# What is NetCDF ?

***And what are its plans for world domination?***

John Caron

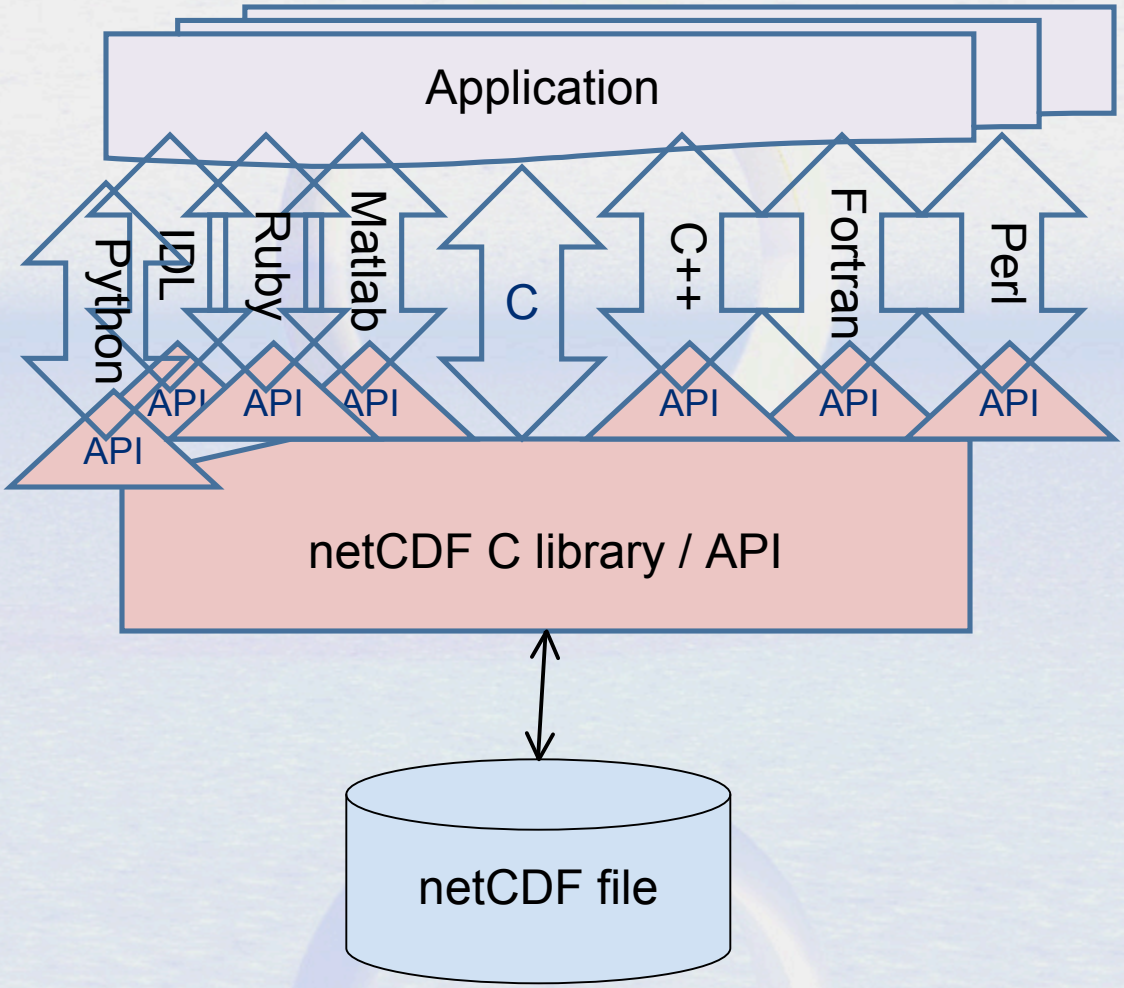
Unidata

August 2009

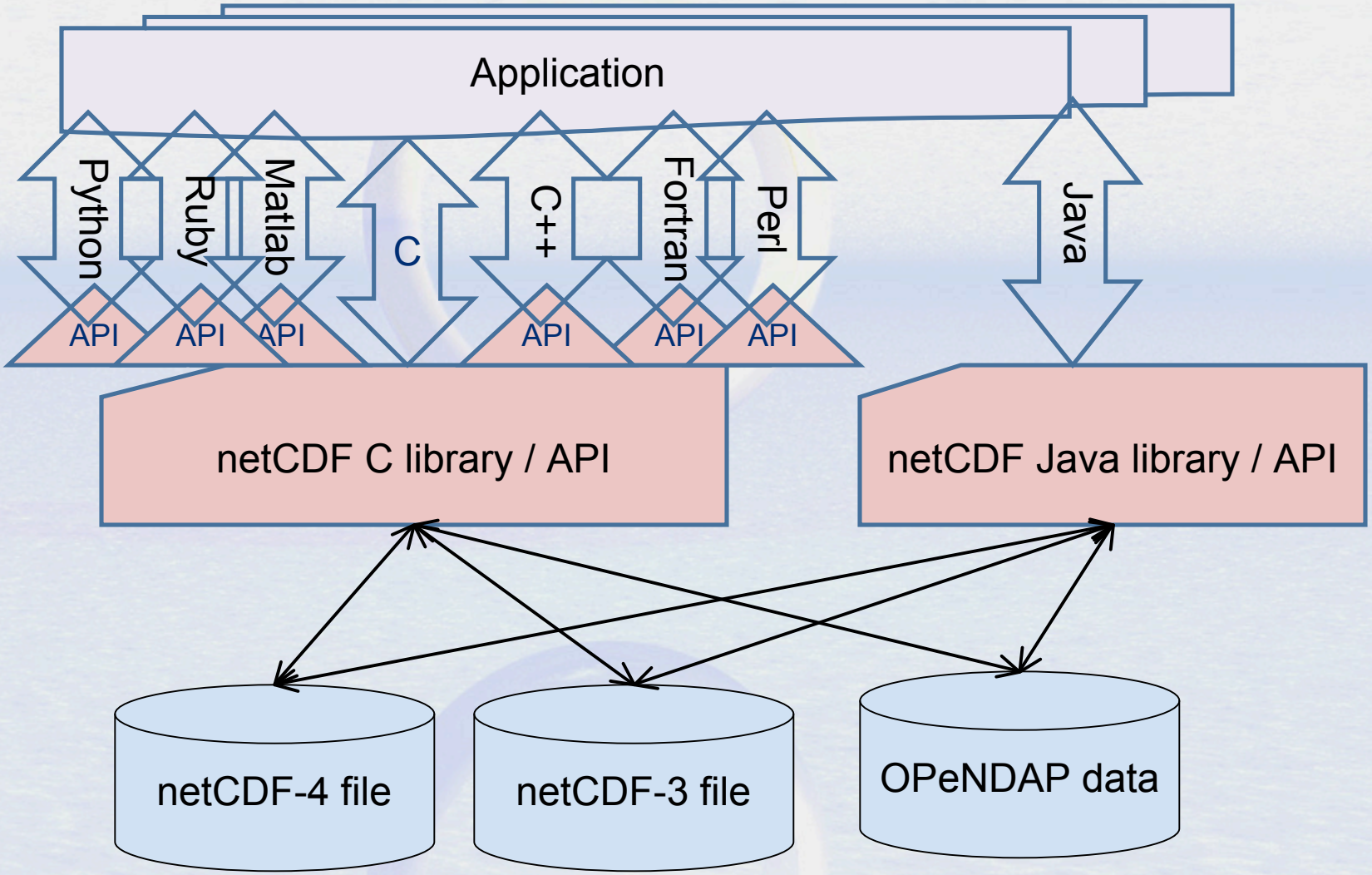
# NetCDF is….

- A file format
- A library
- An Application Programmer's Interface (API)
- A data model
- A dessert topping
- A floor wax

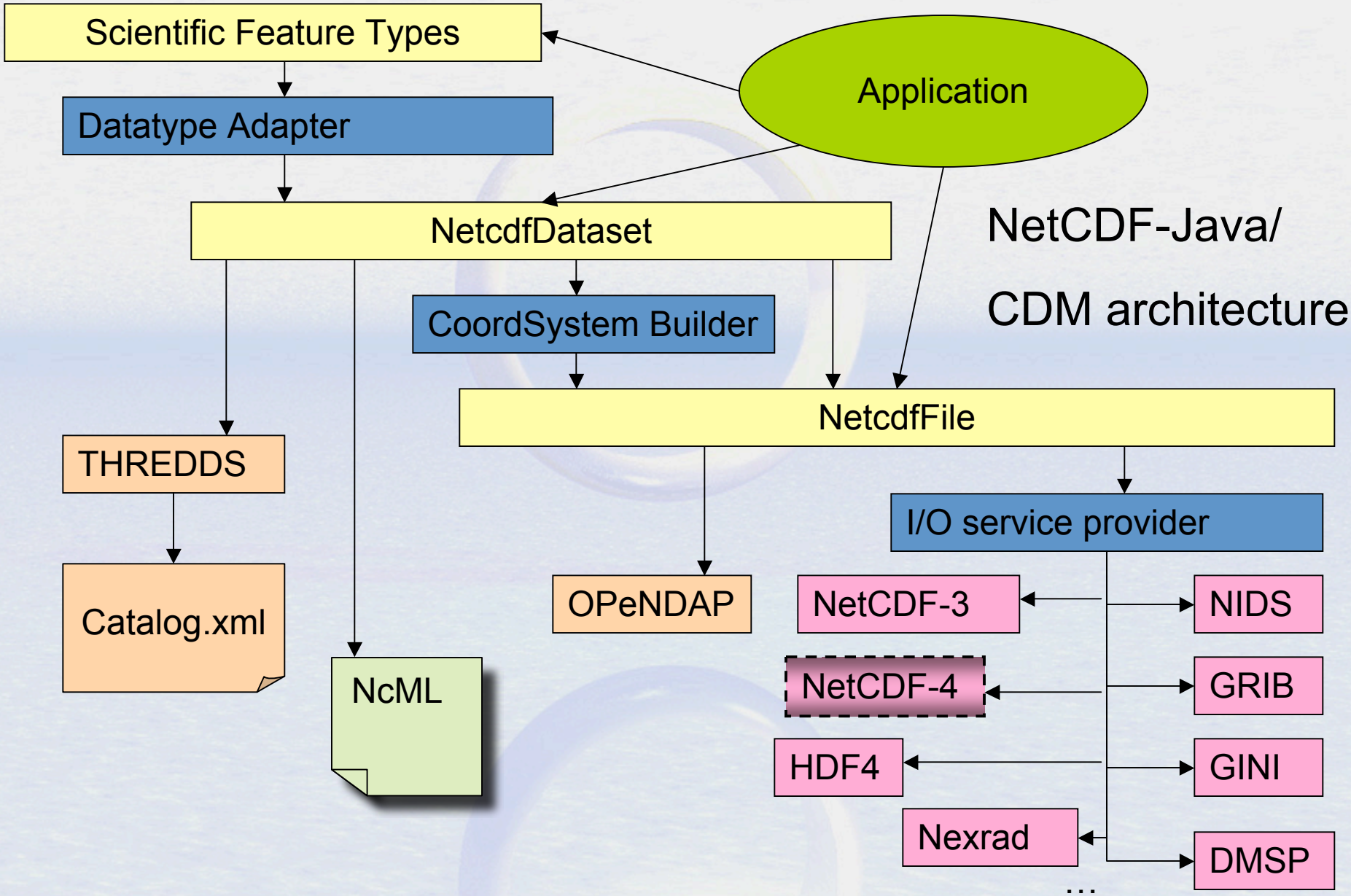
# In the beginning



# Things got more complicated



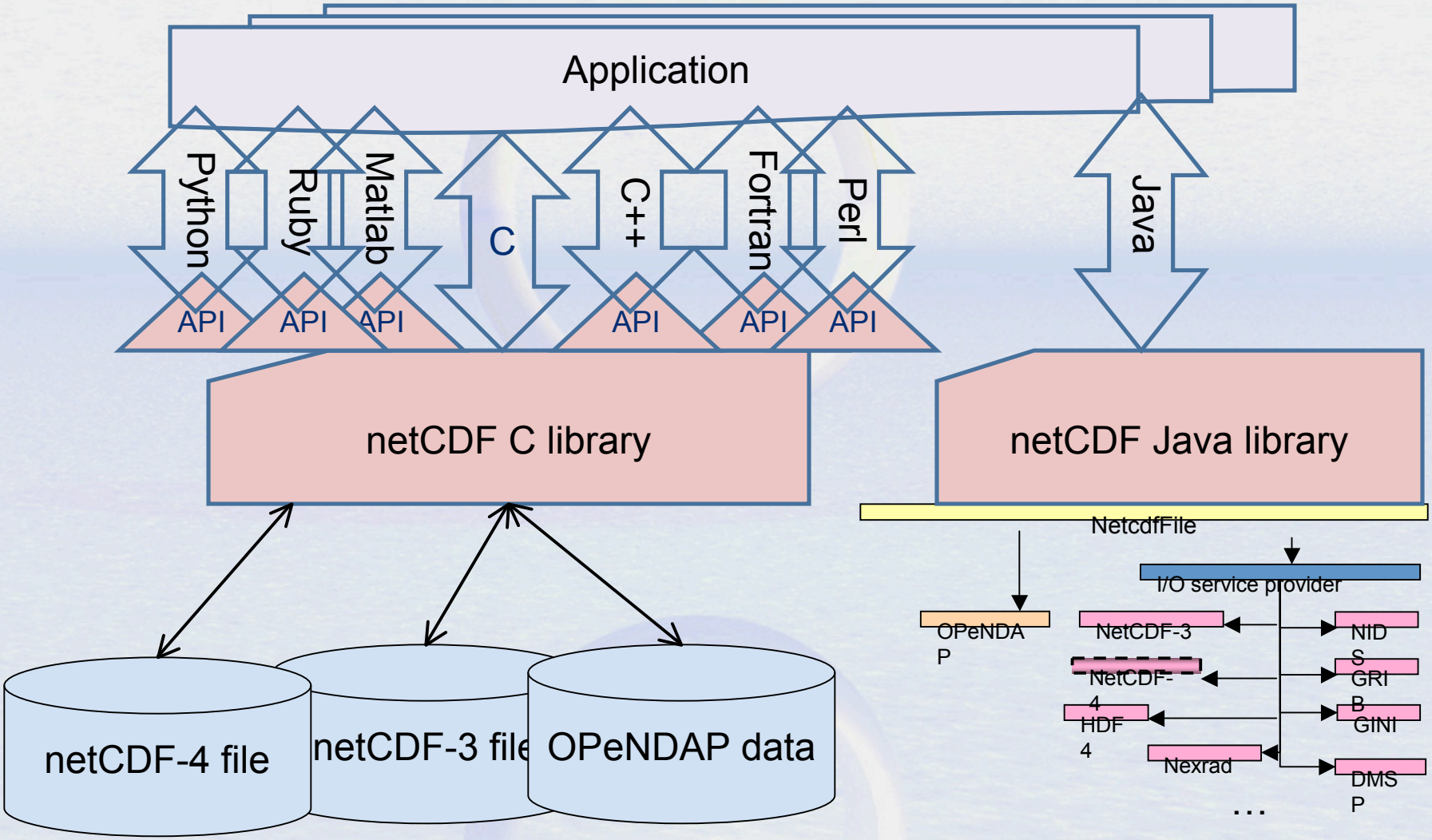
# But wait, there's more!



# Netcdf-Java 4.0 File Formats

- *General*: NetCDF-3, NetCDF-4, HDF5, HDF4, OPeNDAP
- *Gridded*: GRIB-1, GRIB-2, GEMPAK, McIDAS, UAMIV CAMx
- *Point*: BUFR, GEMPAK
- *Radar*: NEXRAD 2&3, DORADE, CINRAD, UF
- *Satellite*: DMSP, GINI, McIDAS, FYSAT
- *Misc*: GTOPO, NLDN, USPLN, etc

# What is netCDF ?



# NetCDF is a…

File format

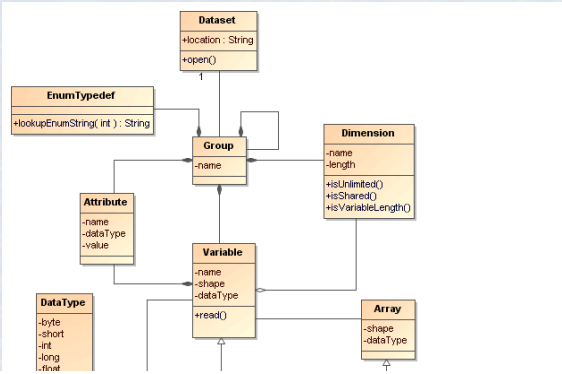
- Store data model objects
- Persistence layer
- NetCDF-3, netCDF-4

Software library

- Implements the API
- C, Java, others

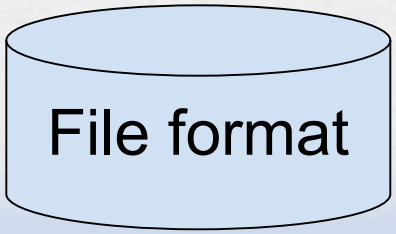
API

An ***API*** is the interface to the Data Model for a specific programming language




An **Abstract Data Model** describes data objects and what methods you can use on them

# NetCDF is a…

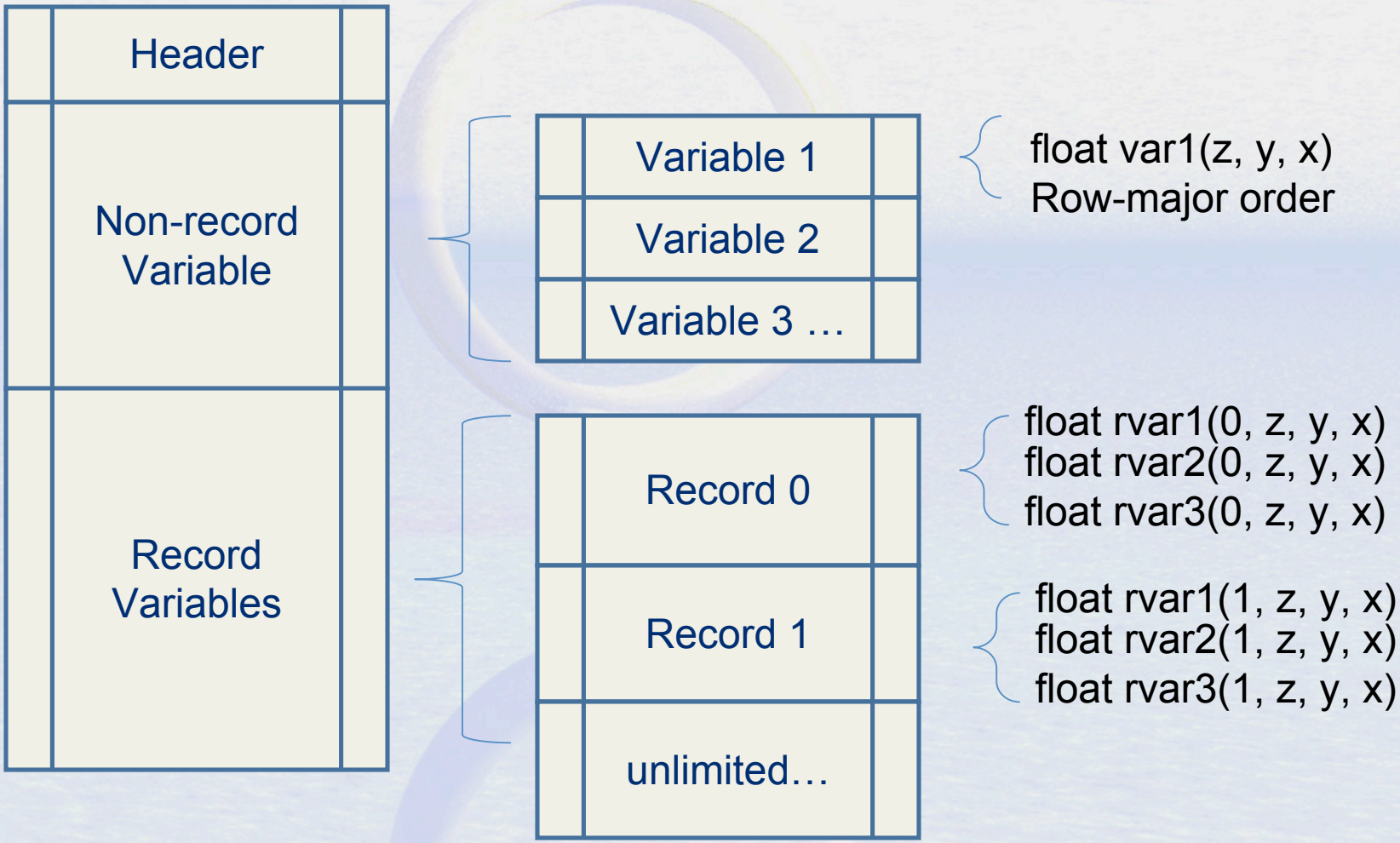



- Stores the objects in the data model
- Persistence layer
- NetCDF-3, netCDF-4

# What you should know about Storage Formats

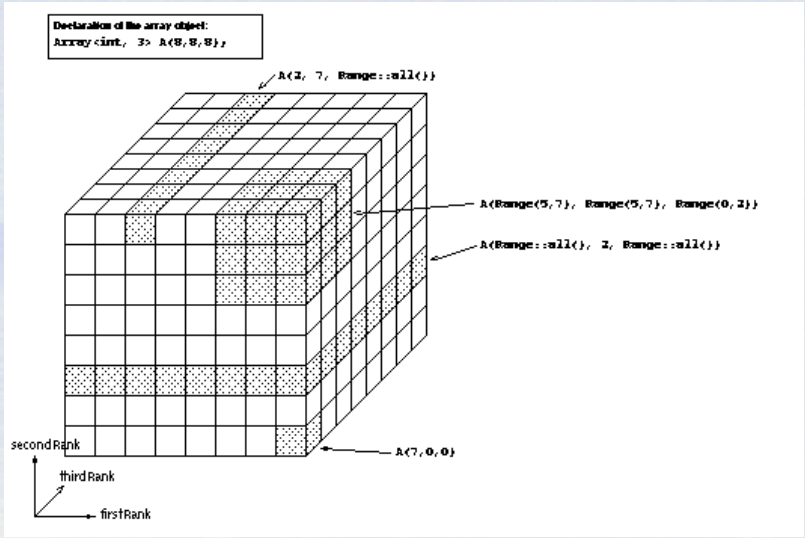
- Locality, locality, locality
- I/O cost is measured in # disk accesses
  - Entire block is read at once
  - Sequential access is 100x faster than random
- Many factors that affect this
  - Local disk, NFS mounted (shared), server RAID
  - The disk is caching sectors
  - The File System / OS is caching pages
  - Library may be caching data
- Applications can try to optimize file layout
  - write, read, common access patterns
  - Only matters for large I/O-bound apps

# NetCDF-3 file format



# NetCDF-4 file format

- Built on HDF-5
- Much more complicated than netCDF-3
- Storage efficiency
  - Compression : can optimize chunking for common I/O pattern
  - Compound types



# Row vs Column storage

- Netcdf-3 is a column store
  - All data for one variable is stored together
- Traditional RDBMS is a row store
  - All fields for one row in a table are stored together
- Netcdf-4 allows both row and column store
  - Row: compound type
  - Column: regular variable
- Recent RDBMS research focusing on possible advantages with column oriented storage

# NetCDF is a…

Software library

- Implements the API
- C, Java, third-party

# NetCDF Libraries

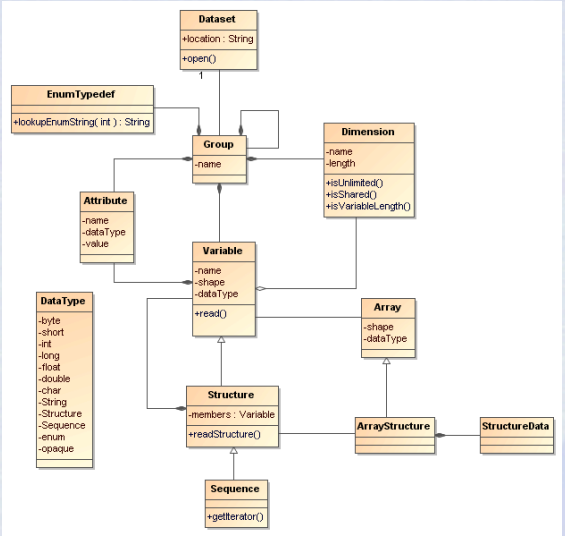
- NetCDF C library – reference implementation
  - Read/write netCDF-3 and netCDF-4
  - Read OPeNDAP (alpha)
- NetCDF  Java Library – exploratory
  - 100% Java == portable
  - Read netCDF-3, netCDF-4, OPeNDAP, many others
  - Only writes netCDF-3 (considering a JNI interface to C library for writing netCDF-4)
  - Thread safe, good for servers, used by the THREDDS Data Server (TDS)

# What you should know about Multicore CPUs

- Commodity CPU's wont get faster – too hot! Lifecycle cost dominated by electricity $$$
- Moores Law -> multiple CPUs on chip
- Multithreaded programs can take advantage of new multicore computer architecture
- Good for servers, harder for client programs to take advantage of this
- New languages (eventually)

# NetCDF is a…


An ***API*** is the interface to the Data Model for a specific programming language




An **Abstract Data Model** describes data objects and what methods you can use on them

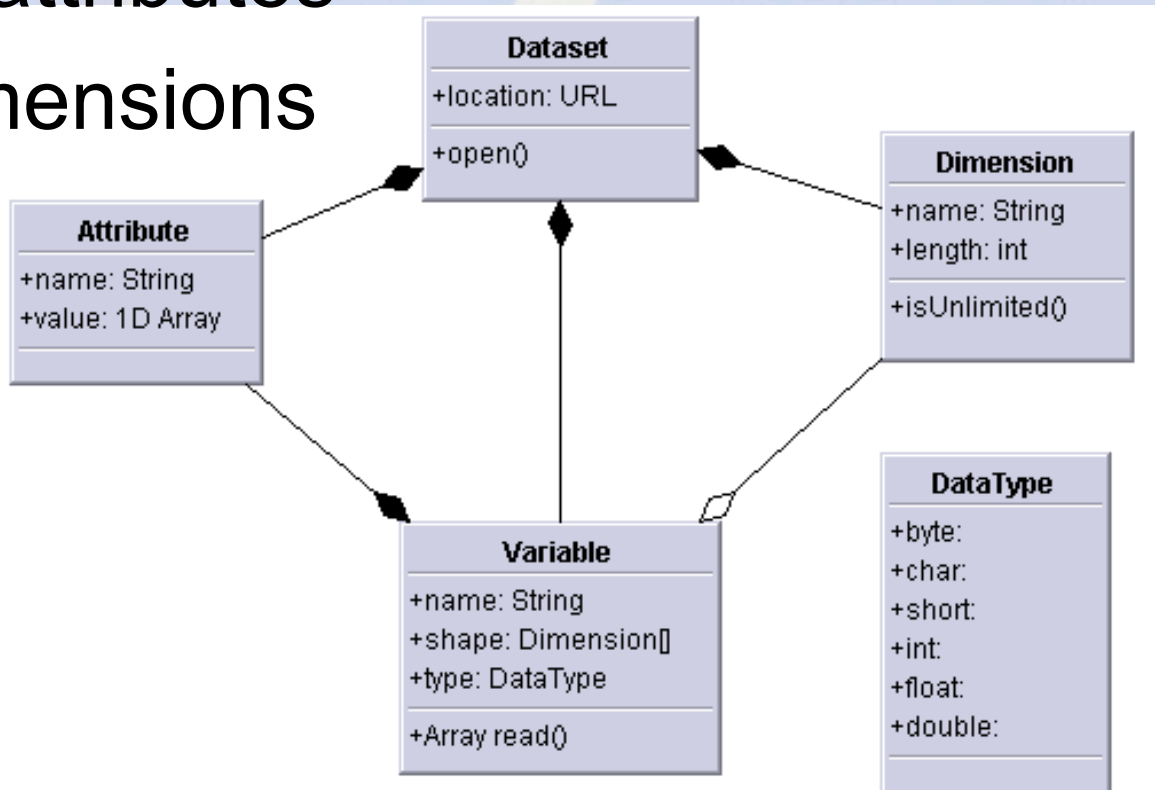
# NetCDF APIs

- Application Programmers Interface
  - Its what you have to deal with
  - Changing this breaks your code
- Lots of language bindings, same data model

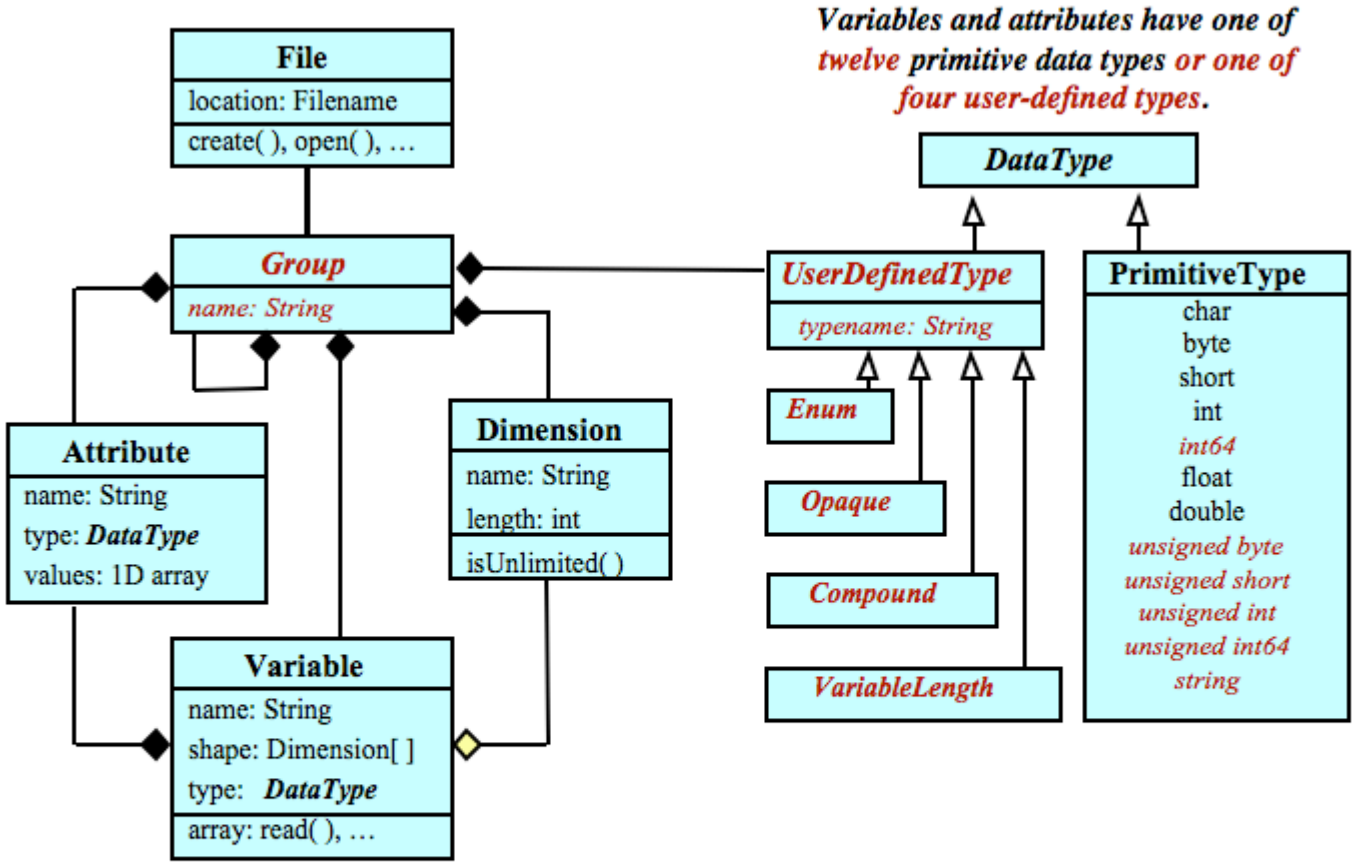
*An **API** is the interface to the Data Model for a specific programming language*

# NetCDF-3 data model

- Multidimensional arrays of primitive values
  - byte, char, short, int, float, double
- Key/value attributes
- Shared dimensions
- Fortran77

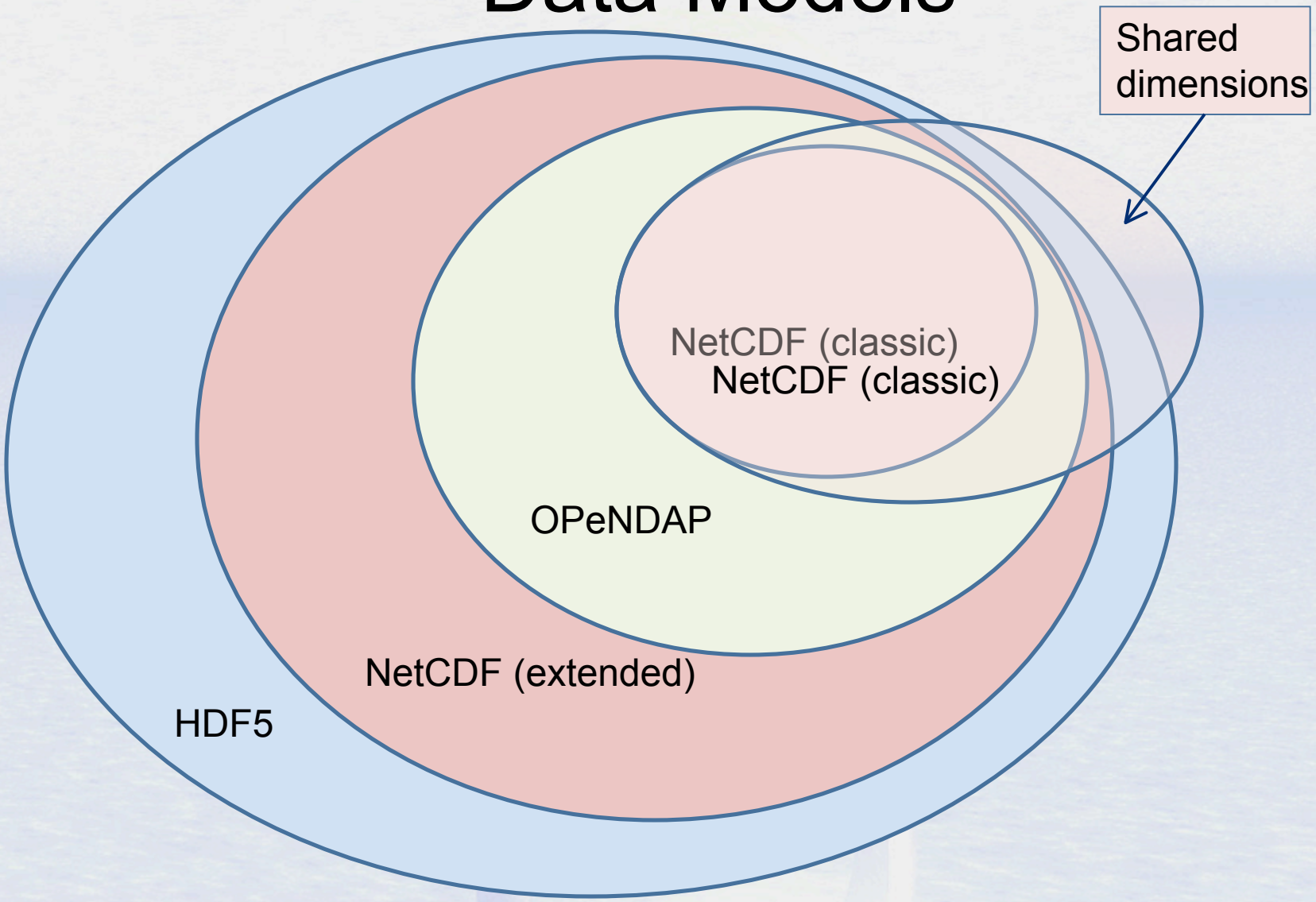


# NetCDF-4 Data Model




A file has a top-level unnamed group. Each group may contain one or more named subgroups, user-defined types, variables, dimensions, and attributes. Variables also have attributes. Variables may share dimensions, indicating a common grid. One or more dimensions may be of unlimited length.

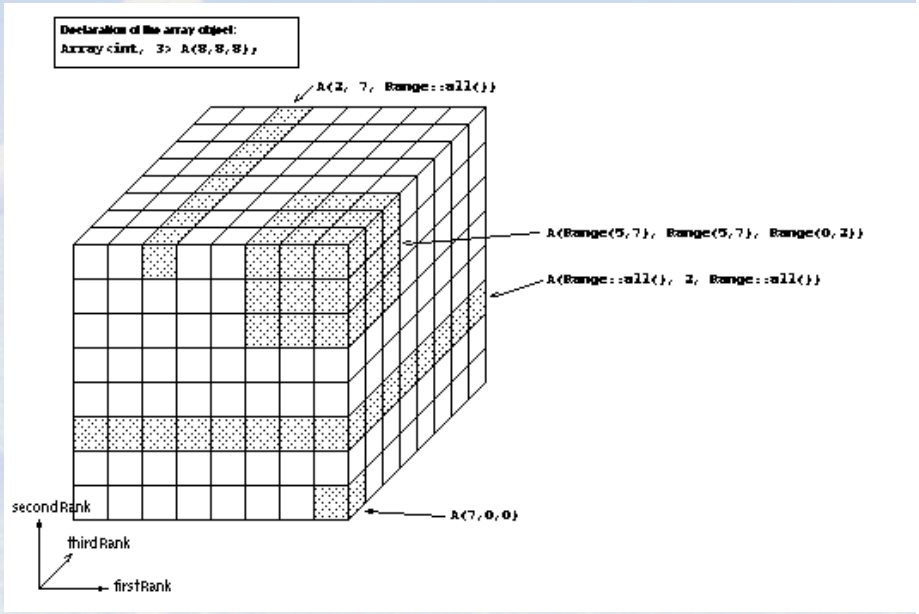
# NetCDF, HDF5, OPeNDAP Data Models



# Gridded Data

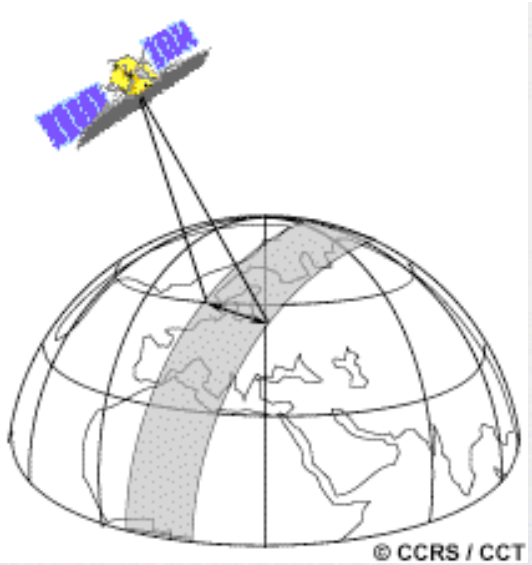
- Cartesian coordinates
- Data is 2,3,4D
- All dimensions have 1D coordinate variables (separable)

```
float gridData(t,z,y,x);
  float t(t);
  float y(y);
  float x(x);
  float z(z);
```



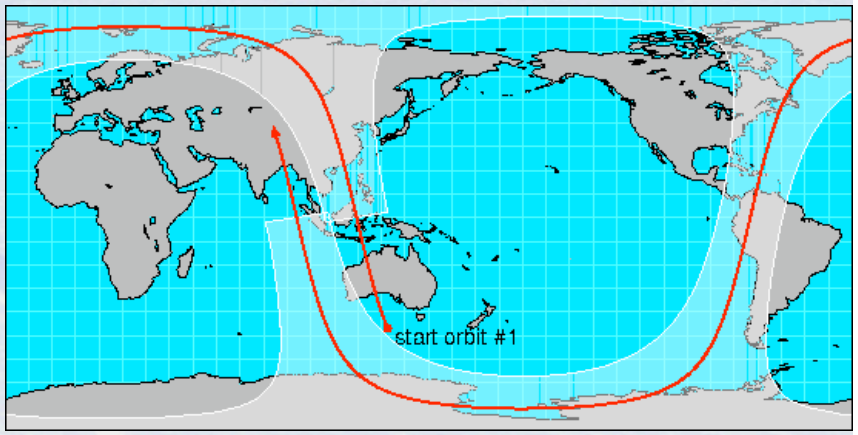

- netCDF: coordinate variables
- OPeNDAP: grid map variables
- HDF: dimension scales

# Swath




- two dimensional
- track and cross-track
- not separate time dimension
- aka *curvilinear coordinates*

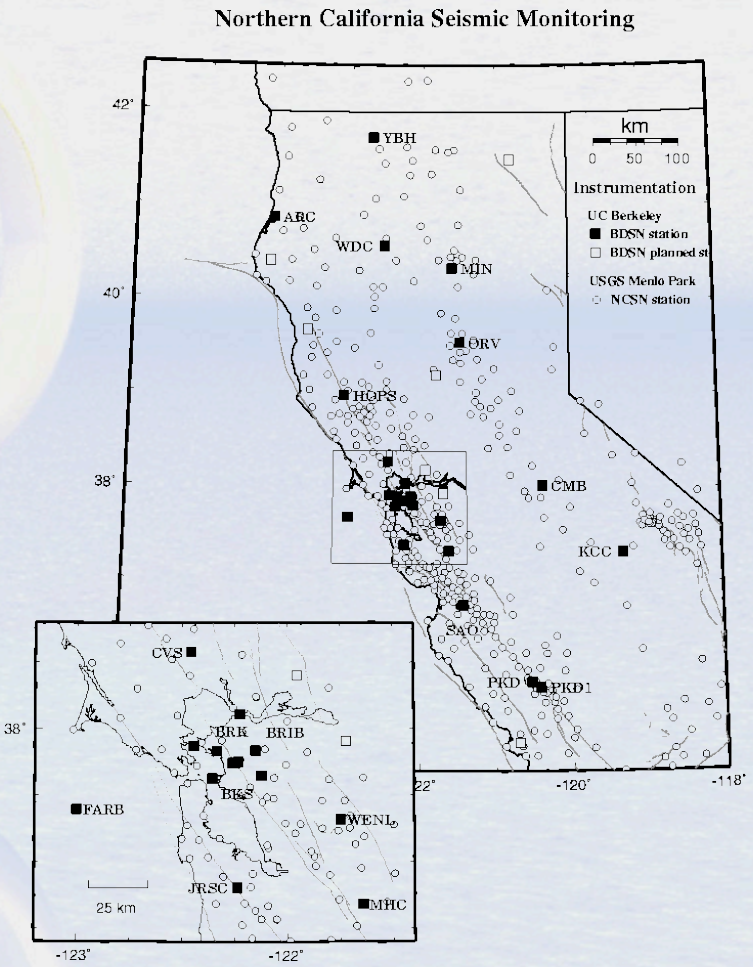
float swathData( track, xtrack)
  float lat(track, xtrack)
  float lon(track, xtrack)
  float alt(track, xtrack)
  float time(track)



# Point Observation Data

- Set of measurements at the same point in space and time = obs
- Collection of obs = dataset
- Sample dimension not connected

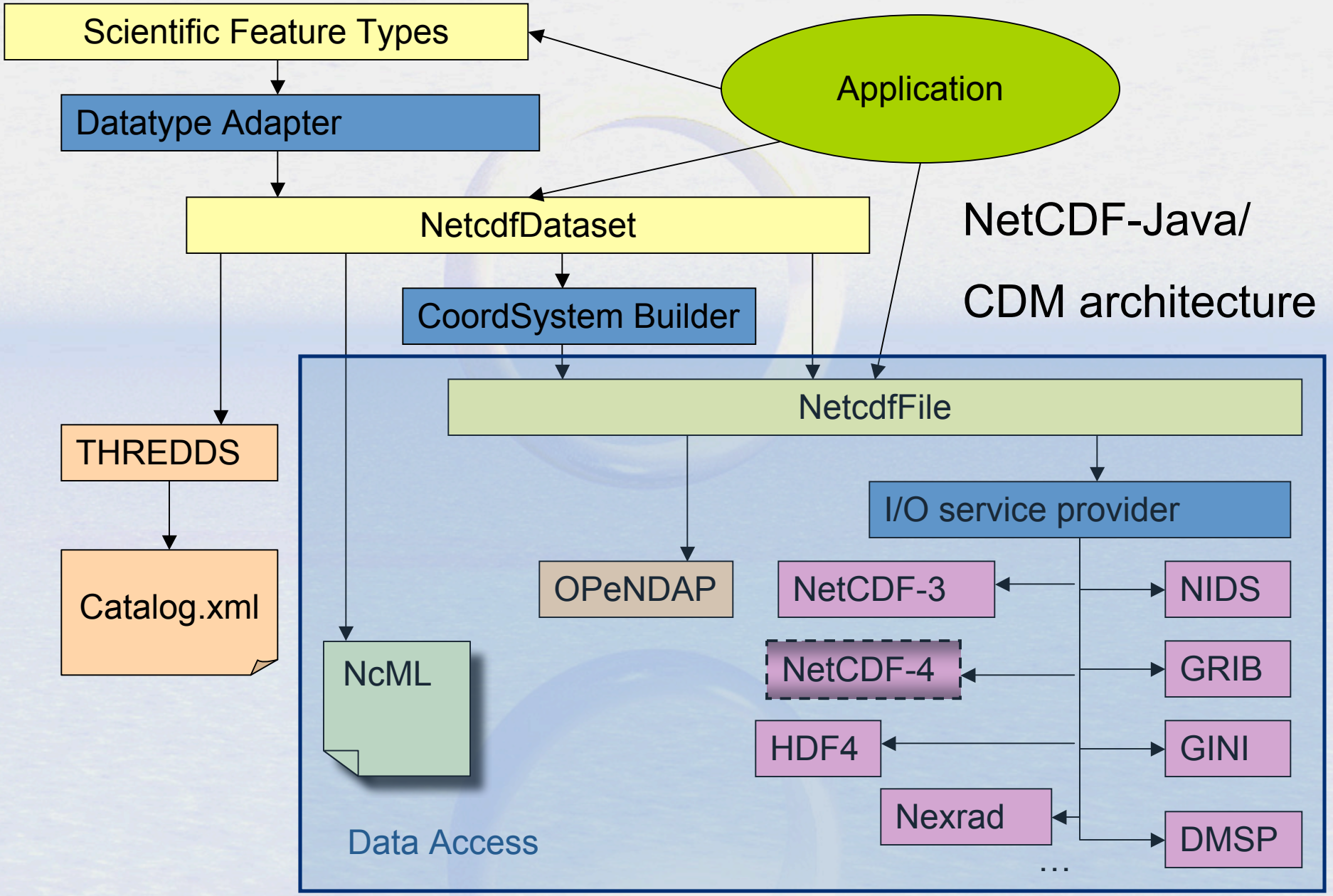
```
float obs1(sample);
float obs2(sample);
  float lat(sample);
  float lon(sample);
  float z(sample);
  float time(sample);
```



# Shared Dimensions Status

- netCDF
  - Shared dimension plus conventions is general solution for coordinates
  - *:coordinates = "lat lon alt time"*
- OPeNDAP
  - No shared dimensions in current data model
  - Shared dimensions will be added to DAP-4
- HDF5
  - No shared dimensions in current data model
  - HDF-EOS added shared dimensions in metadata
  - NetCDF-4 adds a workaround
    - NetCDF-4 not a subset of HDF-5
  - NetCDF-4 does not (yet) read all HDF-5 objects
    - HDF-5 not a subset of NetCDF-4

# Back to API / Data Models



## NetCDF “Index Space” Data Access:

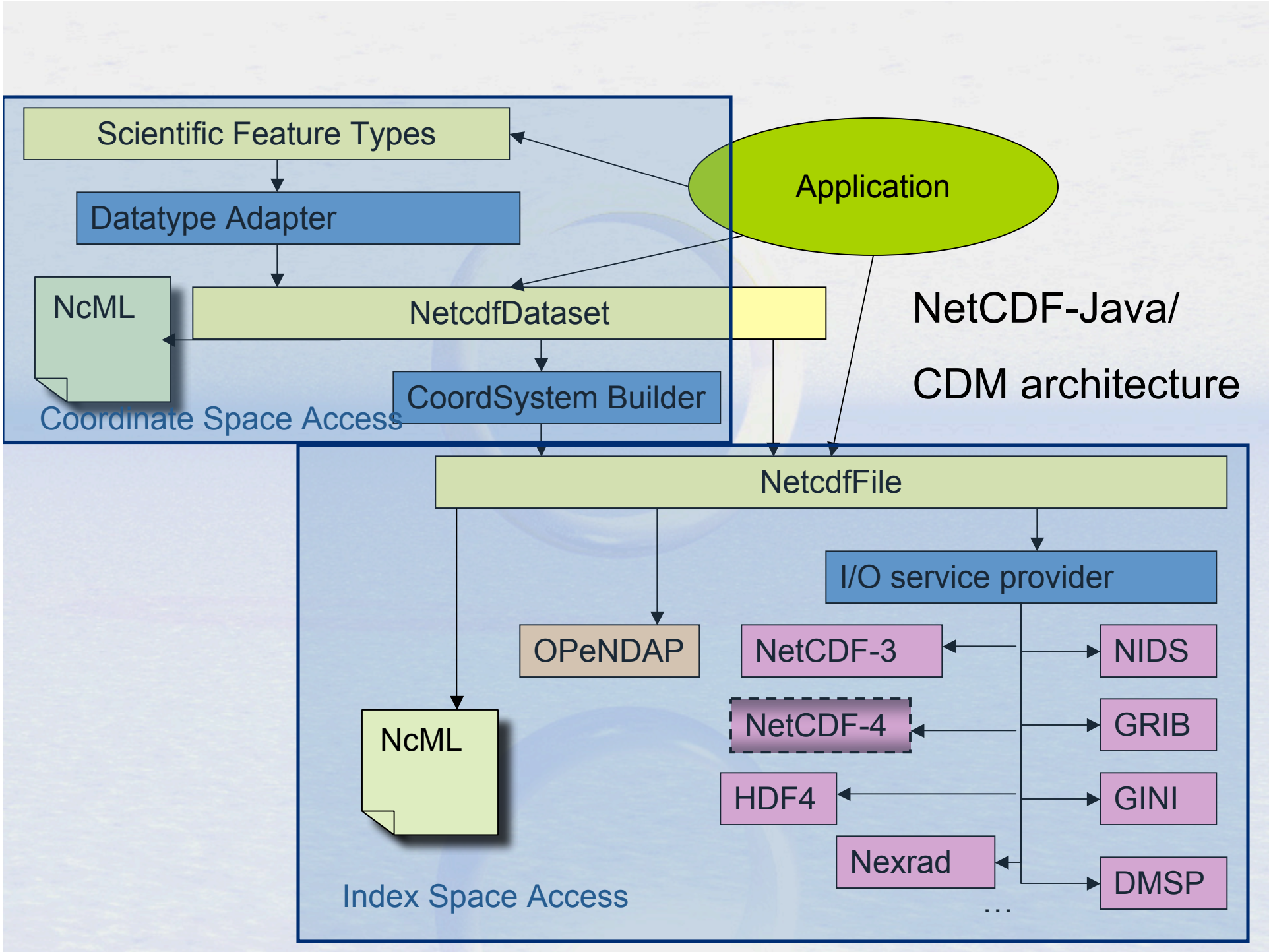
**OPeNDAP URL:**

http://motherlode.ucar.edu:8080/thredds/dodsC/
NAM_CONUS_80km_20081028_1200.grib1.ascii?
Precipitable_water[5][5:1:30][0:1:77]

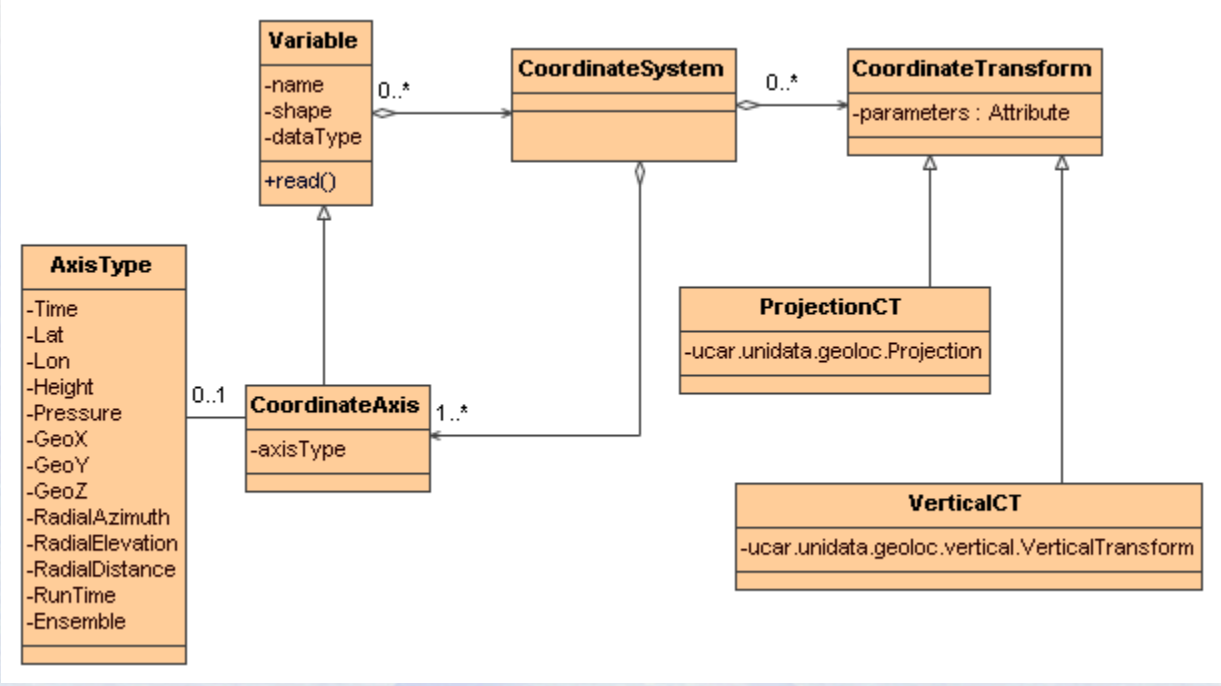
## “Coordinate Space” Data Access:

**NCSS URL:**

http://motherlode.ucar.edu:8080/thredds/ncss/grid/
NAM_CONUS_80km_20081028_1200.grib1?
var=Precipitable_water&
time=2008-10-28T12:00:00Z&
north=40&south=22&west=-110&east=-80


Scientific Feature Types
Datatype Adapter
NcML
NetcdfDataset
CoordSystem Builder
Coordinate Space Access
Application
NetCDF-Java/
CDM architecture
NetcdfFile
I/O service provider
OPeNDAP
NetCDF-3
NIDS
NetCDF-4
GRIB
HDF4
GINI
Nexrad
DMSP
...
NcML
Index Space Access

# Coordinate System UML



# Netcdf-Java Library parses these Conventions

- CF Conventions (preferred)
- COARDS, NCAR-CSM, ATD-Radar, Zebra, GEIF, IRIDL, NUWG, AWIPS, WRF, M3IO, IFPS, ADAS/ARPS, MADIS, Epic, RAF-Nimbus, NSSL National Reflectivity Mosaic, FslWindProfiler, Modis Satellite, Avhrr Satellite, Cosmic, ….
- Write your own *CoordSysBuilder* Java class

# Projections (CF)

- albers_conical_equal_area
- lambert_azimuthal_equal_area
- lambert_conformal_conic
- mcidas_area
- mercator
- orthographic
- rotated_pole
- stereographic (including polar)
- transverse_mercator
- UTM (ellipsoidal)
- vertical_perspective

# Vertical Transforms (CF)

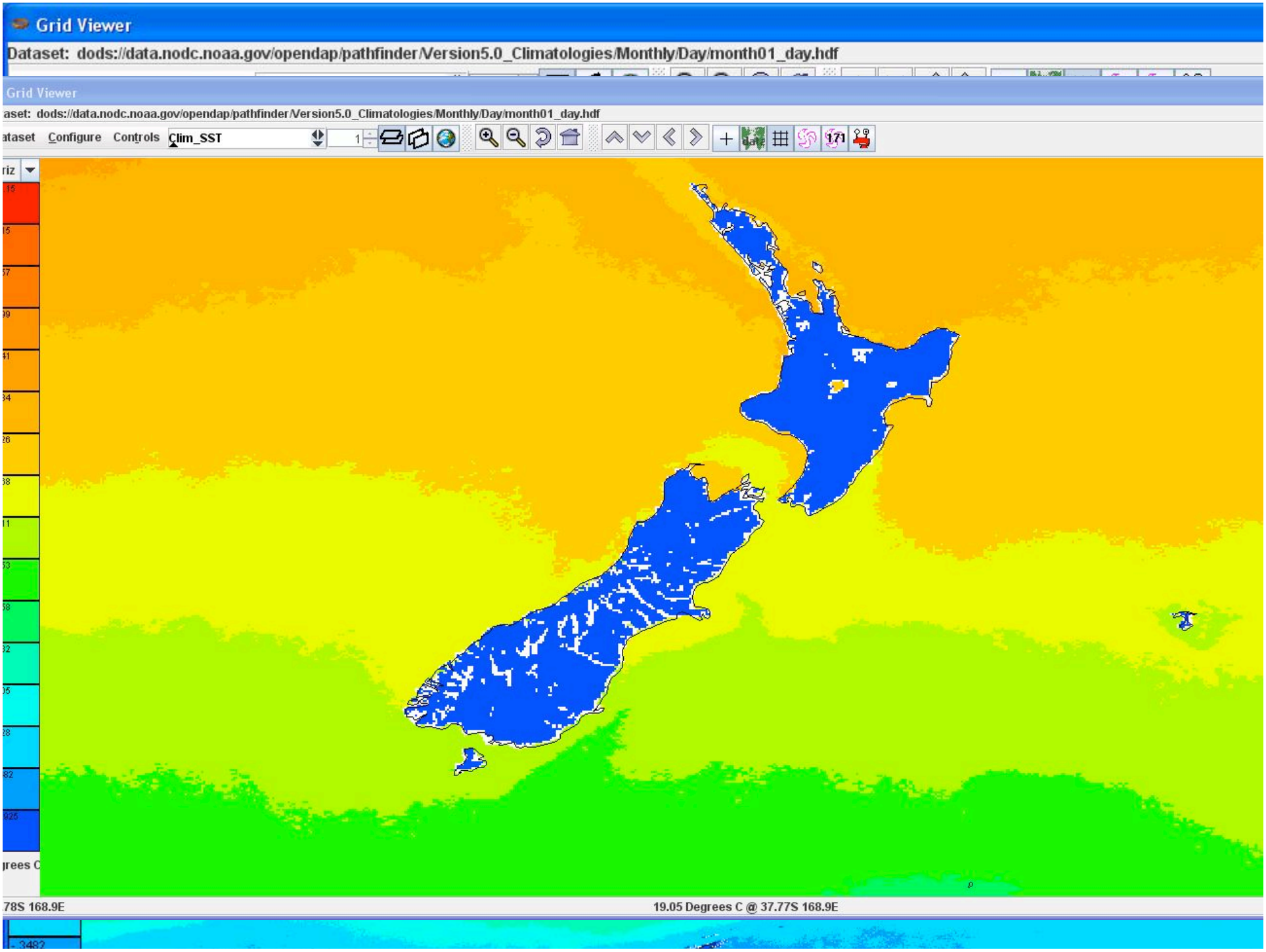
- atmosphere_sigma
- atmosphere_hybrid_sigma_pressure
- atmosphere_hybrid_height
- ocean_s
- ocean_sigma
- existing3DField

# Add your own Transform

- Pluggable framework
  - Add at runtime
  - CoordTransBuilder.registerTransform()
- Implement *CoordTransBuilderIF*

# Coordinate Systems Summary

- How?
  - Write your own Java code, plug into CDM
  - Write your files using CF Conventions
- Why?
  - Standard visualization, debugging, and data manipulation tools
  - Standard servers to make your data remotely accessible


Grid Viewer
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Grid Viewer
aset: dods://data.nodc.noaa.gov/opendap/pathfinder/Version5.0_Climatologies/Monthly/Day/month01_day.hdf
ataset Configure Controls Clim_SST
78S 168.9E
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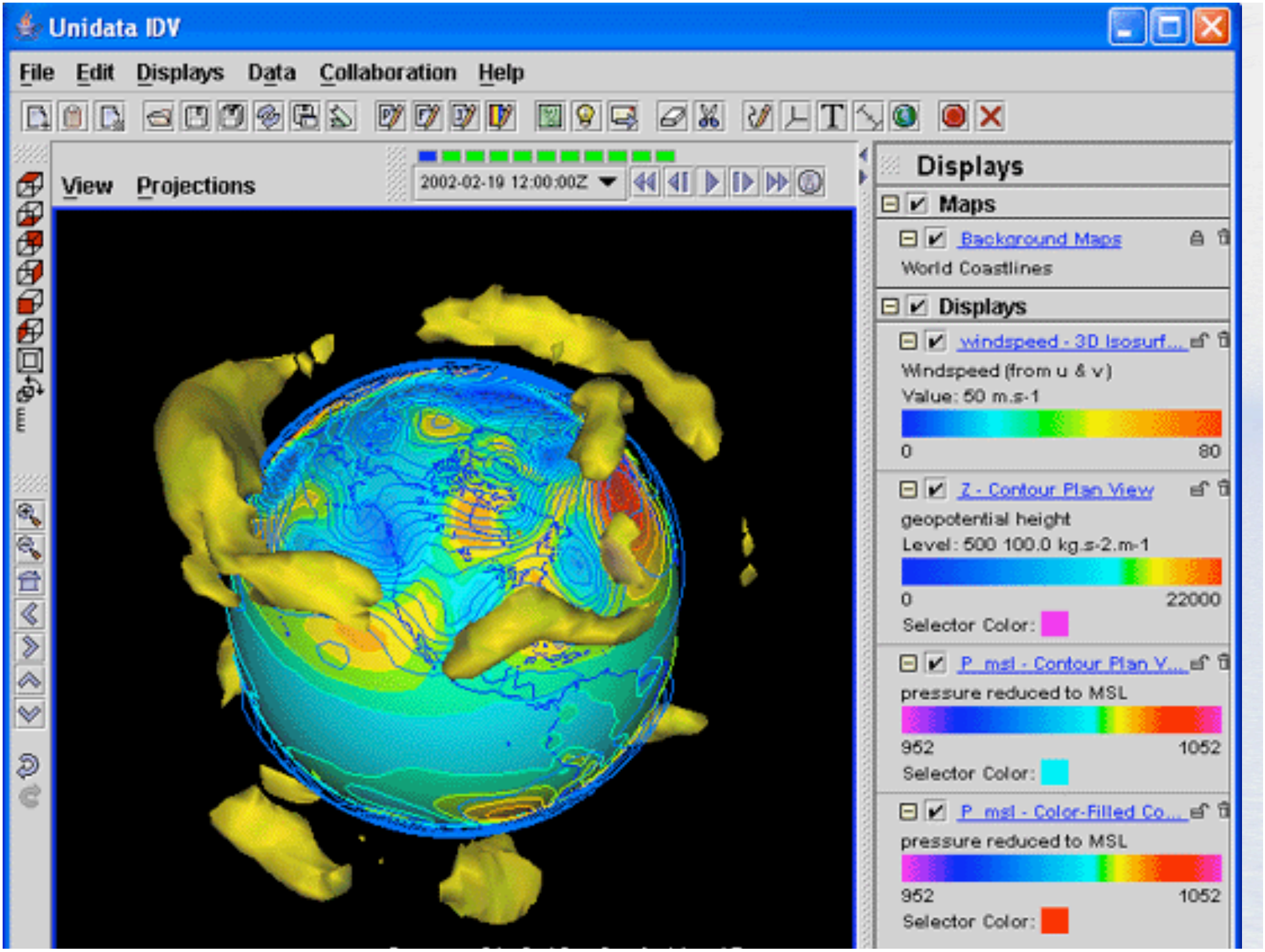
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View Projections
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Displays
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World Coastlines
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windspeed - 3D Isosurf...
Windspeed (from u & v)
Value: 50 m.s-1
0
80
Z - Contour Plan View
geopotential height
Level: 500 100.0 kg.s-2.m-1
0
22000
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P_msl - Contour Plan V...
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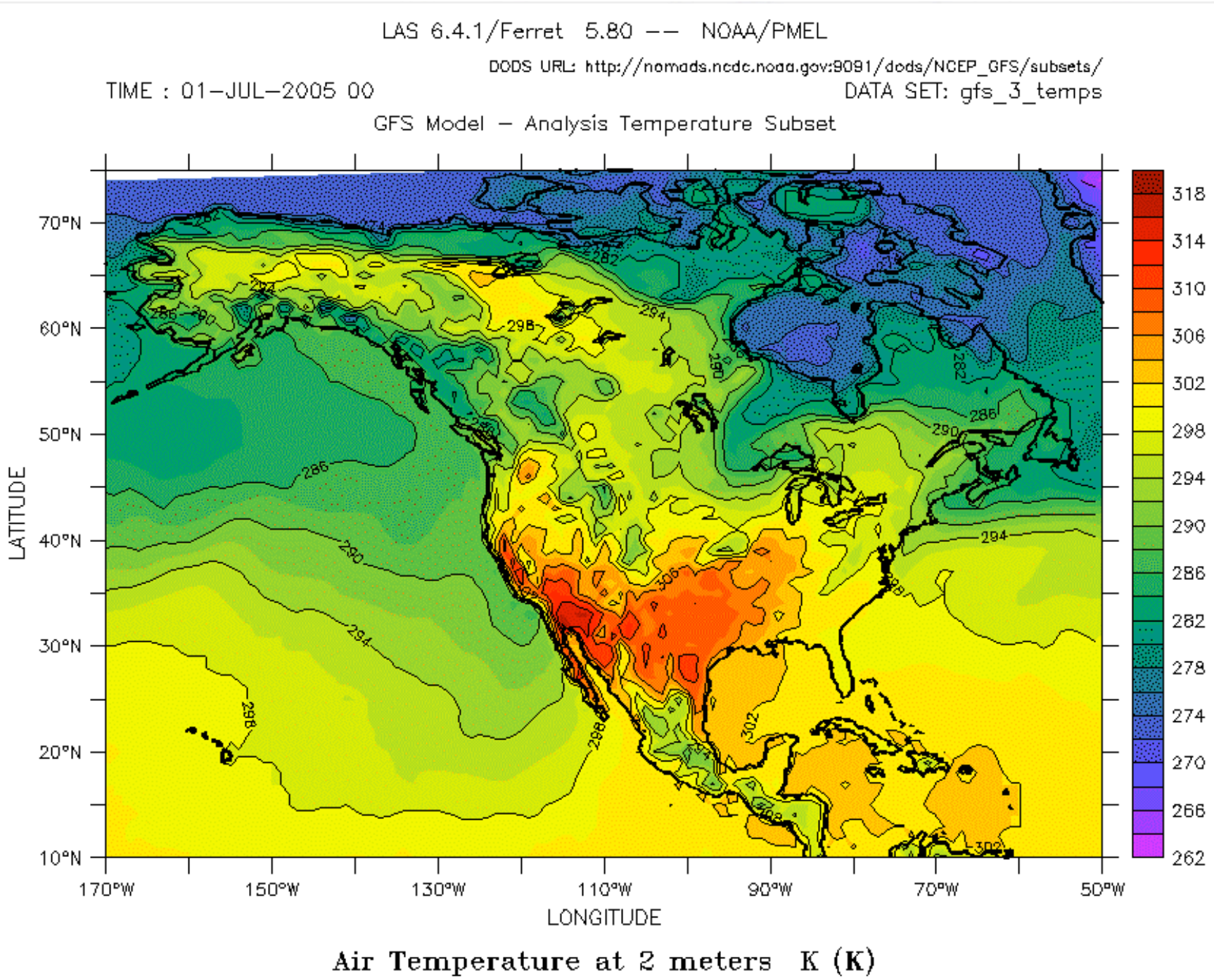
P_msl - Color-Filled Co...
pressure reduced to MSL
952
1052
Selector Color:


LAS 6.4.1/Ferret 5.80 -- NOAA/PMEL
DODS URL: http://nomads.ncdc.noaa.gov:9091/dods/NCEP_GFS/subsets/
TIME : 01-JUL-2005 00
DATA SET: gfs_3_temps
GFS Model - Analysis Temperature Subset
70°N
60°N
50°N
40°N
30°N
20°N
10°N
LATITUDE
170°W
150°W
130°W
110°W
90°W
70°W
50°W
LONGITUDE
318
314
310
306
302
298
294
290
286
282
278
274
270
266
262
Air Temperature at 2 meters K (K)

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Data support in ArcGIS > NetCDF: multidimensional, time series data > An overview of netCDF data

## About netCDF data

Release 9.2

Last modified November 9, 2006

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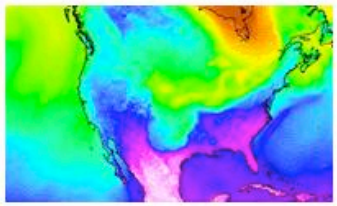
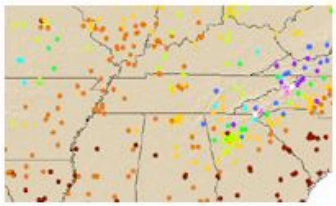
Print all topics in : "An overview of netCDF data"

NetCDF (network Common Data Form) is a file format for storing multidimensional scientific data (variables) such as temperature, humidity, pressure, wind speed and direction. Each of these variables can be displayed through a dimension (such as time) in ArcGIS by making a layer or table view from the netCDF file.





Learn more about netCDF

Learn more about how to add netCDF data to ArcGIS

### Related Topics

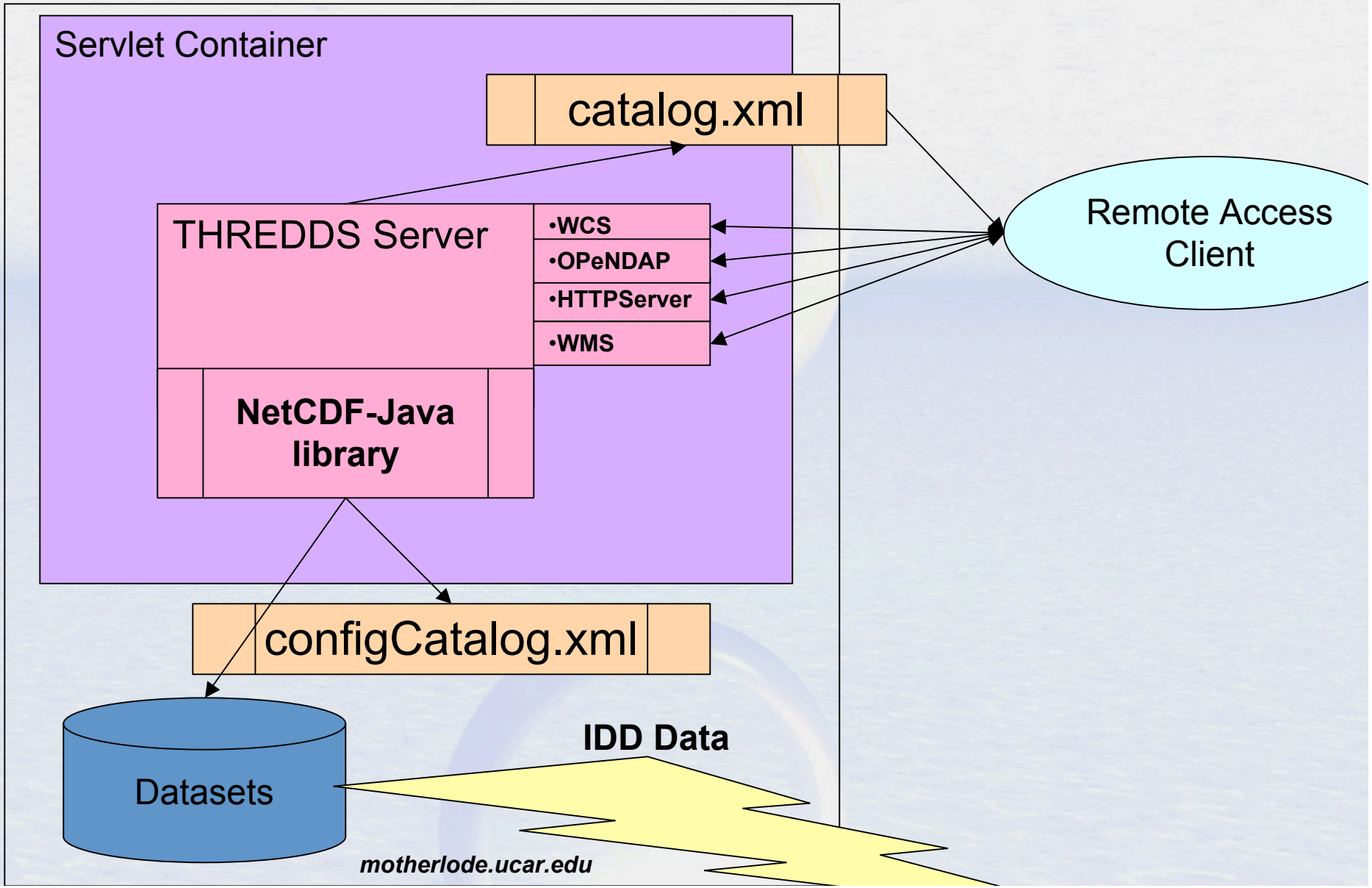
- The storage of netCDF data
- Organizations that use netCDF data
- Adding netCDF data in ArcGIS

Please visit the Feedback page to comment or give suggestions on ArcGIS Desktop Help.

# NetCDF-Java library

- Used as a component in other software (partial)
  - Integrated Data Viewer, ToolsUI (Unidata)
  - Panoply (NASA)
  - ncBrowse (EPIC/NOAA)
  - Java NEXRAD Viewer (NCDC/NOAA)
  - MyWorld GIS (Northwestern)
  - EDC for ArcGIS, ERRDAP (SFSC/NOAA)
  - Live Access Server (PMEL/NOAA)
  - ncWMS (Reading)
  - Matlab plug-in (USGS)

# THREDDS Data Server



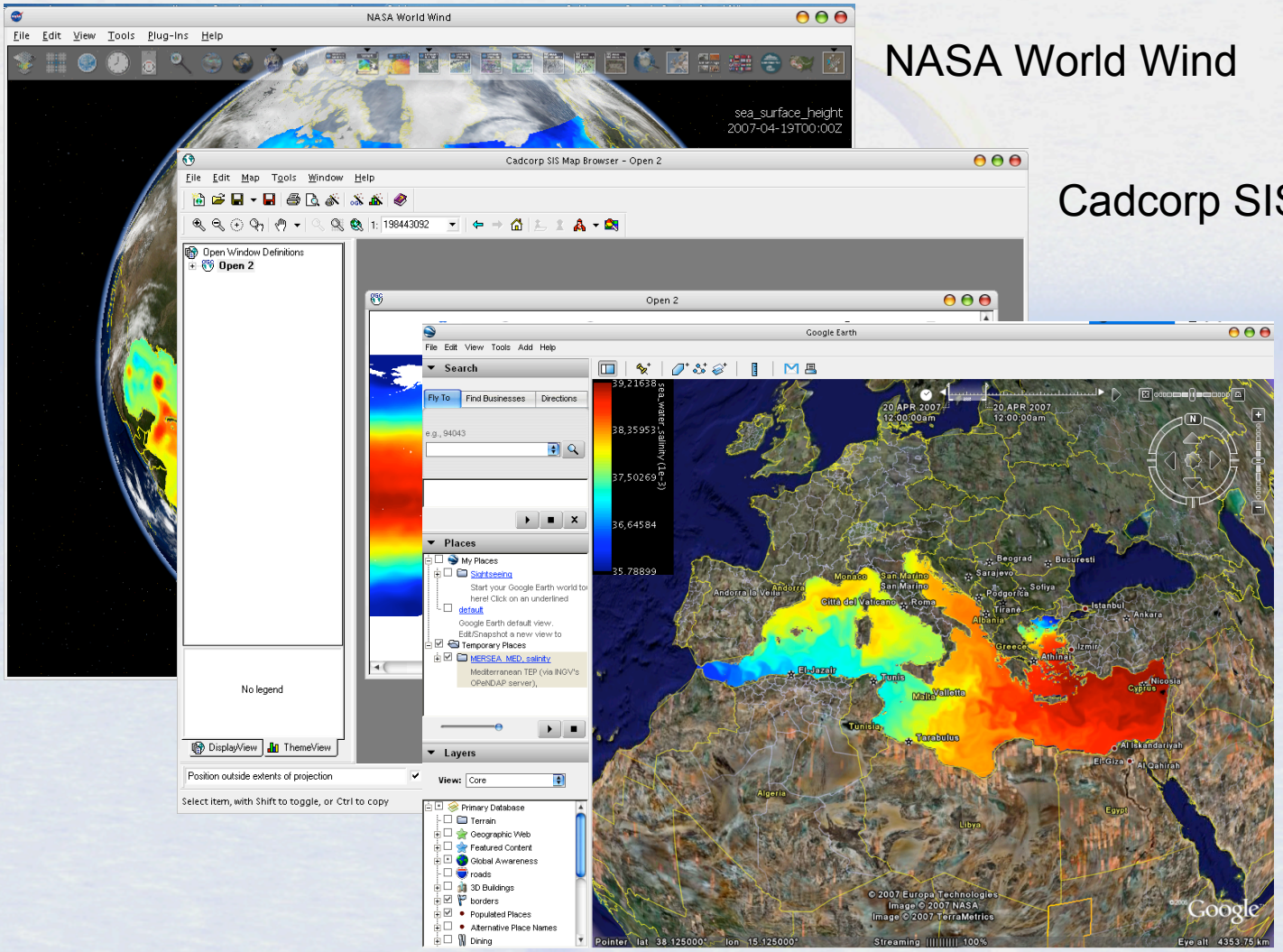
# THREDDS Data Server (TDS)

- Web server for scientific data
- From Unidata
- Provides remote data access
  - OPeNDAP
  - Open Geospatial Consortium (OGC) WMS and WCS
  - HTTP file transfer
  - Experimental data access protocols.

# OGC Web Map Service

- Jon Blower's (Reading, UK) ncWMS integrated with TDS
- Coordinate Space subsetting
- Produces JPEG output
- Fast generation of images
- Reproject images into large number of coordinate systems

# WMS Clients




NASA World Wind

Cadcorp SIS

Google Earth

3rd-party clients can't use the custom WMS extensions

# Web Coverage Service

- Coordinate Space subsetting
- Return formats
  - GeoTIFF floating point, grayscale
  - NetCDF/CF
- No reprojections, resamplings
- Restricted to CDM files that have Grid coordinate system
  - evenly spaced x,y

# NetCDF Markup Language (NcML)

- XML representation of netCDF metadata (like ncdump -h)
- Create new netCDF files (like ncgen)
- Modify (“fix”) existing datasets without rewriting them
- Create virtual datasets as aggregations of multiple existing files.
- Integrated with the TDS

# NcML
# Modify and serve through TDS

```
<dataset name="Polar Orbiter Data" urlPath ="idd/sat/PolarData" >

  <netcdf location="/data/sat/P02393.hdf">
    <attribute name="Conventions" value="CF-1.4"/>
    <variable name="Reflectivity" orgName="R34768">
      <attribute name="units" value="dBZ" />
      <attribute name="coordinates" value="time lat lon" />
    </variable>
  </netcdf>

</dataset>
```

# TDS / NcML
# Modify all files in datasetScan

```
<datasetScan name="Polar Orbiter" path="/data/sat/"
     location= "/data/hdf/polar/">

   <netcdf>
     <attribute name="Conventions" value="CF-1.4"/>
     <variable name="Reflectivity" orgName="R34768">
       <attribute name="units" value="dBZ" />
       <attribute name="coordinates" value="time lat lon" />
     </variable>
   </netcdf>

</datasetScan>
```

# TDS / NcML aggregation

```
<dataset name="WEST-CONUS_4km Aggregation"
    urlPath="satellite/3.9/WEST-CONUS_4km">

  <netcdf>
   <aggregation dimName="time" type="joinExisting">
     <scan  location="/data/satellite/WEST-CONUS_4km/" suffix=".gini"
     />
   </aggregation>
  </netcdf>

</dataset>
```

# Conclusions

- NetCDF is a floor wax and a dessert topping
- A data model is a good way to see the forest through the trees
- We now have a useable merger of netCDF, OPeNDAP, HDF5 technologies
- Add Coordinate information to allow “coordinate space subsetting”
  - NcML/TDS can help
  - But the right way to do this is….

# Conclusion

- I will use CF Conventions
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- I will use CF Conventions
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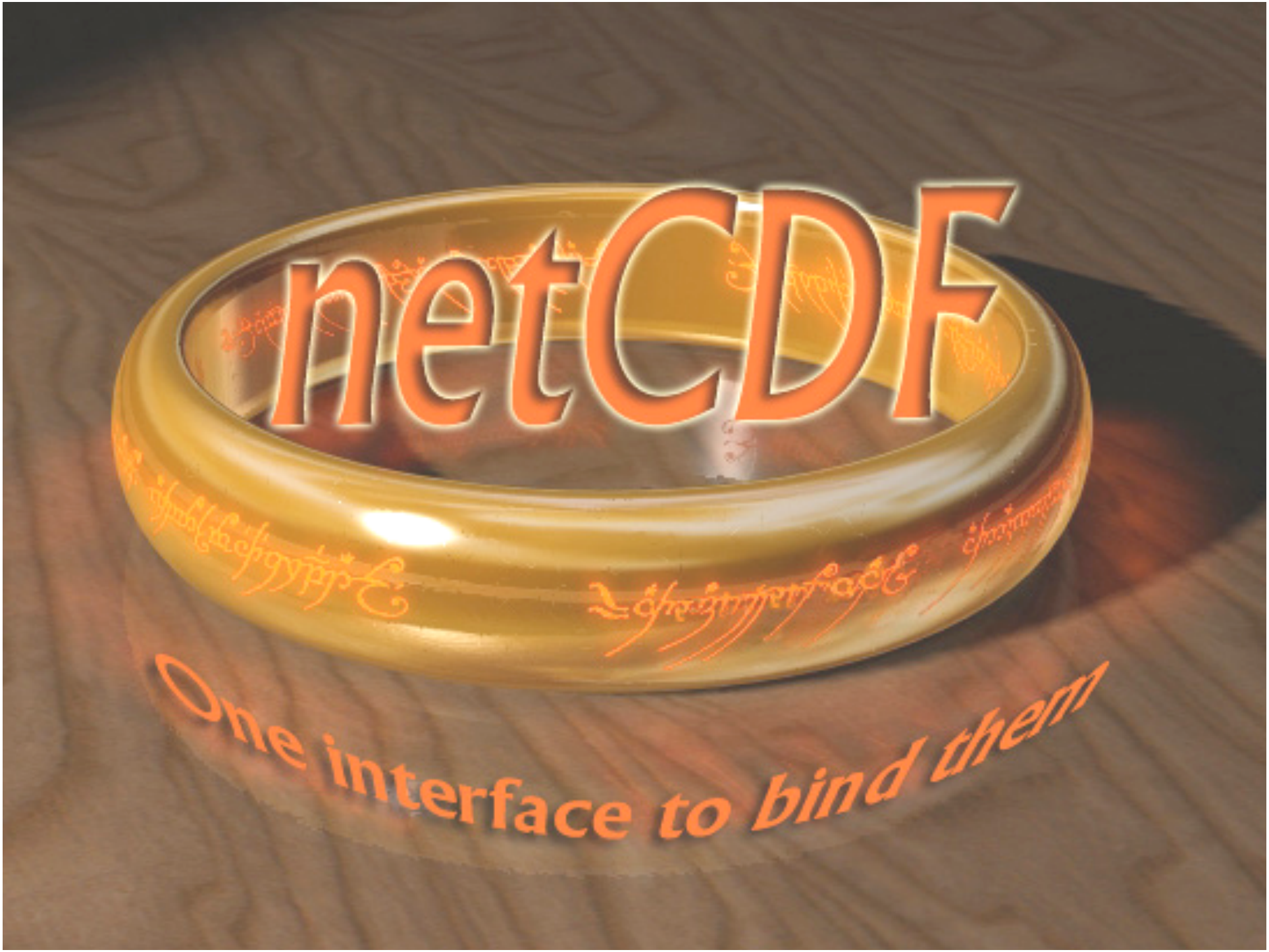
netCDF
One interface to bind them

# NetCDF-Java Common Data Model (Data Access Layer)