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NASA'S EARTH OBSERVING SYSTEM
DATA AND INFORMATION SYSTEM

OPeNDAP[1] and HDF5[2] in the Cloud: Techniques and Best Practices for Serving HDF5 data

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1 Open-source Project for a Network Data Access Protocol
2 Hierarchical Data Format 5

Outline

- Considerations for HDF5 files
  - HDF5 and netCDF-4 interoperability
  - CF[1] conventions
  - HDF5 best practices
    - General considerations
    - Advanced HDF5 features
- Considerations for Amazon S3[2] access via OPeNDAP
  - Reduce initial latency
  - Optimize transfer time
  - Reduce post-transfer processing

1 Climate Forecast Conventions
2 Amazon Simple Storage Service

Considerations for HDF5 files

HDF5/ netCDF-4[1] Interoperability

- To assure maximum interoperability with netCDF-4 use the following:
  - Hierarchical HDF5 file (no loops and multiple parents in a file structure)
  - Creation order on links and attributes
  - Simple numeric datatypes
  - Gzip compression
  - Dataset with dimension scale attached to each dimension

[1] Network Common Data Form, version 4

HDF5/ netCDF-4 Interoperability (cont’d)

- Attributes
  - Scalar or one-dimensional attributes
  - Avoid using these datatypes:
    - Fixed size strings
    - Compound datatype
    - Long double
  - Use UTF-8[1] encoding for names encoding
  - Attribute name should begin with a letter and be composed of letters, digits, and underscores
  - See Unidata documentation

[1] Unicode Transformation Format 8-bit

HDF5/ netCDF-4 Interoperability (cont'd)

- How to achieve netCDF-4 compatibility?
  - Use netCDF-4 library
  - Use augmentation and editing tools
    - Tools modify the existing HDF5 file!

Augmentation and Editing Tools

- Use tools to make HDF5 file netCDF-4 compatible
  - HDF-EOS5[1] augmentation tool
    - Adds dimension scales
  - HDF5 JPSS[2] augmentation tool
    - Hides unsupported data (region references)
    - Adds dimension scales
    - Adds geolocation information
  - HDF5 editing tool (attributes only)
    - Add/modify attributes to make them CF compliant

[1] Hierarchical Data Format - Earth Observing System library and file format, version 5

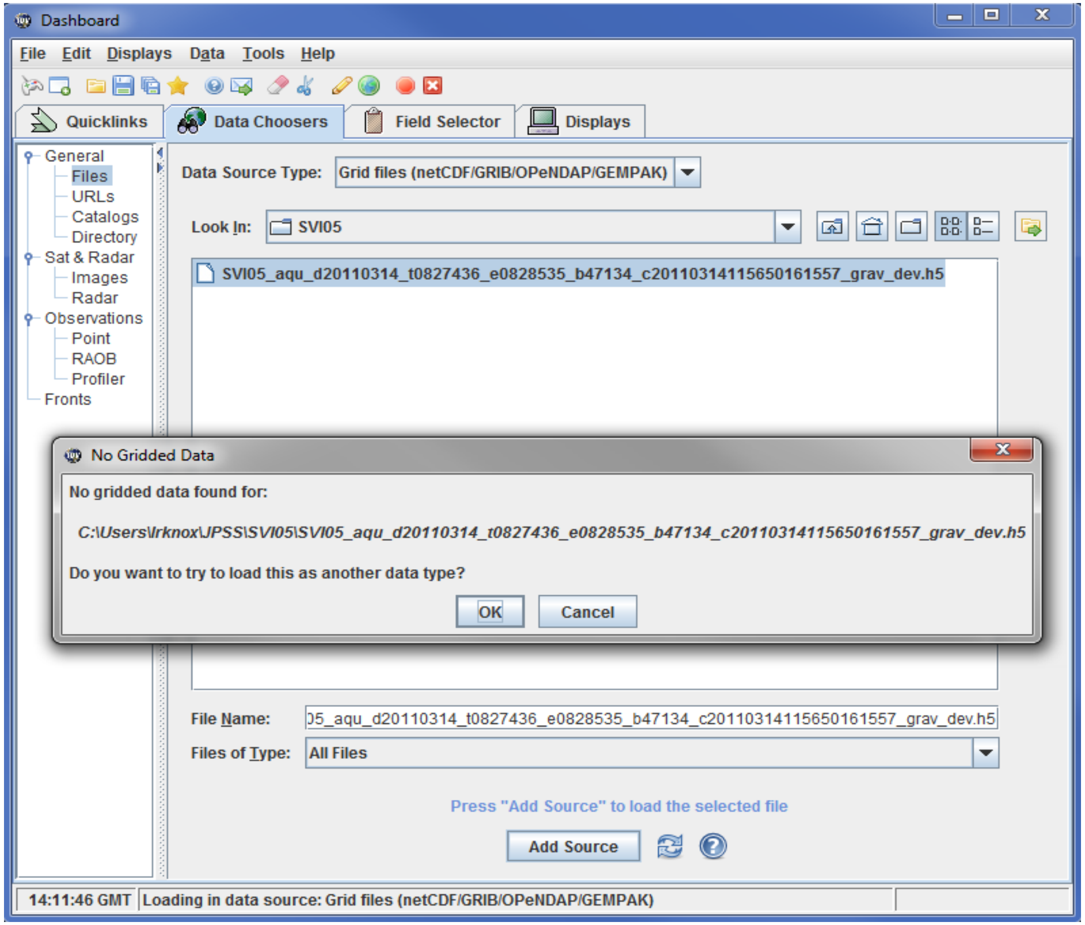
[2] Joint Polar Satellite System

Climate and Forecast (CF) Metadata

- HDF5 attributes
  - long_name
  - units
  - coordinates
  - scale_factor
- To learn more
  - ESDS-RFC-028v1.3 *“Data Interoperability Recommendations for Earth Science”*, Charles S. Zender, Peter J.T. Leonard, July 2016
  - 423-ESO-036 “Dataset Interoperability Recommendations: Part 2” (DRAFT)

Example: Visualizing JPSS data with IDV[1]

Before



Data Source Type: Grid files (netCDF/GRIB/OPeNDAP/GEMPAK)

Look In: SVI05

SVI05_aqu_d20110314_t0827436_e0828535_b47134_c20110314115650161557_grav_dev.h5

No gridded data found for:

C:\Users\lrknox\JPSS\SVI05\SVI05_aqu_d20110314_t0827436_e0828535_b47134_c20110314115650161557_grav_dev.h5

Do you want to try to load this as another data type?

File Name: 05_aqu_d20110314_t0827436_e0828535_b47134_c20110314115650161557_grav_dev.h5

Files of Type: All Files

Press "Add Source" to load the selected file

14:11:46 GMT | Loading in data source: Grid files (netCDF/GRIB/OPeNDAP/GEMPAK)

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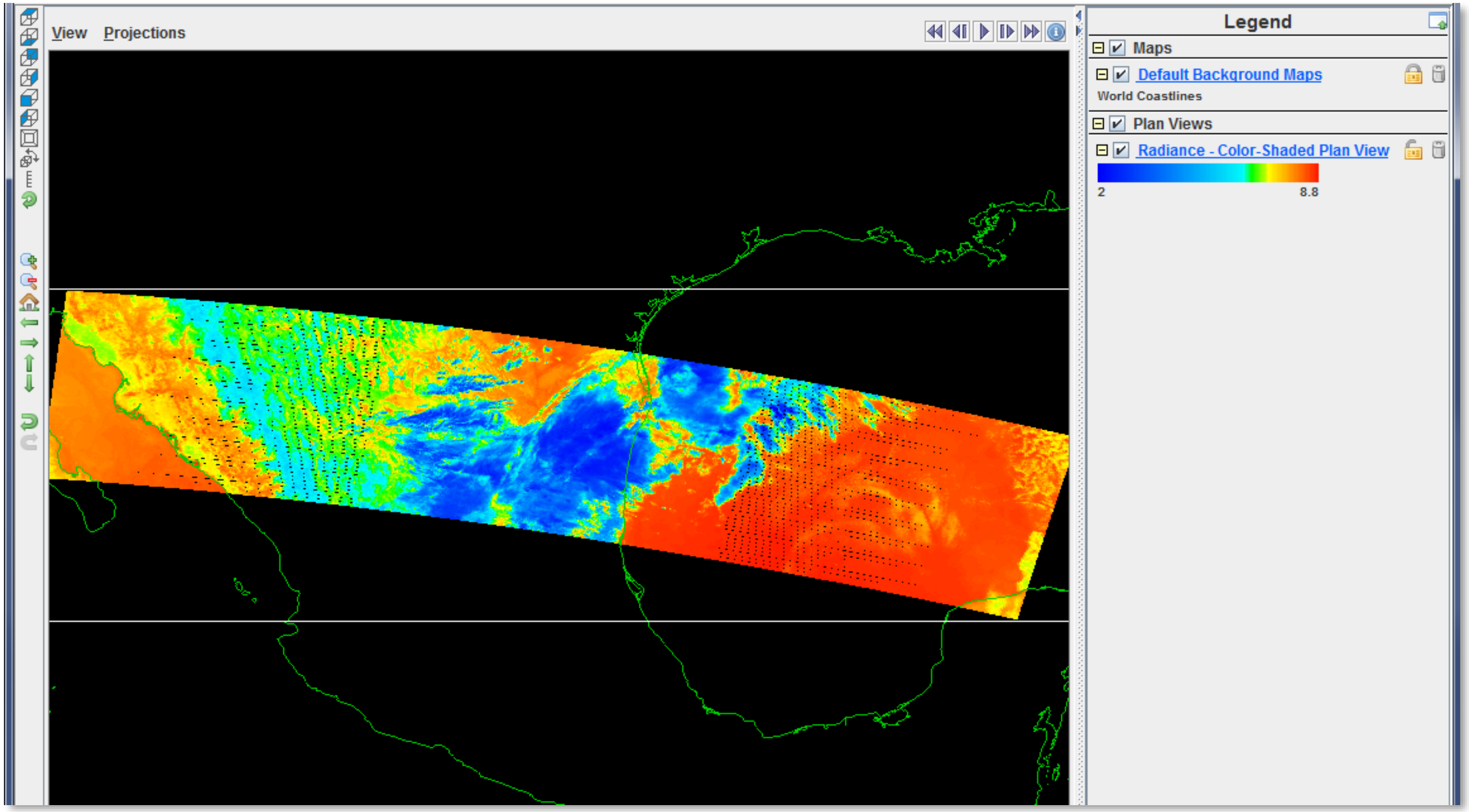
[1] Integrated Data Viewer

Example: Visualizing JPSS data with IDV

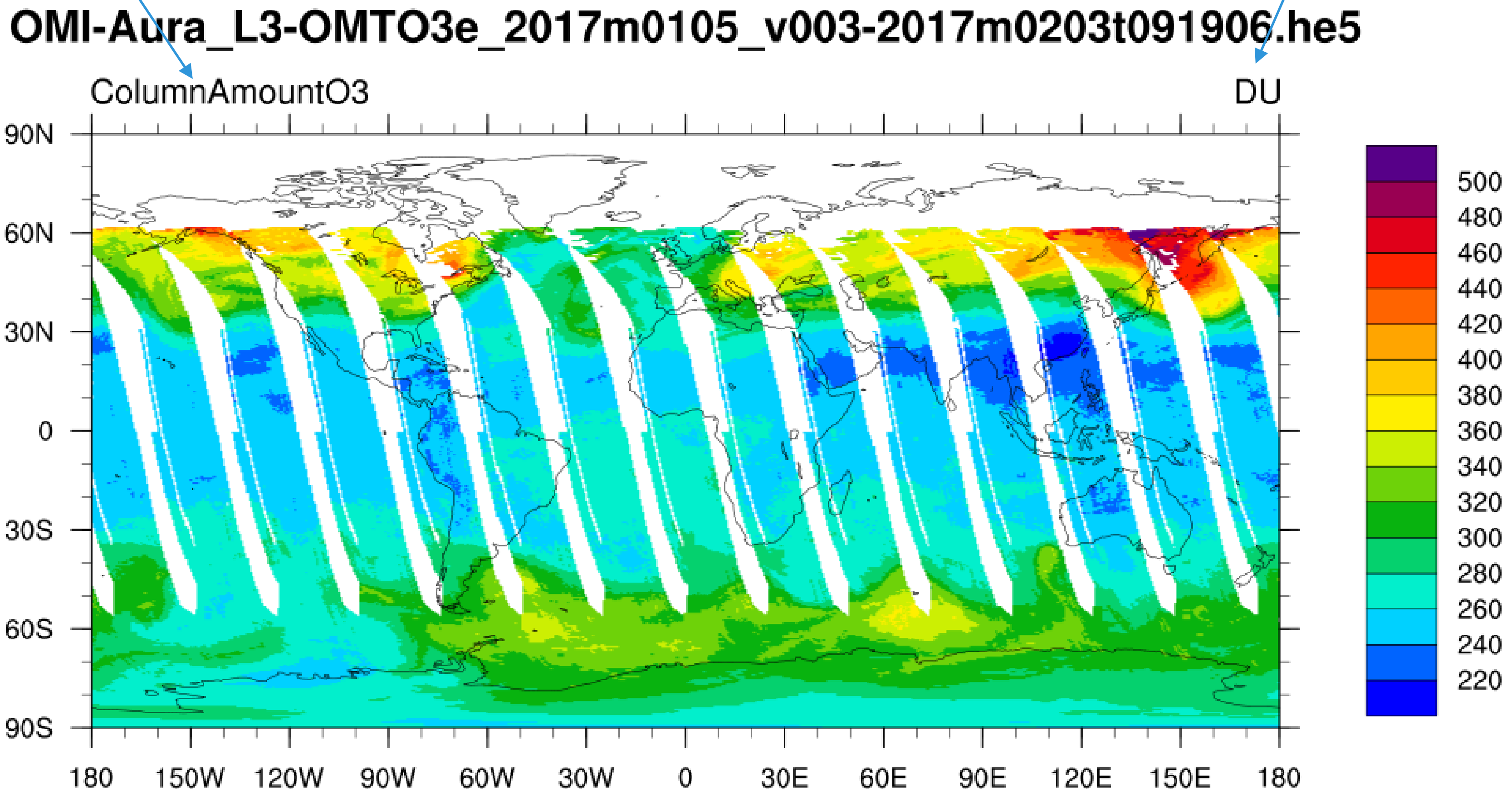


After augmentation and adding CF `scale_factor` and `units` attributes

Example: CF attributes

long_name

units



HDF5 Best Practices

- I*f possible, use the latest HDF5 library releases*
  - Bug fixes
  - Security updated
  - Storage, memory usage and performance optimizations
- Check new features and read how to move to the latest releases without breaking your code.

HDF5 Best Practices

- *Many optimizations are not available by default*
  - To reduce storage size for HDF5 files with many objects and allow better access time set file format to HDF5 1.8.
  - To reduce access time and storage overhead for chunked datasets set file format to HDF5 1.10.
    - Constant look-up speed for chunked datasets with fixed size dimensions

HDF5 Best Practices (cont’d)

- Avoid data duplication by using
  - HDF5 virtual datasets
    - Aggregate data stored in different arrays (HDF5 datasets)
  - Shared attributes, datatypes, dimensional and compression information
    - HDF5 objects can share attributes and other characteristics saving space in the file
  - Contact help@hdfgroup.org to help you with organizing data in HDF5

Considerations for S3 access via OPeNDAP

Hyrax in the Cloud

Hyrax now serves data from S3

- HDF5 data files are subset directly
  - Only those values needed are read
  - This applies to netCDF4, too
  - Extendable to other formats, but…
- Other file types are read from S3 and cached on spinning disk
- Metadata are cached on spinning disk

Considerations for S3 access via OPeNDAP

- Reduce initial latency
- Optimize transfer time
- Reduce post-transfer processing

Reduce Initial Latency

- Reuse connections to S3
- S3 is accessed using HTTP[1]
  - But HTTP uses TCP socket connections
- Open HTTP connections before they are needed
- Re-Open connections that time-out
- Use HTTP 2!
- *This has nothing to do with HDF5 or legacy data. All software that make repeated use of S3 should do this*

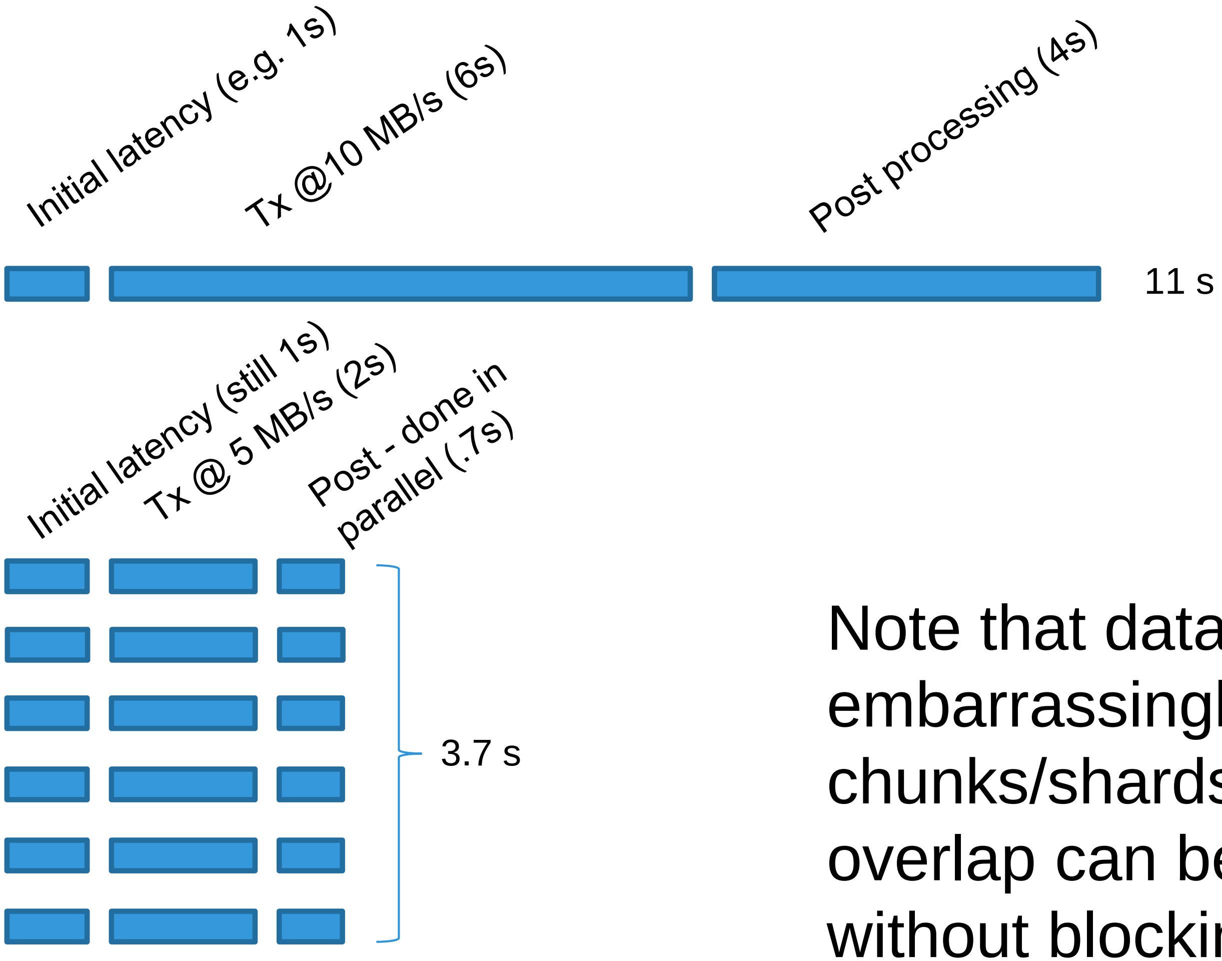
[1] **Hypertext Transfer Protocol**

Optimize Transfer Time

- Decompose data transfers into parallel operations
- S3 transfer rates *do* degrade with parallel access, but overall transfers are still faster
  - Single thread transfer rate: 10MB/s
  - Six (6) thread transfer rate: 5 MB/2*
- For data stored in a contiguous block, break it into ‘virtual’ shards/chunks

Parallel Transfer

Example: 60MB data transfer


Initial latency (e.g. 1s)
Tx @10 MB/s (6s)
Post processing (4s)
11 s
Initial latency (still 1s)
Tx @ 5 MB/s (2s)
Post - done in parallel (.7s)
3.7 s

Note that data access is embarrassingly parallel – chunks/shards that do not overlap can be inserted without blocking

Reduce Post-Transfer Time

- Perform post processing operations in parallel
  - But, do not use compression if possible
- For web services, provide data using its storage byte-order, not the server's – rely on the client to correct it
  - This eliminates 'touching' all of the data values.

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