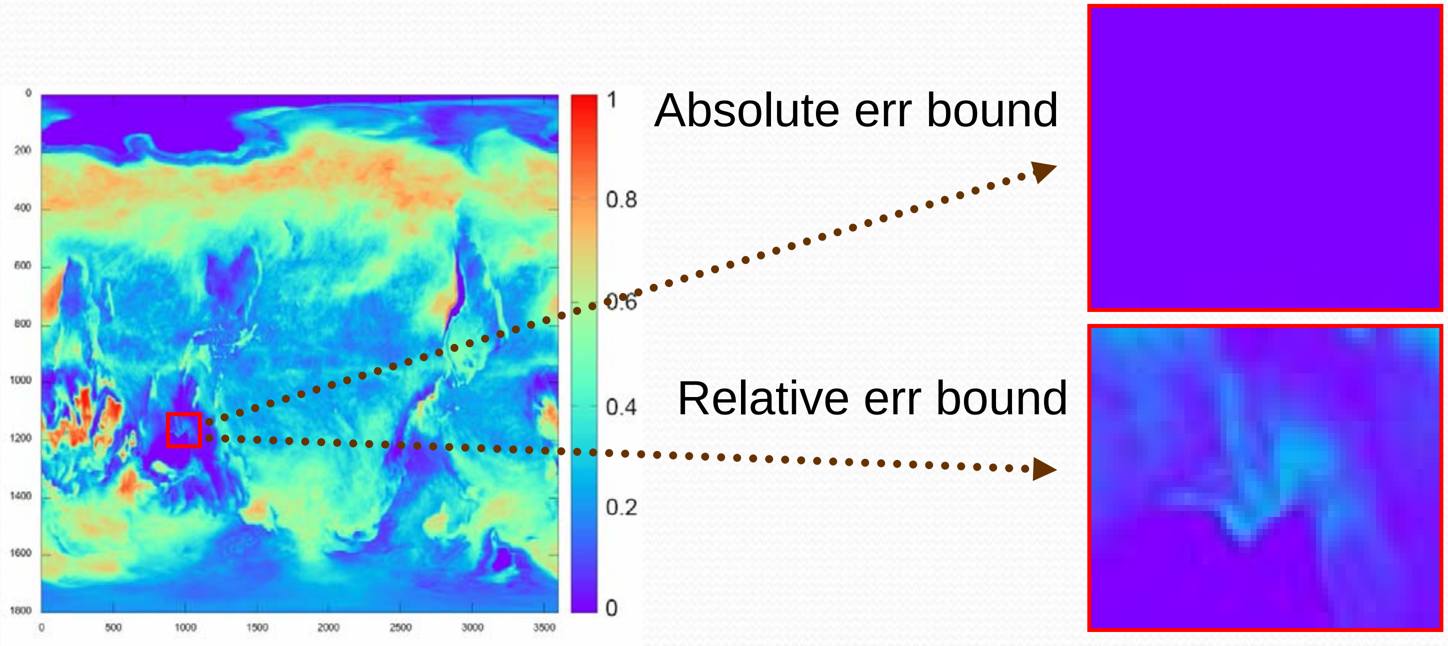
- Point-wise Relative Error Bound:
  - Given a data set $S = \{d_1, d_2, \cdots, d_N\}$ with N data points, the reconstructed data set $S' = \{d'_1, d'_2, \cdots, d'_N\}$, the following inequality holds for each data point:

$$\max_{d_i \in S, d'_i \in S'} \left(\left| \frac{d_i - d'_i}{d_i} \right| \right) \leq \epsilon$$

  where ϵ is a small constant value such as 1%.
- Existing lossy compressors:
  - SZ: AEB, VR_REB, PSNR
  - ZFP: AEB, PRE
  - FPZIP: PRE
  - ISABELA: PW_REB (low compression ratio and high compute cost)

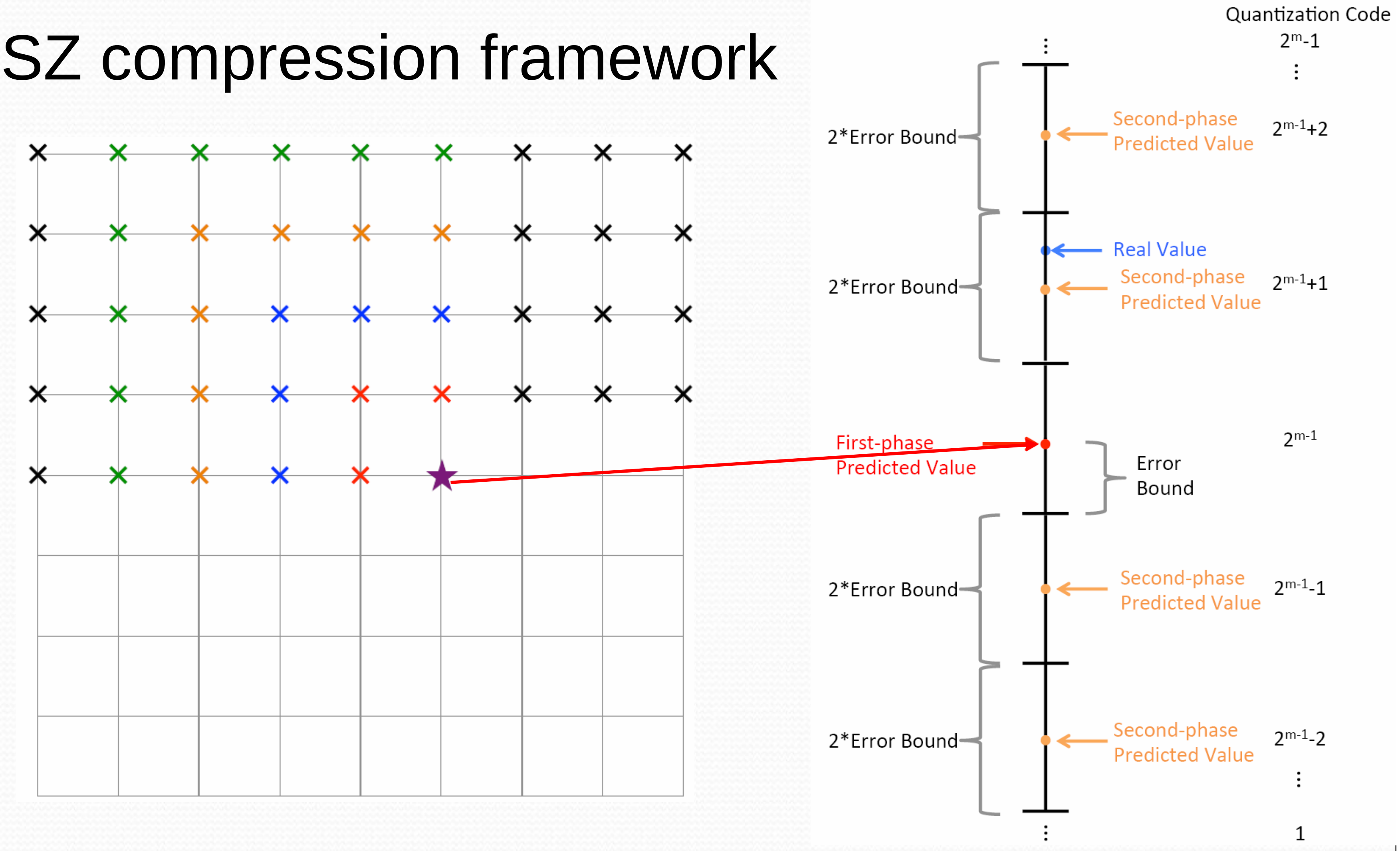
Background (Cont'd)

- Why do we need point-wise relative error control? -- multi-resolution
  - "Point-wise relative error bound" can preserve the details better than "absolute error bound"



Point-wise relative error lossy compression in SZ

- SZ compression framework

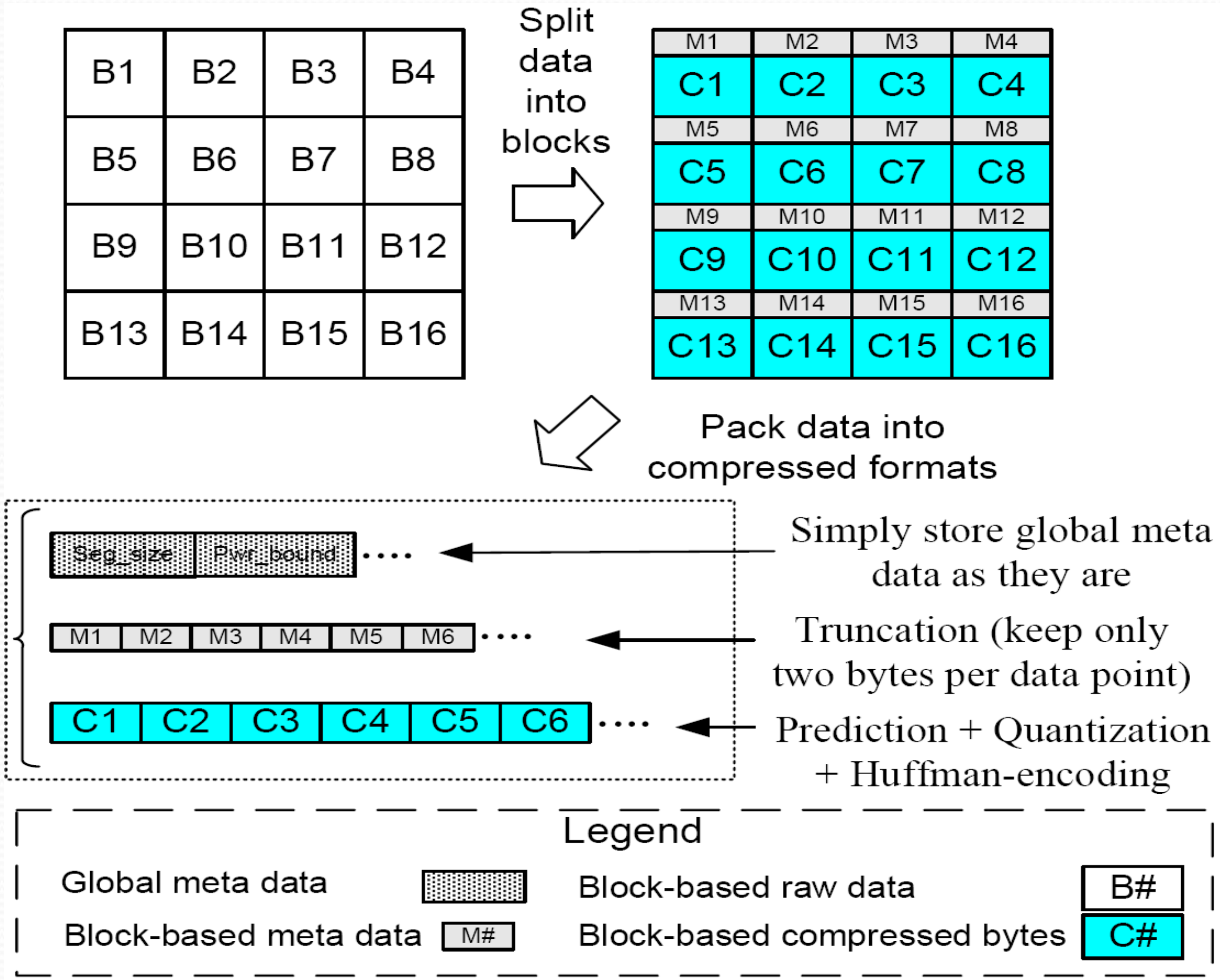


Point-wise relative error lossy compression in SZ (Cont'd)

- Block-based strategy for PW_REL lossy compression in SZ
  - Split the overall data set into blocks
    - e.g., 2D matrix will split into equal-sized blocks, and the block size could be 4x4, 5x5, 6x6, …..
    - Optimal block size is also explored in this paper
  - Compute a statistical value for each block
    - three options: min, avg, max
  - Perform data prediction based on the relative error bound ratio and the statistical value for each block.
  - Perform variable-length encoding (Huffman)

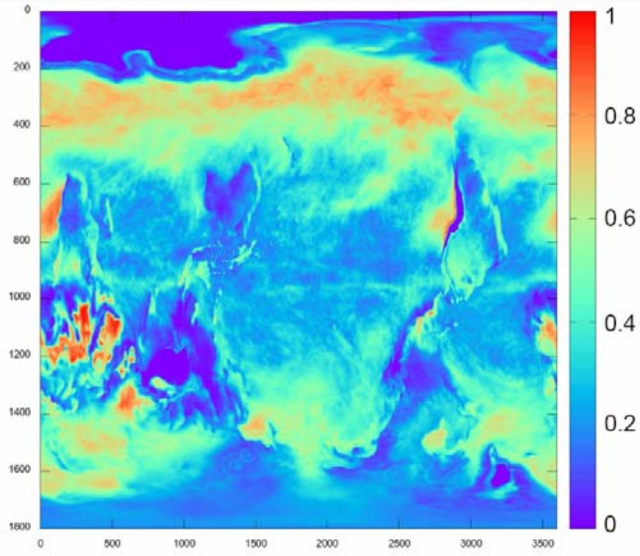
Point-wise relative error lossy compression in SZ (Cont'd)

- Illustration of block-based Strategy



Evaluation

- Experimental Setting
  - SZ vs. ZFP 0.5.1 (precision mode)
  - Data Set: CESM Tylor
    - CLDLOW
    - CLDHGH
    - FLDSC
    - PHIS



Evaluation (Cont'd)

Table II

COMPRESSION RESULTS OF SZ(MIN) WITH DIFFERENT BLOCK SIZES

Compression Ratio					
Setting	**4x4**	**5x5**	**6x6**	**7x7**	**8x8**
1E-2	17.04	18.6	17.13	18.21	17.48
1E-4	4.89	4.99	5.01	5.02	5.02
Maximum Relative Error Bound (i.e., $\max \varepsilon$)					
Setting	**4x4**	**5x5**	**6x6**	**7x7**	**8x8**
1E-2	0.01	0.009997	0.00998	0.009998	0.009998
1E-4	1E-4	1E-4	1E-4	1E-4	1E-4
PSNR					
Setting	**4x4**	**5x5**	**6x6**	**7x7**	**8x8**
1E-2	52.27	52.64	52.92	52.99	53.1
1E-4	92.33	92.56	92.86	92.68	92.83

Evaluation (Cont'd)

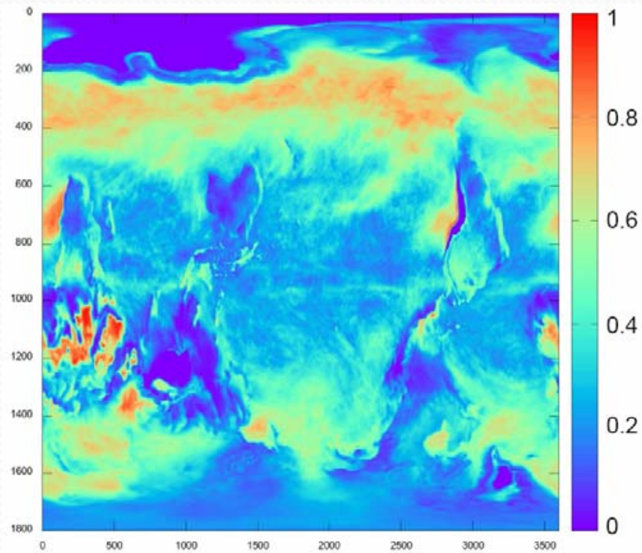
Table I

COMPARISON OF COMPRESSION RESULTS AMONG DIFFERENT COMPRESSORS (CLDLOW FIELD IN CESM-ATM SIMULATION)

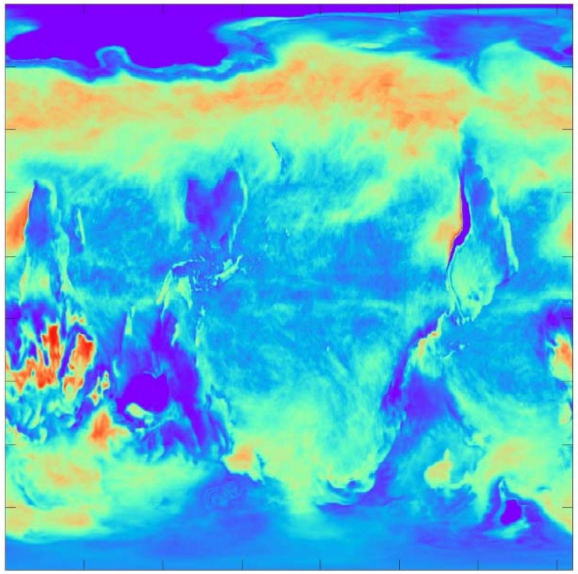
Compressor	Setting	bounded	$\bar{\varepsilon}$	max ε	PSNR	CR
SZ (MIN_mode)	**ϵ=1E-2**	**100%**	0.00466	**0.009997**	52.64	**18.6**
	ϵ=1E-4	**100%**	4.65E-5	**1E-4**	92.56	**4.99**
SZ (AVG_mode)	ϵ=1E-2	98.6268%	1.03E+7	1.66E+13	52.7	18.67
	ϵ=1E-4	98.646%	1.03E+5	1.34E+11	92.7	5.12
SZ (MAX_mode)	ϵ=1E-2	95.171%	1.5E+8	6.2E+14	52.37	19.63
	ϵ=1E-4	95.199%	4.4E+5	1.03E+12	92.4	5.28
ZFP [5]	Pc=16	99.96%	4.2E+5	1.26E+12	85.94	4.04
	Pc=18	99.977%	1.7E+5	4.15E+11	97.86	3.61
	Pc=20	99.984%	2E+5	3.47E+10	109.9	2.98
FPZIP [10]	Pc=15	87.2515%	0.00566	0.0154	51.32	20.3
	Pc=16	**100%**	0.00284	**0.0078**	57.32	**15.87**
	Pc=22	97.2724%	4.4E-5	1.22E-4	93.44	4.49
	Pc=23	**100%**	2.2E-5	**6.1E-5**	87.5	**3.95**
ISABELA [8]	ϵ=1E-2	99.9997%	0.00226	1	58.8	2.59
	ϵ=1E-4	99.9952%	5.15E-05	1	92.8	1.39

Evaluation (Cont'd)

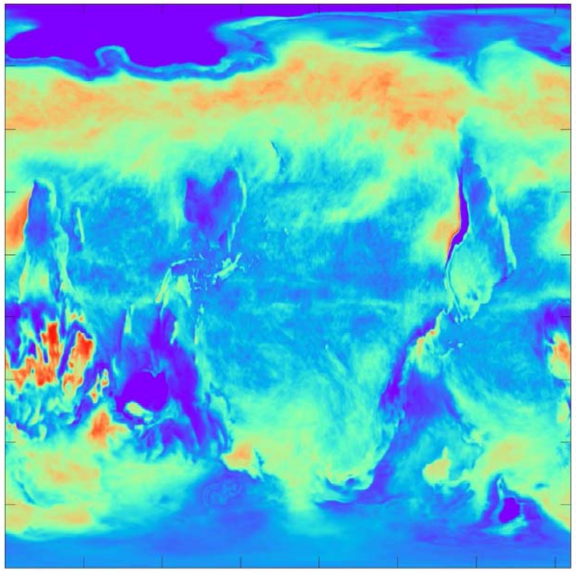
- Overall visualization of original data vs. decompressed data



Original data



(a) Abs_Err_Cmpr

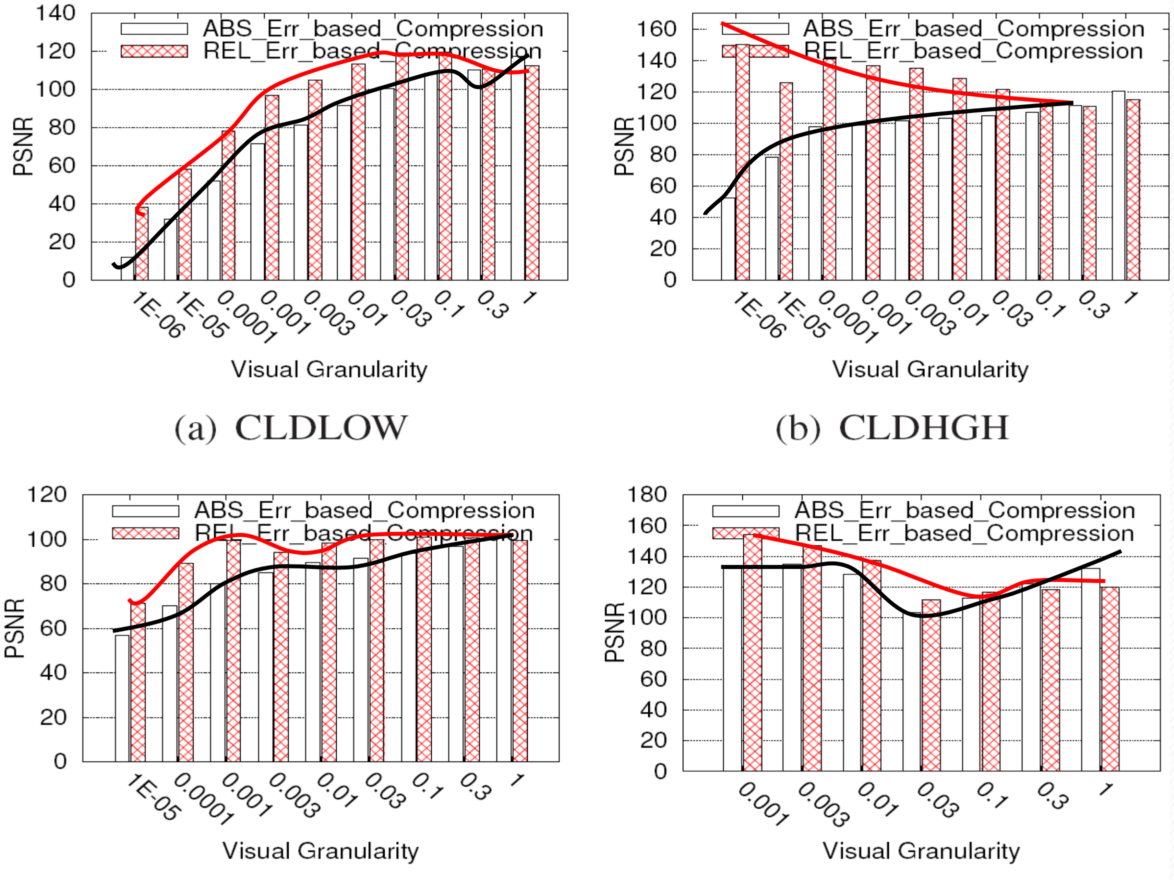


(b) Rel_Err_Cmprs

← Decompressed data

Evaluation (Cont'd)

- Evaluation of PSNR with different visual granularity
  - REL_CMP
    - Red curve
  - ABS_CMP
    - Black curve

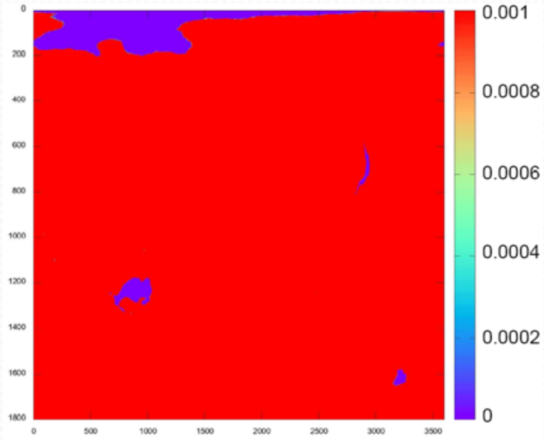


(a) CLDLOW (b) CLDHGH

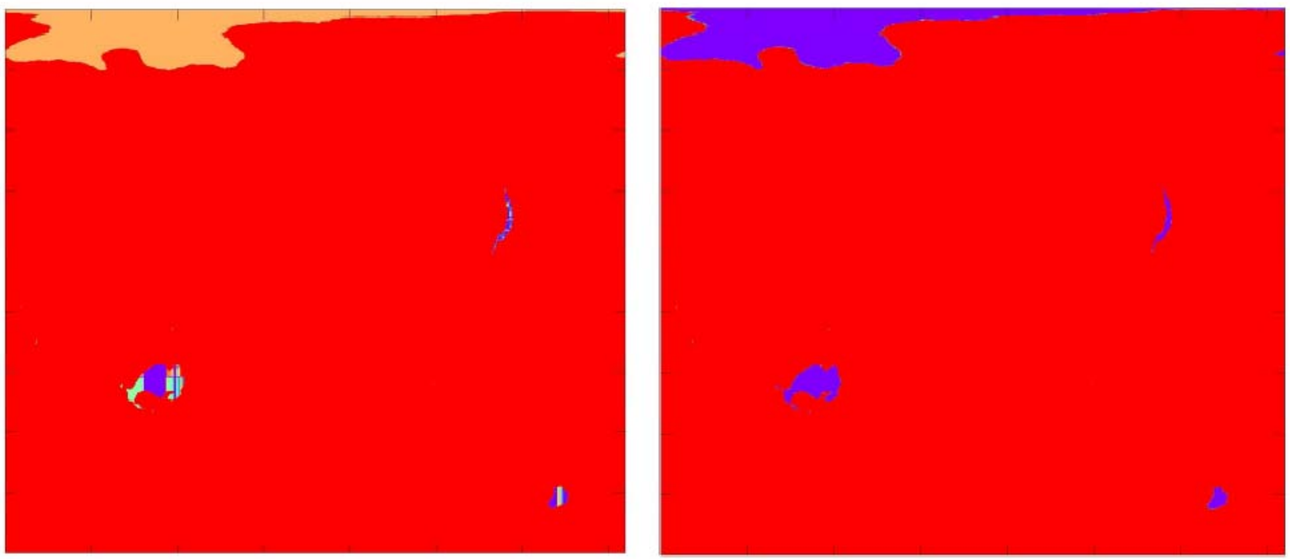
(c) FLDSC (d) PHIS

Evaluation (Cont'd)

- Comparison of the original data and decompressed data with two compress modes, respectively, using the field CLDLOW in the value range [0,0.001].



Original data



(a) Abs_Err_Compression (b) Rel_Err_Compression

Decompressed data

Conclusion

- Design and Implementation:
  - We designed and implemented an efficient strategy based on SZ model, for realizing the demand of “point-wise relative error bound”.
- Improvement of Compression Quality:
  - From the perspective of the compression ratio with the same relative-error bound or similar PSNR, our solution is the best in class.
  - The compression ratio under our solution is higher than those of other state-of-the-art compressors by 17.2–618%.
- Feature of Point-wise Relative Error based Compression:
  - The point-wise relative error based compression leads to the same overall reconstructed visualization as did by the absolute error based compression.
  - The point-wise relative error based compression can preserve the details of the visualization much better than the absolute error based compression.
- Future Work
  - Exploring more effective strategies to improve the compression quality.