Revisiting Wavelet Compression for Large-Scale Climate Data using JPEG 2000 and Ensuring Data Precision

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Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

Introduction: Use Case

- Los Alamos scientist (New Mexico)
  - Computational Ocean Modeler
- Data at Oak Ridge (Tennessee)
  - Parallel Ocean Program (POP)
  - 3600x2400x42 structured grid
  - Typically wants scalar fields (temp, salt, u, v)
- Limited Bandwidth (1MB/s)
  - We don't control arbitrary endpoints
  - Bandwidth issues for various situations that are beyond our control.

Related Work

- Large Data
  - Creates data movement issues
- Distance Visualization
  - Has bandwidth limited channels exacerbating data movement problems
- In situ analysis
  - A response to data movement
- Compression
  - Attempt to have less data movement

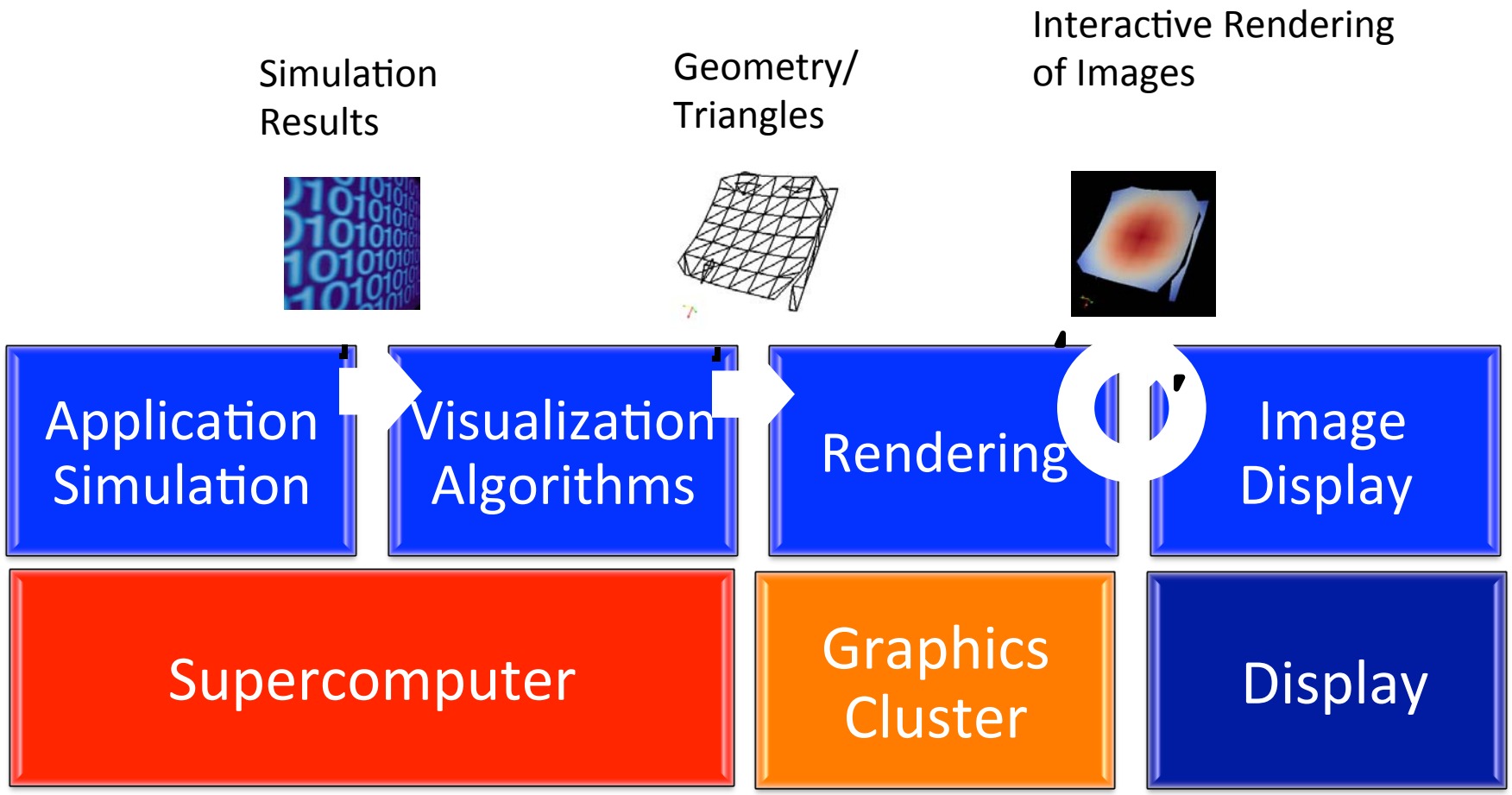
Related Work: Data Compression

- Wavelets have been used extensively for data reduction and multiscale visualization
- Non-wavelet techniques have been developed by vis community for compression, quantization, and multiresolution
- We leverage the signal processing and data compression communities by using JPEG 2000

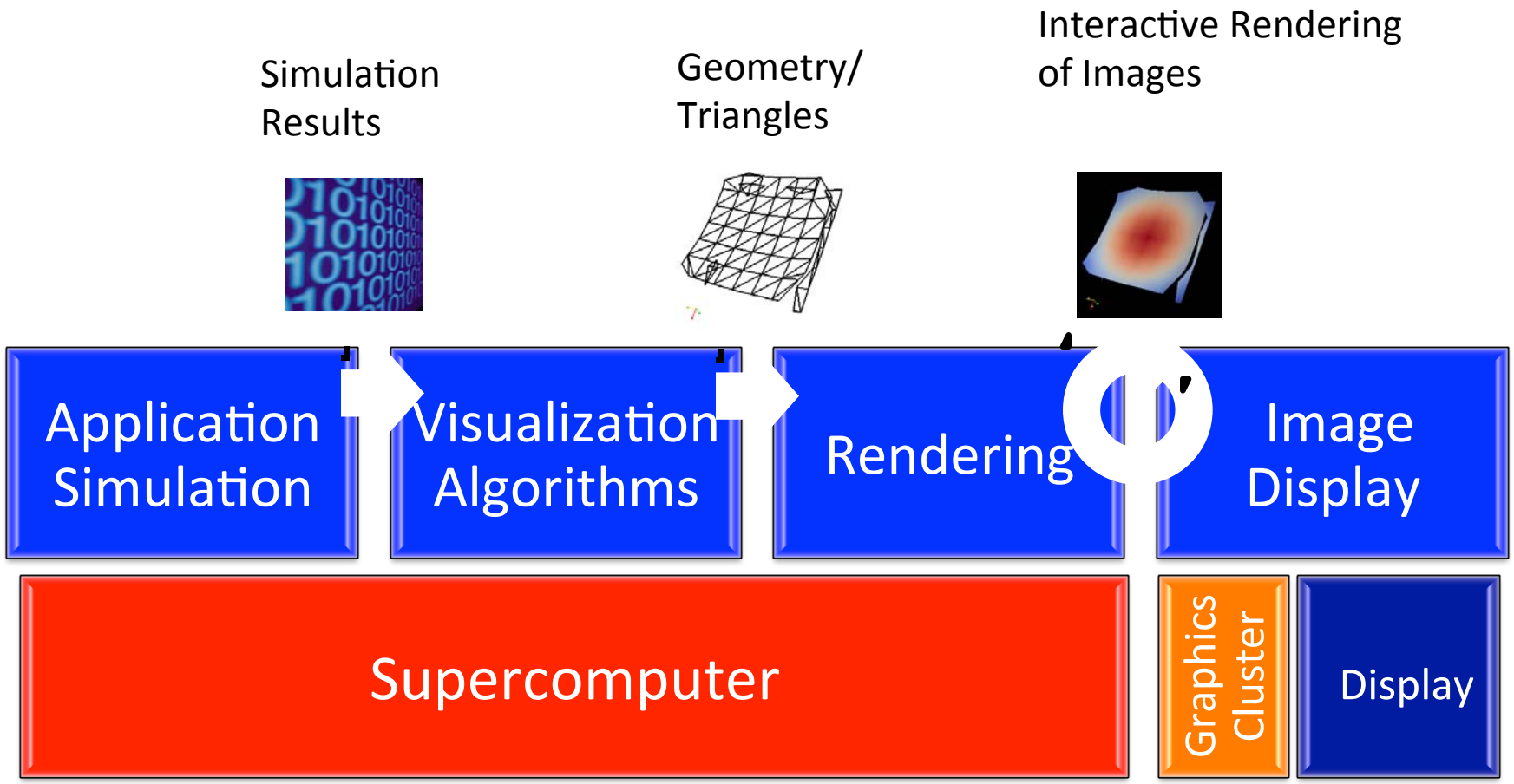
Related Work: Wavelets

- J. Clyne, P. Mininni, A. Norton, and M. Rast. Interactive desktop analysis of high resolution simulations: Application to turbulent plume dynamics and current sheet formation. *New Journal of Physics*, 9(8):301–301, 2007.
- S. Muraki. Approximation and rendering of volume data using wavelet transforms. *Proceedings of the 3rd conference on Visualization '92*, pages 21–28, 1992. ACM ID: 949694.
- J. Woodring and H. Shen. Multiscale time activity data exploration via temporal clustering visualization spreadsheet. *IEEE Transactions on Visualization and Computer Graphics*, 15(1):123–137, 2009.
- Z. Zhu, R. Machiraju, B. Fry, and R. Moorhead. Wavelet-based multiresolutional representation of computational field simulation datasets. In *Visualization '97., Proceedings*, pages 151–158. IEEE, Oct. 1997.
- S. Guthe, M. Wand, J. Gonser, and W. Strasser. Interactive rendering of large volume data sets. In *Visualization Conference, IEEE*, pages 50–60, Los Alamitos, CA, USA, 2002. IEEE Computer Society.
- I. Ihm and S. Park. Wavelet-based 3D compression scheme for very large volume data. In *Graphics Interface*, pages 107–116, 1998.
- T. Kim and Y. Shin. An efficient wavelet-based compression method for volume rendering. In *Computer Graphics and Applications, 1999. Proceedings. Seventh Pacific Conference on*, pages 147–156, 1999.
- F. Rodler. Wavelet based 3D compression with fast random access for very large volume data. In *Computer Graphics and Applications, 1999. Proceedings. Seventh Pacific Conference on*, pages 108–117, 1999.
- A. Trott, R. Moorhead, and J. McGinley. Wavelets applied to lossless compression and progressive transmission of floating point data in 3-D curvilinear grids. In *Visualization '96. Proceedings.*, pages 385–388. IEEE, Nov. 1996.
- C. Wang, J. Gao, L. Li, and H. Shen. A multiresolution volume rendering framework for Large-Scale Time-Varying data visualization. In *Volume Graphics, 2005. Fourth International Workshop on*, pages 11–223, 2005.
- R. Westermann. A multiresolution framework for volume rendering. *Proceedings of the 1994 symposium on Volume visualization*, page 51–58, 1994. ACM ID: 197963.

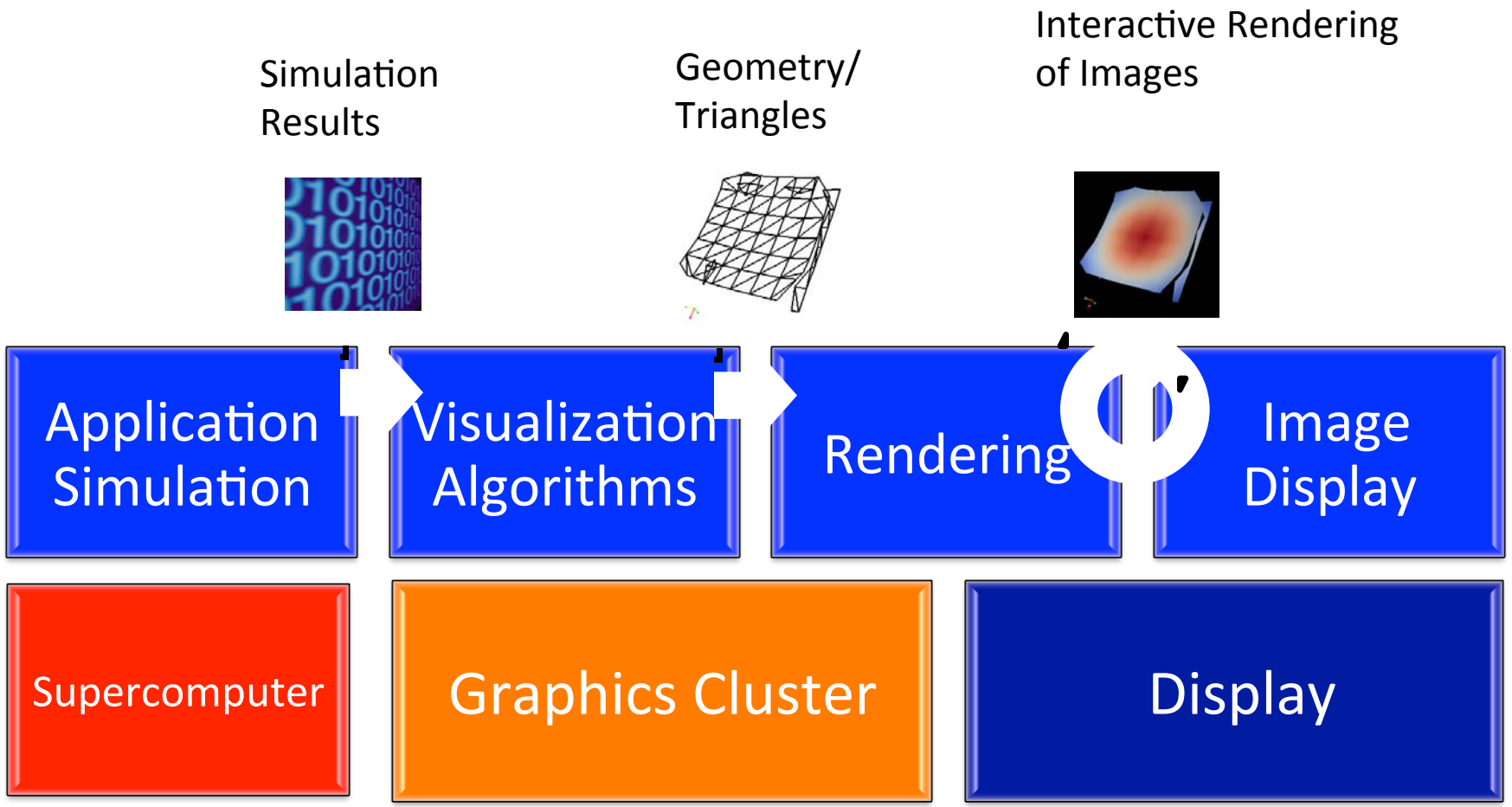
Related Work: Send Geometry



Related Work: Send Imagery



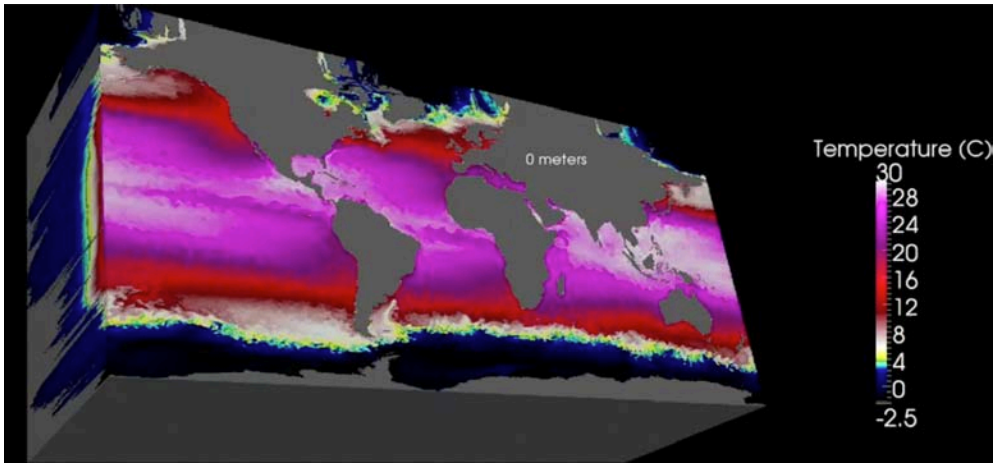
Our Approach: Send Data



Our Approach: Data Compression with Quantified Accuracy

- In visualization and image processing, data compression and the resulting error has been measured as average difference
  - concerned with reducing visual quality differences
- Compression directly in-situ on simulation data as a data reduction mechanism
  - our research focus is to quantify the maximum/L-infinity norm (rather than average/L2 norm) data quality for scientific analysis
  - Provide a solution that automatically compresses simulation data with accuracy guarantees
- (Simulation Data – Compressed Representation) provides an accuracy metric

Our Approach: Compression-Decompression Pipeline



Original Floating Point Data

Masking (Global Average)

Quantization (PCM)

Compression (JPEG2000)

Network

Decompression (JPEG2000)

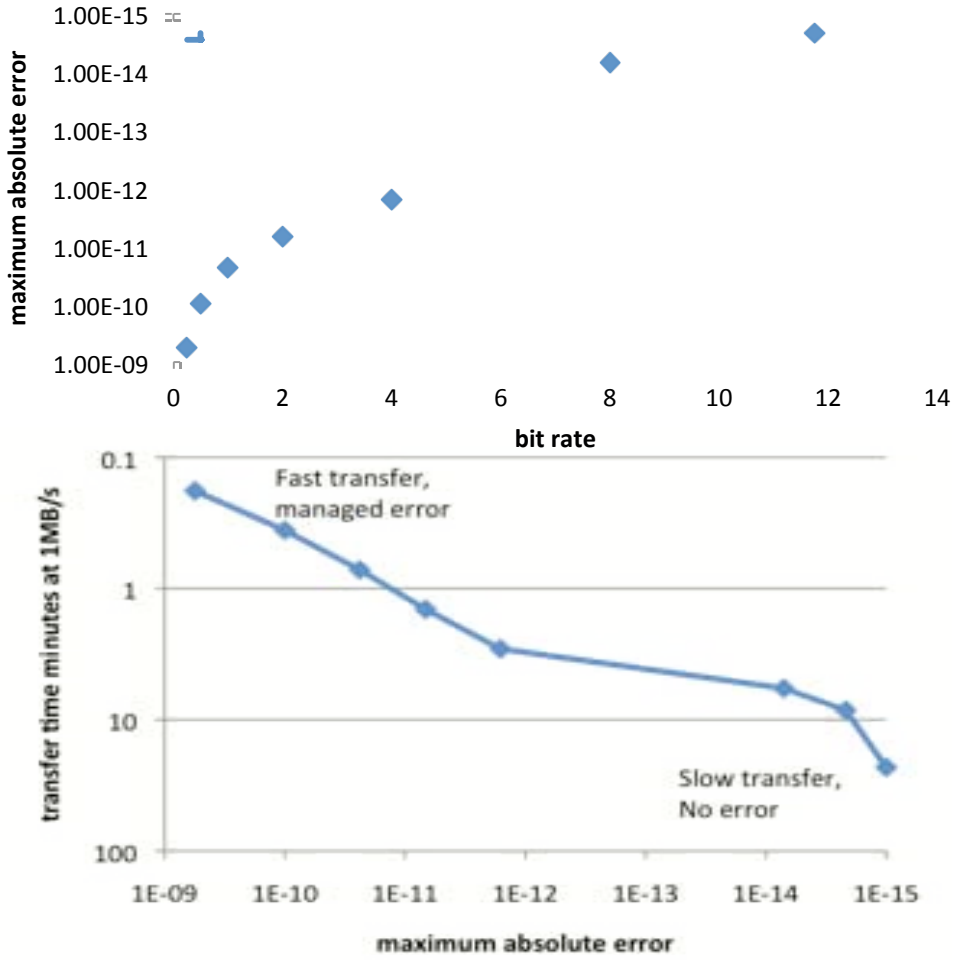
Dequantization (PCM)

UnMasking

Reconstructed Floating Point Data

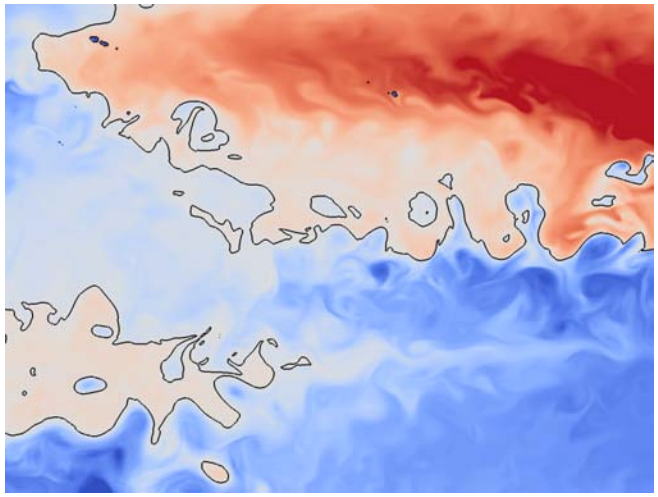
Quantify the Maximum Error (L-infinity norm) so the Scientist Knows the Data Precision

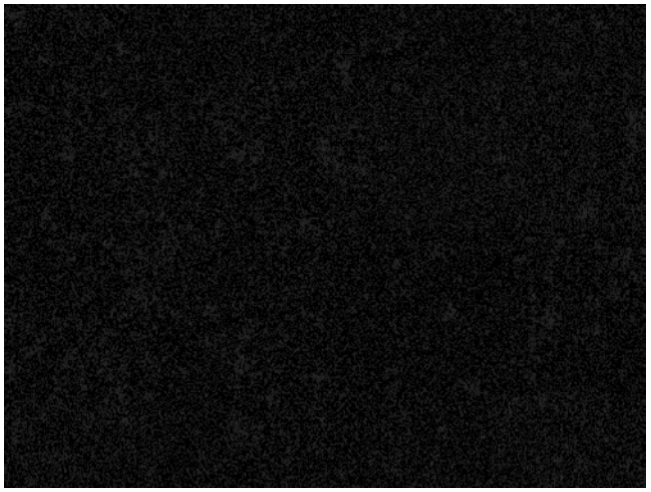
- We measure the maximum point error so there is a guarantee that the data are accurate to *x* decimal places
- The user can trade read I/O time vs. data accuracy in a quantifiable manner



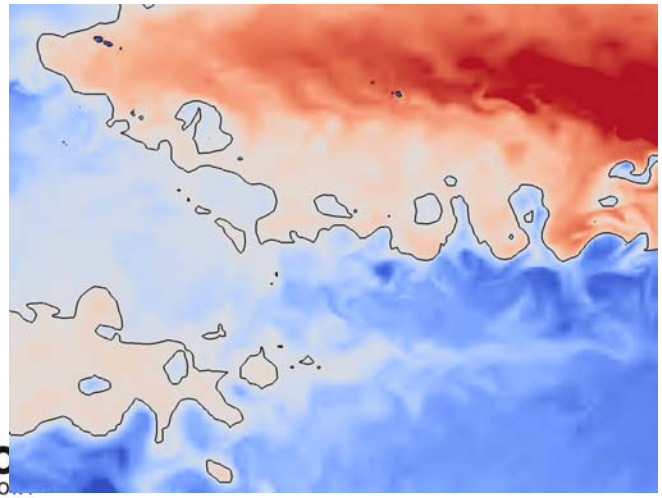
Results: Data Differencing

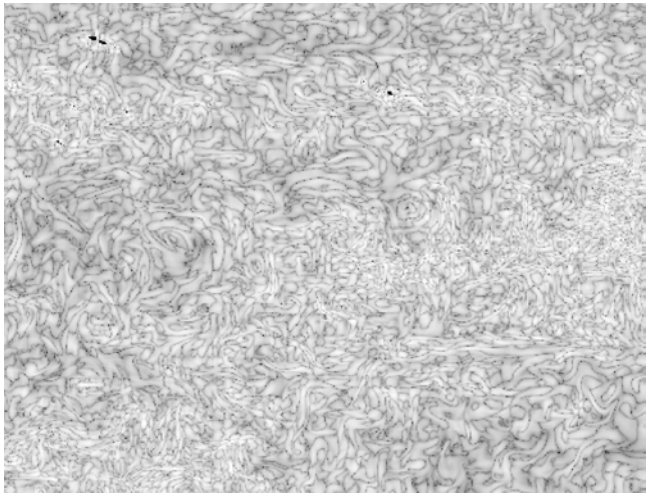
Bitrate = 8
Max Error
=1.49e-09
345 MB





Bitrate = .25
Max Error
=0.000303
11 MB





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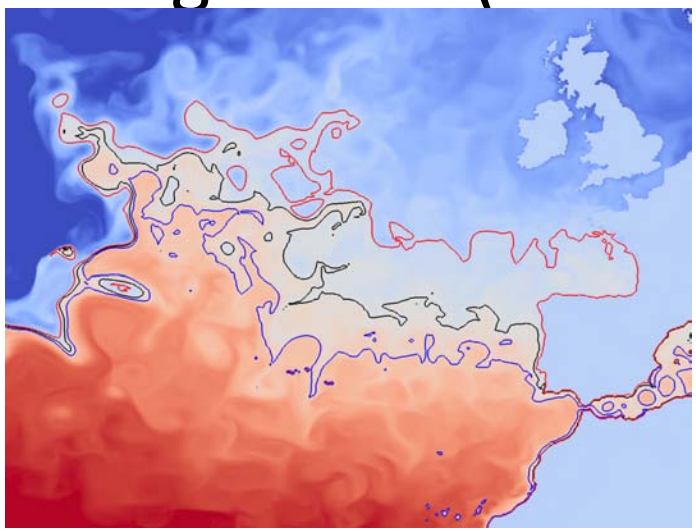
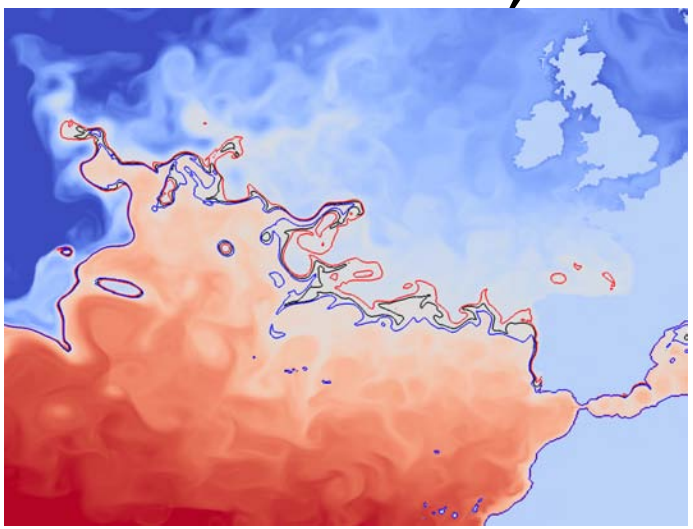
Isovalues on Compressed Simulation Data with Bounding Error - (32 bits, 3200x2400x42, 1.4 GB)

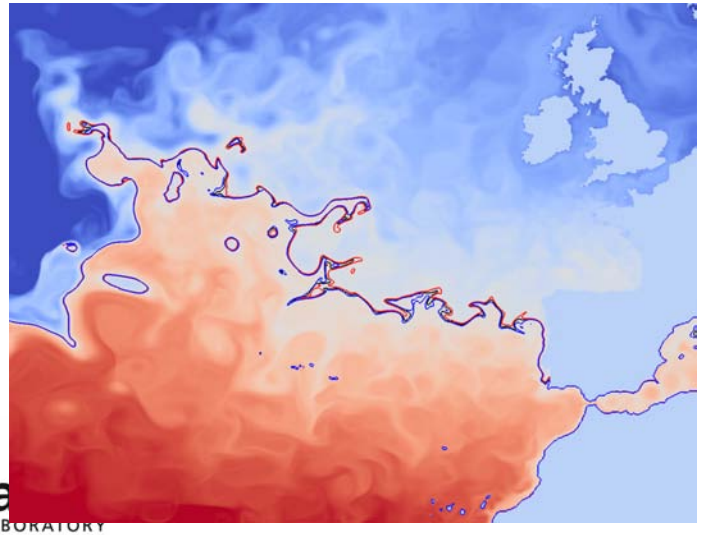
0.25 bits
10.8 MB

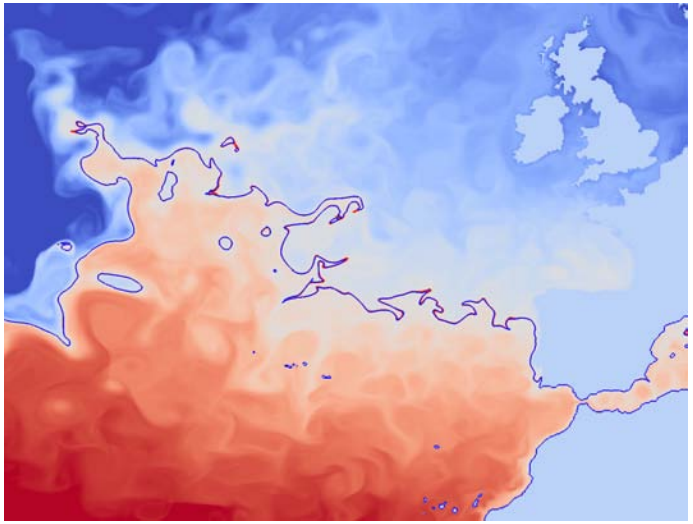




0.5 bits
21.6 MB

1.0 bits
43.3 MB





2.0 bits
86.5 MB

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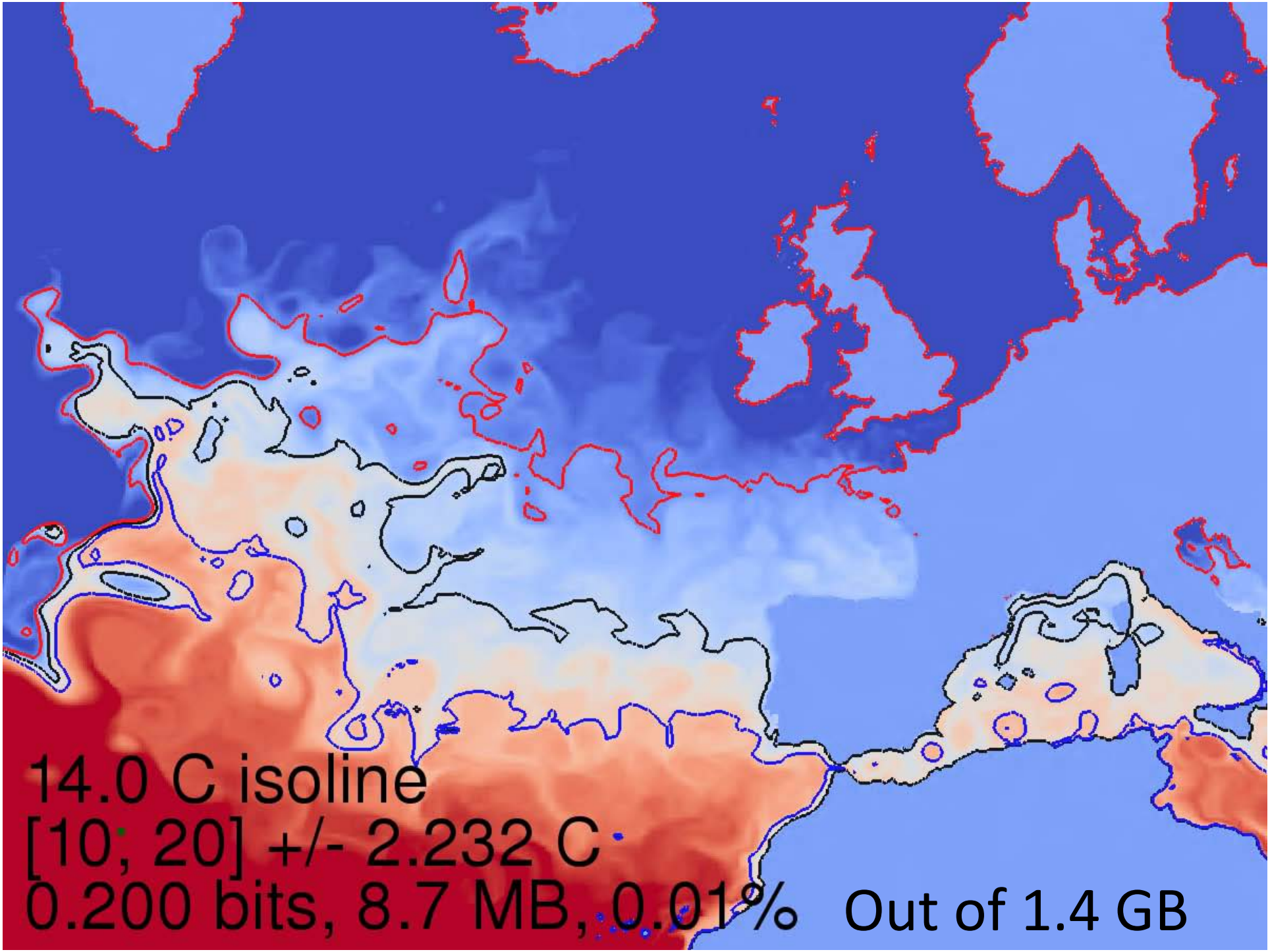
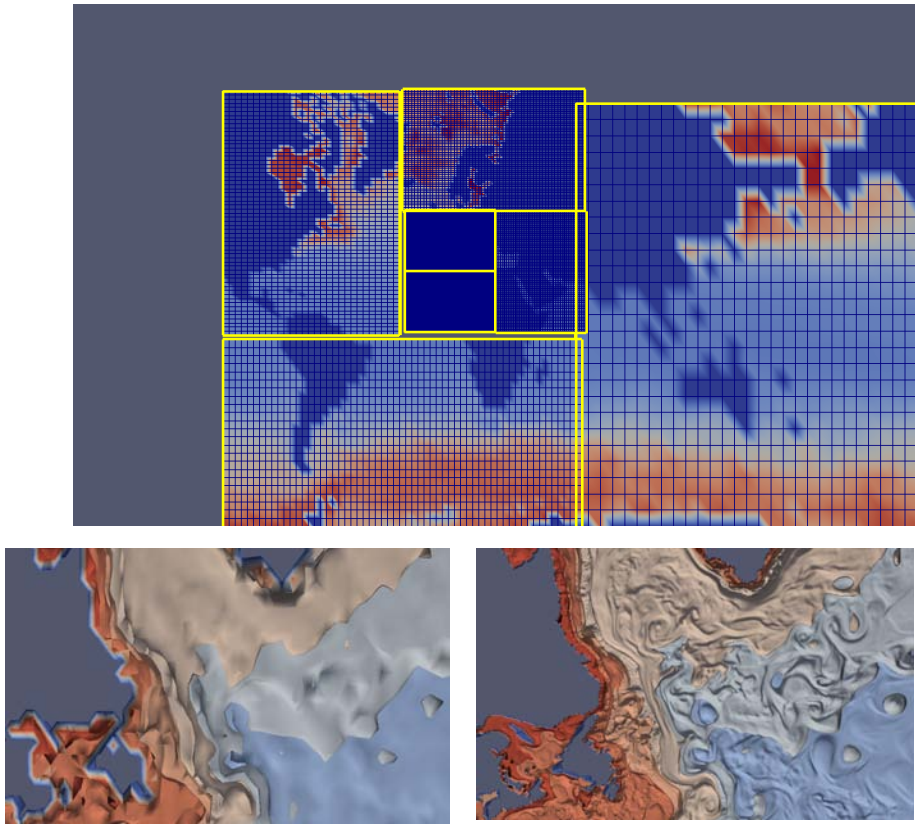
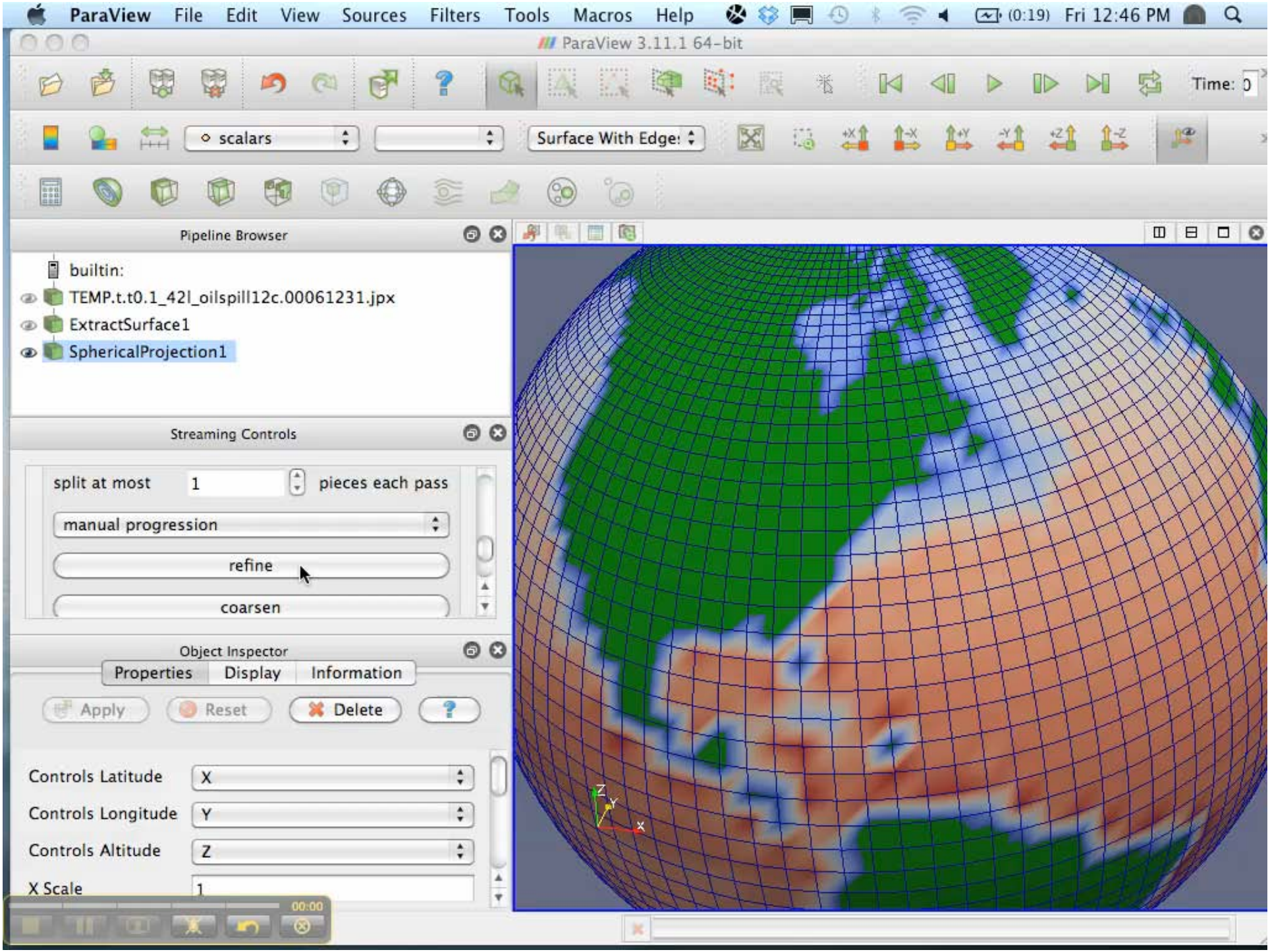

14.0 C isoline
[10; 20] +/- 2.232 C
0.200 bits, 8.7 MB, 0.01% Out of 1.4 GB

Multi-resolution Compression and Streaming

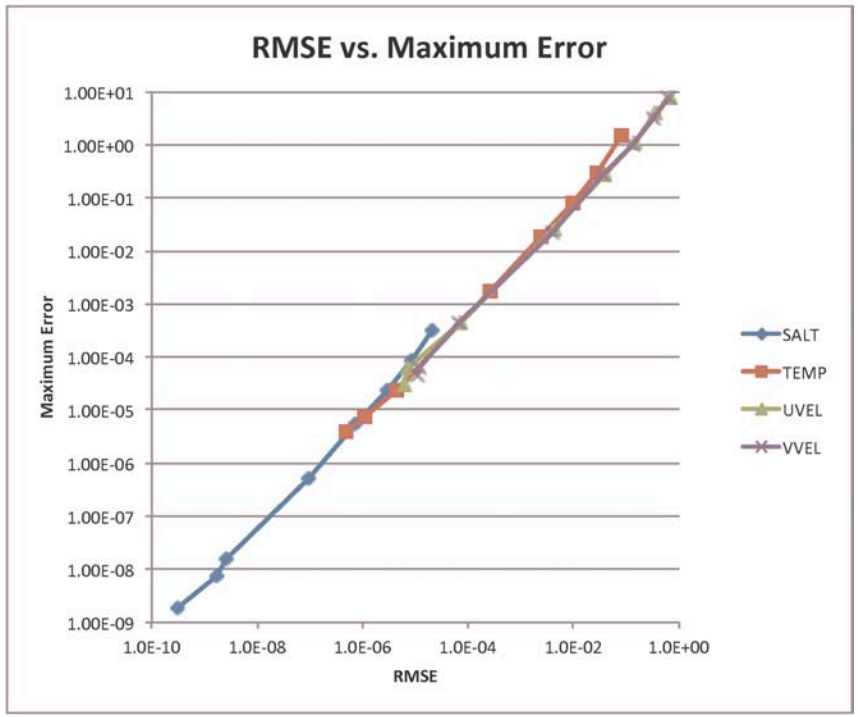
- A multi-resolution representation of simulation data is created using spatial compression or sampling
- View in a multi-resolution visualization and analysis tool
- Mat Maltrud, Climate Scientist, LANL: "This new distance visualization technology will increase our productivity by significantly reducing the amount of time spent in transferring and analyzing our remote data."

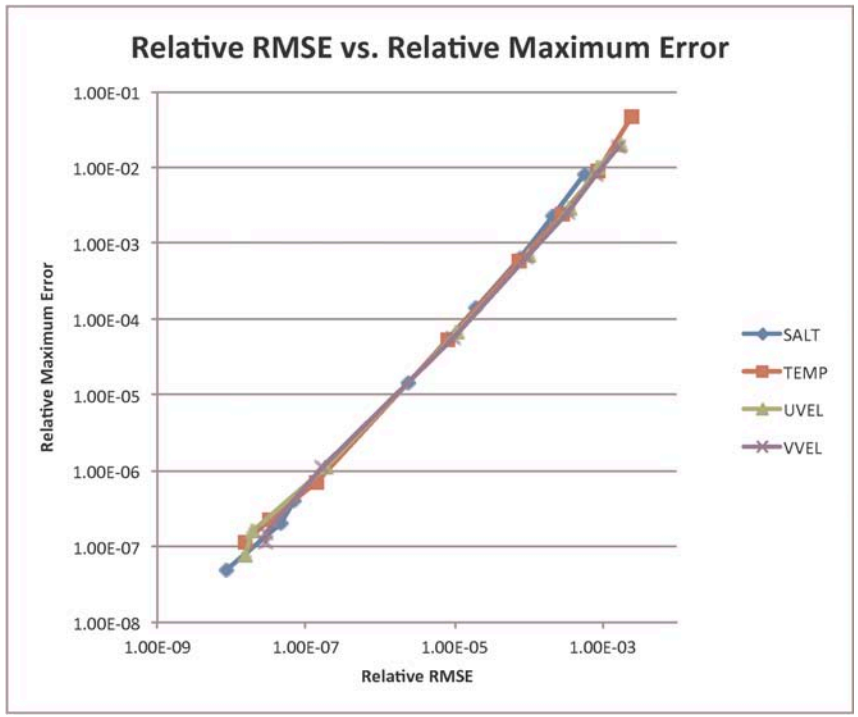


Images from multi-resolution streaming ParaView


ParaView File Edit View Sources Filters Tools Macros Help
ParaView 3.11.1 64-bit
Time: 0
scalars
Surface With Edge:
Pipeline Browser
builtin:
TEMP.t.t0.1_42l_oilspill12c.00061231.jpx
ExtractSurface1
SphericalProjection1
Streaming Controls
split at most 1 pieces each pass
manual progression
refine
coarsen
Object Inspector
Properties Display Information
Apply Reset Delete
Controls Latitude X
Controls Longitude Y
Controls Altitude Z
X Scale 1

RMSE vs. Relative Max Error





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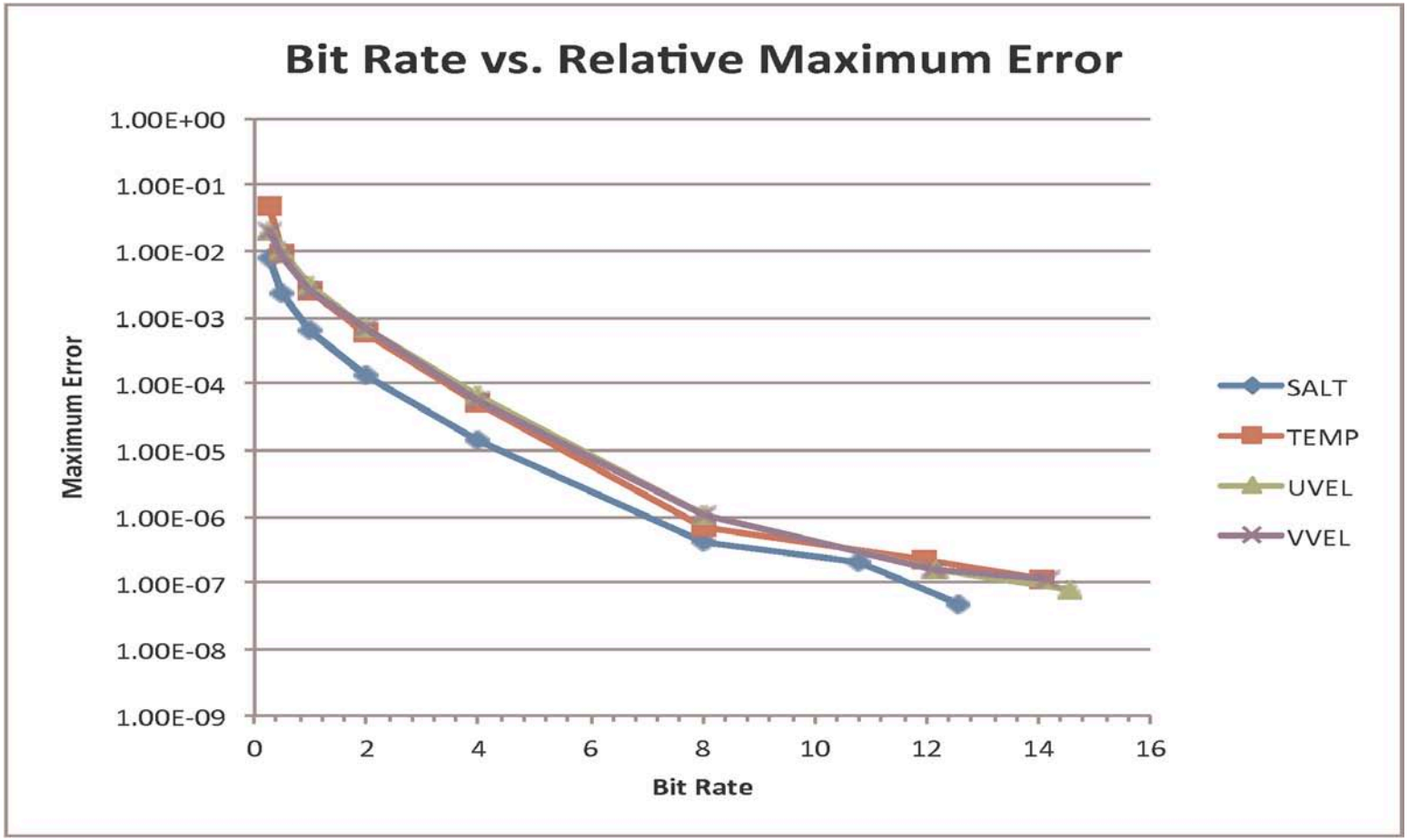
Relationship between bit rate and Maximum Error



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