Supported by EU H2020 LandSupport, EOSC-hub, CopHub.AC, PARSEC; DE BigDataCube

JACOBS UNIVERSITY

rasdaman raster data manager

Datacubes for Analysis-Ready Data: Standards & State of the Art

ESIP Winter Meeting, Bethesda, USA, 2020-jan-10

P. Baumann

Jacobs University, rasdaman GmbH

Technically co-sponsored by:

CODATA Germany

ESI

Array Analytics Research @ Jacobs U

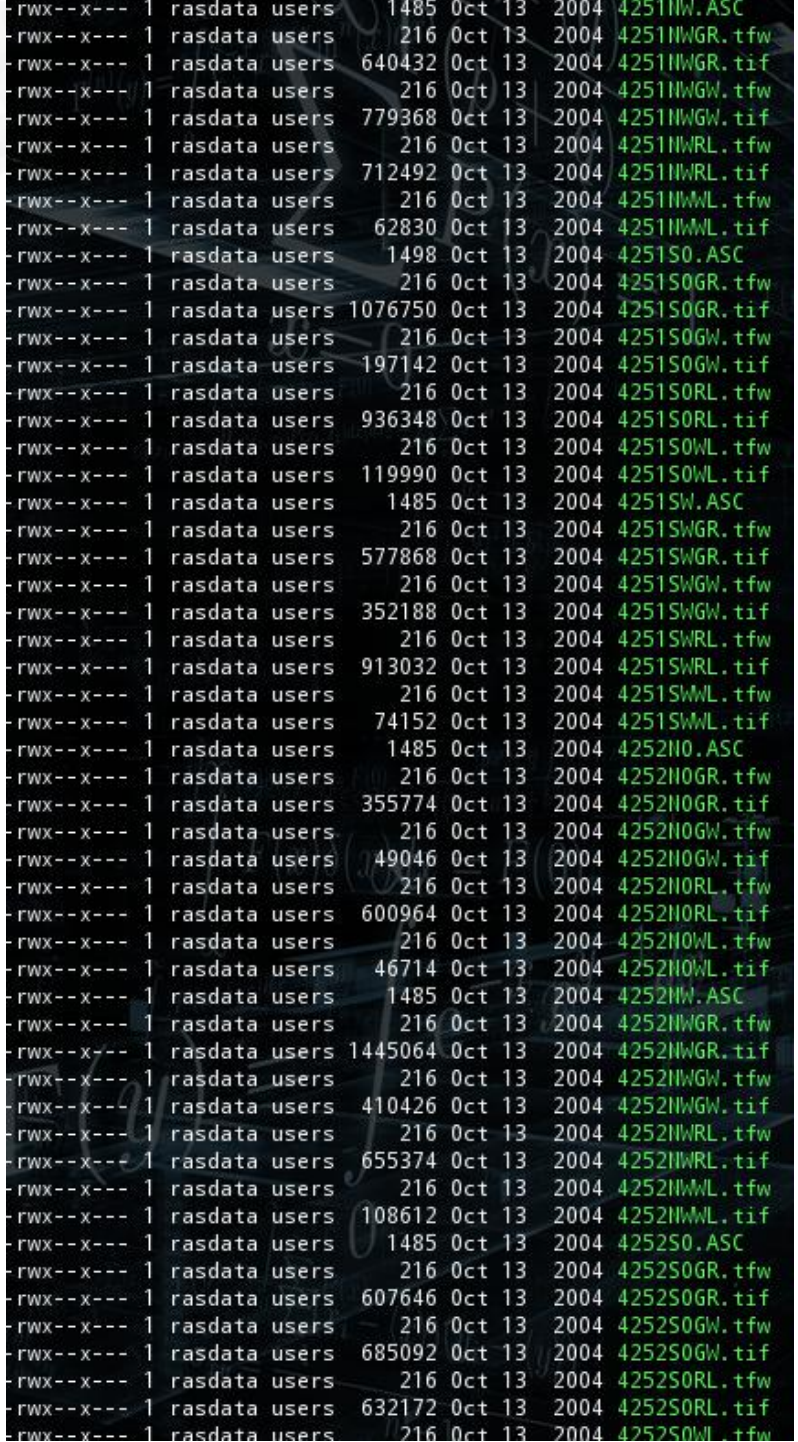
- Large-Scale Scientific Information Systems research group
  - Flexible, scalable n-D array services
  - www.jacobs-university.de/lsis
- Main visible results:
  - 160+ publications on datacubes
  - pioneer Array DBMS, rasdaman
  - standardization: OGC Coverages, ISO SQL

Hiring PhD students, PostDocs

Roadmap

- Introduction
- Coverages & Datacubes
- OGC Coverage Data model
- OGC Coverage Service model
- Datacube technology: the rasdaman example
- Wrap-Up

Introduction



```
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-rwx--x--- 1 rasdata users   62830 Oct 13  2004 4251NWWL.tif
-rwx--x--- 1 rasdata users    1498 Oct 13  2004 4251SO.ASC
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4251SOGR.tfw
-rwx--x--- 1 rasdata users 1076750 Oct 13  2004 4251SOGR.tif
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-rwx--x--- 1 rasdata users  577868 Oct 13  2004 4251SWGR.tif
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4251SWGW.tfw
-rwx--x--- 1 rasdata users  352188 Oct 13  2004 4251SWGW.tif
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4251SWRL.tfw
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-rwx--x--- 1 rasdata users   46714 Oct 13  2004 4252NOWL.tif
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-rwx--x--- 1 rasdata users    1485 Oct 13  2004 4252SO.ASC
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4252SOGR.tfw
-rwx--x--- 1 rasdata users  607646 Oct 13  2004 4252SOGR.tif
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4252SOGW.tfw
-rwx--x--- 1 rasdata users  685092 Oct 13  2004 4252SOGW.tif
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4252SORL.tfw
-rwx--x--- 1 rasdata users  632172 Oct 13  2004 4252SORL.tif
-rwx--x--- 1 rasdata users     216 Oct 13  2004 4252SOWL.tfw
```

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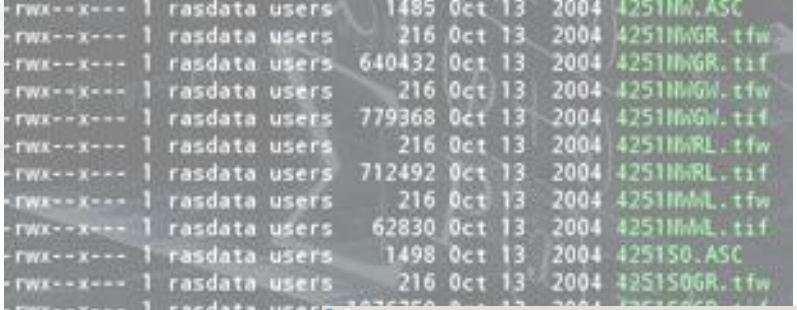
rasdaman raster data manager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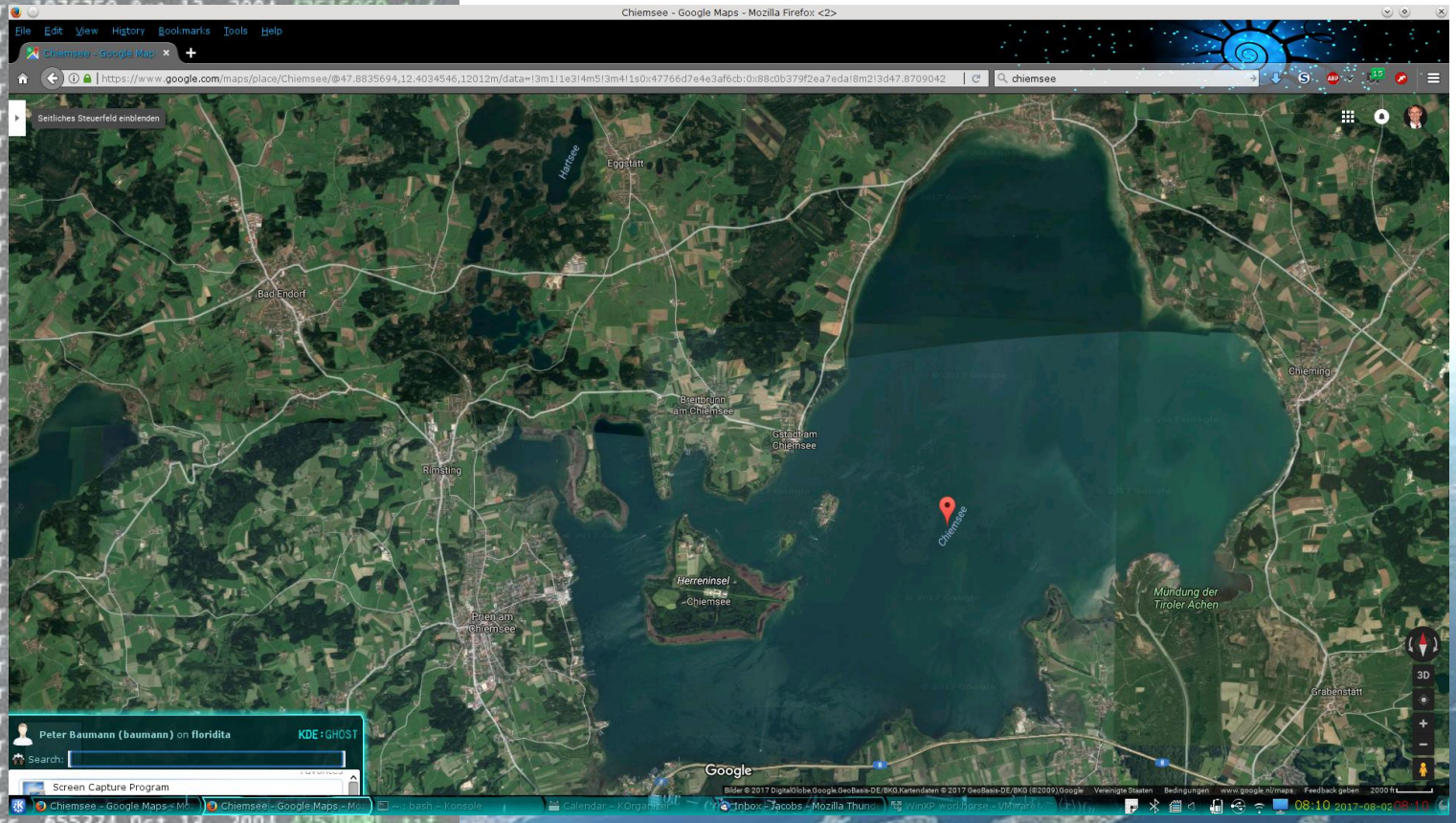
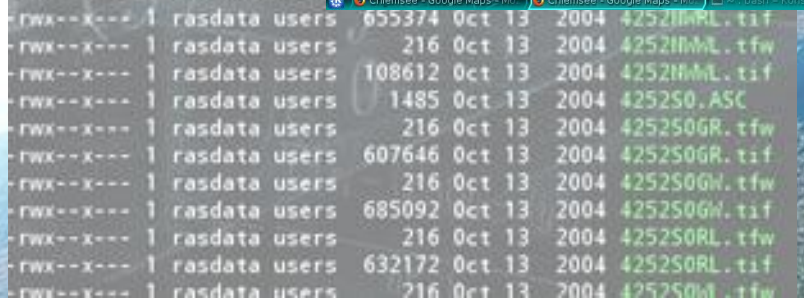
-rwx--x--- 1 rasdata users 1498 Oct 13 2004 4251S0.ASC
-rwx--x--- 1 rasdata users 216 Oct 13 2004 4251S0GR.tfw


Chiemsee - Google Maps - Mozilla Firefox <2>
File Edit View History Bookmarks Tools Help
Seitliches Steuerfeld einblenden
Hartsee
Eggstatt
Bad Endorf
Breitbrunn am Chiemsee
Gstadt am Chiemsee
Chieming
Rimsting
Chiemsee
Herreninsel
Chiemsee
Prien am Chiemsee
Mündung der Tiroler Achen
Grabenstatt
Google
Peter Baumann (baumann) on floridita
KDE:GHOST
Search:
Screen Capture Program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-rwx--x--- 1 rasdata users 108612 Oct 13 2004 4252NWWL.tif
-rwx--x--- 1 rasdata users 1485 Oct 13 2004 4252S0.ASC
-rwx--x--- 1 rasdata users 216 Oct 13 2004 4252S0GR.tfw
-rwx--x--- 1 rasdata users 607646 Oct 13 2004 4252S0GR.tif
-rwx--x--- 1 rasdata users 216 Oct 13 2004 4252S0GW.tfw
-rwx--x--- 1 rasdata users 685092 Oct 13 2004 4252S0GW.tif
-rwx--x--- 1 rasdata users 216 Oct 13 2004 4252S0RL.tfw
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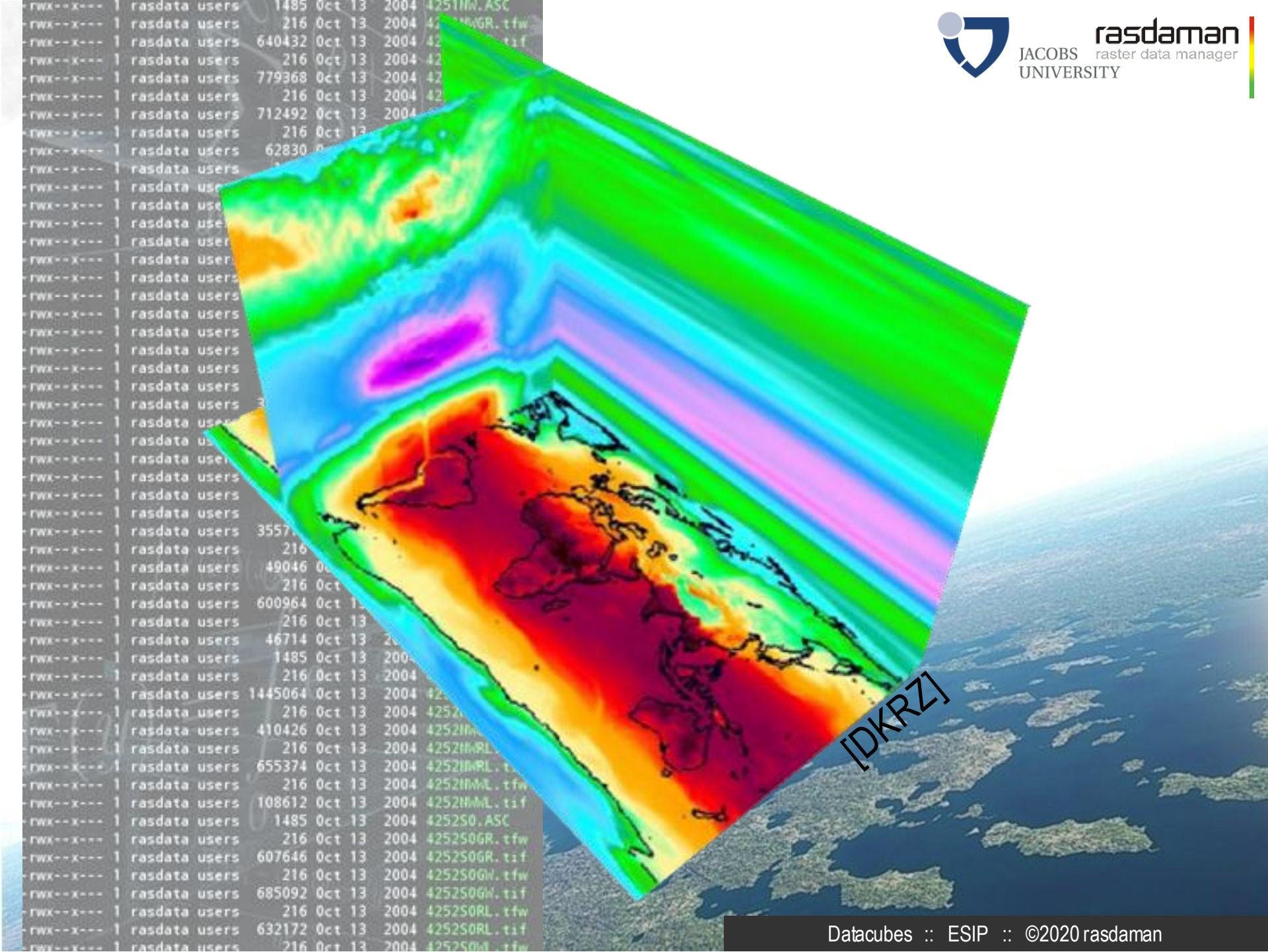
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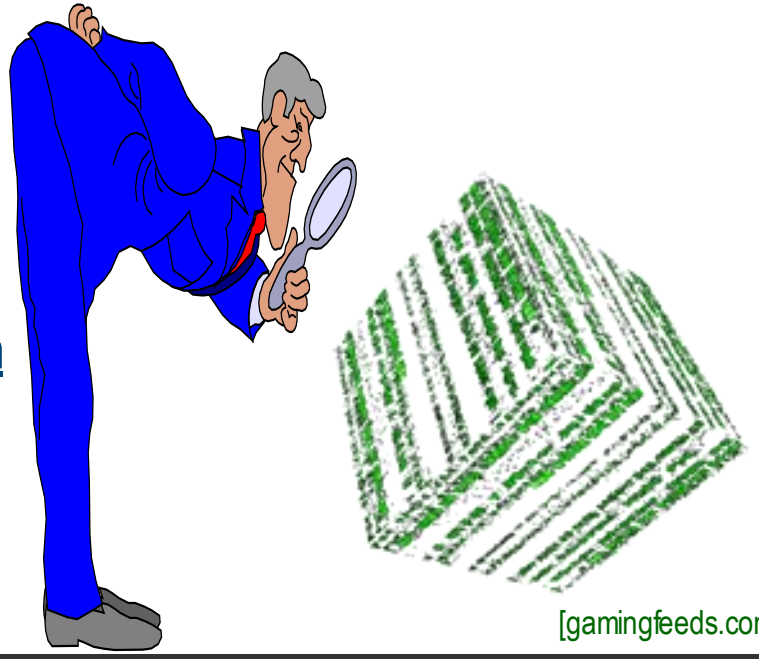
[DKRZ]
Datacubes :: ESIP :: ©2020 rasdaman

OGC Coverage Implementation Schema

the rasdaman team

Jacobs University | rasdaman GmbH

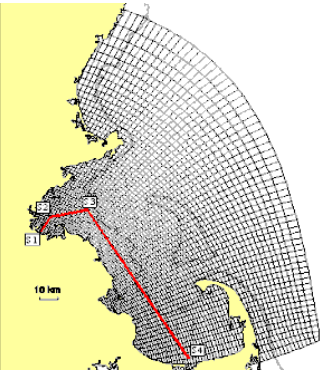
www.jacobs-university.de/lsis | www.rasdaman.com

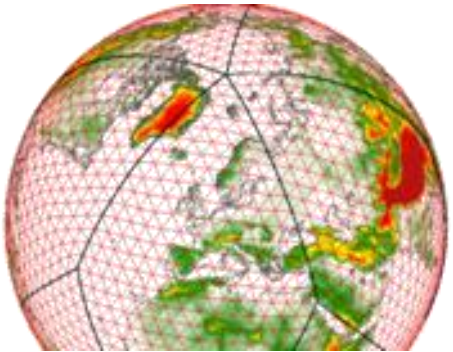


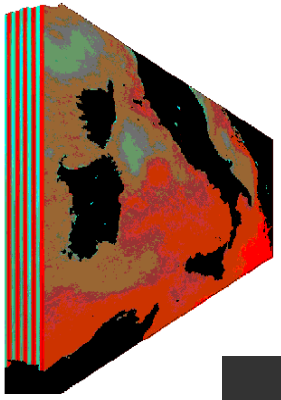
[gamingfeeds.com]

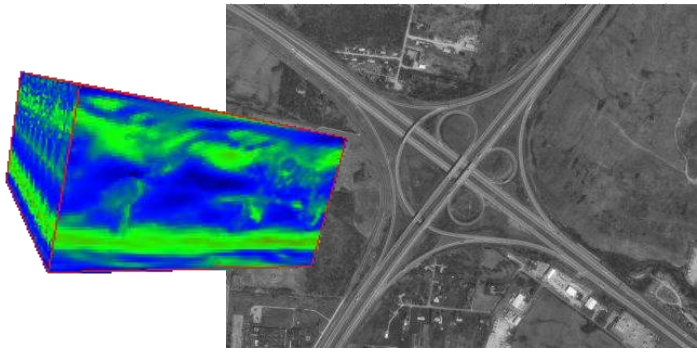
Features & Coverages

- The basis of all: geographic feature
- Feature subtype: coverage
  - aka space-time varying phenomenon
  - Spatio-temporal regular & irregular grids, point clouds, meshes
- Usually, Big Geo Data are coverages



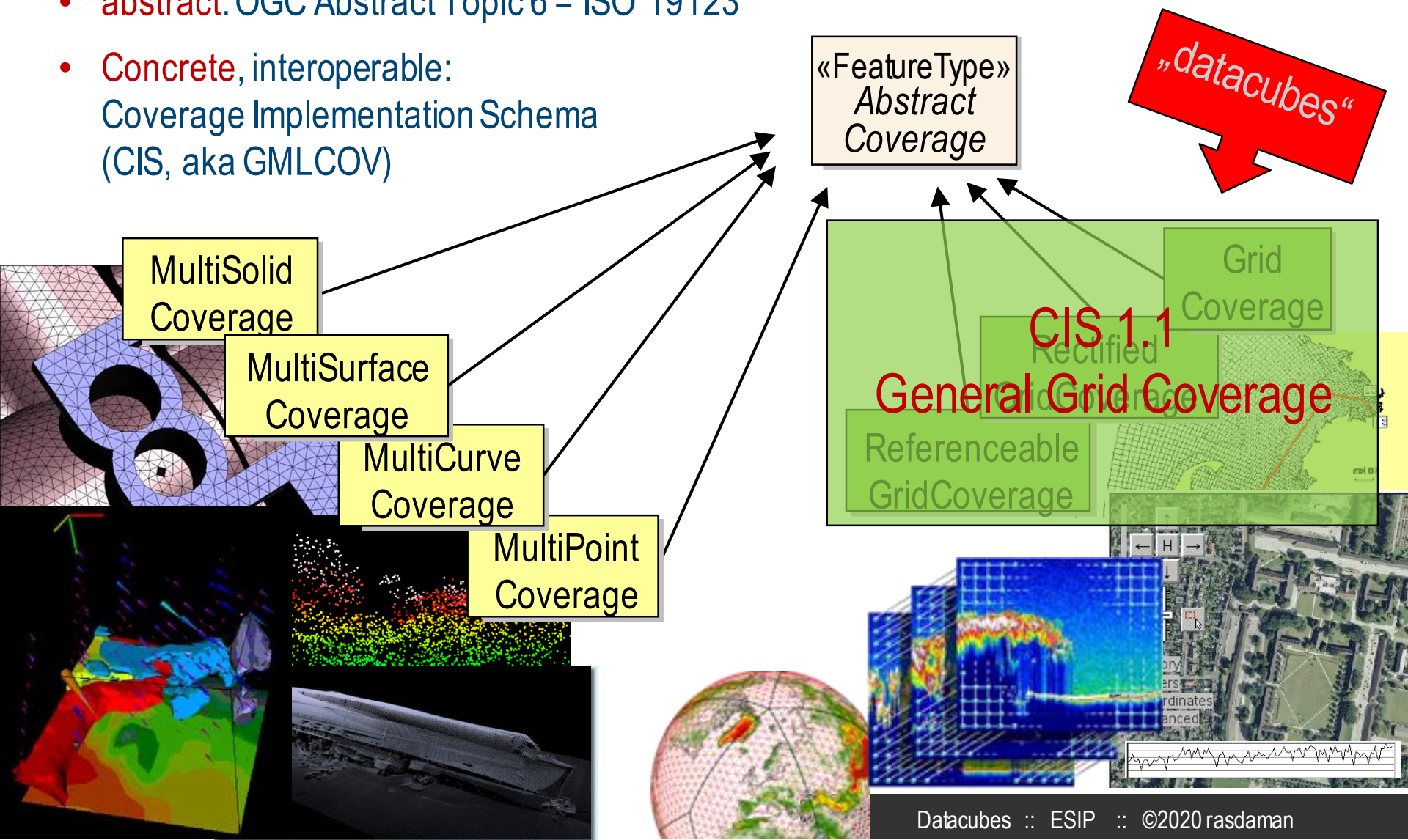




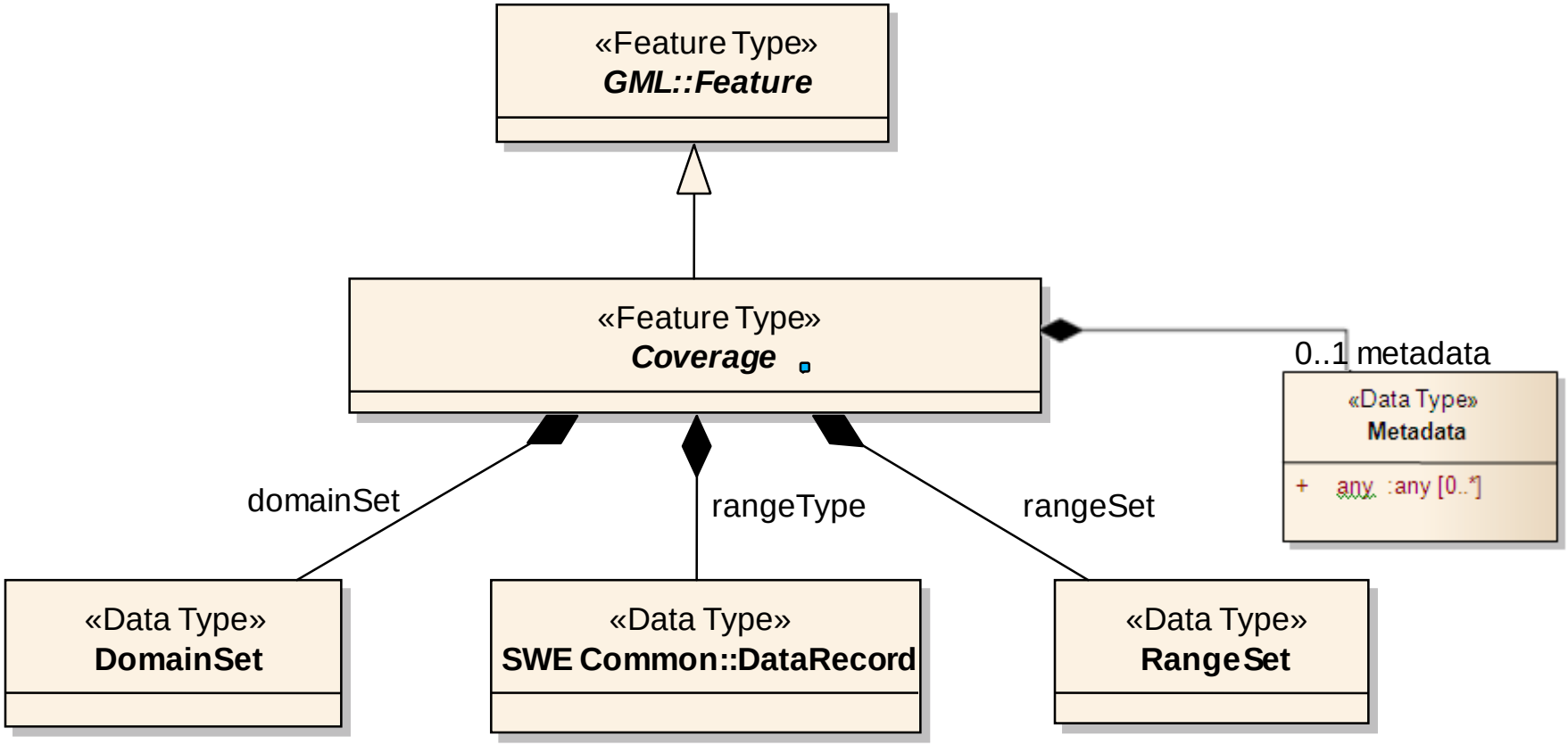


Coverages= Grids, Point Clouds, Meshes

- abstract: OGC Abstract Topic 6 = ISO 19123
- Concrete, interoperable:
  Coverage Implementation Schema
  (CIS, aka GMLCOV)



Coverage Definition



[OGC 09-146r2]

A Simple Coverage, in GML

```
<generalGridCoverage ...  gml:id="CIS_001">

    <domainSet>
        <generalGrid srsName="http://www.opengis.net/def/crs-compound?
                              1=http://www.opengis.net/def/crs/EPSG/0/4979
                            &amp;2=http://www.opengis.net/def/crs/OGC/0/AnsiDate"
            axisLabels="Lat Long h date">
            <regularAxis   axisLabel="Lat"  uomLabel="deg" lowerBound="40"  upperBound="60" resolution="10"/>
            <regularAxis   axisLabel="Long" uomLabel="deg" lowerBound="-10" upperBound="10"  resolution="10"/>
            <irregularAxis axisLabel="h"    uomLabel="m">
                <c>  0</c>
                <c>100</c>
            </irregularAxis>
            <irregularAxis axisLabel="date" uomLabel="d">
                <c>2015-12-01</c>
                <c>2015-12-02</c>
            </irregularAxis>
            <gridLimits srsName="http://www.opengis.net/def/crs/OGC/0/Index4D" axisLabels="i j k l">
                <indexAxis axisLabel="i" lowerBound="0" upperBound="2"/>
                <indexAxis axisLabel="j" lowerBound="0" upperBound="2"/>
                <indexAxis axisLabel="k" lowerBound="0" upperBound="1"/>
                <indexAxis axisLabel="l" lowerBound="0" upperBound="1"/>
            </gridLimits>
        </generalGrid>
    </domainSet>

    <rangeSet>
        <dataBlock>
               <v>01</v> <v>02</v> <v>03</v> <v>04</v> <v>05</v> <v>06</v> <v>07</v> <v>08</v> <v>09</v>
               <v>01</v> <v>02</v> <v>03</v> <v>04</v> <v>05</v> <v>06</v> <v>07</v> <v>08</v> <v>09</v>
               <v>01</v> <v>02</v> <v>03</v> <v>04</v> <v>05</v> <v>06</v> <v>07</v> <v>08</v> <v>09</v>
               <v>01</v> <v>02</v> <v>03</v> <v>04</v> <v>05</v> <v>06</v> <v>07</v> <v>08</v> <v>09</v>
        </dataBlock>
    </rangeSet>

    <rangeType>
        <swe:DataRecord>
            <swe:field name="panchromatic">
                <swe:Quantity definition="http://opengis.net/def/property/OGC/0/Radiance">
                    <swe:uom code="W.m-2.sr-1.nm-1"/>
                </swe:Quantity>
            </swe:field>
        </swe:DataRecord>
    </rangeType>

</generalGridCoverage>
```

A Simple Coverage, in JSON

```
{   "type": "CoverageByDomainAndRangeType",
    "domainSet":{
        "type": "DomainSetType",
        "generalGrid":{
            "type":          "GeneralGridCoverageType",
            "srsName":    "http://www.opengis.net/def/crs/OGC/0/Index2D",
            "axisLabels": ["i", "j"],
            "axis": [{      "type": "IndexAxisType“, "axisLabel": "i", "lowerBound": 0, "upperBound": 2
            },{             "type": "IndexAxisType“, "axisLabel": "j", "lowerBound": 0, "upperBound": 2  }]
        }
    },
    "rangeSet": {     "type": "RangeSetType",
                      "dataBlock": { "type": "VDataBlockType",  "values": [1,2,3,4,5,6,7,8,9] }     },
    "rangeType": {   "type": "DataRecordType",
                      "field":[{     "type": "QuantityType",
                                     "definition": "ogcType:unsignedInt",
                                     "uom": { "type": "UnitReference", "code": "10^0“ }     }]
    }
}
```

A Simple Coverage, in RDF

```
<http://www.opengis.net/cis/1.1/examples/CIS_05_2D>
 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
 <http://www.opengis.net/cis/1.1/CoverageByDomainAndRangeType> .

<http://www.opengis.net/cis/1.1/examples/CIS_05_2D>
 <http://www.opengis.net/cis/1.1/domainSet>
 <http://www.opengis.net/cis/1.1/examples/CIS_DS_05_2D> .
<http://www.opengis.net/cis/1.1/examples/CIS_DS_05_2D>
 <http://www.opengis.net/cis/1.1/generalGrid>
 <http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_05_2D> .
<http://www.opengis.net/cis/1.1/examples/CIS_DS_05_2D>
 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
 <http://www.opengis.net/cis/1.1/DomainSetType> .
<http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_05_2D>
 <http://www.opengis.net/cis/1.1/axis>
 <http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_I_05_2D> .
<http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_05_2D>
 <http://www.opengis.net/cis/1.1/axis>
 <http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_J_05_2D> .
<http://www.opengis.net/cis/1.1/examples/CIS_DS_GG_05_2D>
 <http://www.opengis.net/cis/1.1/axisLabels>
 <http://www.opengis.net/cis/1.1/axisLabels0> .
<http://www.opengis.net/cis/1.1/axisLabels0> <http://www.w3.org/1999/02/22-rdf-syntax-ns#first> "i" .
<http://www.opengis.net/cis/1.1/axisLabels0> <http://www.w3.org/1999/02/22-rdf-syntax-ns#rest> <http://www.opengis.net/cis/1.1/axisL
<http://www.opengis.net/cis/1.1/axisLabels1> <http://www.w3.org/1999/02/22-rdf-syntax-ns#first> "j" .
<http://www.opengis.net/cis/1.1/axisLabels1> <http://www.w3.org/1999/02/22-rdf-syntax-ns#rest> <http://www.w3.org/1999/02/22-rdf-sy
```

Sample Coverages

http://schemas.opengis.net/cis/1.1/

Index of /cis/1.1

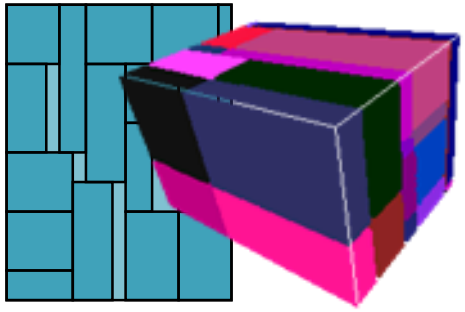
Name	Last modified	Size
Parent Directory		-
gml/	2017-09-22 15:07	-
json/	2017-09-22 15:07	-
rdf/	2017-09-22 15:07	-

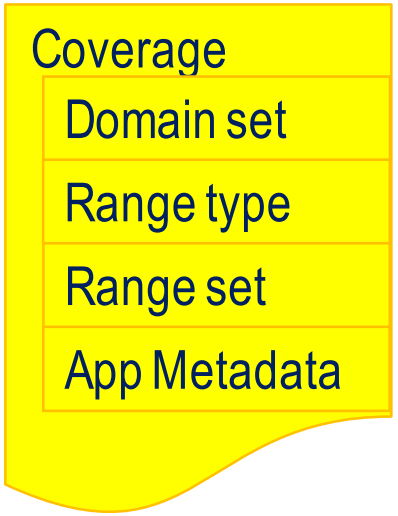
Index of /cis/1.1/json/examples

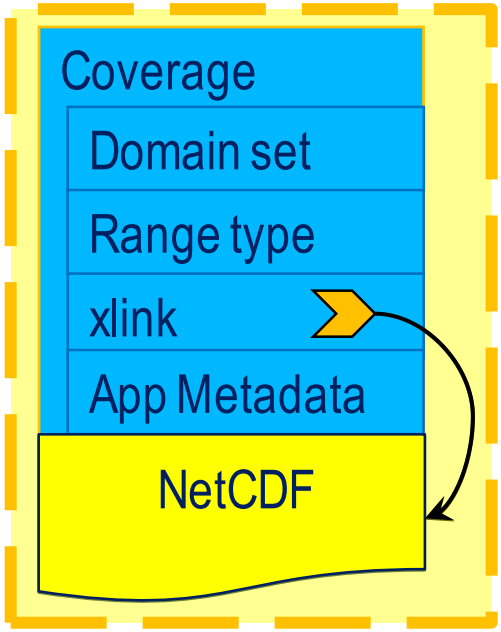
Name	Last modified	Size	Description
Parent Directory		-	
00_metadata.json	2017-09-22 15:00	1.7K	
05_2D_index.json	2017-09-22 15:00	1.4K	
10_2D_regular.json	2017-09-22 15:00	2.0K	
11_2D_regular_fileref.json	2017-09-22 15:00	1.9K	
12_2D_regular_fileref_multiband.json	2017-09-22 15:00	4.7K	
15_with-envelope.json	2017-09-22 15:00	2.6K	
20_3D_height.json	2017-09-22 15:00	2.4K	
25_3D_time.json	2017-09-22 15:00	2.6K	
30_4D_height+time.json	2017-09-22 15:00	2.9K	
40_1D_regular.json	2017-09-22 15:00	1.8K	
45_2D_distorted.json	2017-09-22 15:00	2.0K	
46_irregular+distorted.json	2017-09-22 15:00	2.4K	
50_3D_partitioned-1.json	2017-09-22 15:00	3.5K	
55_1D_timeseries-partitioned.json	2017-09-22 15:00	8.0K	
60_3D_timeseries-multipart.json	2017-09-22 15:00	2.4K	
65_1D_timeseries-interleaved.json	2017-09-22 15:00	1.2K	
70_2D_interpolation.json	2017-09-22 15:00	2.2K	
80_sensormodel.json	2017-09-22 15:00	1.9K	
90_point-cloud.json	2017-09-22 15:00	2.8K	

Encoding Coverages

- Single file encoding:
  - Informationally complete: GML, JSON, RDF, …
    - *Caveat: GeoJSON, CovJSON does not work*
  - Further formats: GeoTIFF, NetCDF, JPEG2000, GRIB, …
- Multipart: container(“header” + file1 + file2 + …)
  - Multipart/MIME, zip, GMLJP2, SAFE, GeoPackage, ...
  - Built-in collections / tiling







Discrete vs Continuous Coverages

- Grid coverages: Continuous = Discrete + interpolation method(s)
- CIS 1.1: optional list of interpolation identifiers

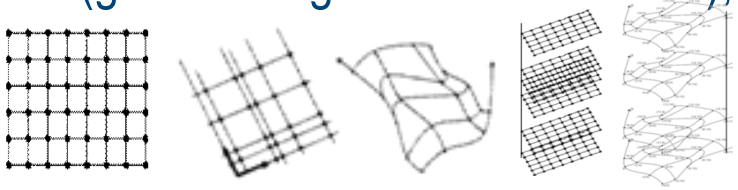
```
<interpolationRestriction>
  <allowedInterpolation>http://www.opengis.net/def/interpolation/OGC/1/nearest-neighbor</allowedInterpolation>
  <allowedInterpolation>http://www.opengis.net/def/interpolation/OGC/1/linear</allowedInterpolation>
<interpolationRestriction>
```

- Identifiers not hardwired into coverage standard
  - to be defined by OGC-NA

Summary

datacubes

- Coverage = regular & irregular grids, point clouds, meshes
- Coverage Implementation Schema 1.1
  = backwards-compatible evolution of GMLCOV 1.0
  - Grids: Regular + irregular (generalizing CIS 1.0 & GML 3.3), SensorML



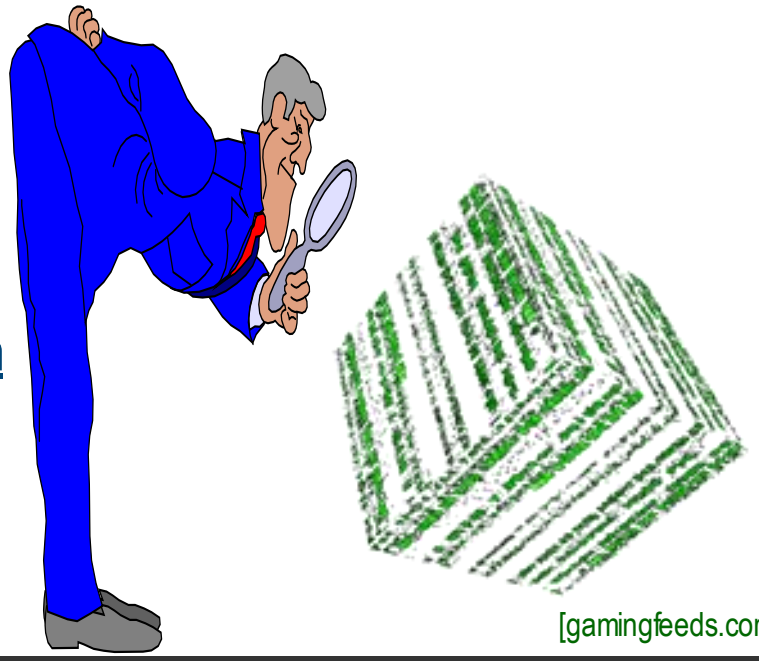
  - Interpolation
  - Representations
    - *domain/range, „position/value pair“, partitioned, JSON, RDF, ...*
  - Practice-driven packaging
  - See http://schemas.opengis.net/cis/1.1/ for schemas + examples
- *OGC CIS 1.0 = ISO 19123-2*

OGC Web Coverage Service (WCS)

the rasdaman team

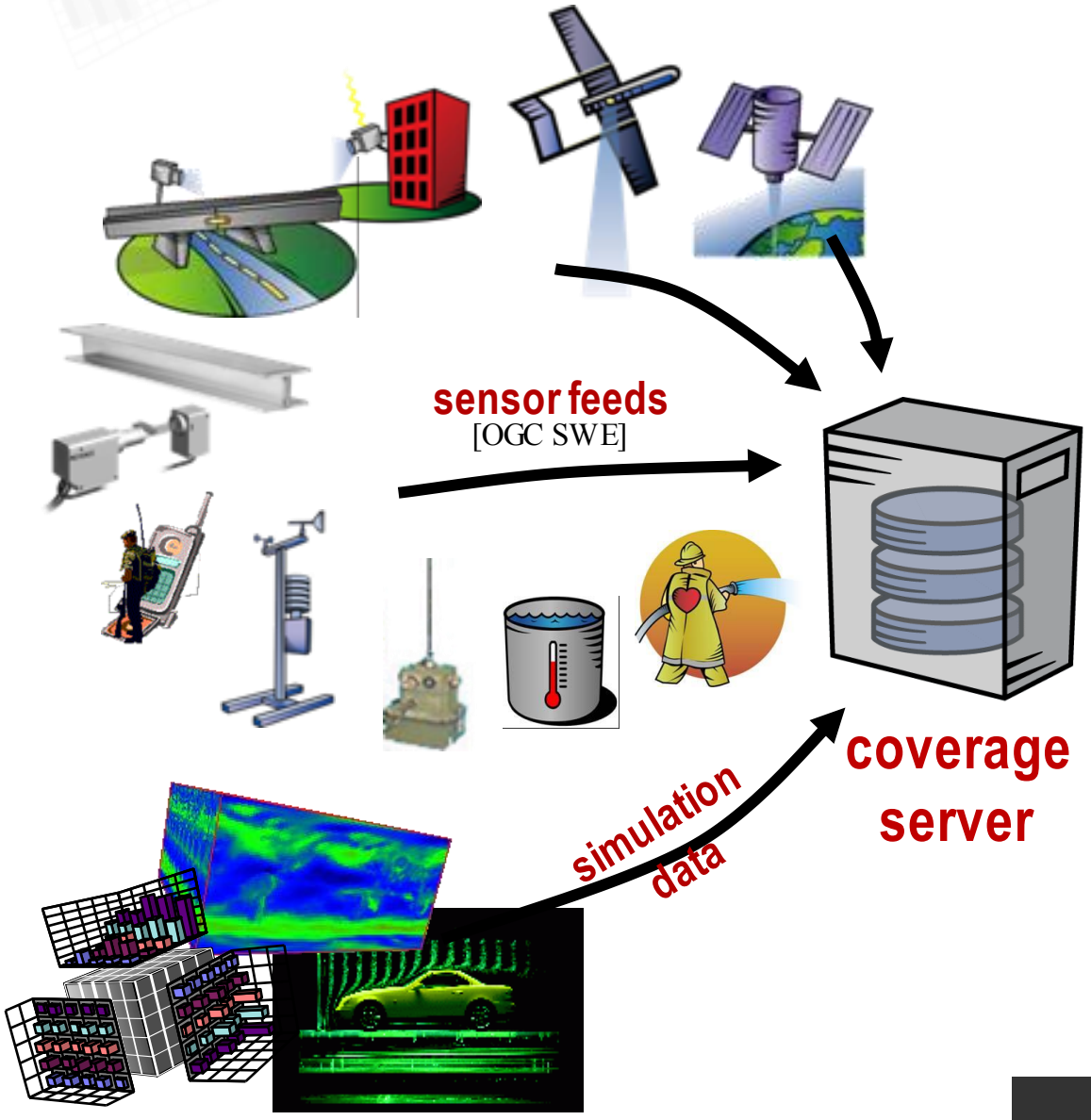
Jacobs University | rasdaman GmbH

www.jacobs-university.de/lsis | www.rasdaman.com

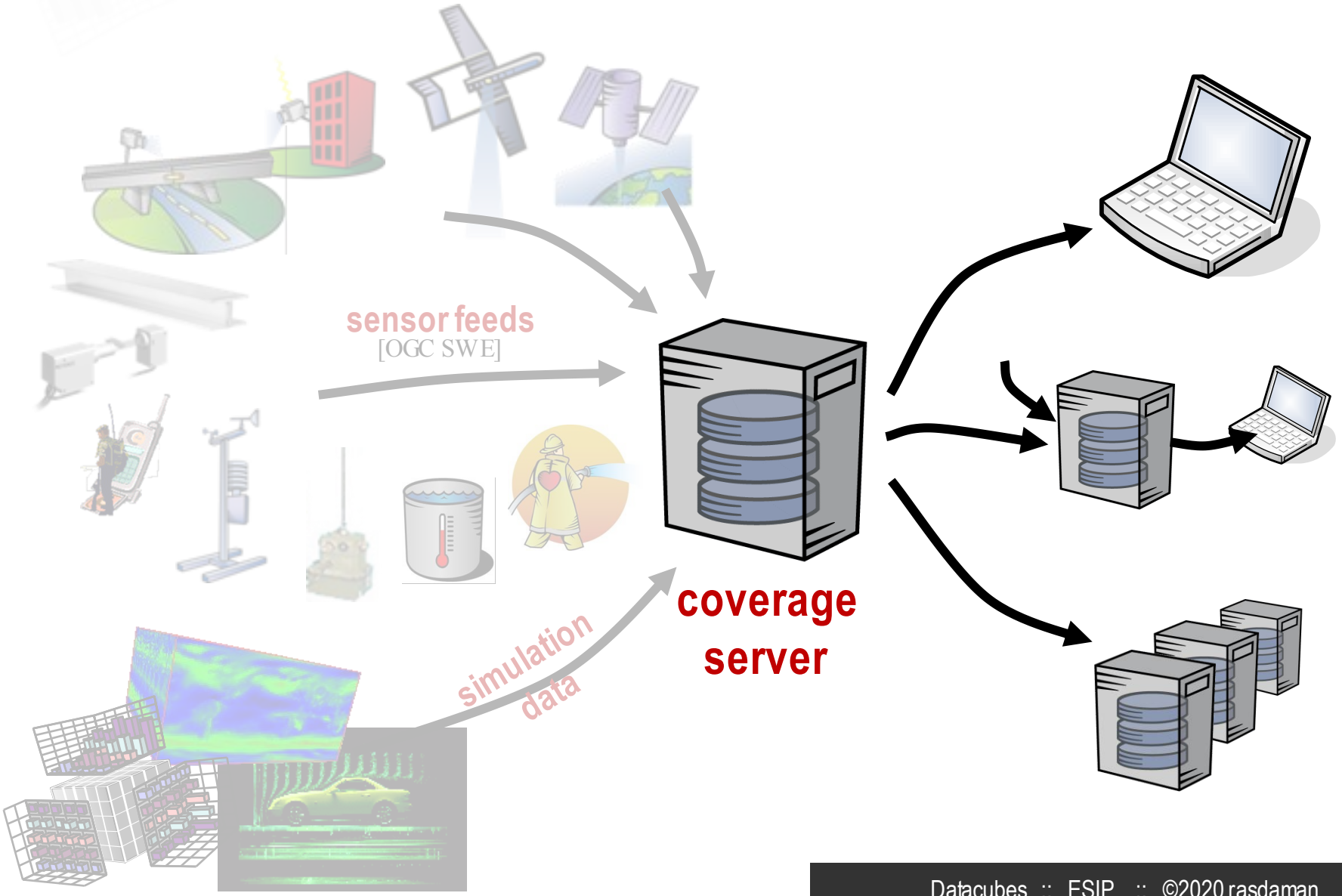


[gamingfeeds.com]

Facing the Coverage Tsunami



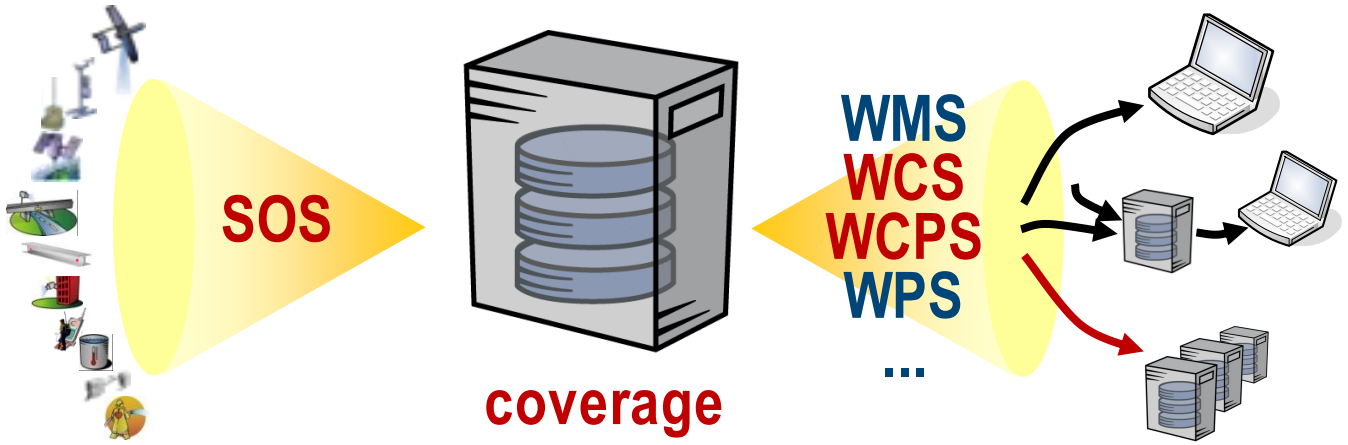
Taming the Coverage Tsunami



Serving Coverages

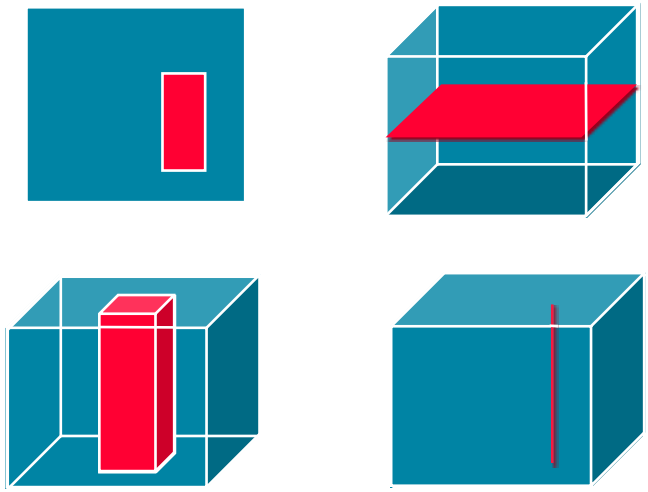
SWE SOS:
upstream data capturing

CIS & WCS:
downstream access
& processing services



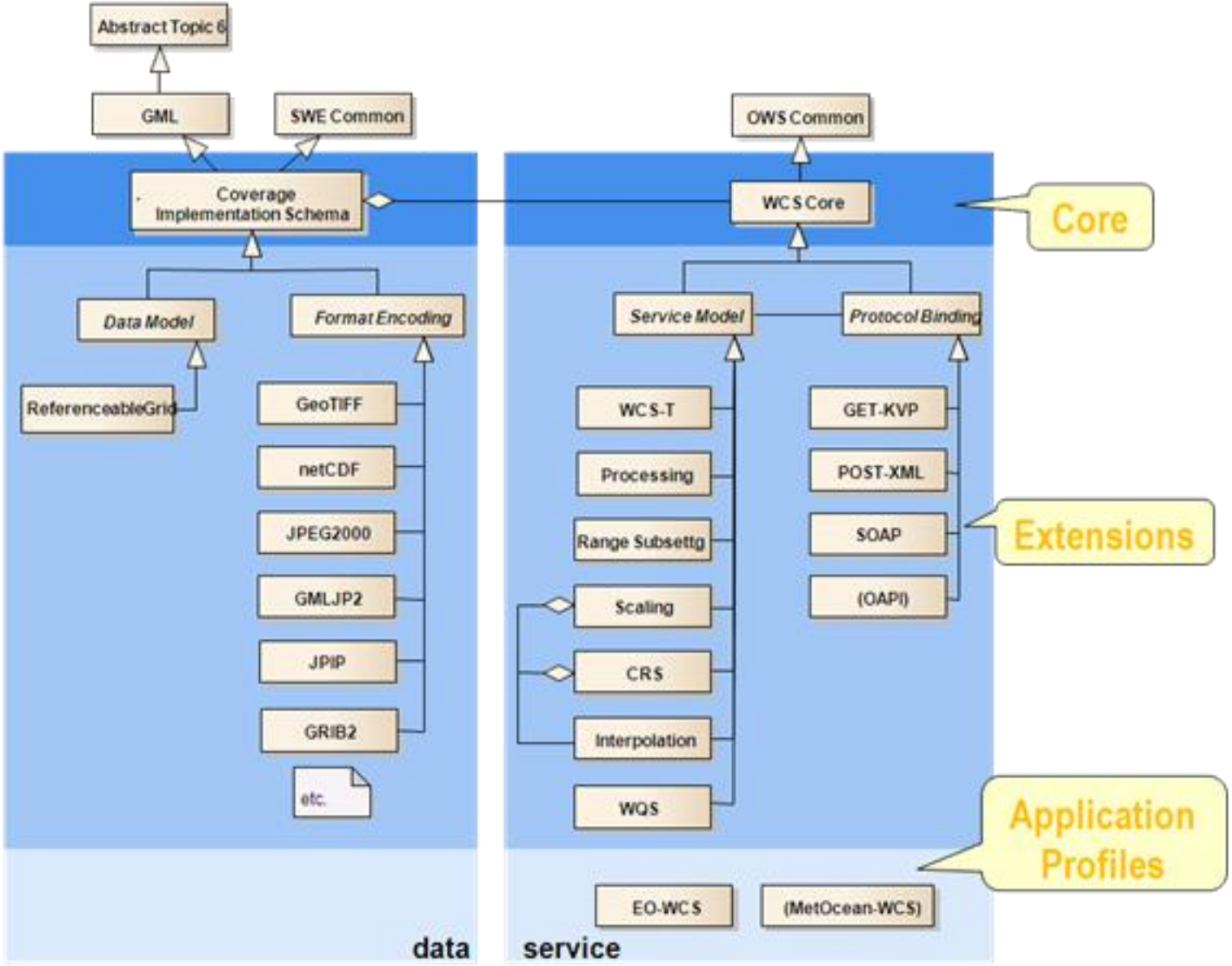
OGC Web Coverage Service (WCS)

- WCS Core: access to spatio-temporal coverages & subsets
  - Encoding on the fly
  - subset = trim | slice



- WCS Extensions: optional functionality facets
- *rasdaman implements WCS Core & all Extensions*
  - *reference implementation*

Coverages & WCS: The Big Picture



WCS Core

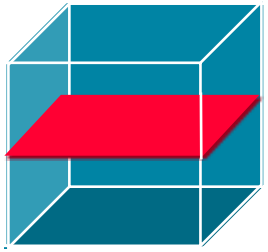
WCS Core *GetCoverage*

- Download a coverage (or a subset thereof), values guaranteed unchanged
- Ex: „*download coverage c001*“

  http://www.acme.com/wcs ? SERVICE=WCS & VERSION=2.0
  & REQUEST=GetCoverage & COVERAGEID=c001

- Ex: „*coverage c001, lat/long cutout, time slice t=2009-11-06T23:20:52*”

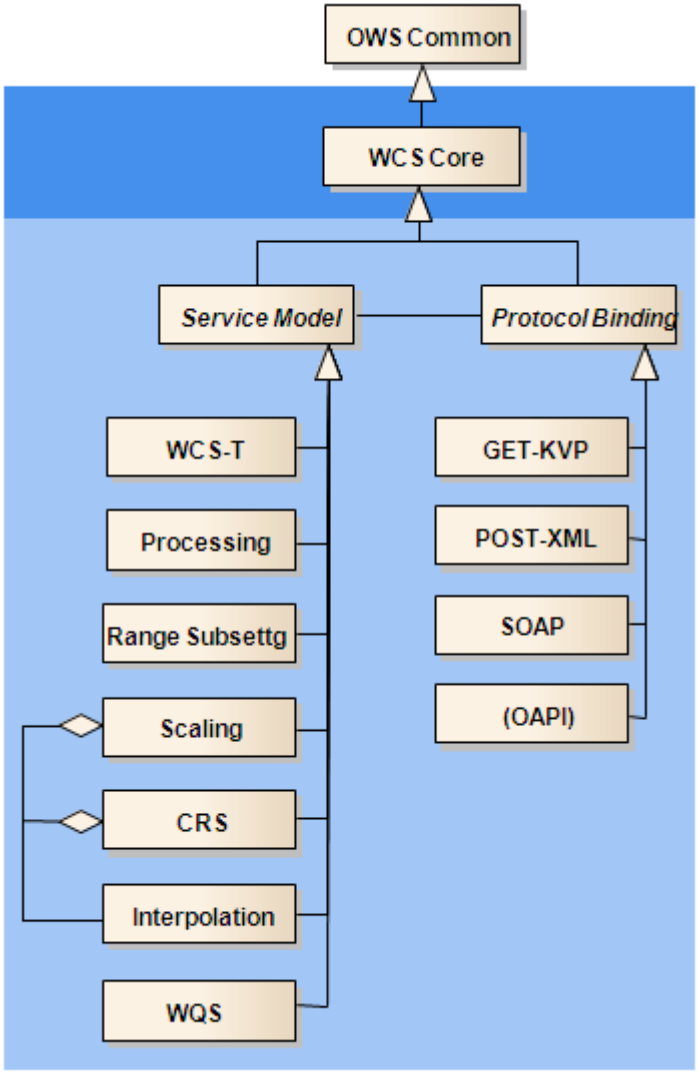
  http://www.acme.com/wcs ? SERVICE=WCS & VERSION=2.0
  & REQUEST=GetCoverage & COVERAGEID=c001
  & SUBSET=Long(100,120) & SUBSET=Lat(50,60)
  & SUBSET=time("2009-11-06T23:20:52")



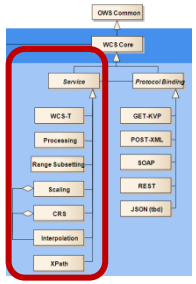
- Ex: “*coverage c001, in GeoTIFF*”

  http://www.acme.com/wcs ? SERVICE=WCS & VERSION=2.0
  & REQUEST=GetCoverage & COVERAGEID=c001 & FORMAT=“image/tiff“

WCS Extensions (selected)



WCS Range Subsetting [OGC 12-039]

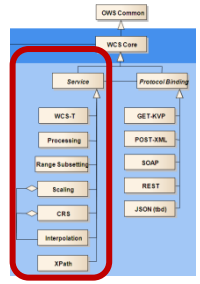


- Extract range components
  - „bands“, „variables“
- Request:

```
http://www.acme.com/wcs?SERVICE=WCS & VERSION=2.0
  & REQUEST=GetCoverage & COVERAGEID=c001
  & RANGESUBSET=red
```

  - *or:* …& RANGESUBSET=nir,red,green &…
  - *or:* …& RANGESUBSET=green,red,blue &…
  - *or:* …& RANGESUBSET=nir:green &…
  - *or:* …& RANGESUBSET=band01,band03:band05,band19:band21 &…

WCS CRS [OGC 11-053]

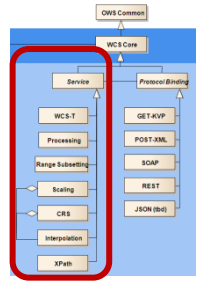


- Express coordinates in CRSs different from Native CRS
  - Result coverage
  - Subsetting coordinates
- Request:

```
http://www.acme.com/wcs?SERVICE=WCS & VERSION=2.0
  & REQUEST=GetCoverage & COVERAGEID=c001
  & SUBSETTINGCRS=http://www.opengis.net/def/crs/EPSG/0/4326
  & OUTPUTCRS=http://www.opengis.net/def/crs/EPSG/0/4326
```

- CRS definitions as URLs → OGC resolver
  - EPSG + many more CRSs
- CRSs supported → Capabilities document

WCS Transaction [OGC 13-057]



= WCS-T: Modify coverage offerings on a server via Web

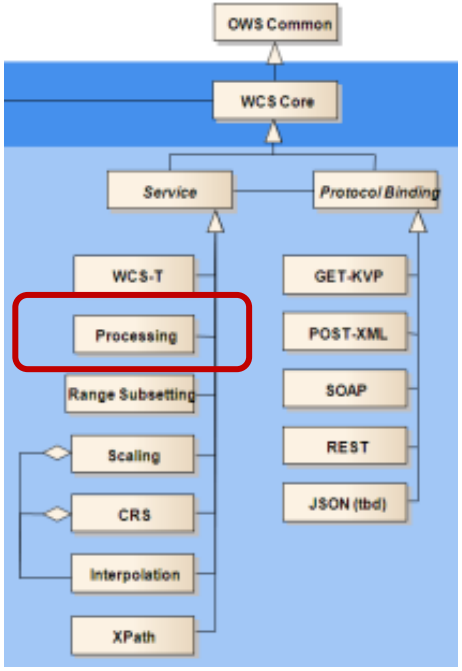
- New request types:
  InsertCoverage + *DeleteCoverage* + *UpdateCoverage* (incl. partial replacement)

- Core design goal: *GetCoverage* → *InsertCoverage*

- Ex:

```
http://www.acme.com/wcs
    ? SERVICE=WCS  & VERSION  = 2.0
    & REQUEST=InsertCoverage
    & COVERAGEREF=http://bcme.com/archive/hurricane.nc
    & USEID=new
```

WCS Processing Extension & WCPS

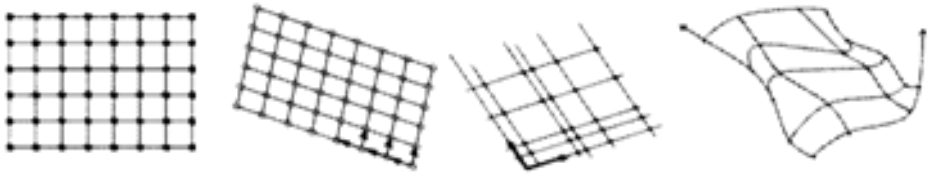


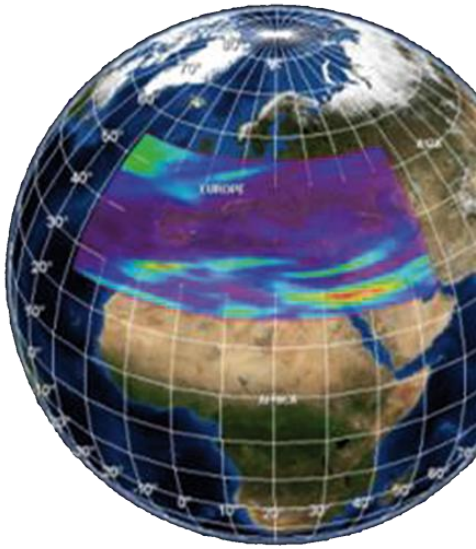
OGC WCPS: Space/Time Datacubes

- Web Coverage Processing Service (WCPS)
  - spatio-temporal datacube analytics language

```
A[ Lat(10.2),Long(8.4),date("2017-12-04")]
```

  - space & time, regular & irregular grids



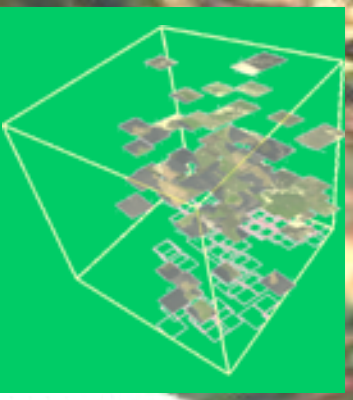


- "From MODIS scenes M1, M2, M3: difference red & nir, as TIFF"
  - "…but only those where nir exceeds 127 somewhere"

```
for $c in ( M1, M2, M3 )
where some( $c.nir > 127 )
return encode( $c.red - $c.nir, "image/tiff" )
```

[SSDBM 2009, SSDBM 2010, Geoinformatica 2010]

OGC WCPS: Elevation & Image Fusion

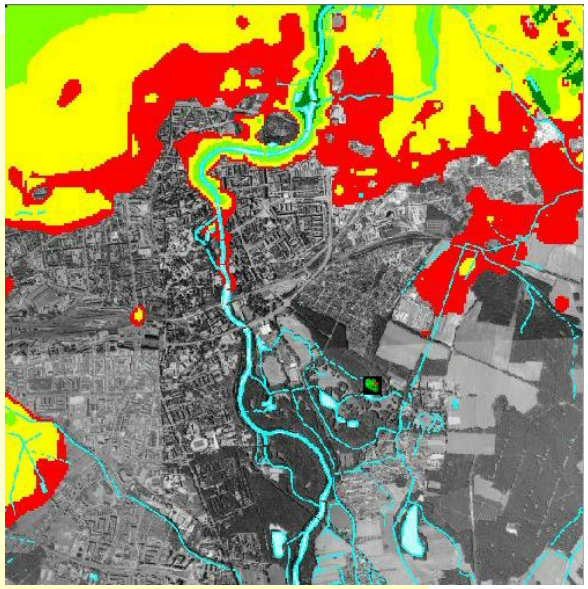


```
for $s in (SatImage), $d in (DEM)
where $s/metadata/@region = "Glasgow"
return
  encode(
    struct {
      red:   (char) $s.b7[x0:x1,x0:x1],
      green: (char) $s.b5[x0:x1,x0:x1],
      blue:  (char) $s.b0[x0:x1,x0:x1],
      alpha: (char) scale( $d, 20 )
    },
    "image/png"
  )
```

[JacobsU, Fraunhofer; data courtesy BGS, ESA]

WCPS Emulating WMS

```
for $p in (OrthoPhoto),
    $wl in (WaterLines), $wa in (WaterAreas),
    $d in (DEM)
return
    encode(  (unsigned char) (
          $p * { 1, 1, 1 }
       overlay
          $wl * { 0, 128, 255 }
       overlay
          $wa * { 191, 255, 255 }
       overlay
          switch $d
          case $d > 260 return { red:255, green:0, blue:0 }
          case $d > 262 return { red:0, green:255, blue:0 }
          case $d > 264 return { red:0, green:0,  blue:255 }
          default       return { red:0, green:0, blue:0 }
          end
       ),
      "image/png" )
```



Semantic Interoperability: WCPS vs WPS

- WCPS: semantics in query

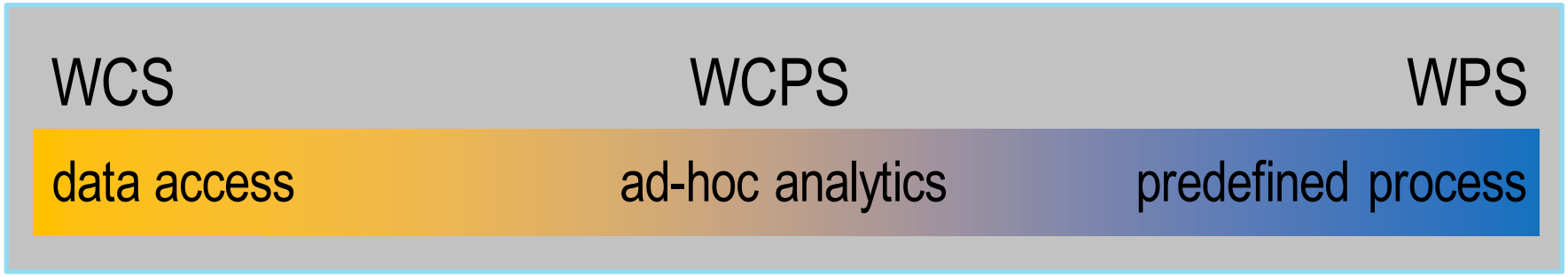
```
for $c in ( M1, M2, M3 )
return encode abs( $c.red - $c.nir ), "hdf" )
```

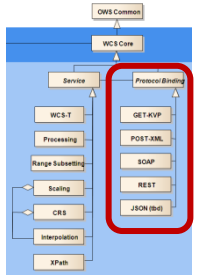
- WPS: semantics in human-readable text

```
<ProcessDescriptions ...>
  <ProcessDescription processVersion="2" storeSupported="true" statusSupported="false">
    <ows:Identifier>Buffer</ows:Identifier>
    <ows:Title>Create a buffer around a polygon.</ows:Title>
    <ows:Abstract>Create a buffer around a single polygon. Accepts the polygon as GML and
provides GML output for the buffered feature. </ows:Abstract>
    <ows:Metadata xlink:title="spatial" />
    <ows:Metadata xlink:title="geometry" />
    <ows:Metadata xlink:title="buffer" />
    <ows:Metadata xlink:title="GML" />
    <DataInputs>
      <Input>
        <ows:Identifier>InputPolygon</ows:Identifier>
        <ows:Title>Polygon to be buffered</ows:Title>
        <ows:Abstract>URI to a set of GML that describes the polygon.</ows:Abstract>
        <ComplexData defaultFormat="text/XML" defaultEncoding="base64" defaultSchema="http
://foo.bar/gml/3.1.0/polygon.xsd">
          <SupportedComplexData>
                                                                    1,1           Top
```

OGC Big Data Coverage Service Portfolio

- OGC standards cover full range
  from data-intensive to processing-intensive „Big Data“ coverage services



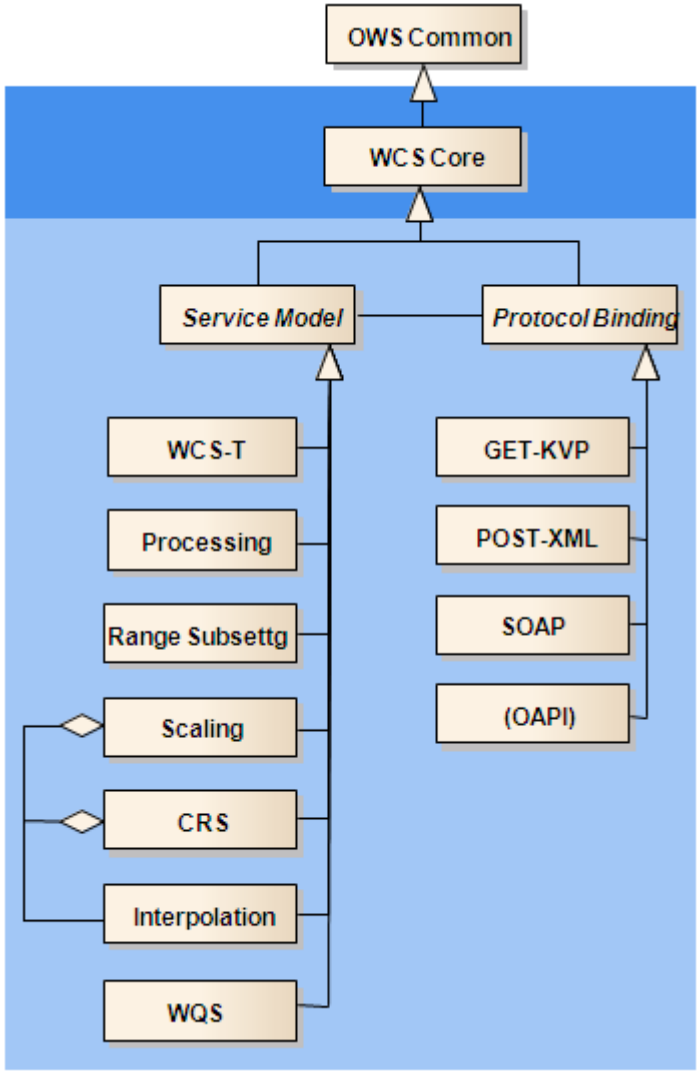


WCS Protocol Bindings

- Up to now: GET/KVP in examples
- Identical WCS functionality across various protocols:
  - GET/KVP [OGC 09-147r2]
  - XML-POST [OGC 09-148r1]
  - SOAP [OGC 09-149r1] + WSDL
  - REST [OGC 12-174]
    - *Draft, dismissed*
  - OAPI
    - *In progress*

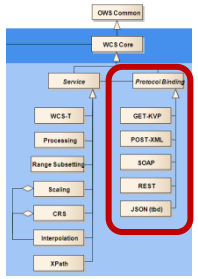
New: OAPI - Coverages

- Recent OGC activity
  towards unified W*S interfaces
  - Catalog, WFS, WCS, WMS, WMTS, WPS
- OAPI-Coverages:
  - based on CIS 1.1
  - Workspace:
    https://github.com/opengeospatial/ogc_api_coverages
- Basically quite similar functionality,
  new syntax & conventions ↳



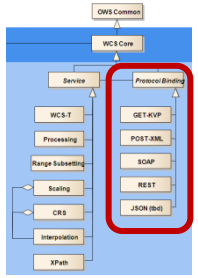
OAPI – Coverages: Overview

under work, may (and will) change



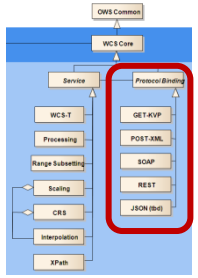
- http://acme.com/oapi/collections/{collectionid}/coverage/all
  - Complete coverage = domainset, rangetype, rangeset, metadata = GetCov
- http://acme.com/oapi/collections/{collectionid}/coverage/domainset
  - domain set (space/time location of data)
- http://acme.com/oapi/collections/{collectionid}/coverage/rangetype
  - range type (i.e., description of data semantics)
- http://acme.com/oapi/collections/{collectionid}/coverage/metadata
  - coverage's application metadata (if any)
- http://acme.com/oapi/collections/{collectionid}/coverage/rangeset
  - range set = actual values in Native Format
- http://acme.com/oapi/collections/{collectionid}/coverage/description
  - coverage description = domainset, rangetype, metadata (not rangeset)

OAPI – Coverages: Subsetting



- OAPI-Common style (2D only):
  - http://acme.com/oapi/collections/{collectionid}/coverages?
    bbox=160.6,-55.95,-170,-25.89
- OAPI-Coverages style (cf WCS GetCoverage):
  - http://acme.com/oapi/collections/{collectionid}/coverages/{coverageid}?
    SUBSET=time("2019-03-27")
    - *coverage slice @ timestamp*
  - http://acme.com/oapi/collections/{collectionid}/coverages?
    SUBSET=Lat(160.6,-55.95) & SUBSET=Lon(-170,-25.89)
    &SUBSET=time("2019-03-27")
  - http://acme.com/oapi/collections?
    wcps=for $c in (Landsat8) return encode($c.red - $c.nir, “image/tiff“)

OAPI-Coverages Demo (rasdaman)



- Demo 1: Coverage Subsetting
  - Ex: http://54.93.148.198:8080/rasdaman/collections/S2_NDVI_84?
    subset=Lat(51.9:52.1)&subset= Long(-4.1:-3.9)&subset=ansi("2018-11-14")]
    &f=image/png
    doIt!

- Demo 2: WCPS on 2D, 3D sat & climate coverages
  - OpenAPI def file URL -> swagger editor to get this image:
  - http://54.93.148.198:8080/rasdaman/collections?
    q=for $c in (S2_FALSE_COLOR_84)
    return encode((($c.0 - $c.1)/($c.0 + $c.1)) [Lat(51.9:52.1), Long(-4.1:-3.9), ansi("2018-11-14")] , "jpeg")
    doIt!

    http://54.93.148.198:8080/rasdaman/collections?
    q=for $c in (S2_FALSE_COLOR_84)
    return avg((($c.0 - $c.1)/($c.0 + $c.1)) [Lat(51.9:52.1), Long(-4.1:-3.9), ansi("2018-11-14")])
    doIt!

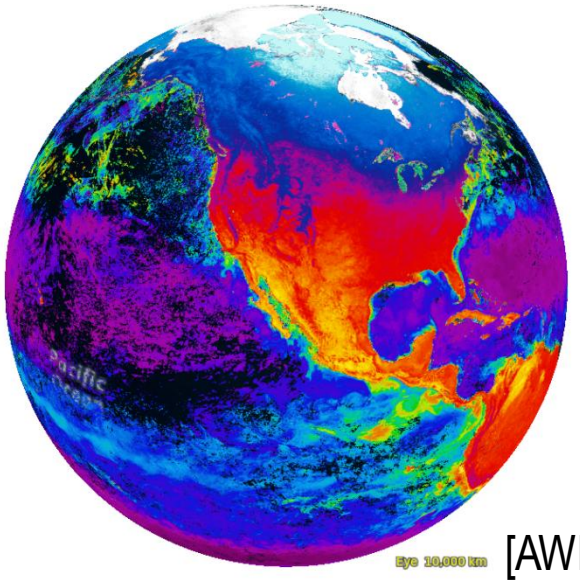
- Sprint proposed scheme:

  http://www.acme.com/oapi/collections?wcps={wcps-query}

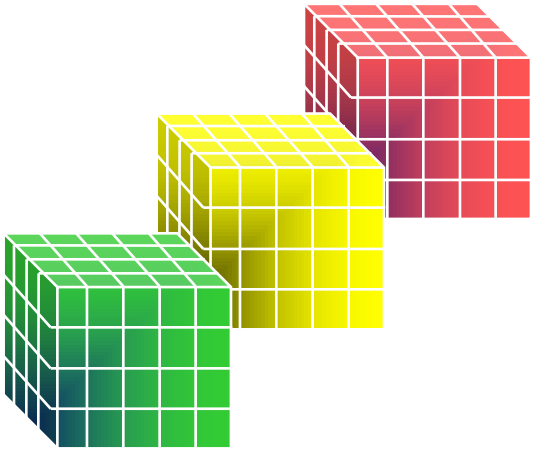
ESIP summary

Summary

- OGC WCS Core
  - Coverage subsetting, formatting
- OGC WCS Extensions
  - Various optional, bespoke functionality
- OGC WCPS
  - Spatio-temporal datacube analytics language
- pixel-level conformance tests for interoperability
- robust, scalable, mature
  - proven on multi-Petabytes in EarthServer
  - extensible, such as OAPI



[AWI]



rasdaman

the rasdaman team

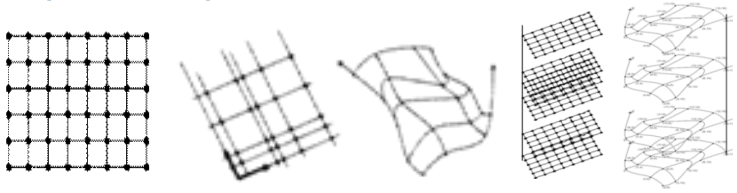
Jacobs University | rasdaman GmbH

www.jacobs-university.de/lsis | www.rasdaman.com

rasdaman: Agile Array Analytics

= „raster data manager“: SQL + n-D arrays

- Pioneered Array Databases & datacubes since 1992: patents, publications
- Scalable parallel “tile streaming” architecture
- Any spatio-temporal regular & irregular grid

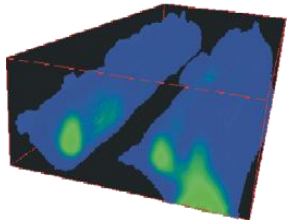


- Standards blueprint, reference implementation, innovation awards

Array SQL in a Nutshell

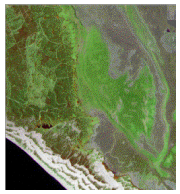
- selection & section

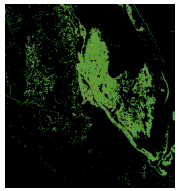
```
select c.data[ *:*, 100:200, *:*, 42 ]
from ClimateSimulations as c
```



- result processing

```
select ls.img * (ls.img.green > 130)
from   LandsatArchive as ls
```





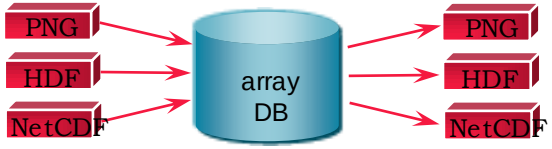
- search & aggregation

```
select mri.data
from   MRI as img, masks as am
where  some( mri.data > 250 and m.valid )
```

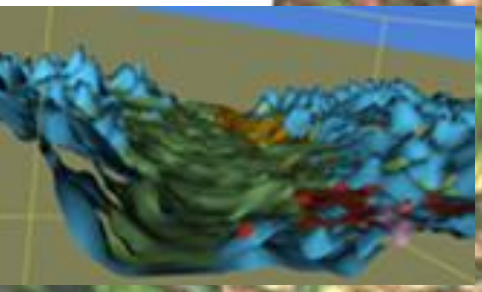
- nest & unnest: array ↔ table

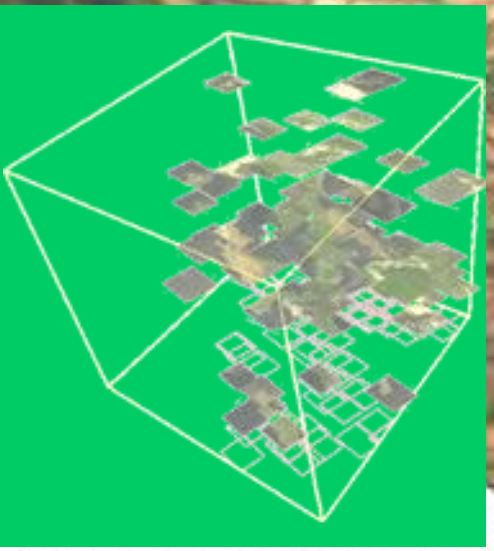
- data format conversion

```
select encode( ls.img, „image/png“ )
from   LandsatArchive as ls
```



Visualization





```
select
  encode(
    struct {
      red:   (char) s.b7[x0:x1,x0:x1],
      green: (char) s.b5[x0:x1,x0:x1],
      blue:  (char) s.b0[x0:x1,x0:x1],
      alpha: (char) scale( d, 20 )
    },
    "png"
  )
from SatImage as s, DEM as d
```

[JacobsU, Fraunhofer; data courtesy BGS, ESA]

Basic Linear Algebra Ops

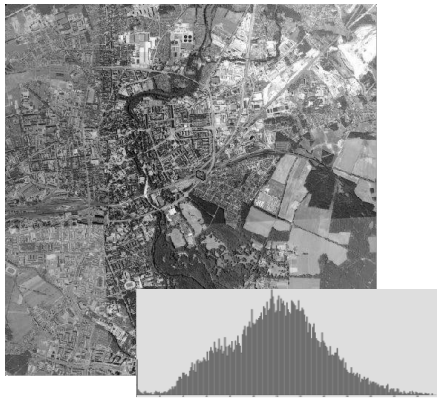
$$(\mathbf{AB})_{ij} = \sum_{k=1}^{m} A_{ik} B_{kj}$$

- Matrix multiplication

```
select marray i in [0:m], j in [0:p]
       values condense +
              over     k in [0:n]
              using    a [ i, k ] * b [ k, j ]
from   matrix as a, matrix as b
```

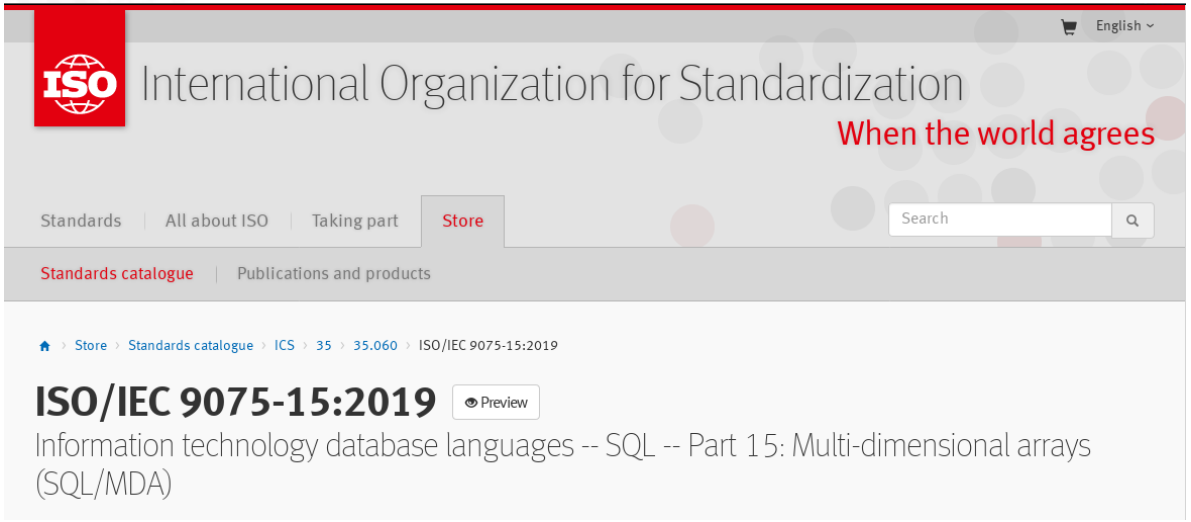
- Histogram

```
select marray bucket in [0:255]
       values count_cells( img = bucket )
from   img
```



Standards: ISO Array SQL

[SSDBM 2014]




```
create table LandsatScenes(
    id: integer not null, acquired: date,
    scene: row( band1: integer, ..., band7: integer ) mdarray [ 0:4999,0:4999] )
```

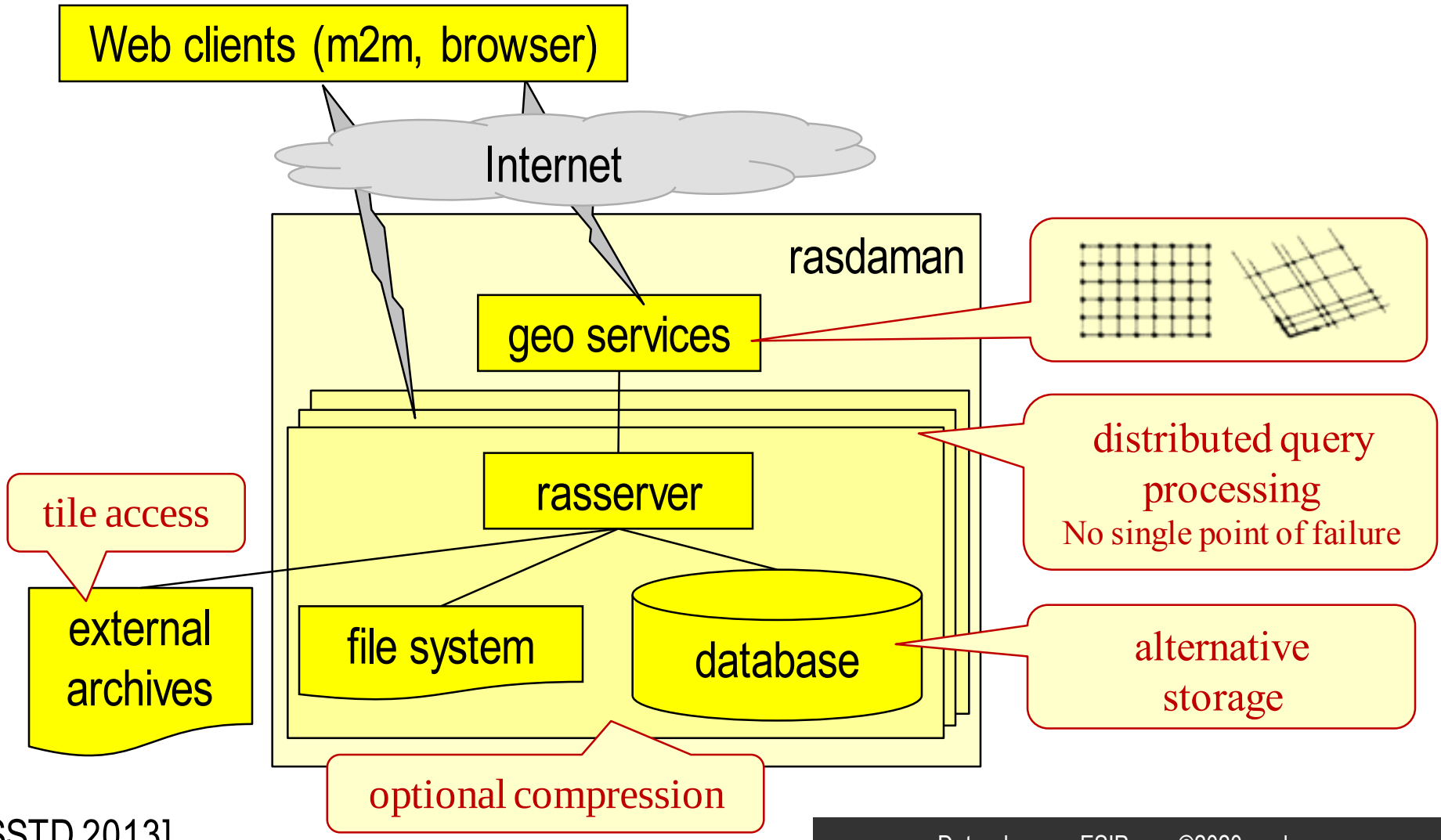
```
select  id, encode(scene.band1-scene.band2)/(scene.band1+scene.band2)), „image/tiff“ )
from    LandsatScenes
where acquired between „1990-06-01“ and „1990-06-30“ and
          avg( scene.band3-scene.band4)/(scene.band3+scene.band4)) > 0
```

Extending the QL: User-Defined Functions

- UDF = external code dynamically linked into server
  - rasdaman: Same API as clients, auto-generated adapter code → easy to use
  - Integrated with tile management, parallelization, ...
- Ex: "*NDVI from raw Landsat subset, orthorectified with Orfeo Toolbox*"

```
select
  encode(
    otb.orthoRectifFilter(
      ((l-img.red-l-img.nir)/(l.img.red+l.img.nir))[x0:x1,y0:y1],
      outputSpacing, deformationFieldSpacing
    ),
    "image/png"
  )
from   LandsatRawArchive as l
```

Architecture

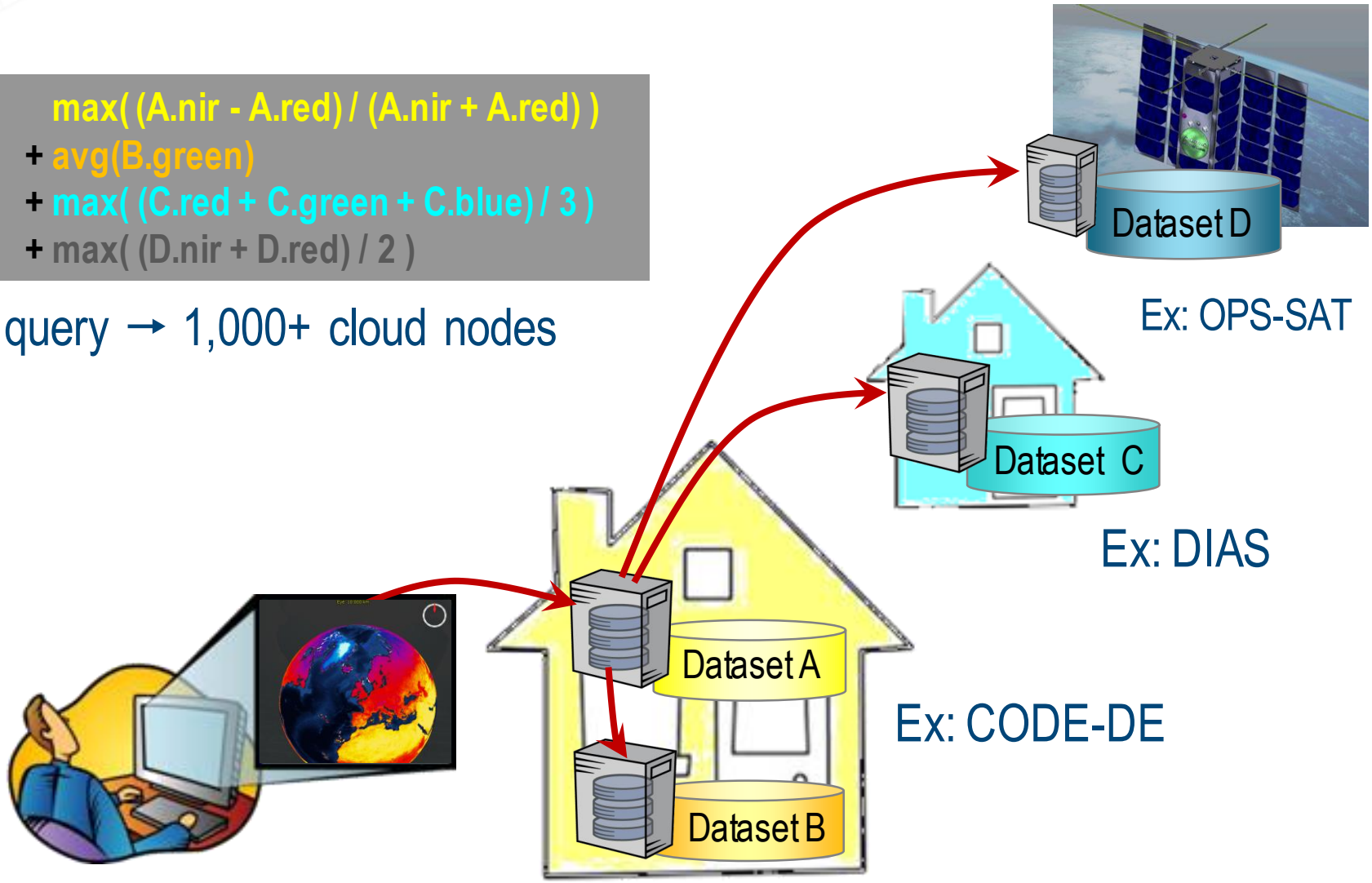


[SSTD 2013]

Parallel, Distributed Processing

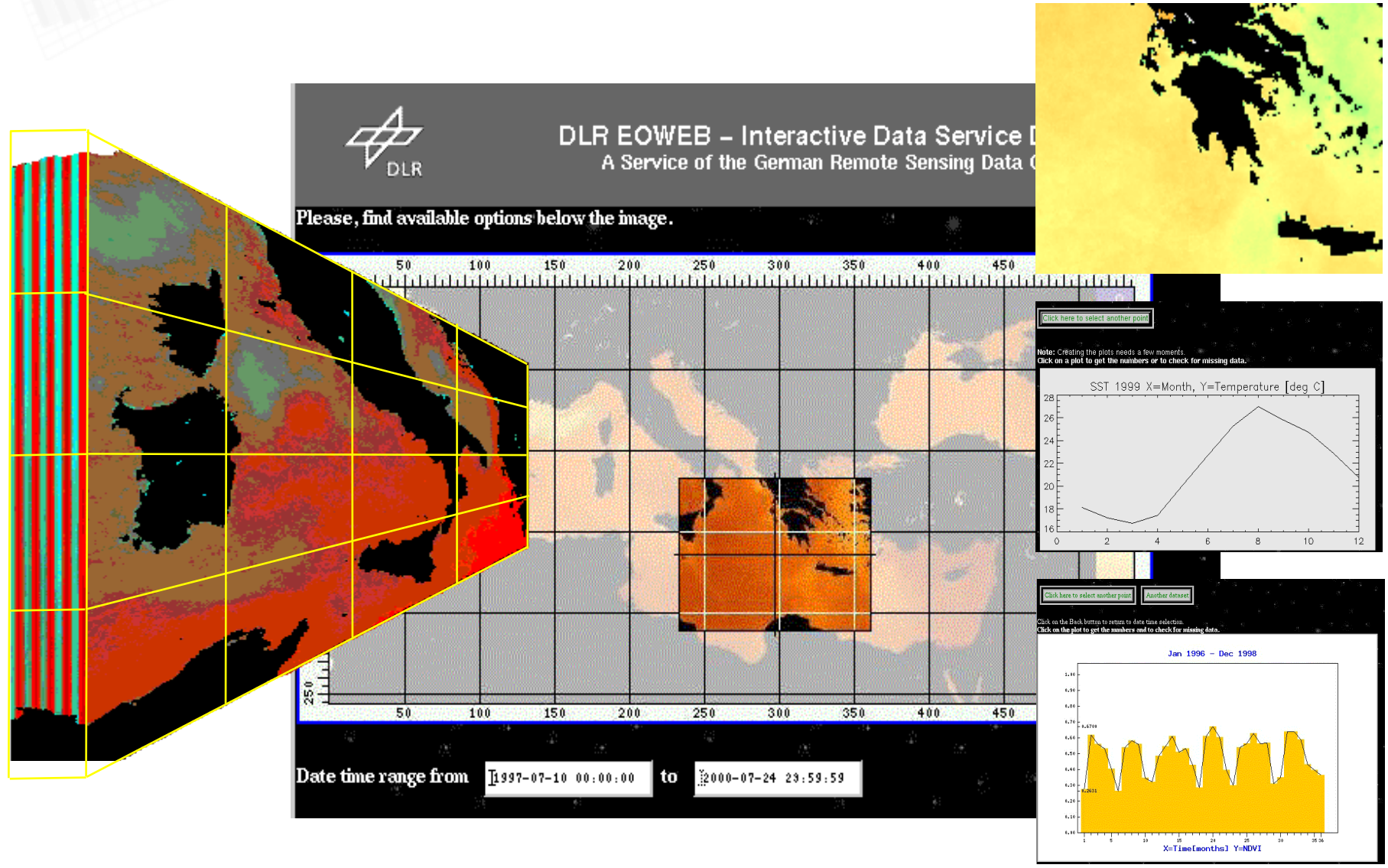
```
  max( (A.nir - A.red) / (A.nir + A.red) )
+ avg(B.green)
+ max( (C.red + C.green + C.blue) / 3 )
+ max( (D.nir + D.red) / 2 )
```

1 query → 1,000+ cloud nodes



Applications

Ortho Image Timeseries



[Diedrich et al 2002, using rasdaman]

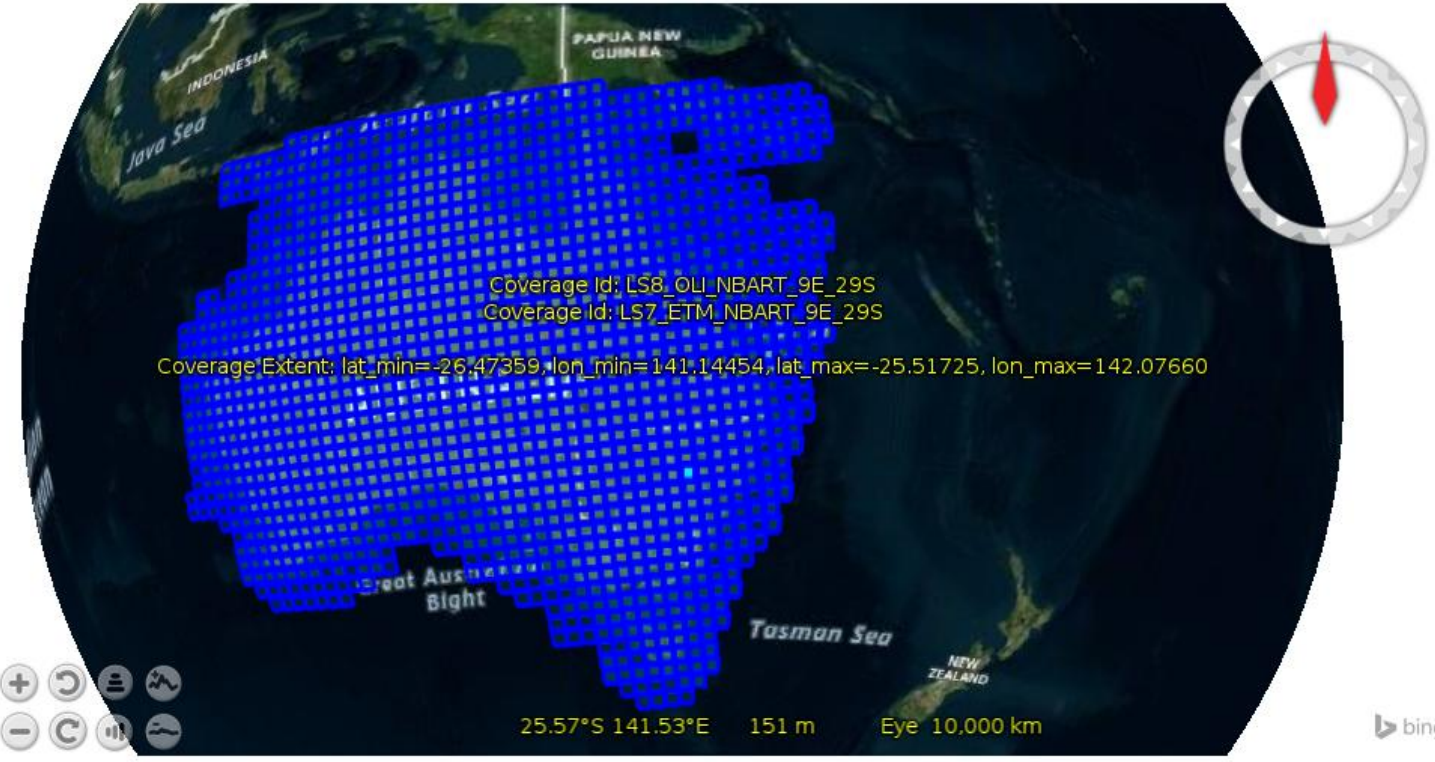
NCI Australia: Landsat8

GetCapabilities | DescribeCoverage | GetCoverage | ProcessCoverages | DeleteCoverage | InsertCoverage

WCS service endpoint: http://rasdaman.nci.org.au/rasdaman/ows [Get Capabilities]

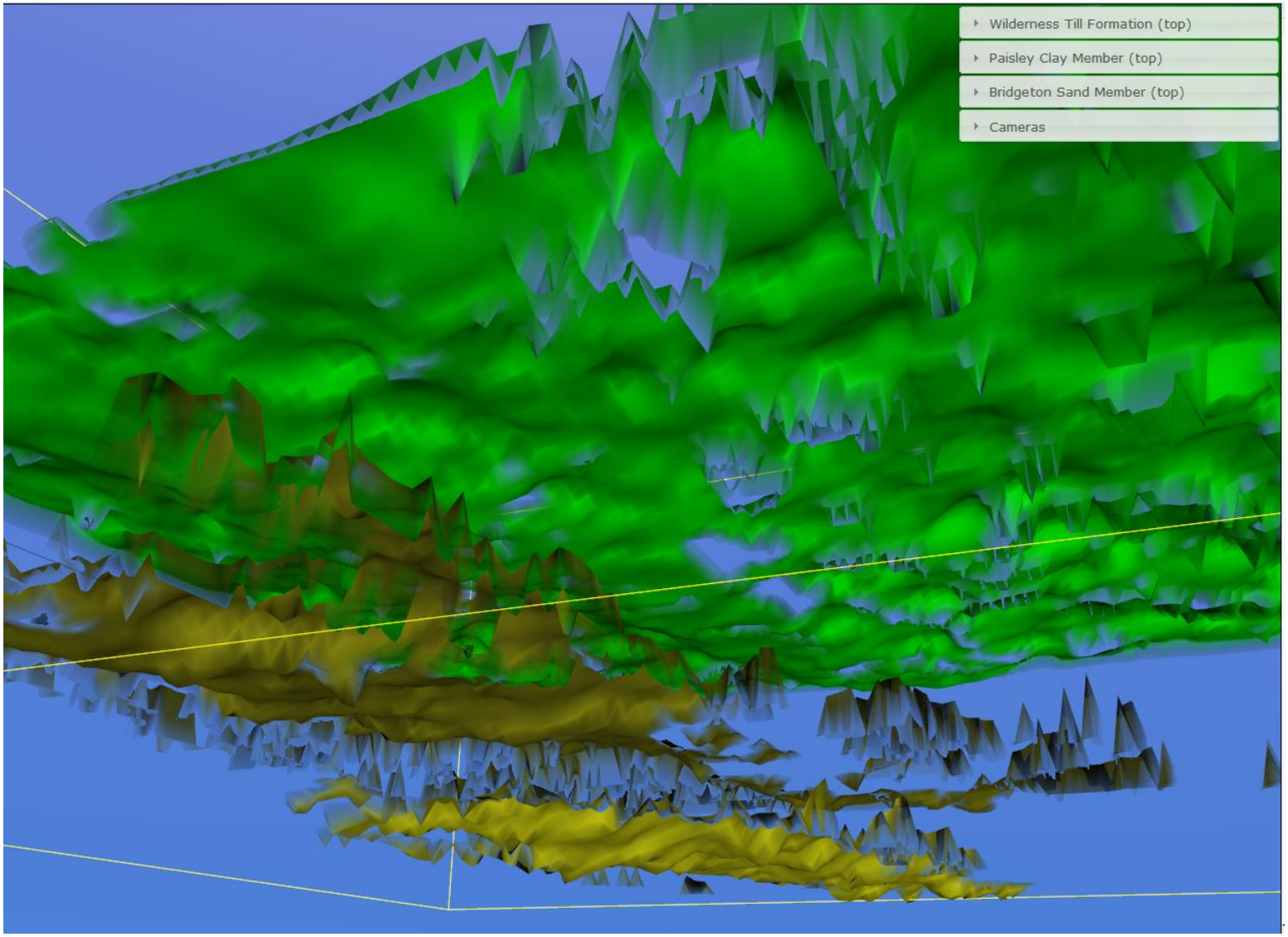
Available coverages

Footprint of geo-referenced coverages



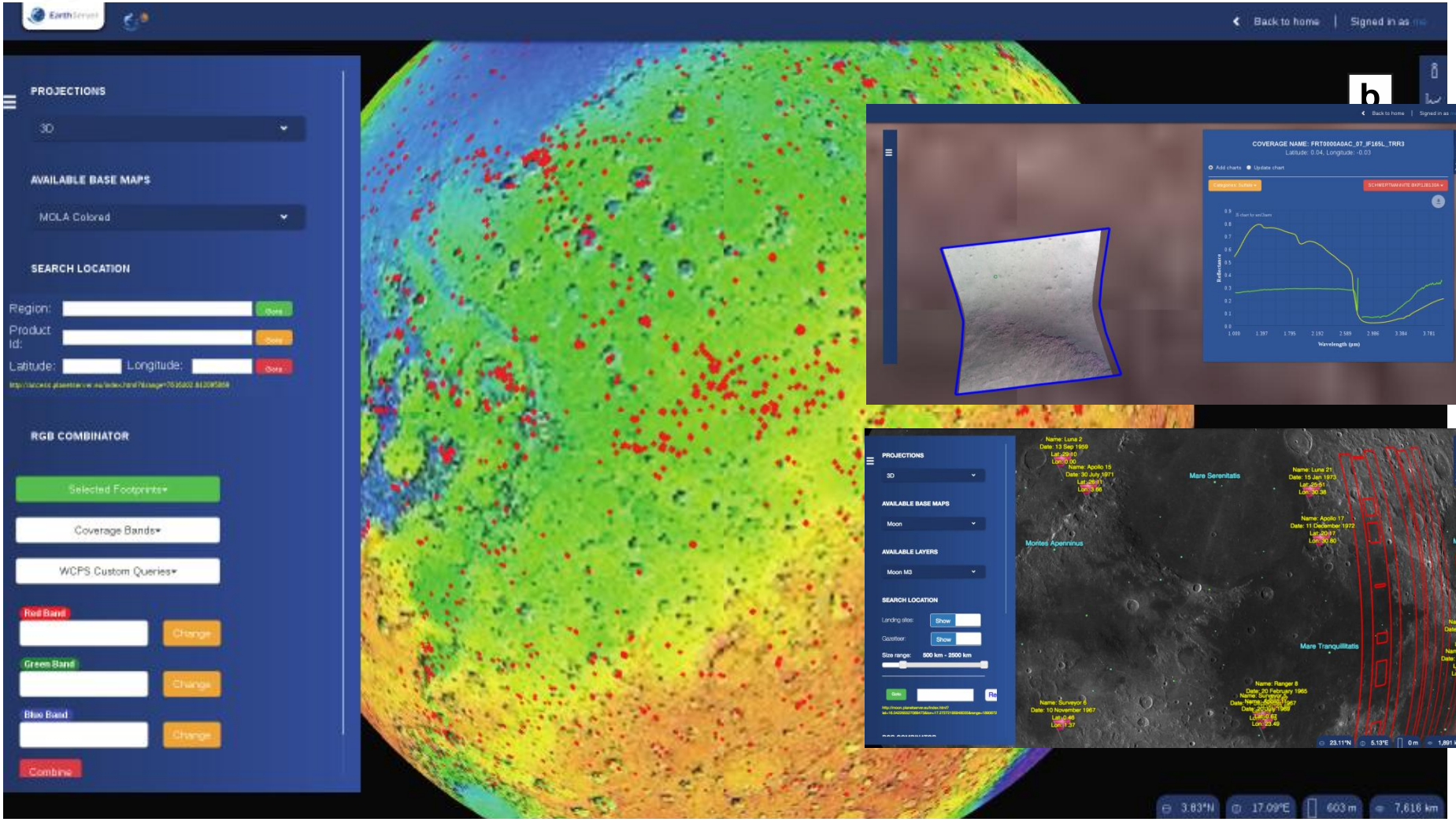
[rasdaman backend]

Geophysics



[data: BGS, visualization: Fraunhofer, server: rasdaman]
[BGS, rasdaman backend]

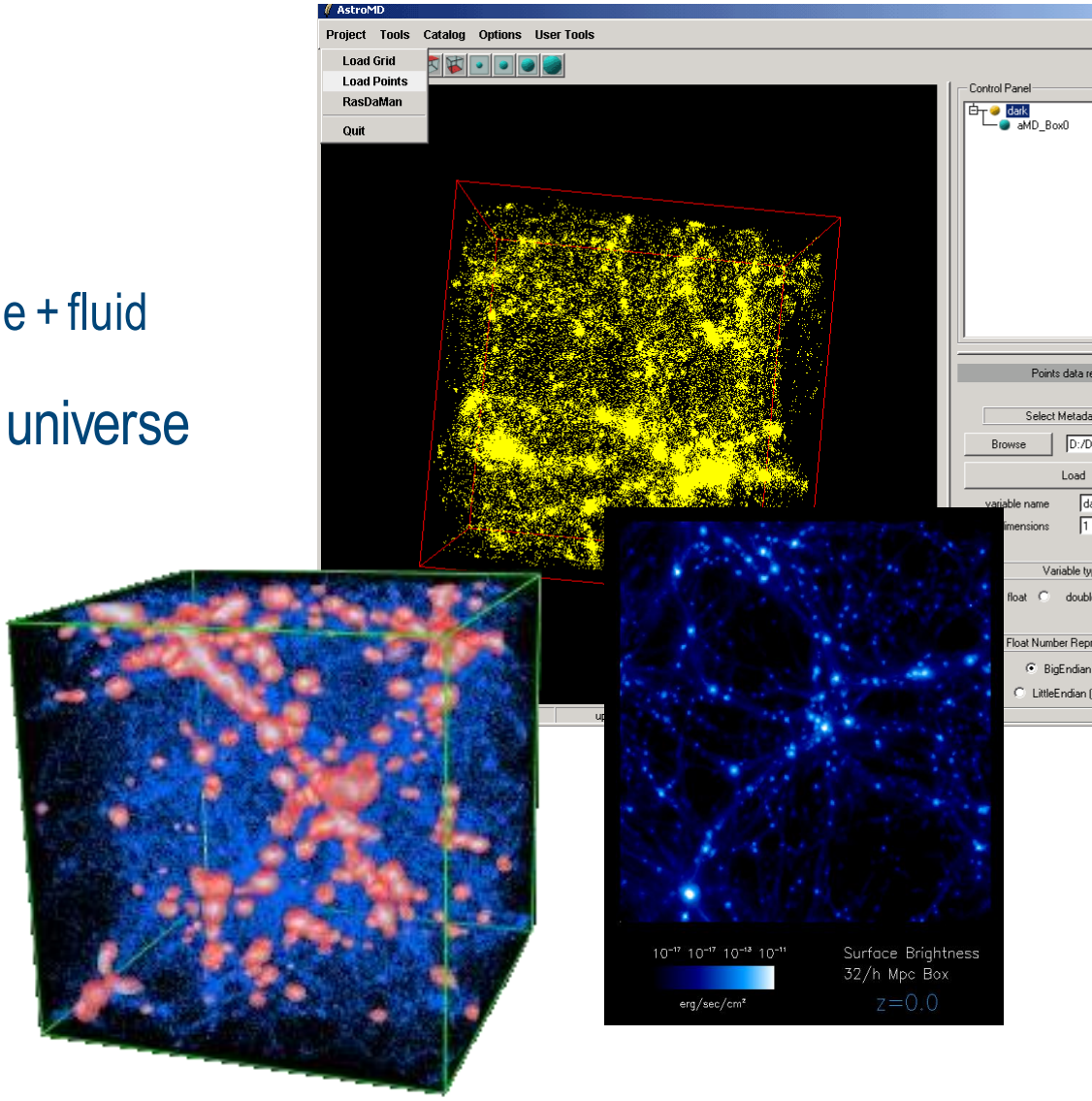
PlanetServer



[rasdaman backend]

Cosmological Simulation

- Modelling domain: 4D
  - Dark matter, baryonic matter
    → Coupled simulation: particle + fluid
- Results: 3D/4D cutouts from universe
  - Eg, 64 Mpc^3
    (1 pc = 3.27 light years)
- Screenshots: AstroMD
  [Gheller, Rossi 2001]
- 2019: IVOA
  considering datacubes

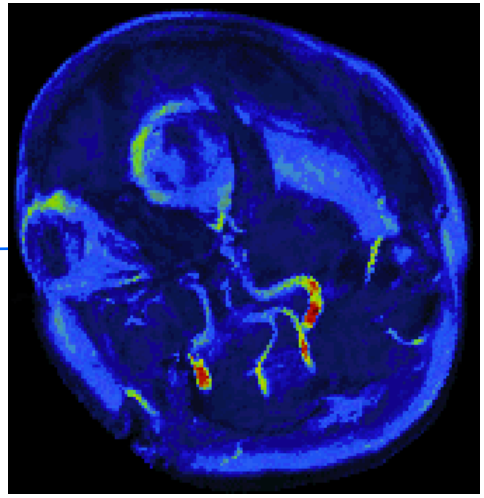


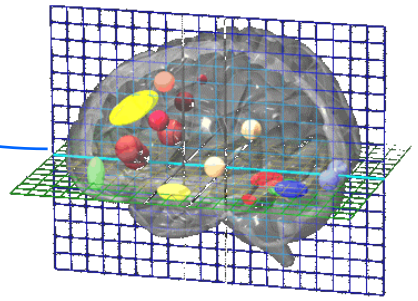
Human Brain Imaging

- Goal: understand structural-functional relations in brain
- temperature, electrical, oxygen consumption, ...
  → „activation maps“
- Ex: “*a parasagittal view of all scans containing critical Hippocampus activations, TIFF-coded*“

```
select encode( ht.img[$1,*:*,*:*], “tiff“
)
from   HeadTomograms as ht,
       HippocampusMask as m
where  count_cells( ht.img > $2 and m.a )
       / count_cells( m.a )
       > $3
```

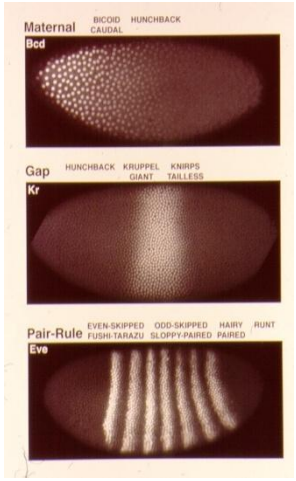
`$1` = slicing position, `$2` = intensity threshold value, `$3` = confidence

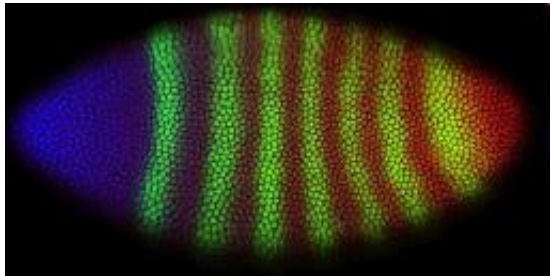


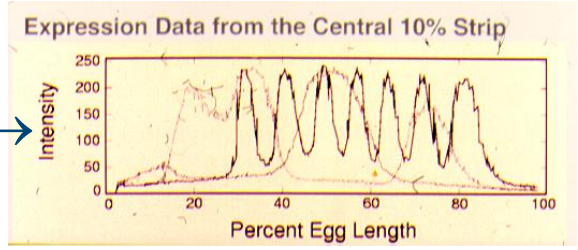


Gene Expression Analysis

- Goal: capture spatio-temporal expression patterns in genes





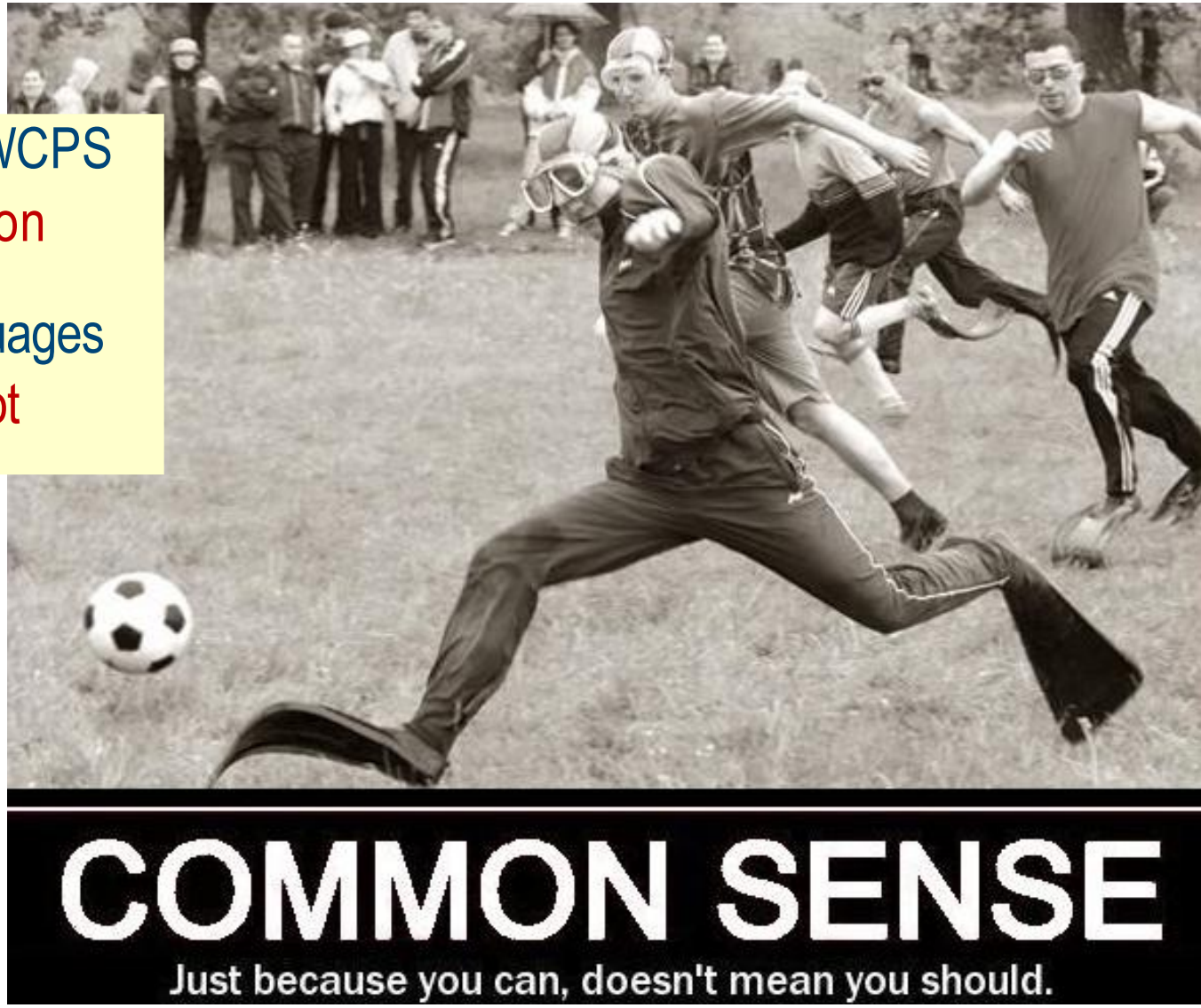



```
select jpeg( scale( {1c,0c,0c}*e[0,*:*,*:*]
                  +{0c,1c,0c}*e[1,*:*,*:*]
                  +{0c,0c,1c}*e[2,*:*,*:*], 0.2 ) )
from EmbryoImages as e
where oid(e)=193537
```

[Samsonova et al 2013]

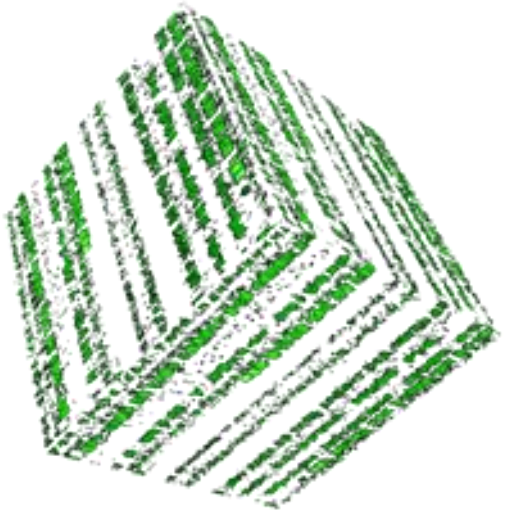
What Code to Ship?

- ISO SQL & OGC WCPS are safe in evaluation
- programming languages (like python) are not



[pinterest]

Summary



- rasdaman = declarative, high-level datacube queries
  + scalable architecture
  + location-transparent federation
  + security
  - language-based approach offers range of optimization opportunities
  - full-stack distributed datacube engine
  - blueprint for SQL/MDA
- www.rasdaman.org, www.rasdaman.com