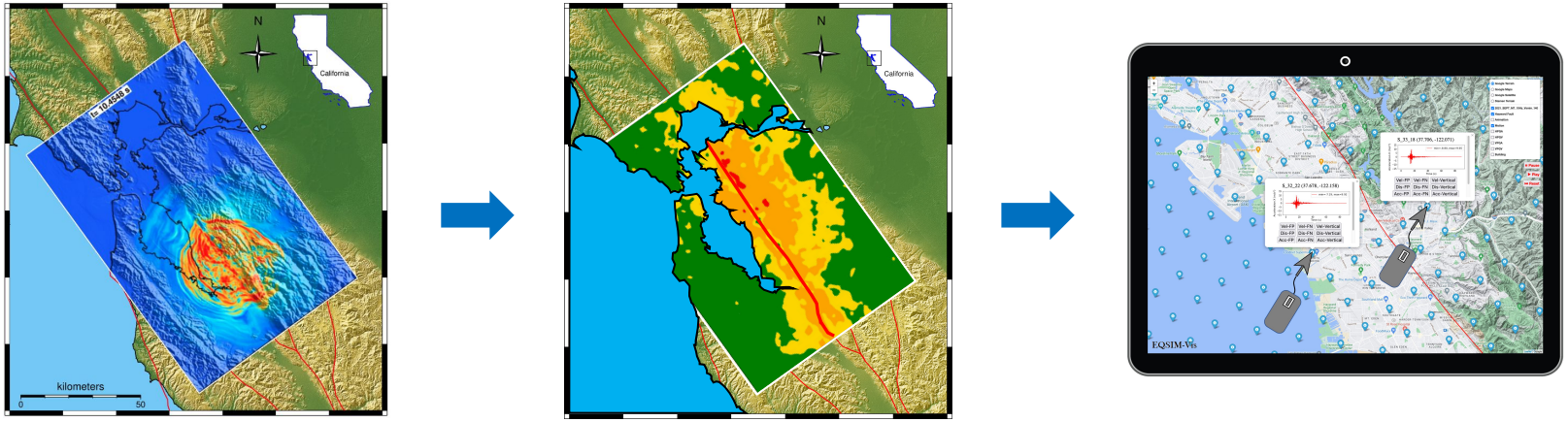

Scalable Data Schemas for Effective and Efficient Management of Simulated Ground Motion Datasets

A PEER – LBNL workshop

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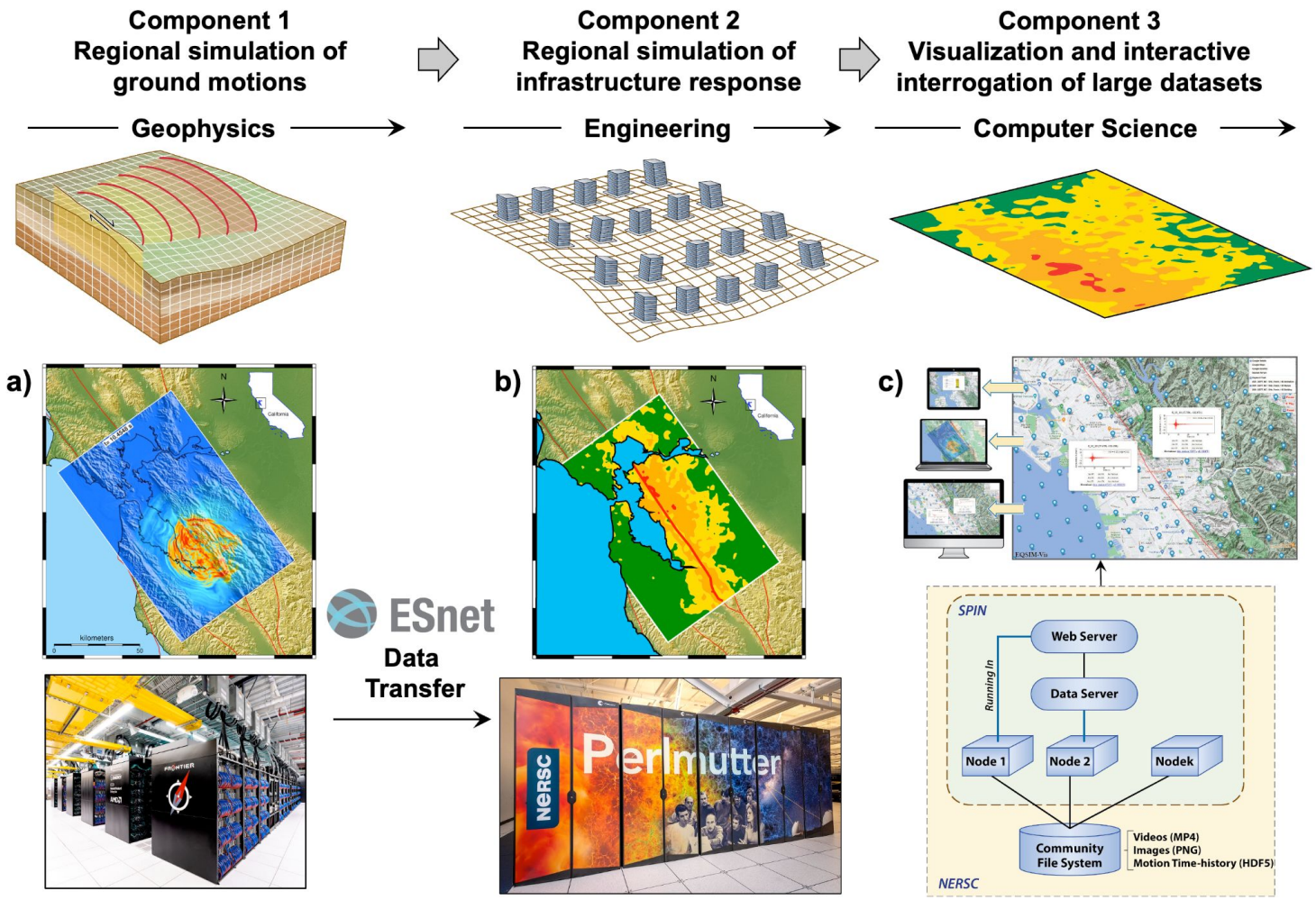
U.S. DEPARTMENT OF ENERGY | Office of Cybersecurity, Energy Security, and Emergency Response

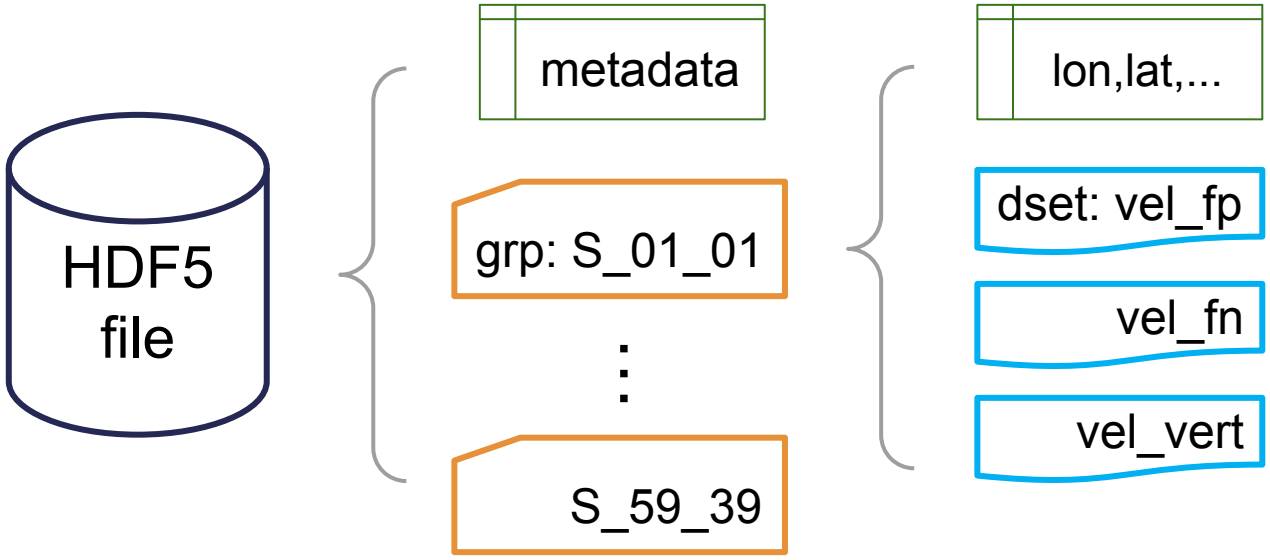
EXASCALE COMPUTING PROJECT

Data management in the EQSIM workflow



Managing EQSIM data with HDF5

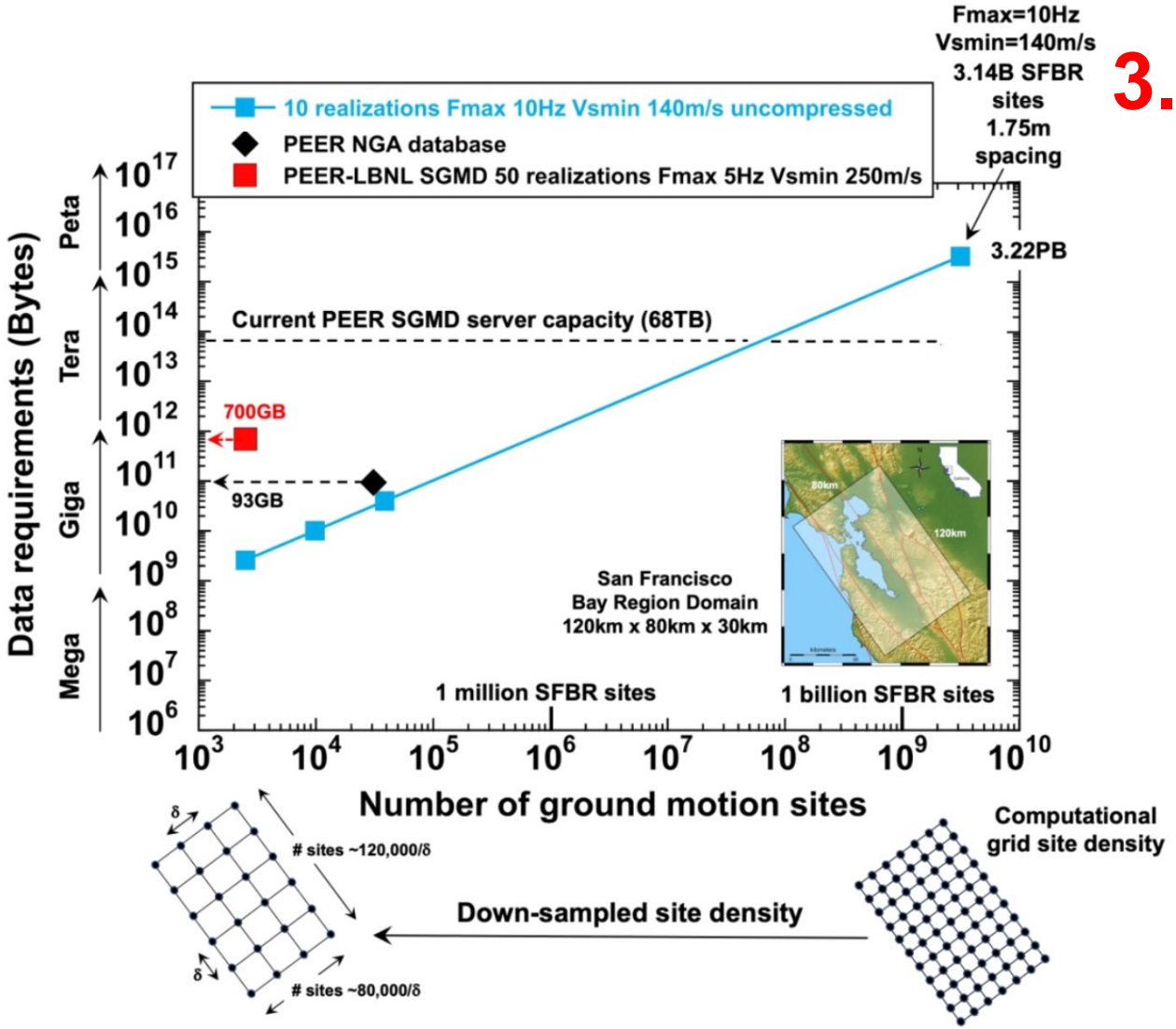
- HDF5 (Hierarchical Data Format v5) is a data model, library, and file format for managing large and complex scientific data.
  - Fast parallel I/O, easy cross platform sharing, keep metadata with data.
  - Maintained for over 25 years and widely adopted by the scientific community and the industries.



Challenges in EQSIM data management

- ***5Hz*** Hayward Fault simulations, Vs_{min}=250, 120x80km domain
  - 512 Frontier nodes, 6 machine hours for 90s simulation time
  - **2km** spacing, 2,301 x {FP, FN, Vert} ground velocity motions
    - dt=1.2ms, ~**2GB** each, **110GB** total for 50 runs
    - SGMD >**700GB** total of {vel,acc,disp}x{FP,FN,Vert} in ASCII format
  - **6.25m** spacing, **246 million** x {FP, FN, Vert} ground velocity motions
    - Downsample 16x, dt=19ms, ~**25TB** each, **1.2PB** total for 50 runs
- ***10Hz*** Hayward Fault, Vs_{min}=250
  - 3072 Frontier nodes, 10 machine hours for 90s simulation time
  - **3.125m** spacing, **1 billion** x {FP, FN, Vert} ground velocity motions
    - Downsample 15x, dt=9ms, **208TB** each

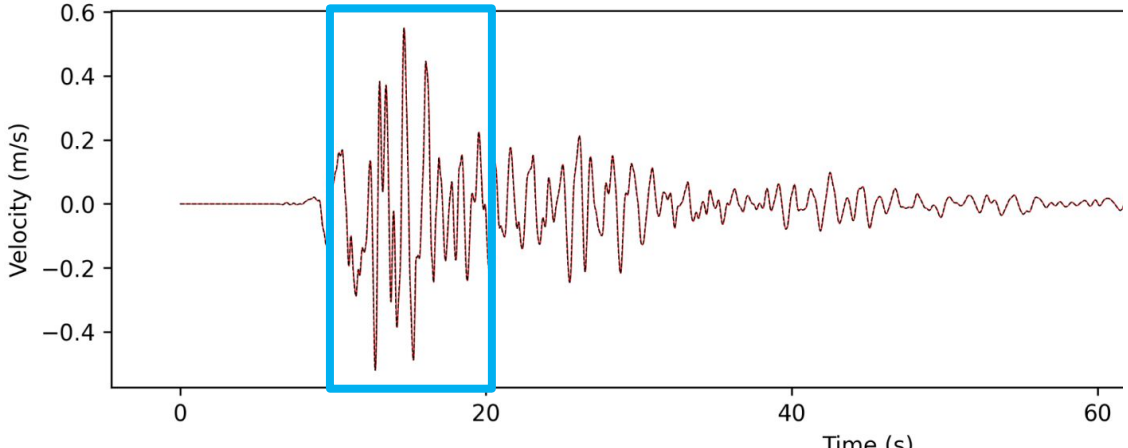
Data becomes impractical to store

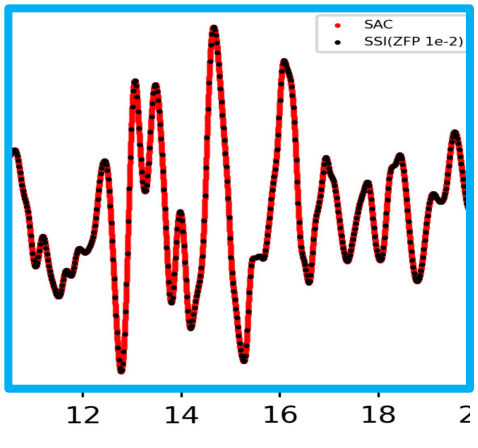


3.22PB

We need data reduction

- Lossless vs lossy compression
  - Split data into small “chunks”, often exploits similarity in values of nearby elements
    - [1.401, 1.419, 1.431, 1.445]
    - find deltas from 1.401 [0, 0.018, 0.03, 0.044]
    - store the deltas with compact encoding to reduce the size, 32→20 bytes
  - Lossless preserves all information, 1.401→ z_0 →**1.401**
  - (Error-bounded)Lossy discards some information, 1.401→$z_{0.01}$→**1.407**/**1.399**/…
  - Compression ratio: lossless often **< 2**, lossy can be **10 to 100**

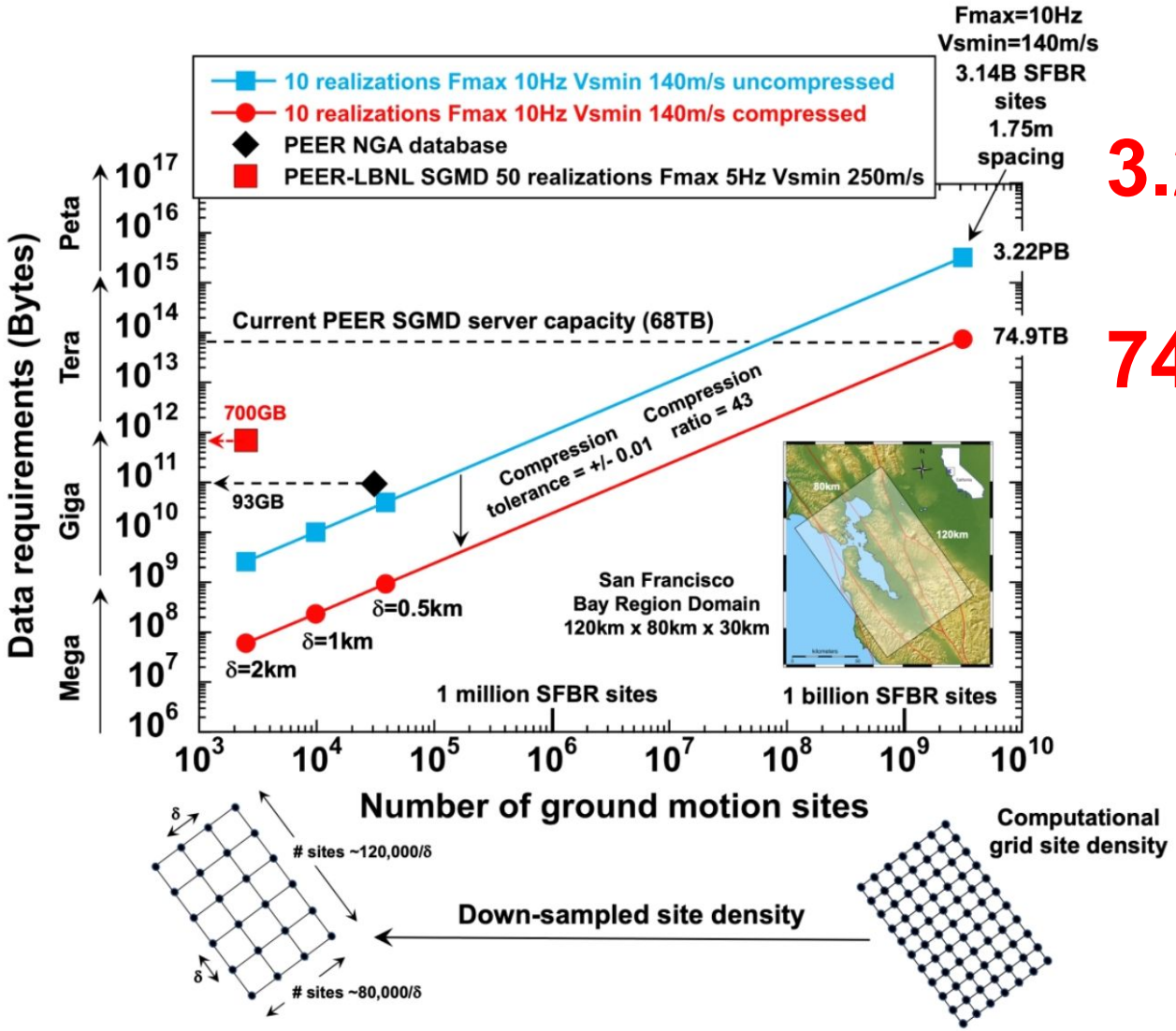




Data reduction through lossy compression

- ***5Hz*** Hayward Fault simulations, Vs_{min}=250, 120x80km domain
  - **6.25m** spacing, **246 million** x {FP, FN, Vert} ground velocity motions
    - ZFP-compressed HDF5 file, error bound=0.01, dt=19ms
    - ~**25TB** compressed to ~**290GB**.
    - 50 runs: **1.2PB** compressed to **14TB**.
- ***10Hz*** Hayward Fault, Vs_{min}=250
  - **3.125m** spacing, **1 billion** x {FP, FN, Vert} ground velocity motions
    - ZFP-compressed HDF5 format, error bound=0.01, dt=9ms
    - 1 run: **208TB** compressed to **4TB**

Data reduction through lossy compression



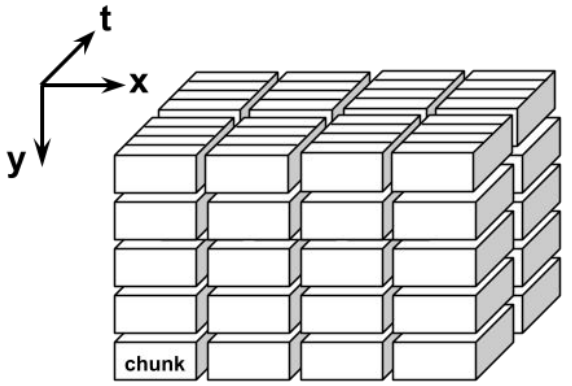
3.22PB

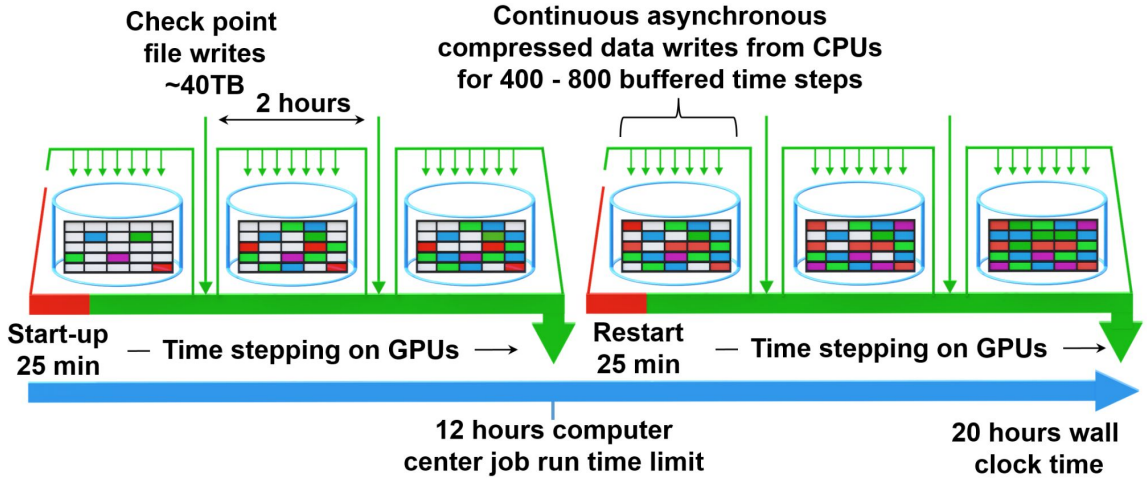
↓

74.9TB

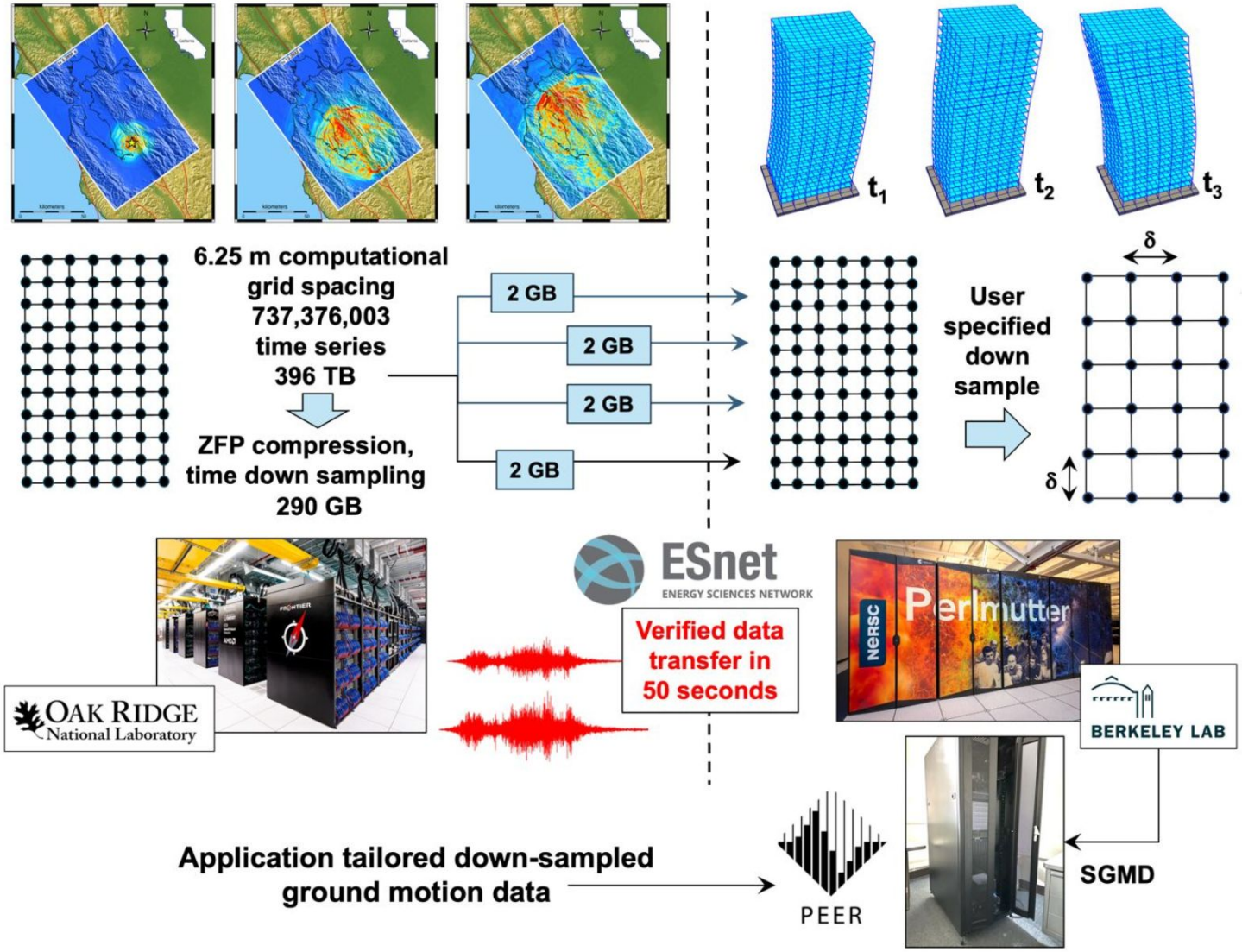
Optimizing parallel data write during simulation

- HDF5 data chunking
  - Required by compression
  - More contiguous writes
- Data buffering
  - Reduce the number of writes
  - More efficient parallel I/O
- Asynchronous I/O
  - Overlaps computation with I/O utilizing idle CPU cores when GPU is computing





Managing data across facilities

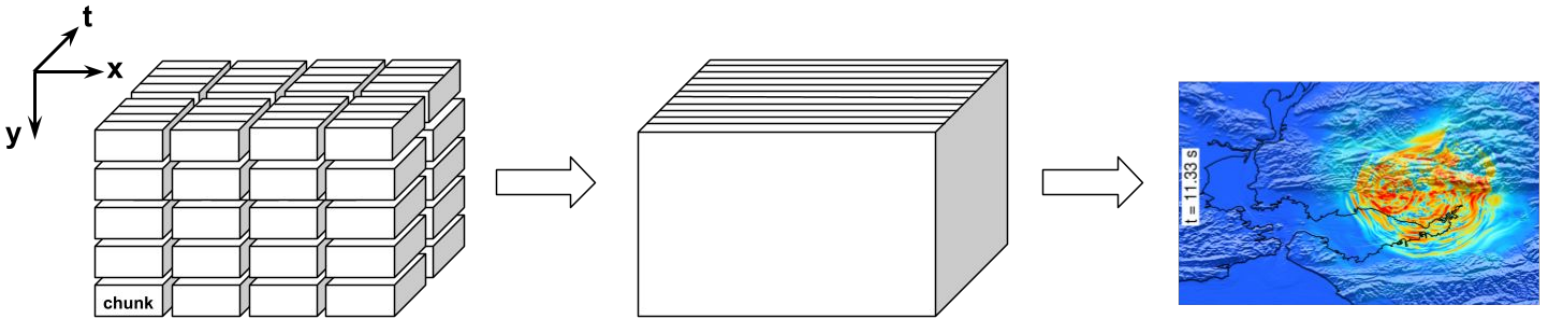


Optimizing data read for analysis and visualization

- Data uses write-optimized chunked (t,x,y,z) layout
- Visualization needs individual (x,y) cross-sections

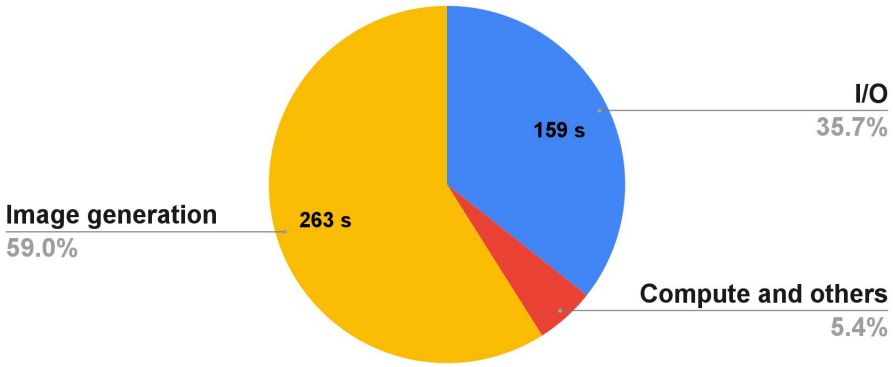
} **mismatch**

- Serial data access is too slow
  - Original serial code to generate animation takes several **hours**
- Efficient parallel data access must be **chunk-aware**
  - Distribute the workload with chunk-aligned domain decomposition
  - Read entire chunk (instead of row) and cache in memory for data extraction

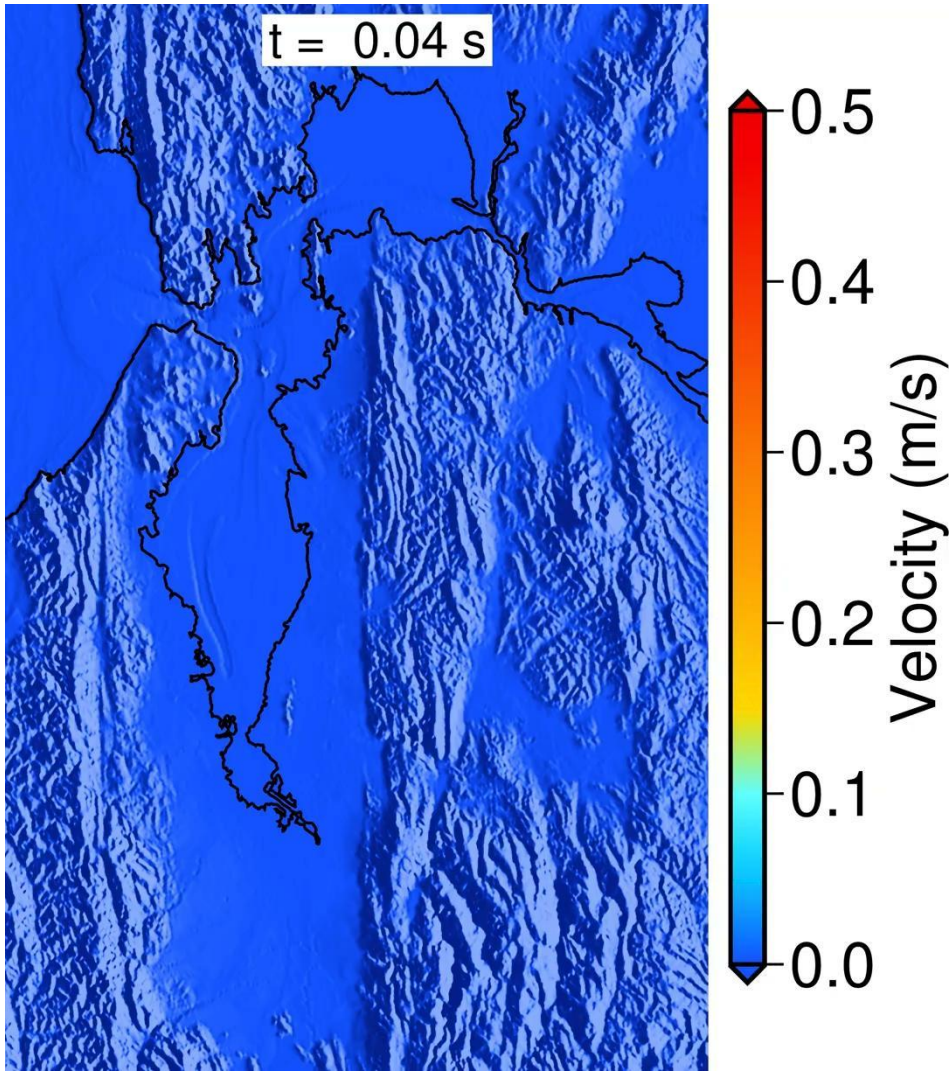


Chunk-aware parallel processing

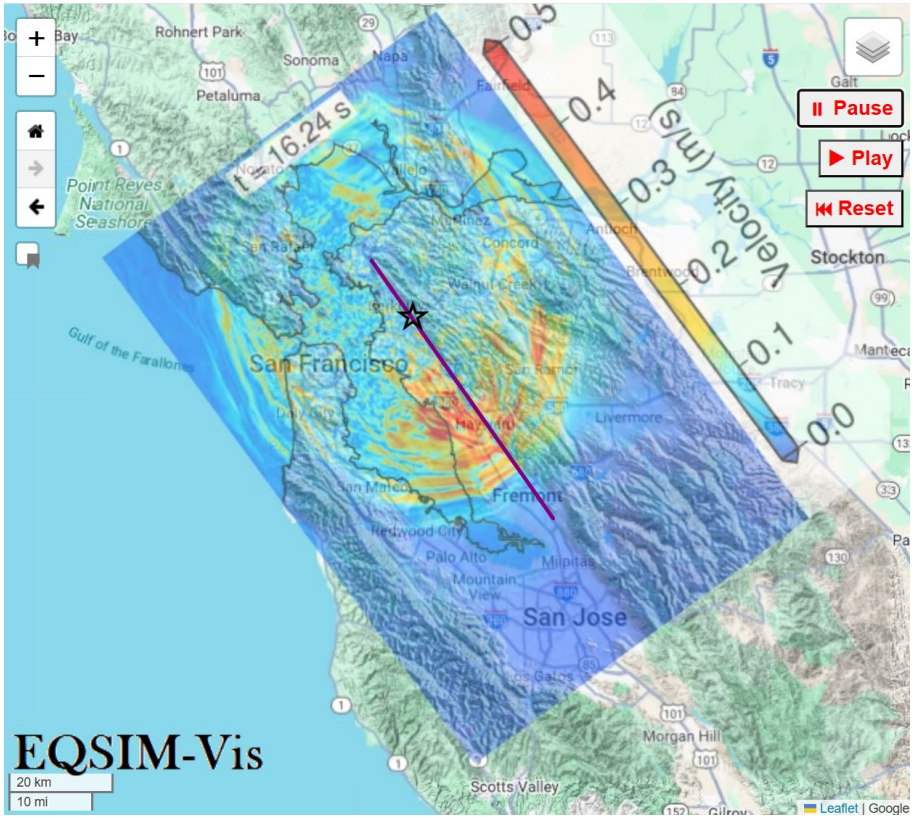
- **2 horizontal components**
- **190 GB** compressed data (ZFP lossy, accuracy=0.01)
- **9 TB** uncompressed
- Downsample in time (2x) space (10x)
- Serial processing takes **10+ hours**

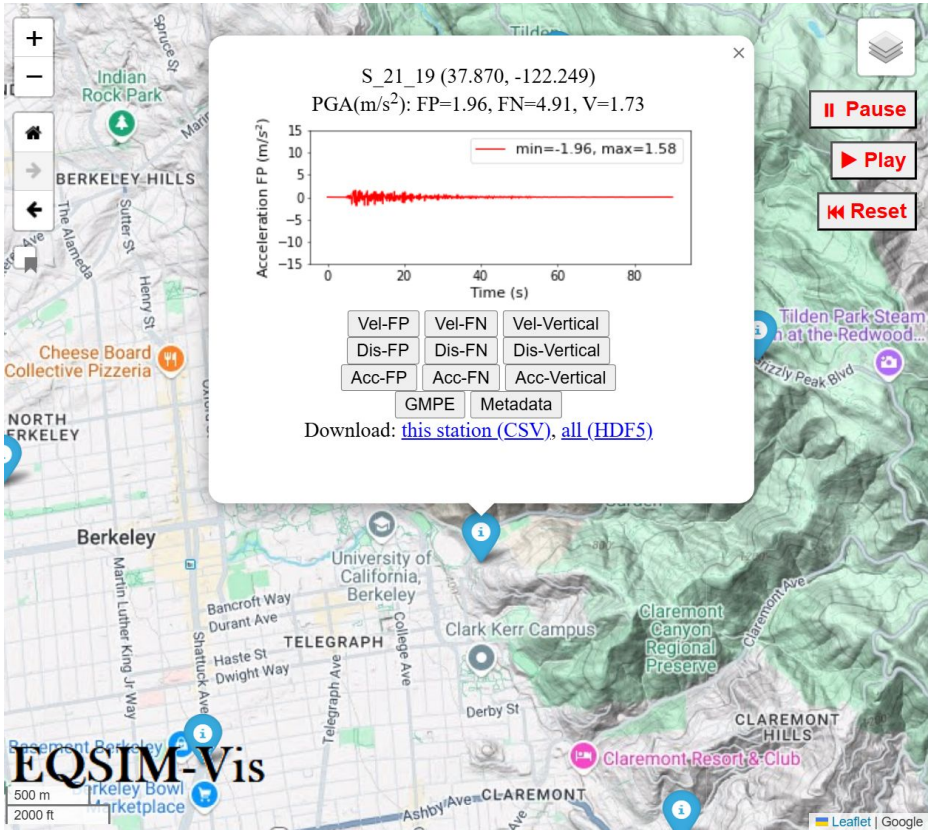


7 minutes on 8 Perlmutter nodes with chunk-aware processing



EQSIM-Vis: inspect ground motions on an interactive map





Summary

- HDF5 is effective for managing large data
  - Cross-platform, multi-language support (C, Python, MATLAB)
  - Self-describing, stores metadata together with data
  - Efficiently parallel I/O
  - Transparent compression support
- Effective error-bounded lossy compression can significantly reduce the total data size.
- Storage-aware parallel processing is key to efficient data analysis and visualization
- Visualization tools such as EQSIM-vis enables efficient data inspection.

Thanks!

Questions?

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