The Ophidia project: towards a High Performance Data Analytics and Machine Learning framework for climate change

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enes
EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

EOSC-hub

cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Outline

- EOSC, ECAS and EOSC-hub
- Ophidia
  - Architecture 1.0
    - Storage model
    - Primitives
    - Data and metadata operators
  - Architecture 2.0
    - Workflow support
      - Some real use cases
    - PyOphidia
    - Native I/O server for in-memory analytics
- ECASLab in the context of EOSC-hub
    - Jupyter-Hub, Grafana, Workflow IDE
- Future work and conclusions
    - Looking forward
    - Website and more

EOSC,

ECAS & Ophidia

The context: European Open Science Cloud

- ✓ The **European Open Science Cloud (EOSC)** is an ambitious program will offer a **virtual environment** with **open** and **seamless services** for storage, management, **analysis** and **re-use of research data**, **across borders** and **scientifc disciplines** by federating existing scientifc data infrastructures, currently dispersed across disciplines and Member States.

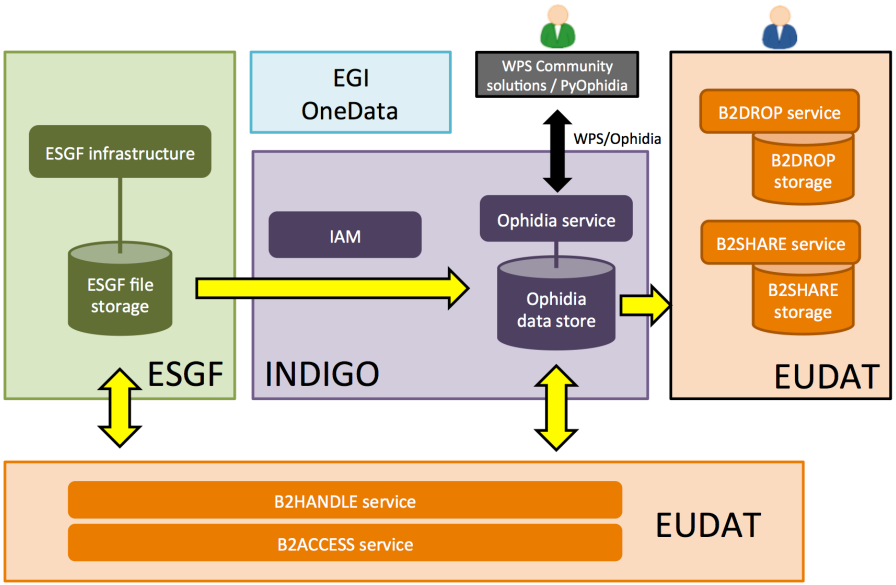
- ✓ This programme will deliver an **Open Data Science Environment** that **federates existing scientific data infrastructures** to offer European science and technology researchers and practitioners seamless access to services for storage, management, analysis and re-use of research data presently restricted by geographic borders and scientific disciplines.

- ✓ **EOSC-hub** is a key infrastructural project in the **EOSC** landscape

ENES Climate Analytics Service (ECAS)

- ✓ The **ENES Climate Analytics Service (ECAS)**, is a **Thematic Services** in EOSC-hub to supports climate data analysis
- ✓ Enable **server-side** analytics workflows for Earth system researchers and beyond
- ✓ Induce cultural change: No more "**download and process at home**"
- ✓ Involved institutions: CMCC and DKRZ

ECAS builds on top of the **Ophidia big data analytics framework** integrating components from INDIGO-DataCloud, EUDAT and EGI



EOSC-hub

The European Commission launched the European Open ScienceCloud Initiative to capitalise on the data revolution. **EOSC will provide European science, industry and public authorities with world-class digital infrastructure that bring state of the art computing and data storage** capacity to the fingertips of any scientists and engineer in the EU.

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DKRZ DEUTSCHES KLIMARECHENZENTRUM

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Ophidia: a scientific big data analytics framework

Ophidia (http://ophidia.cmcc.it) is a CMCC Foundation research project addressing fast and big data challenges for eScience

It provides support for declarative, parallel, server-side data analysis exploiting parallel computing techniques and database approaches

It provides end-to-end mechanisms to support complex experiments and large processing workflows on scientific datacubes

Ophidia

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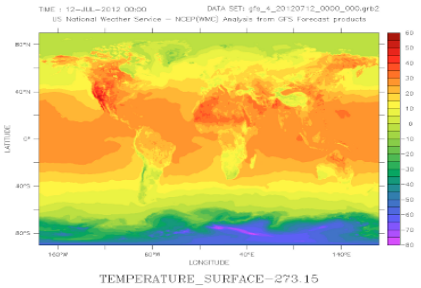
Data analytics requirements for Ophidia

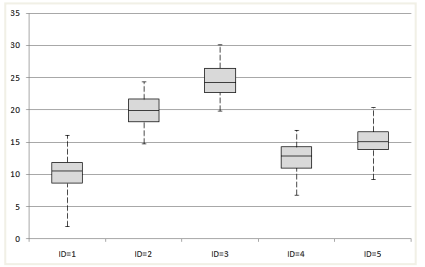
Requirements and needs focus on:

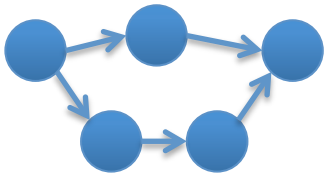
- *Time series analysis*
- *Data subsetting*
- *Model intercomparison*
- *Multimodel means*
- *Massive data reduction*
- *Data transformation (through array-based primitives)*
- *Param. Sweep experiments (same task applied on a set of data)*
- *Climate change signal*
- *Maps generation*
- *Ensemble analysis*
- *Data analytics worflow support*

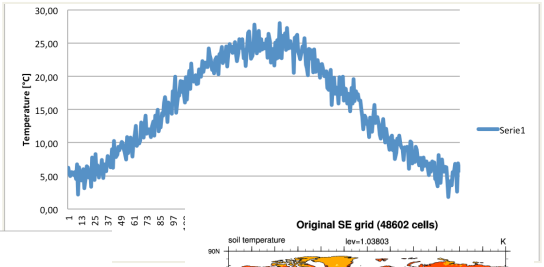
But also…

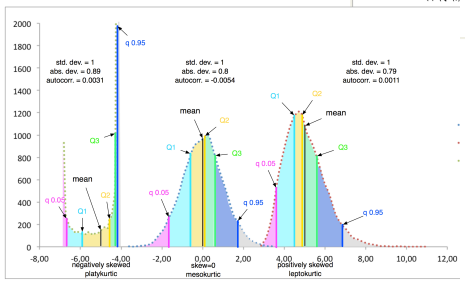
- *Performance*
- *re-usability*
- *extensibility*

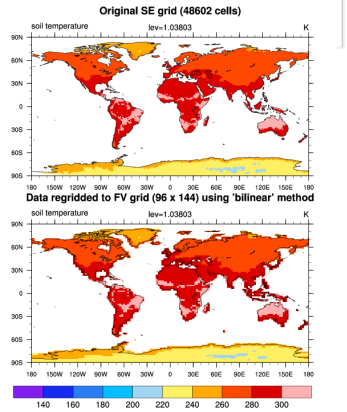










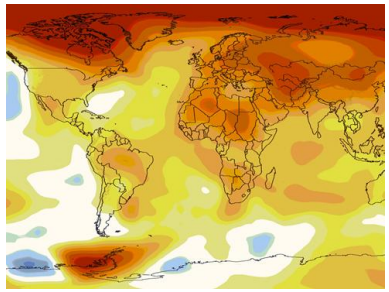


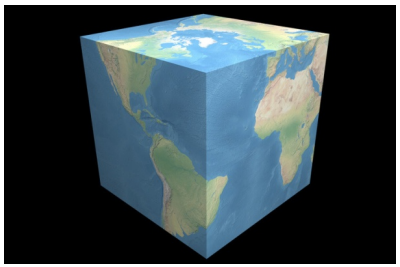
Ophidia in a nutshell

- ✔ ***Big data stack for scientific data analysis***
- ✔ ***Features:*** *time series analysis (array-based analysis), data subsetting (by value/index), data aggregation, model intercomparison, OLAP, etc.*
- ✔ *Use of parallel operators and parallel I/O*
- ✔ ***Support for complex workflows / operational chains***
- ✔ *Extensible:* ***simple API*** *to support framework extensions like new operators and array-based primitives*
  - ✔ *currently 50+ operators and 100+ primitives provided*
- ✔ ***Multiple interfaces*** *available (WS-I, GSI/VOMS, OGC-WPS).*
- ✔ *Programmatic access via C and* ***Python APIs***
- ✔ *Support for both* ***batch & interactive*** *data analysis*

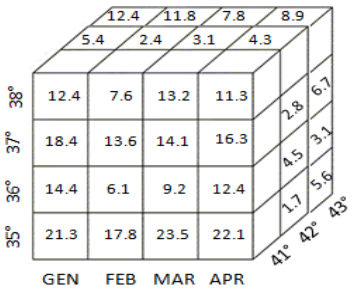
Big data and HPC convergence as a paradigm shift to large-scale data analysis experiments

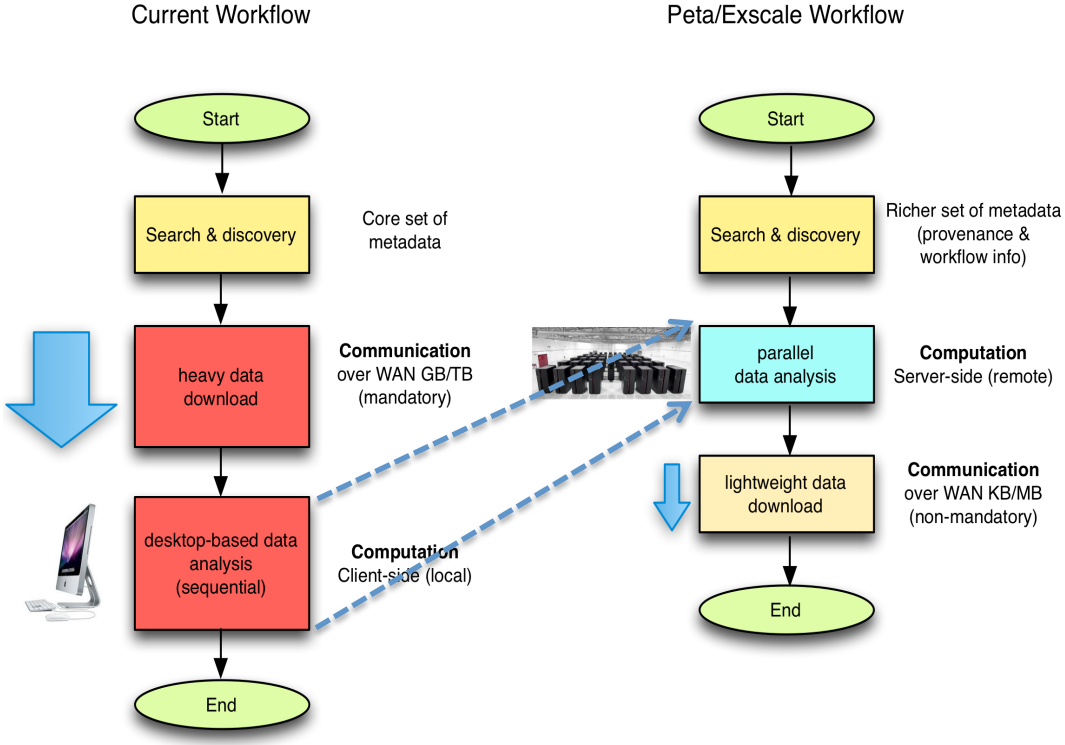
- *Volume, variety, velocity are key challenges for big data in general and eScience contexts too*
- *High Performance Data Analytics solutions are becoming key to manage data analysis at scale*
- *In-memory analytics can help reducing time to solution*
- *Workflow management has to orchestrate millions of analytics jobs*





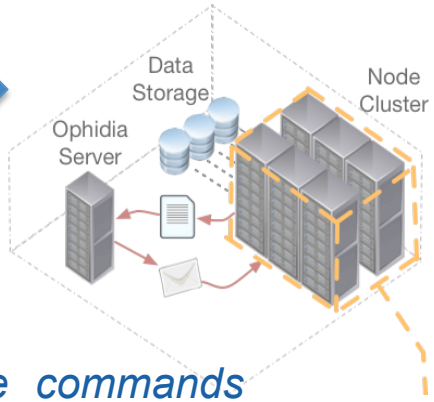
Earth System Grid Federation ESGF

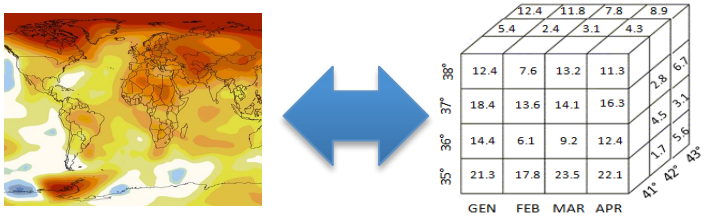




*S. Fiore, A. D'Anca, C. Palazzo, I. Foster, D. N. Williams, G. Aloisio, "**Ophidia: toward bigdata analytics for eScience**", ICCS2013 Conference, Procedia Elsevier, Barcelona, June 5-7, 2013*

Server-side paradigm and the datacube abstraction



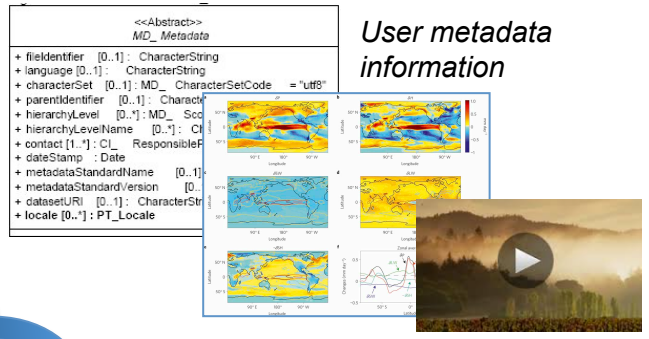


***Oph_Term**: a terlminal-like commands interpreter serving as a client for the Ophidia framework*

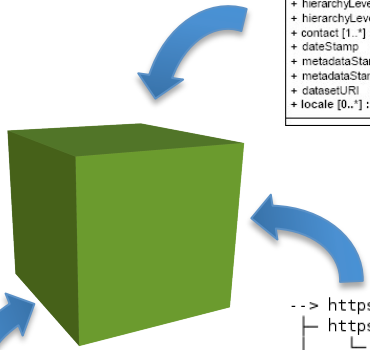
***Ophidia framework**: declarative, parallel server-side processing*

*Through the **oph_term** the user can send commands to the Ophidia framework to manipulate datasets*

Three interaction modes:
Operators, Workflows, Python Apps



User metadata information



System metadata of the datacube (size, distribution, etc.)

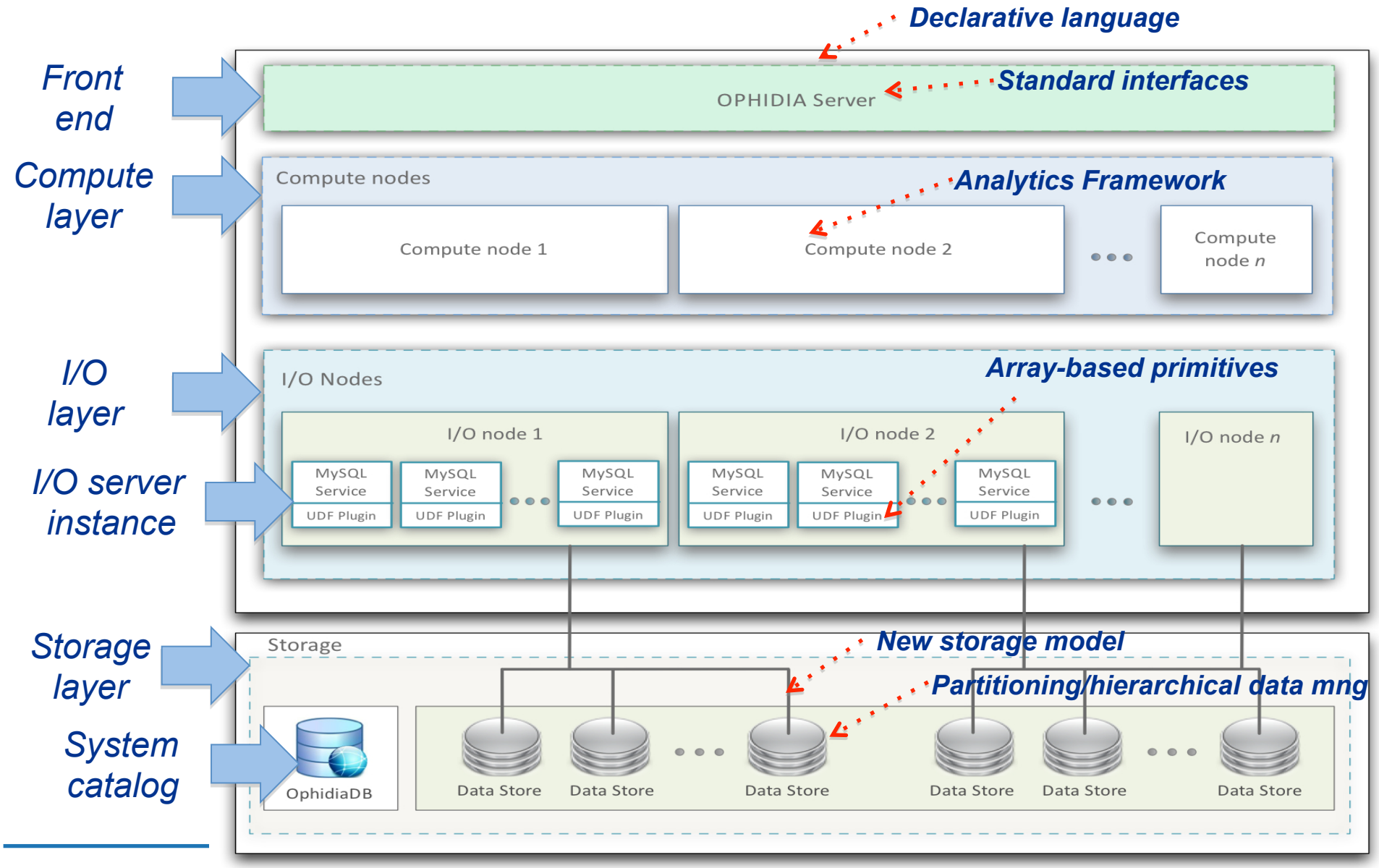
Metadata provenance

```
--> https://ophidia.cmcc.it:8443/162/169 (ROOT)
  ├─ https://ophidia.cmcc.it:8443/162/170 (oph_reduce)
  │    └─ https://ophidia.cmcc.it:8443/162/171 (oph_merge)
  │         ├─ https://ophidia.cmcc.it:8443/162/172 (oph_aggregate2)
  │         └─ https://ophidia.cmcc.it:8443/162/173 (oph_rollup)
  │              ├─ https://ophidia.cmcc.it:8443/162/174 (oph_reduce)
  │              └─ https://ophidia.cmcc.it:8443/162/175 (oph_reduce)
  ├─ https://ophidia.cmcc.it:8443/162/176 (oph_aggregate)
  └─ https://ophidia.cmcc.it:8443/162/177 (oph_aggregate)
```

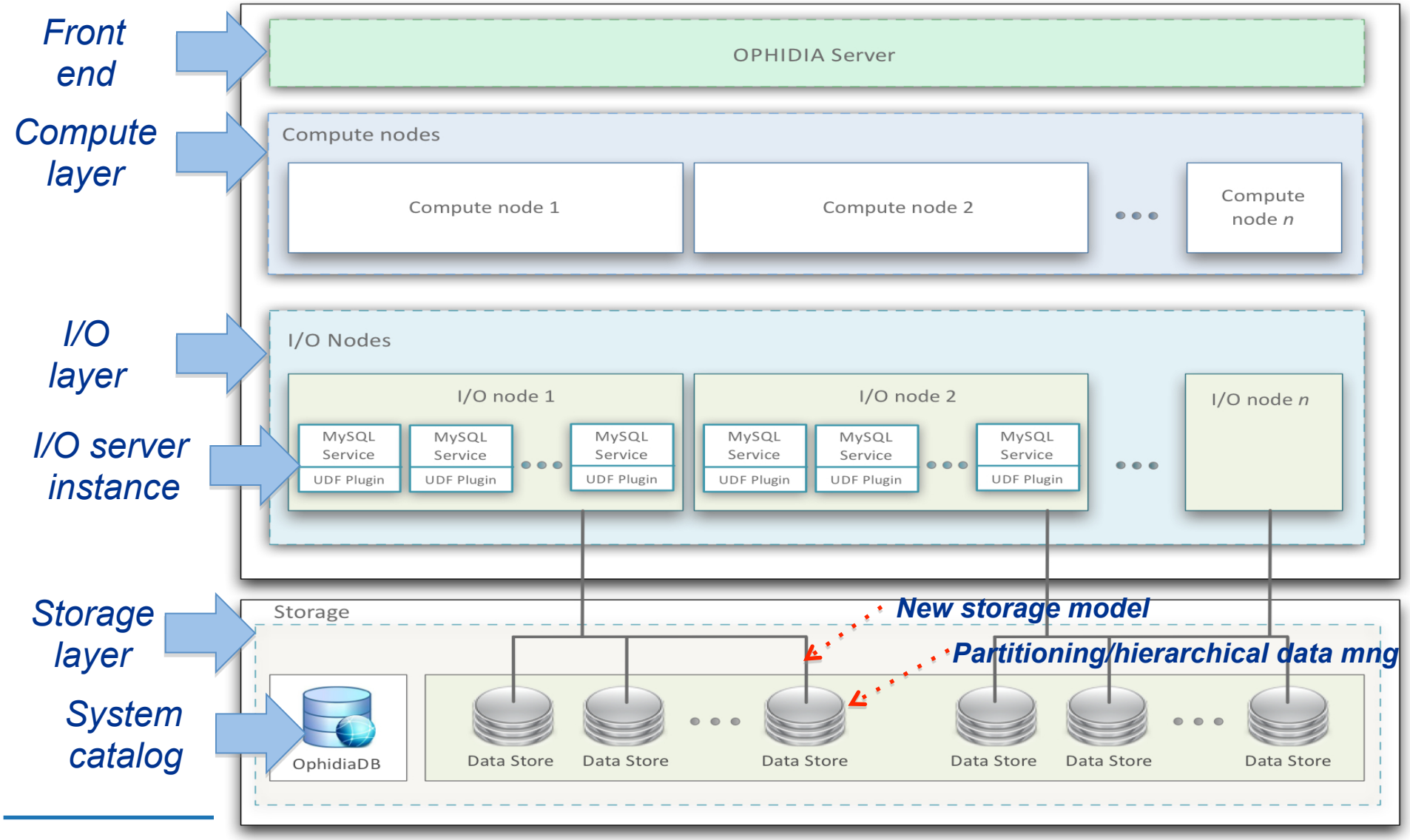
Ophidia architecture 1.0

Storage model, primitive & operators

Ophidia Architecture (sw stack view)



Storage model and chunks distribution



Ophidia storage model

- *The Ophidia storage model is a **two-step based evolution** of the **star schema** to support **scientific data management***
- *It relies on **implicit** (array-based) and **explicit** (tuple-based) **dimensions** for specific representations of data*
- *The first step includes the **support for array**-based data*
- *The second step includes a **key mapping** related to a set of foreign keys*
- *The second step makes the Ophidia storage model and implementation **independent of the number of dimensions**!*

Storage model (dimension-independent) & implementation
Array-based support and hierarchical storage

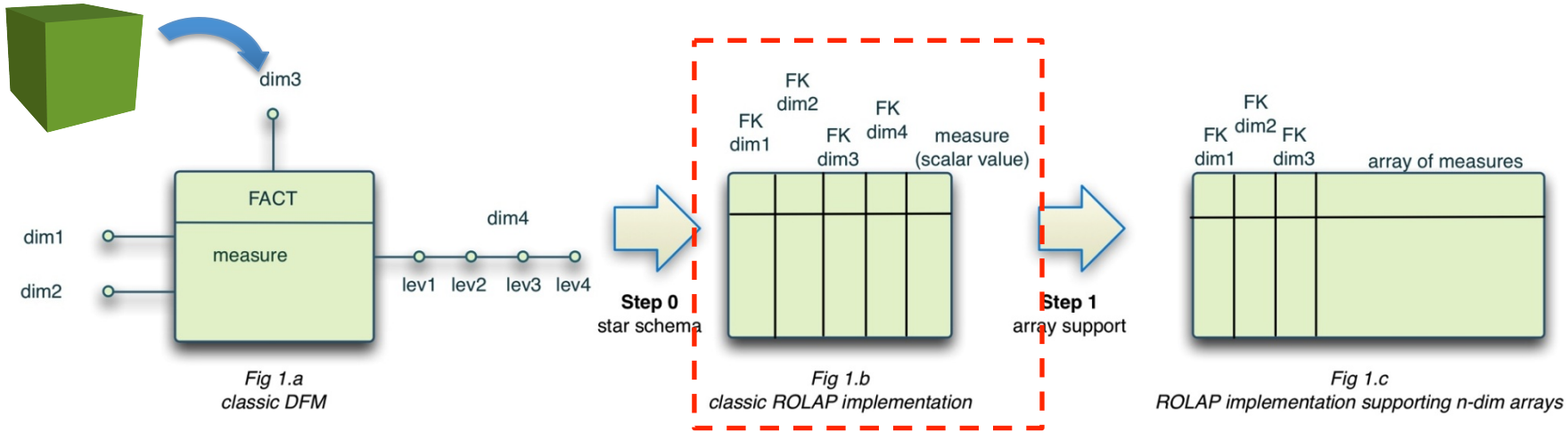


Fig 1.a
classic DFM

Fig 1.b
classic ROLAP implementation

Fig 1.c
ROLAP implementation supporting n-dim arrays

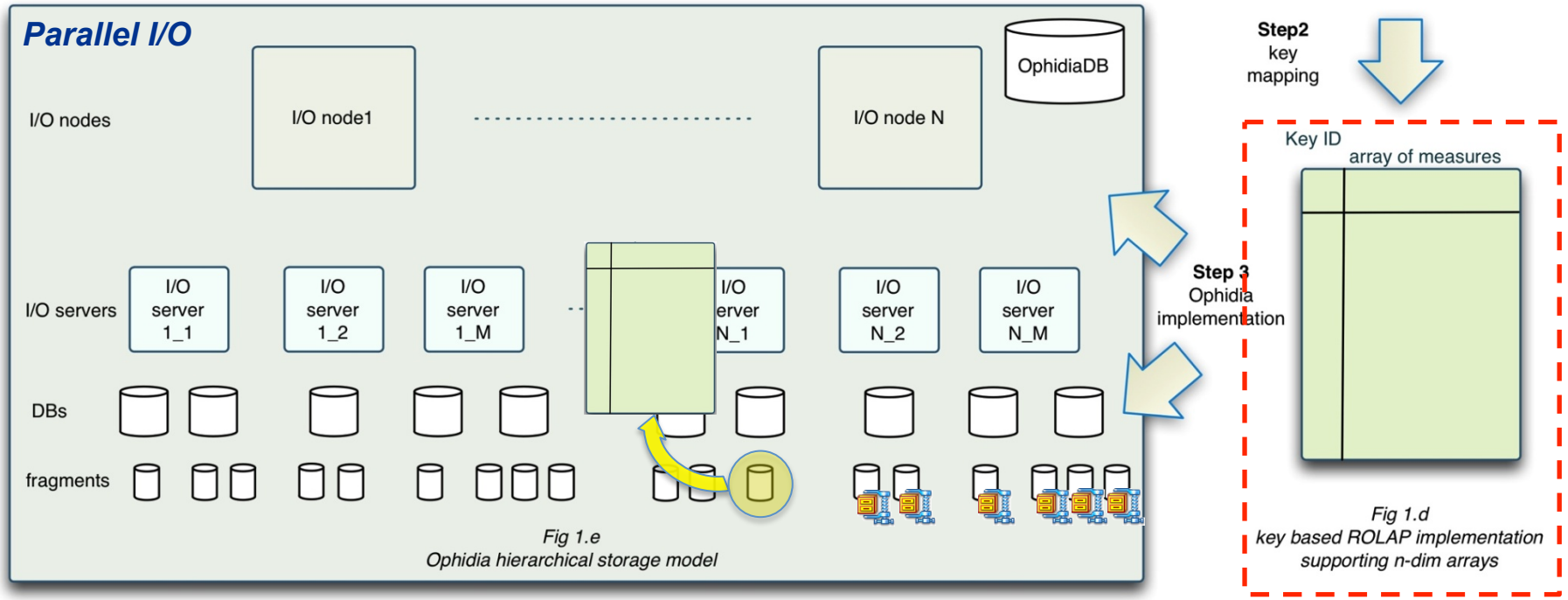
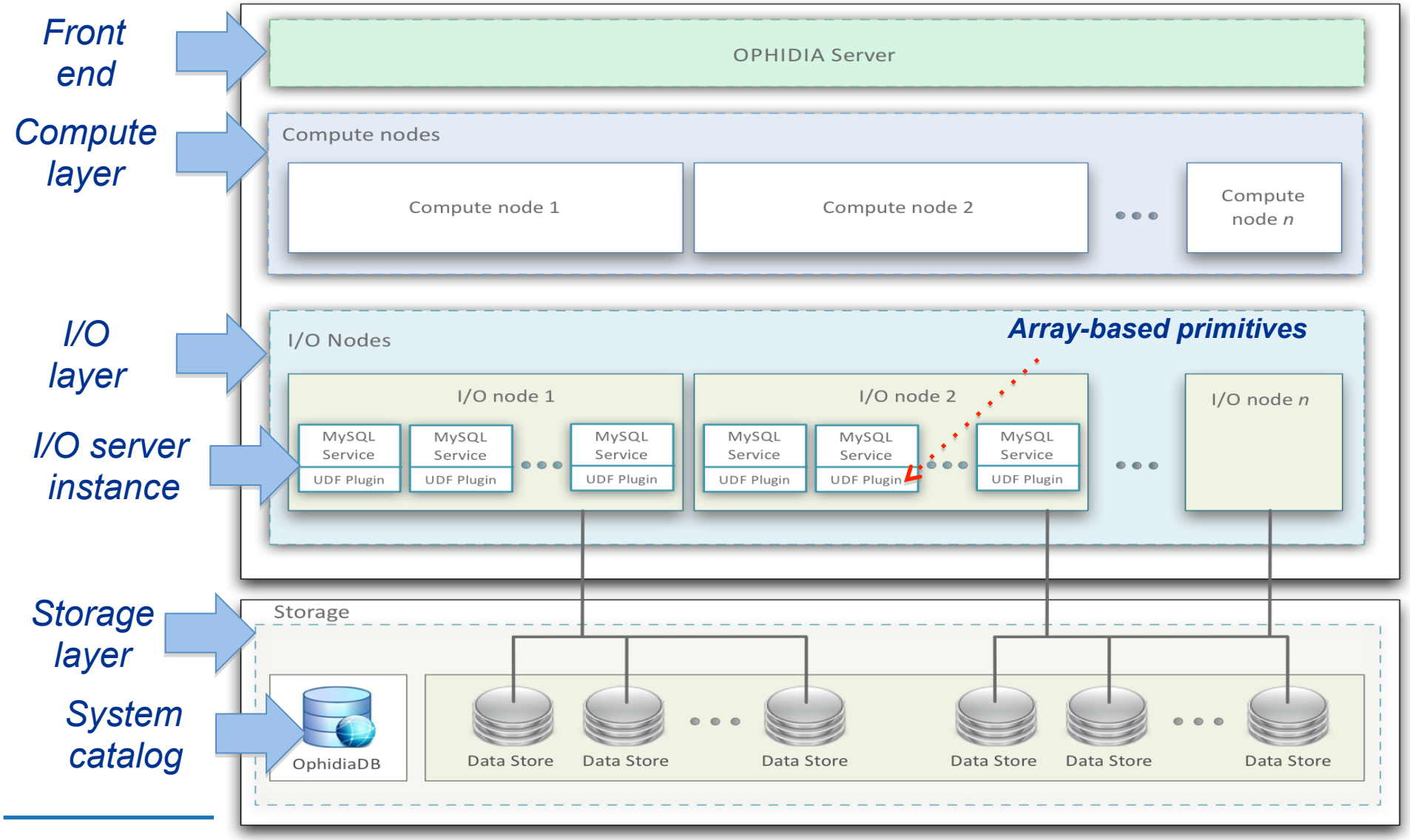


Fig 1.e
Ophidia hierarchical storage model

Fig 1.d
key based ROLAP implementation
supporting n-dim arrays

Array-based primitives



Array based primitives (about 100)

- *Ophidia provides a **wide set of array-based primitives** to perform data summarization, sub-setting, predicates evaluation, statistical analysis, compression, etc.*
- *Primitives come as plugins and are applied on a single datacube chunk (fragment)*
- *They are provided both for **byte**-oriented and **bit**-oriented arrays*
- ***Primitives can be nested** to get more complex functionalities*
- ***Compression is a primitive too!***
- *New primitives can be easily integrated as additional plugins*

Array based primitives: OPH_MATH (“SIGN”)

oph_math(measure, “OPH_SIGN”, "OPH_DOUBLE”)

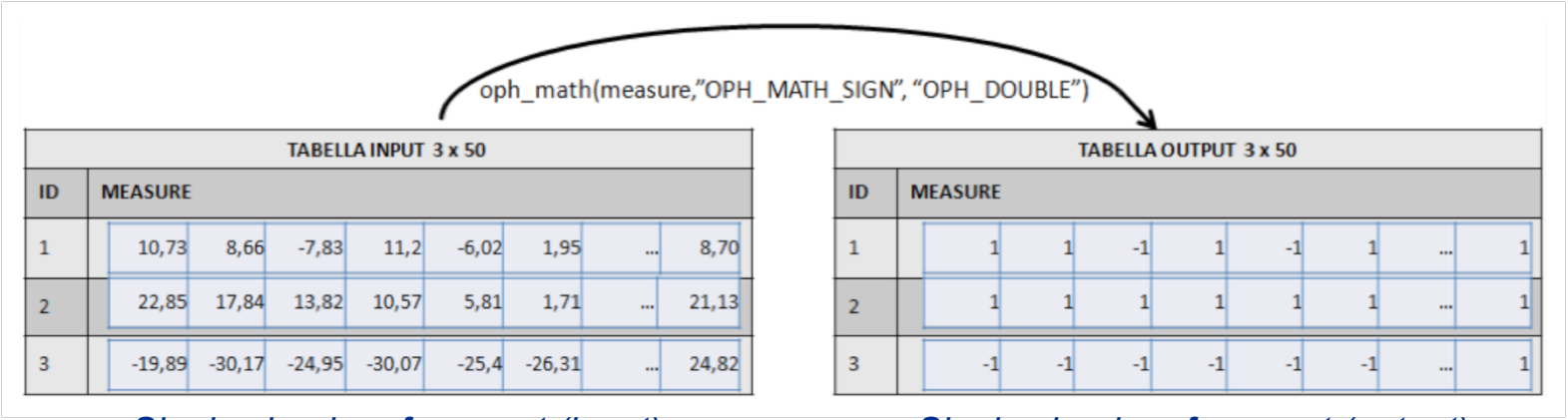
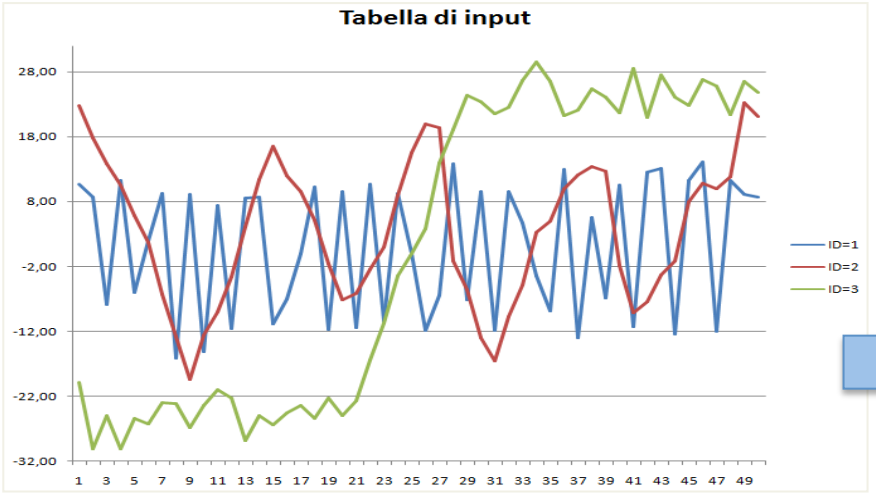


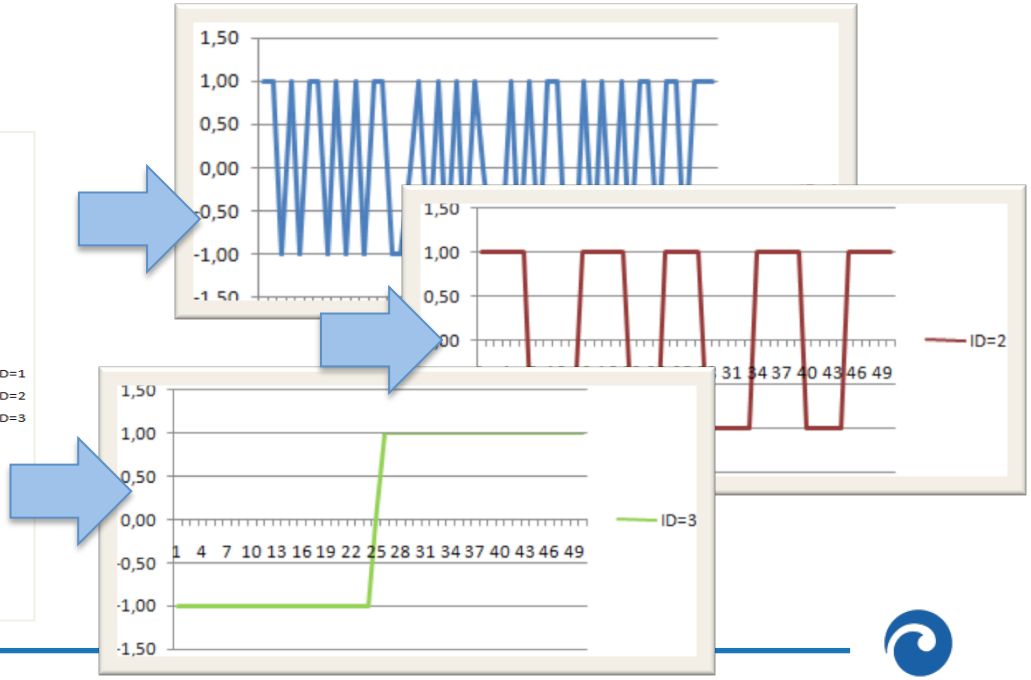
TABELLA INPUT 3 x 50								
ID	MEASURE							
1	10,73	8,66	-7,83	11,2	-6,02	1,95	...	8,70
2	22,85	17,84	13,82	10,57	5,81	1,71	...	21,13
3	-19,89	-30,17	-24,95	-30,07	-25,4	-26,31	...	24,82

TABELLA OUTPUT 3 x 50								
ID	MEASURE							
1	1	1	-1	1	-1	1	...	1
2	1	1	1	1	1	1	...	1
3	-1	-1	-1	-1	-1	-1	...	1

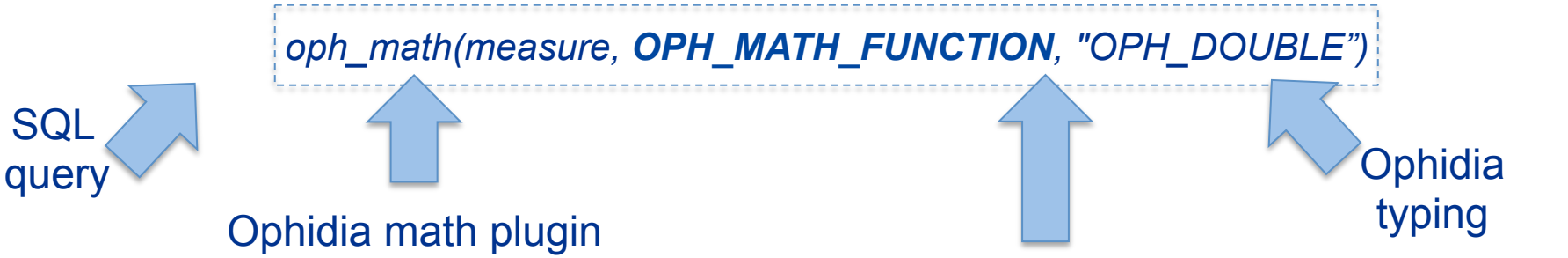
Single chunk or fragment (input)

Single chunk or fragment (output)





Array-based primitives: OPH_MATH support



OPH_MATH_FUNCTION can be one of the macros in the table below

OPH_MATH_FUNCTION MACROS

OPH_MATH_ABS	OPH_MATH_DEGREES	OPH_MATH_RAND
OPH_MATH_ACOS	OPH_MATH_EXP	OPH_MATH_ROUND
OPH_MATH_ASIN	OPH_MATH_FLOOR	**OPH_MATH_SIN**
OPH_MATH_ATAN	OPH_MATH_LN	OPH_MATH_SIGN
OPH_MATH_CEIL	OPH_MATH_LOG10	OPH_MATH_SQRT
OPH_MATH_COS	OPH_MATH_LOG2	OPH_MATH_TAN
OPH_MATH_COT	OPH_MATH_RADIANS	…

Array based primitives: OPH_BOXPLOT

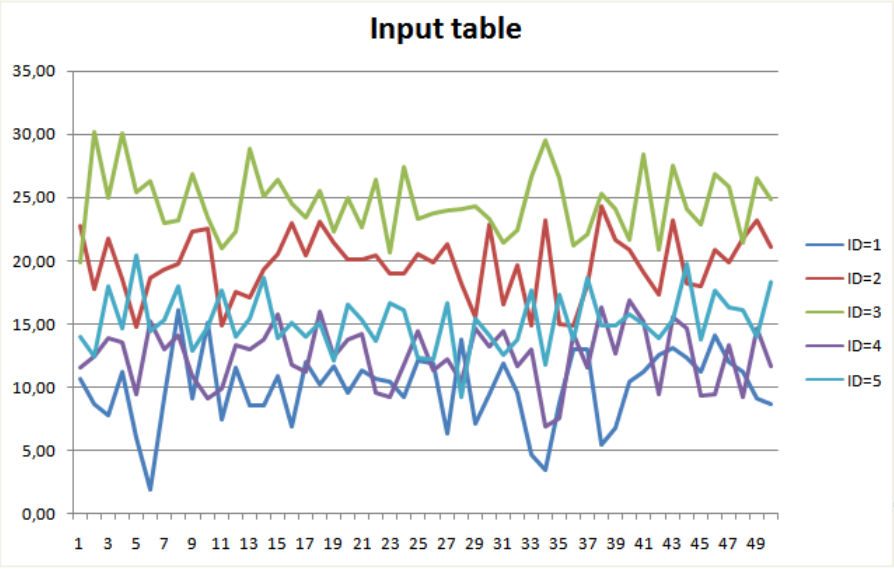
***oph_boxplot**(measure, "OPH_DOUBLE")*

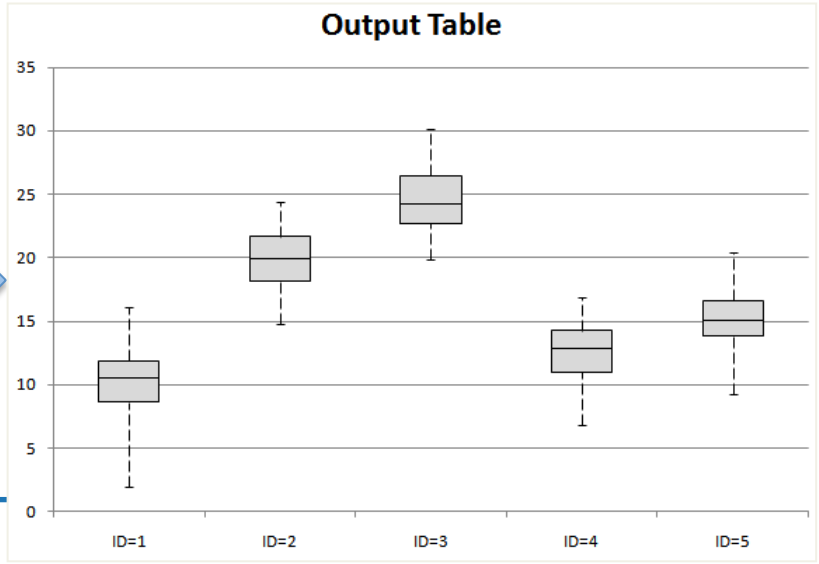
Single chunk or fragment (input)

INPUT TABLE 5 tuples x 50 elements										
ID	MEASURE									
1	10,73	8,66	7,83	11,20	6,02	1,95	9,25	16,11	...	8,70
2	22,85	17,84	21,82	18,57	14,81	18,71	19,31	19,83	...	21,13
3	19,89	30,17	24,95	30,07	25,40	26,31	22,95	23,18	...	24,82
4	11,60	12,49	13,91	13,53	9,48	15,27	13,05	14,17	...	11,66
5	13,94	12,43	17,95	14,70	20,41	14,46	15,37	18,00	...	18,30

Single chunk or fragment (output)

OUTPUT TABLE 5 tuples x 5 elements (summary)					
ID	MEASURE				
1	1,95	8,64	10,47	11,87	16,11
2	14,81	18,14	19,93	21,66	24,35
3	19,89	22,74	24,24	26,45	30,17
4	6,87	10,99	12,85	14,28	16,93
5	9,23	13,87	15,05	16,61	20,41





Array based primitives: nesting feature

oph_boxplot(oph_subarray(oph_uncompress(measure), 1,18), "OPH_DOUBLE")

Single chunk or fragment (input)

INPUT TABLE 5 tuples x 50 elements

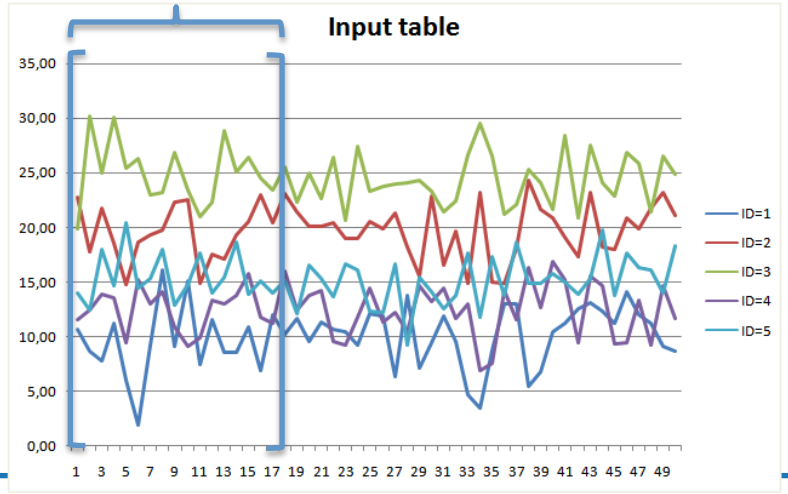
ID	MEASURE									
1	10,73	8,66	7,83	11,20	6,02	1,95	...	16,11	...	8,70
2	22,85	17,84	21,82	18,57	14,81	18,71	...	19,83	...	21,13
3	19,89	30,17	24,95	30,07	25,40	26,31	...	23,18	...	24,82
4	11,60	12,49	13,91	13,53	9,48	15,27	...	14,17	...	11,66
5	13,94	12,43	17,95	14,70	20,41	14,46	...	18,00	...	18,30

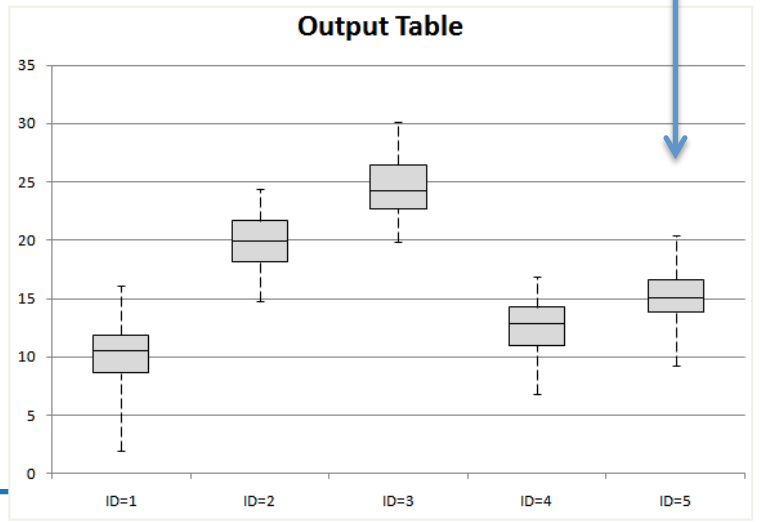
Single chunk or fragment (output)

OUTPUT TABLE 5 tuples x 5 elements (summary)

ID	MEASURE				
1	1,95	8,64	10,47	11,87	16,11
2	14,81	18,14	19,93	21,66	24,35
3	19,89	22,74	24,24	26,45	30,17
4	6,87	10,99	12,85	14,28	16,93
5	9,23	13,87	15,05	16,61	20,41

subarray(measure, 1,18)





Array based primitives: oph_aggregate

oph_aggregate(measure,"oph_avg")

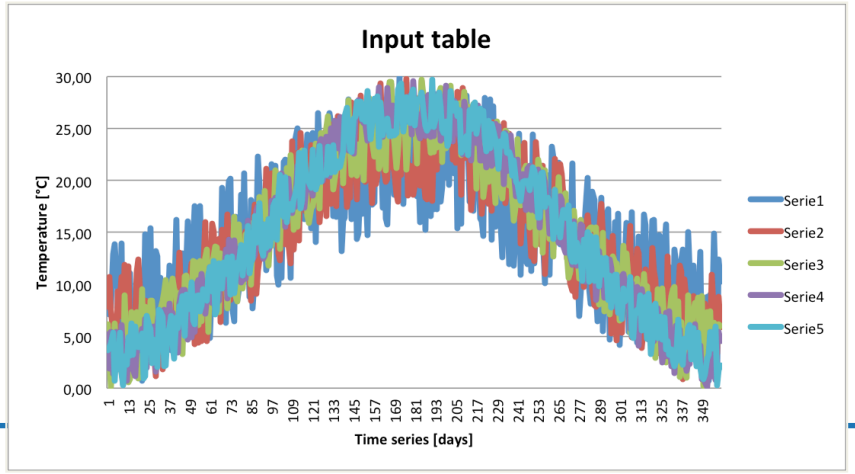
Single chunk or fragment (input)

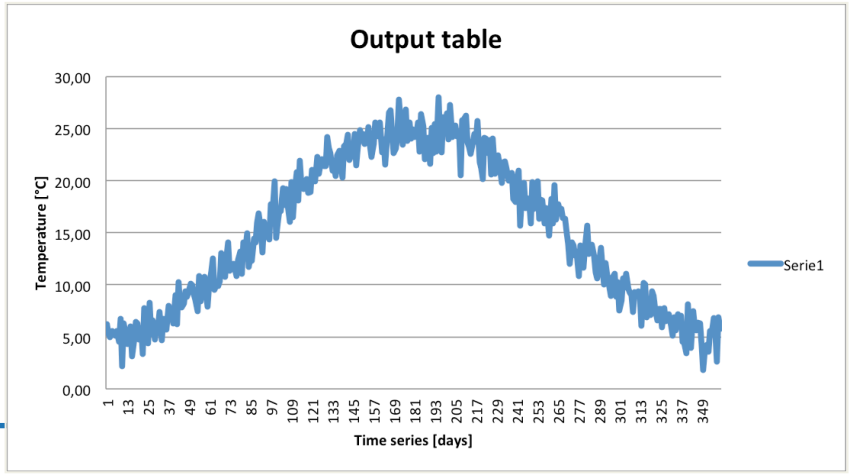
INPUT TABLE 5 tuples x 360 elements										
ID	MEASURE									
1	8,40	7,73	7,36	12,68	13,34	11,17	9,09	2,04	...	7,75
2	7,85	10,71	7,23	5,14	4,68	2,61	9,17	8,50	...	6,57
3	6,40	3,48	0,44	2,81	6,16	2,01	3,61	3,83	...	5,88
4	5,60	4,68	5,54	5,84	5,47	5,37	5,30	7,24	...	3,06
5	3,55	4,10	4,59	5,07	6,97	2,07	3,06	3,06	...	7,88

Vertical aggregation

OUTPUT TABLE 1 tuple x 360 elements							
ID	MEASURE						
1	6,25	5,35	5,00	5,57	5,41	...	5,11

Single chunk or fragment (output)





Clustering Primitive

oph_ccluster_kcluster

Description

Behaviour

It computes clusters from input data through the use of k-means or k-medians algorithms.

Parameters

- input measure type: Ophidia typing. Supported types are: 'oph_double'; 'oph_float'; 'oph_long'; 'oph_int'; 'oph_short'; 'oph_byte'.
- output measure type: Ophidia typing. Supported types are: 'oph_double'; 'oph_float'; 'oph_long'; 'oph_int'; 'oph_short'; 'oph_byte'.
- measure: input measures.
- k: number of requested clusters.
- method: clustering algorithm. Supported algorithms are:
  - 'KMEANS' (default);
  - 'KMEDIANS'.
- level: type of output. Supported outputs are:
  - 'CENTROIDS': only centroid values for each cluster (spatial information is lost) (output is oph_double);
  - 'LABELS': returns an integer between 0 and k-1 for each point according to found clusters (output is oph_int);
  - 'ALL' (default): returns the centroid value of the corresponding cluster for each point (output is oph_double).
- npass: number of iterations for the EM algorithm. At each iteration means or medians are computed and there is a new cluster assignment. With more iterations, results are more accurate. Default value is 1.

Return type

Binary-array.

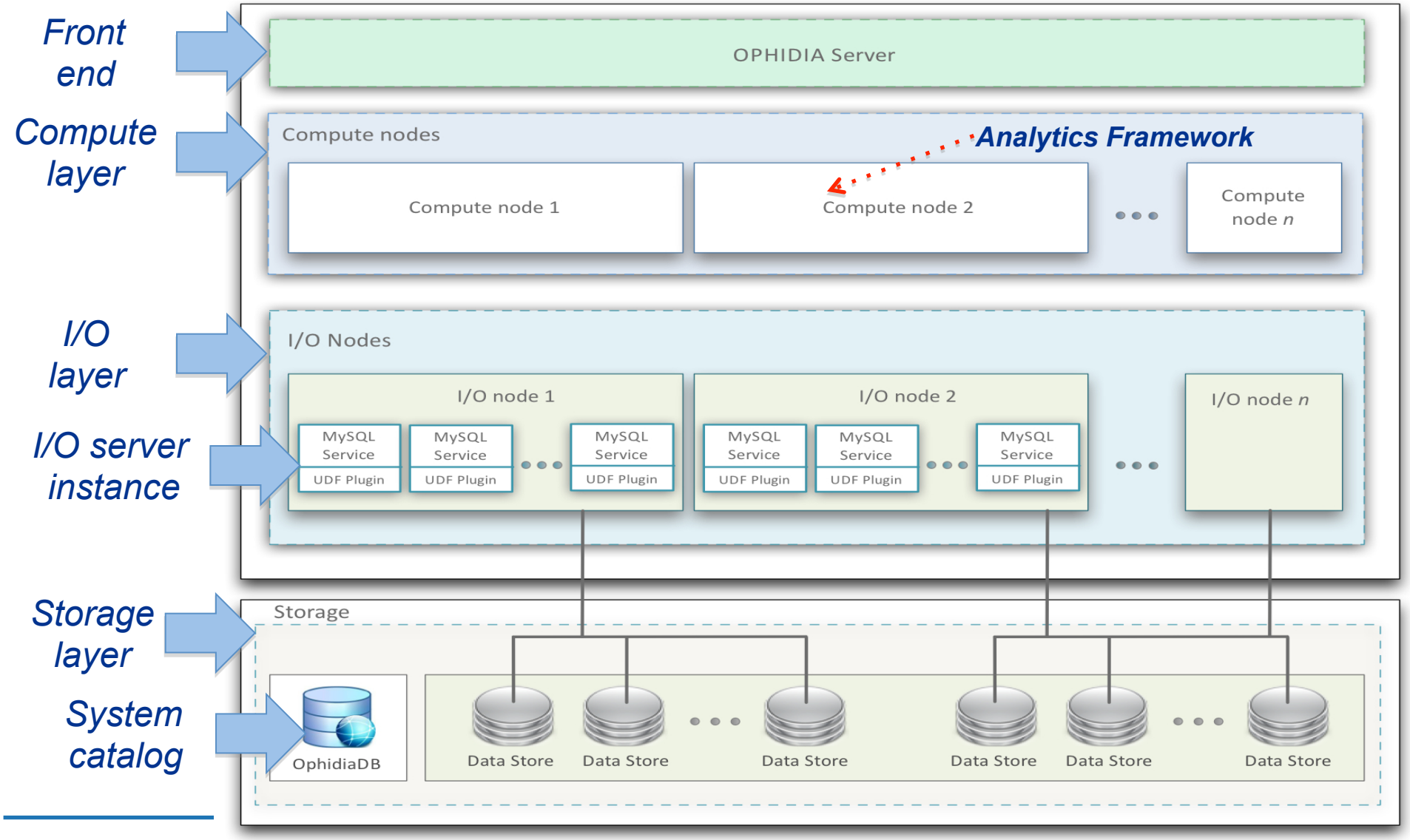
Examples

Group data into 2 clusters, with 10 EM iterations, and return the centroid value for each input point.

```
oph_ccluster_kcluster('OPH_DOUBLE','OPH_DOUBLE',measure,2,'KMEANS',10,'ALL')
```

Adding a new data mining primitive can ben done in several cases by basically developing a new primitive…

Analytics framework and operators



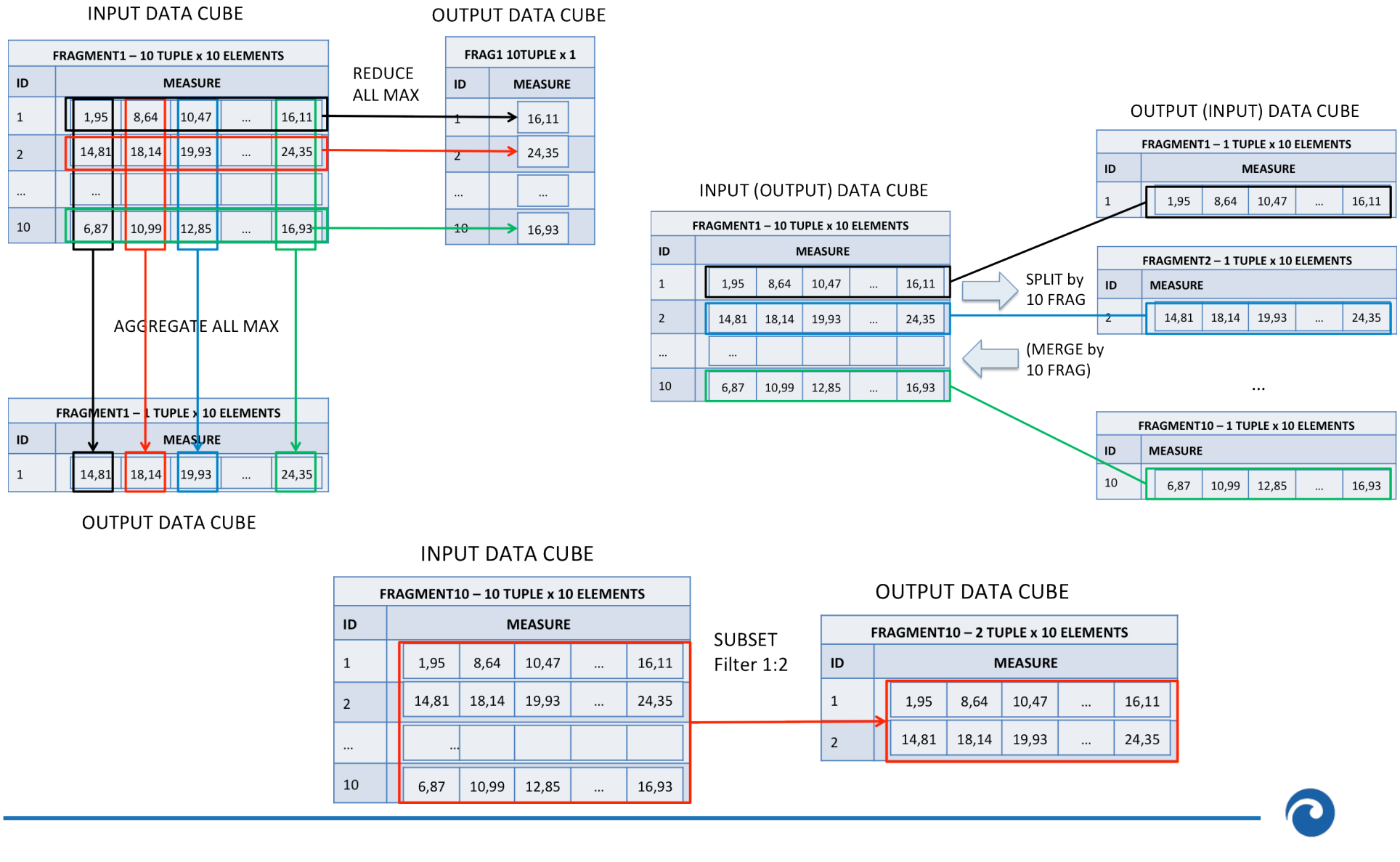
The analytics framework: datacube operators

Data Operator	Description
OPH_CONCATNC	Concatenates a NetCDF file to a data cube.
OPH_DELETE	Deletes a data cube.
OPH_DUPLICATE	Duplicates a data cube.
OPH_EXPLORECUBE	Shows the content of a data cube.
OPH_EXPORTNC	Exports a whole data cube into a single NetCDF file.
OPH_IMPORTNC	Creates new a data cube importing data from a NetCDF file.
OPH_INTERCOMPARISON	Generates the difference value-by-value between two homogeneous data cubes.
OPH_INTERCUBE	It executes an operation between two data cubes and returns a new data cube as result of the specified operation applied element by element.
OPH_MERGECUBES	Merges the measures of n input data cubes creating a new data cube with the union of the n measures.
OPH_PUBLISH	Generates web pages representing the data stored in the fragments.
OPH_RANDCUBE	Creates a new data cube with random data.
OPH_REDUCE	Applies a data reduction operation along one or more implicit dimensions.
OPH_SCRIPT	Executes a bash script.
OPH_SUBSET	Extracts a subset from a data cube using the values of the dimensions.

Metadata Operator	Description
OPH_CUBEELEMENTS	Computes and displays the total number of elements contained in a data cube.
OPH_CUBEIO	Shows the provenance of a data cube.
OPH_CUBESCHEMA	Displays the metadata and dimension information associated to a data cube.
OPH_CUBESIZE	Computes and displays the total size (on disk) of a data cube.
OPH_FIND	Finds a data cube.
OPH_LIST	Displays the list of data cubes and containers available.
OPH_LOGGINGBK	Shows session and job information.
OPH_MAN	Shows a description about an operator or primitive.
OPH_METADATA	Manages metadata information.
OPH_OPERATORS_LIST	Displays the list of available operators.

About 50 operators for data and metadata processing

The analytics framework: “datacube” operators



The analytics framework: “data” operators

```
[37..4416] >> oph_explorecube cube=http://127.0.0.1/ophidia/35/67;subset_dims=lat|lon|time;subset_filter=39:42|15:19|1:275;show_time=yes;
[Request]:
operator=oph_explorecube;cube=http://127.0.0.1/ophidia/35/67;subset_dims=lat|lon|time;subset_filter=39:42|15:19|1:275;show_time=yes;sessionid=http://127.0.0.1/ophidia/sessions/3
7438378083214166664146373728392441 6/experiment;exec_mode=sync;ncores=1;cwd=/;

[JobID]:
http://127.0.0.1/ophidia/sessions/37438378083214166664146373728392441 6/experiment?106#224

[Response]:
tos
---

+===========+===========+=============================================================================================================================================================+
| lat       | lon       | tos                                                                                                                                                         |
+===========+===========+=============================================================================================================================================================+
| 39.500000 | 15.000000 | 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20 |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39.500000 | 17.000000 | 287.3930664062, 286.8287048340, 286.5860595703, 286.9228210449, 288.5254516602, 292.3968200684, 295.8656921387, 297.2062072754, 295.7126464844               |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39.500000 | 19.000000 | 287.6926879883, 287.0508117676, 286.7896118164, 287.0781555176, 288.6802062988, 292.6882629395, 296.4769287109, 297.6632385254, 296.3418273926               |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 40.500000 | 15.000000 | 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20 |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 40.500000 | 17.000000 | 287.1098632812, 286.5683593750, 286.2949829102, 286.5216674805, 288.0316772461, 291.7698974609, 295.4139709473, 296.8489685059, 295.4132995605               |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 40.500000 | 19.000000 | 287.4010009766, 286.7818298340, 286.4914245605, 286.7260742188, 288.3006286621, 292.1842346191, 296.0237731934, 297.2694702148, 295.9751892090               |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 41.500000 | 15.000000 | 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20, 1.00000002e+20 |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 41.500000 | 17.000000 | 286.5835876465, 286.0175781250, 285.7146911621, 285.9142761230, 287.4476623535, 291.1032104492, 294.7090454102, 296.0852355957, 294.7053222656               |
|-----------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 41.500000 | 19.000000 | 286.9717712402, 286.3946838379, 286.0617675781, 286.1446228027, 287.6101989746, 291.2955017090, 295.2700195312, 296.5146179199, 295.3194274902               |
+===========+===========+=============================================================================================================================================================+

Summary
-------

Selected 9 rows out of 9
```

The analytics framework: “metadata” operators

```
[37..4416] >> oph_cubeio
[Request]:
operator=oph_cubeio;session
;

[JobID]:
http://127.0.0.1/ophidia/se

[Response]:
Cube Provenance
---------------

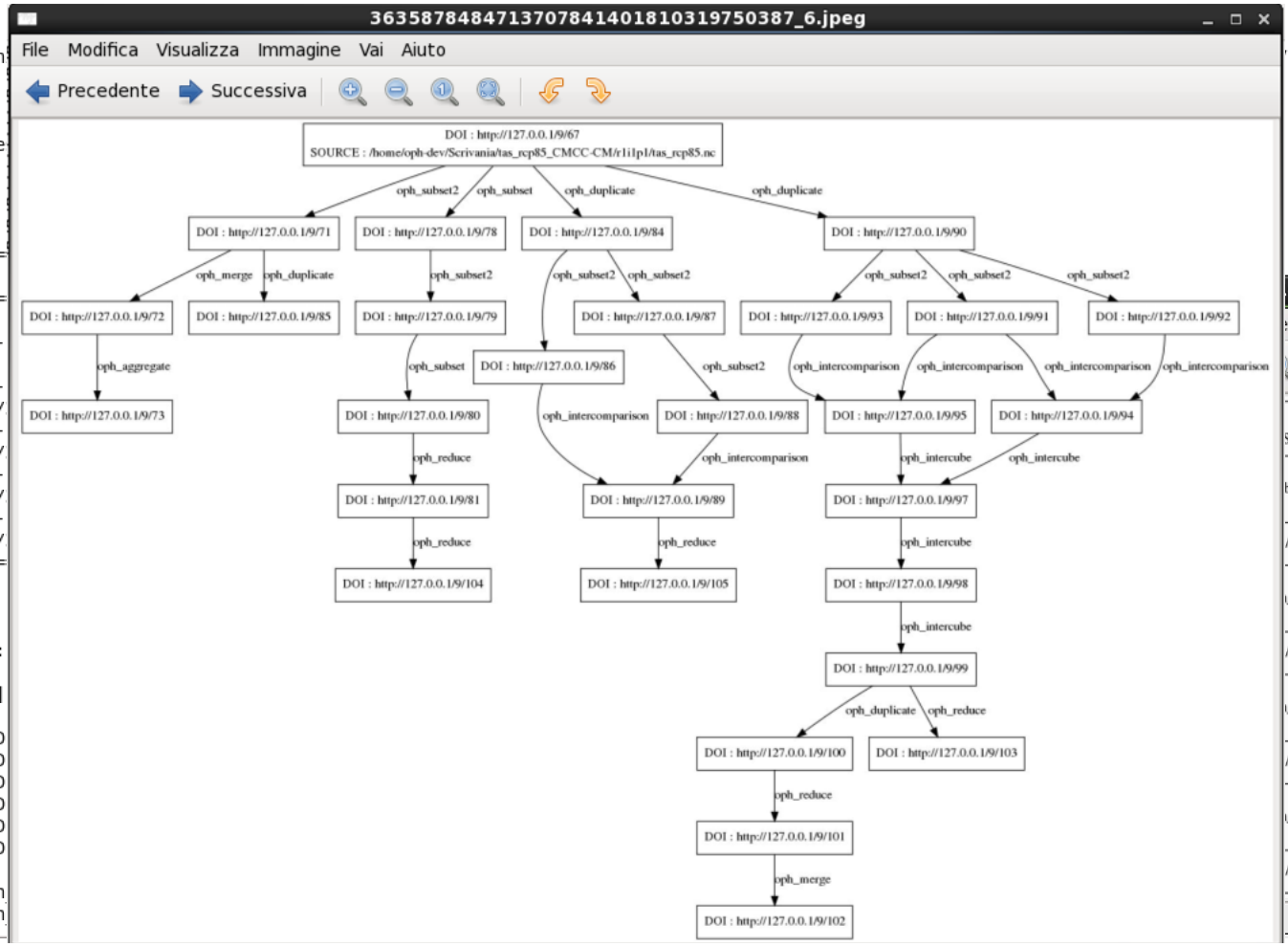
+==========================
| INPUT CUBE
+==========================
|
|--------------------------
|
|--------------------------
| http://127.0.0.1/ophidia/
|--------------------------
| http://127.0.0.1/ophidia/
|--------------------------
| http://127.0.0.1/ophidia/
|--------------------------
| http://127.0.0.1/ophidia/
+==========================

Cube Provenance Graph
---------------------

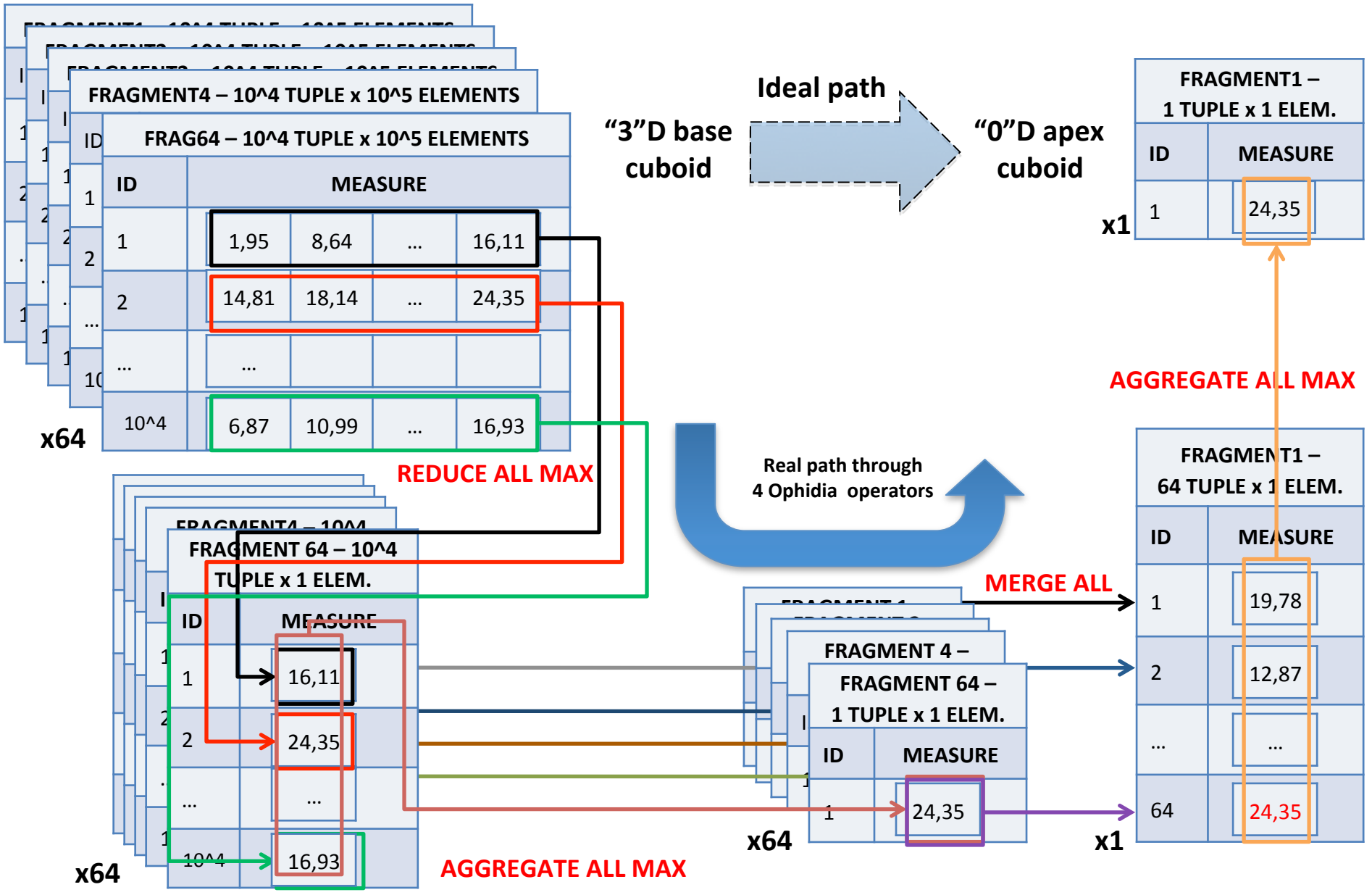
Directed Graph DOT string :
digraph DG {
        node    [shape=box]

        0       [label="PID
        1       [label="PID
        2       [label="PID
        3       [label="PID
        4       [label="PID
        5       [label="PID

        1->0    [label="oph
        2->1    [label="oph
```



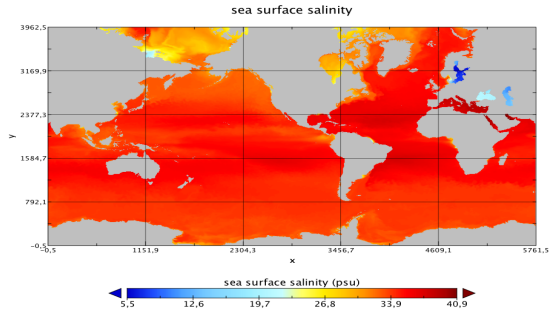
Pipelining analytics operators to reduce data

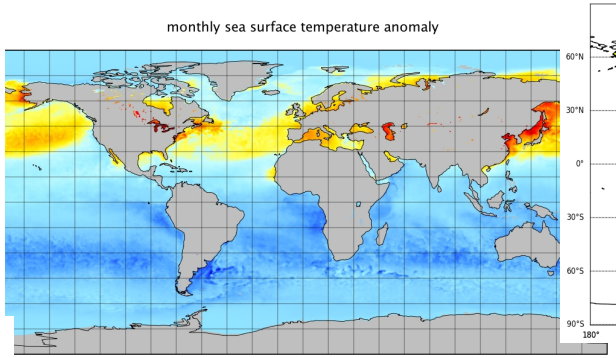


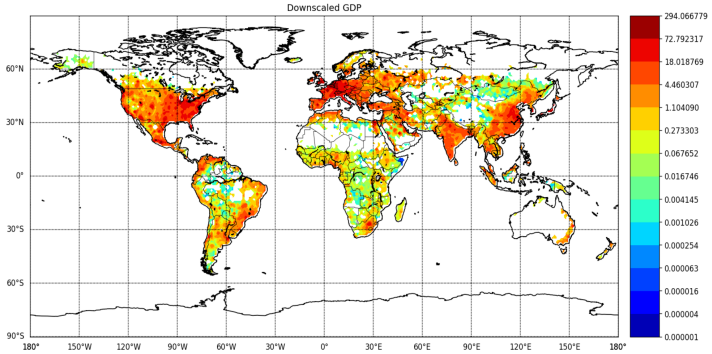
Ophidia architecture 2.0

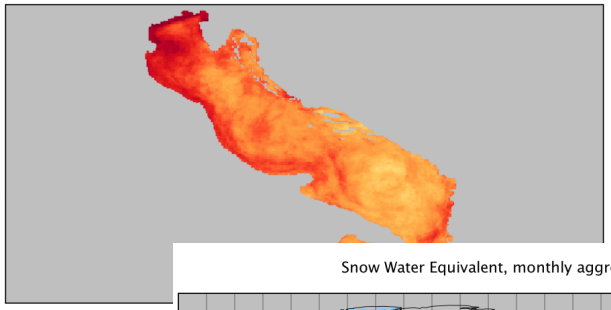
Workflows management, python applications, in-memory analytics

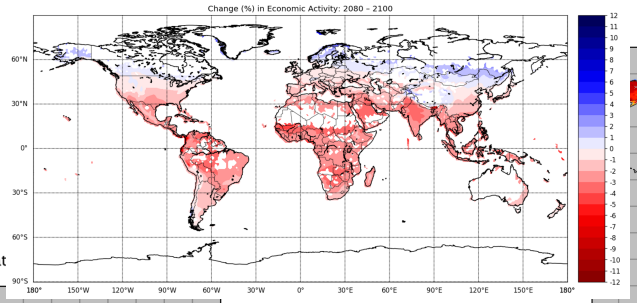
Efficient support for advanced analytics experiments

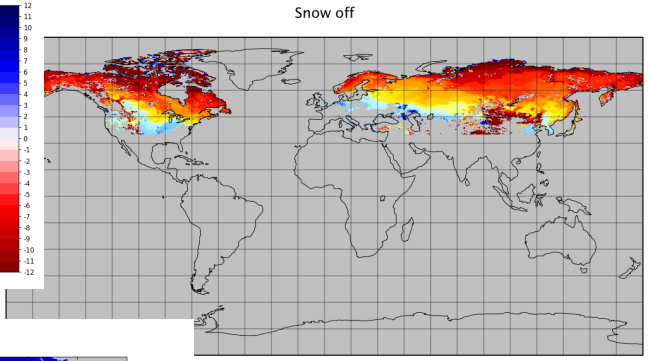


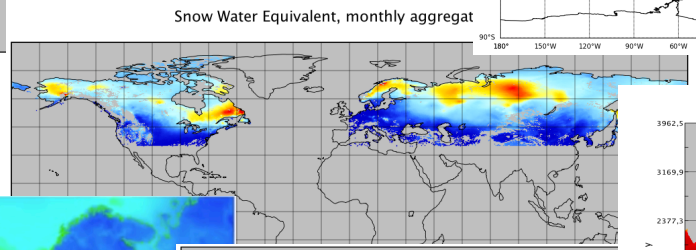


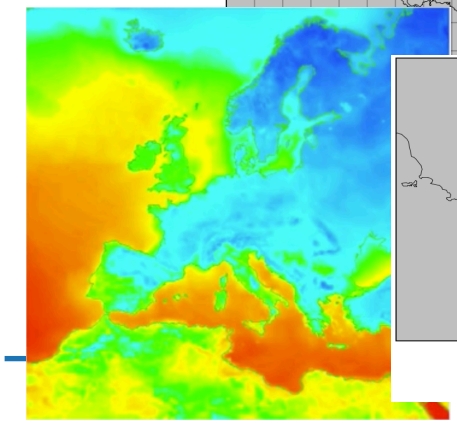


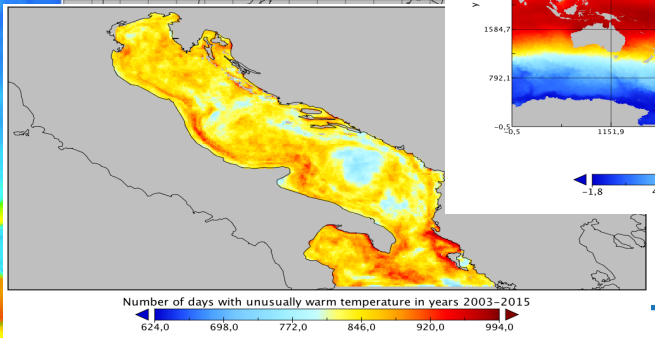


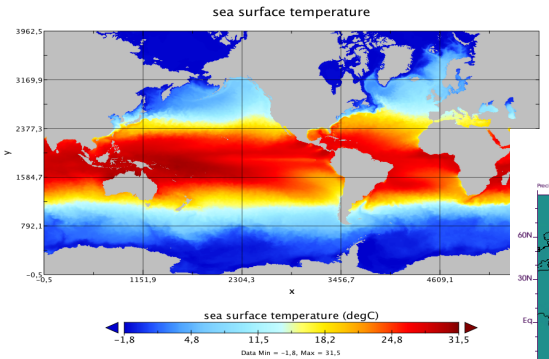


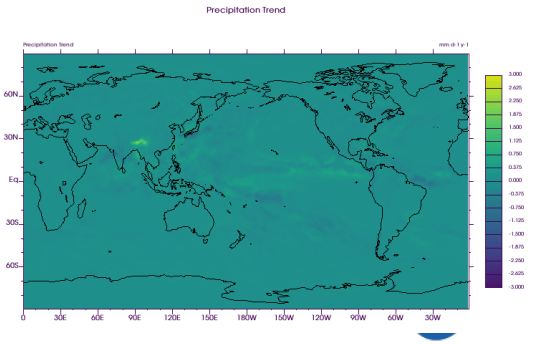












Architecture 2.0

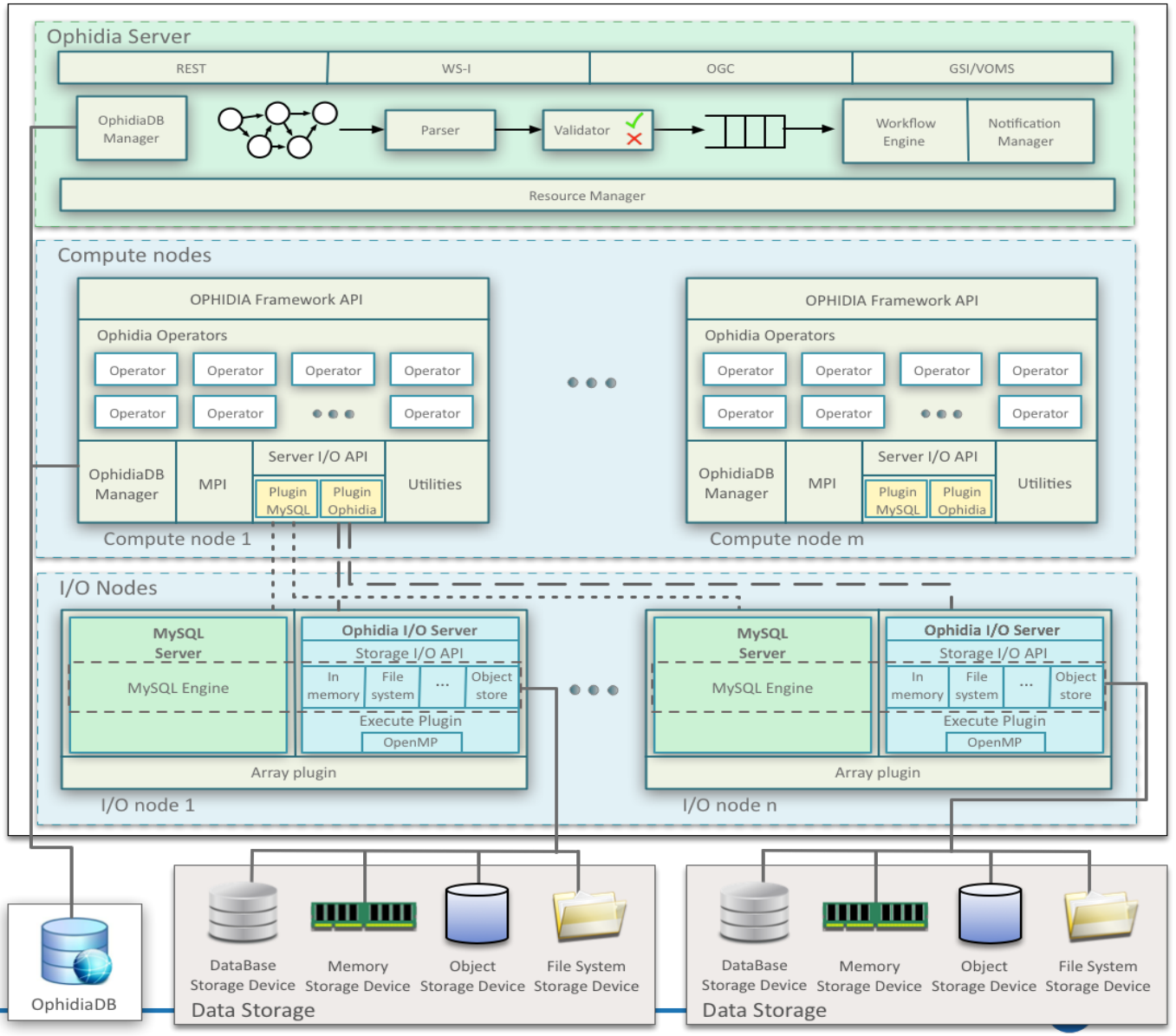
Workflow support on the server side

Separation of concerns between framework and I/O components

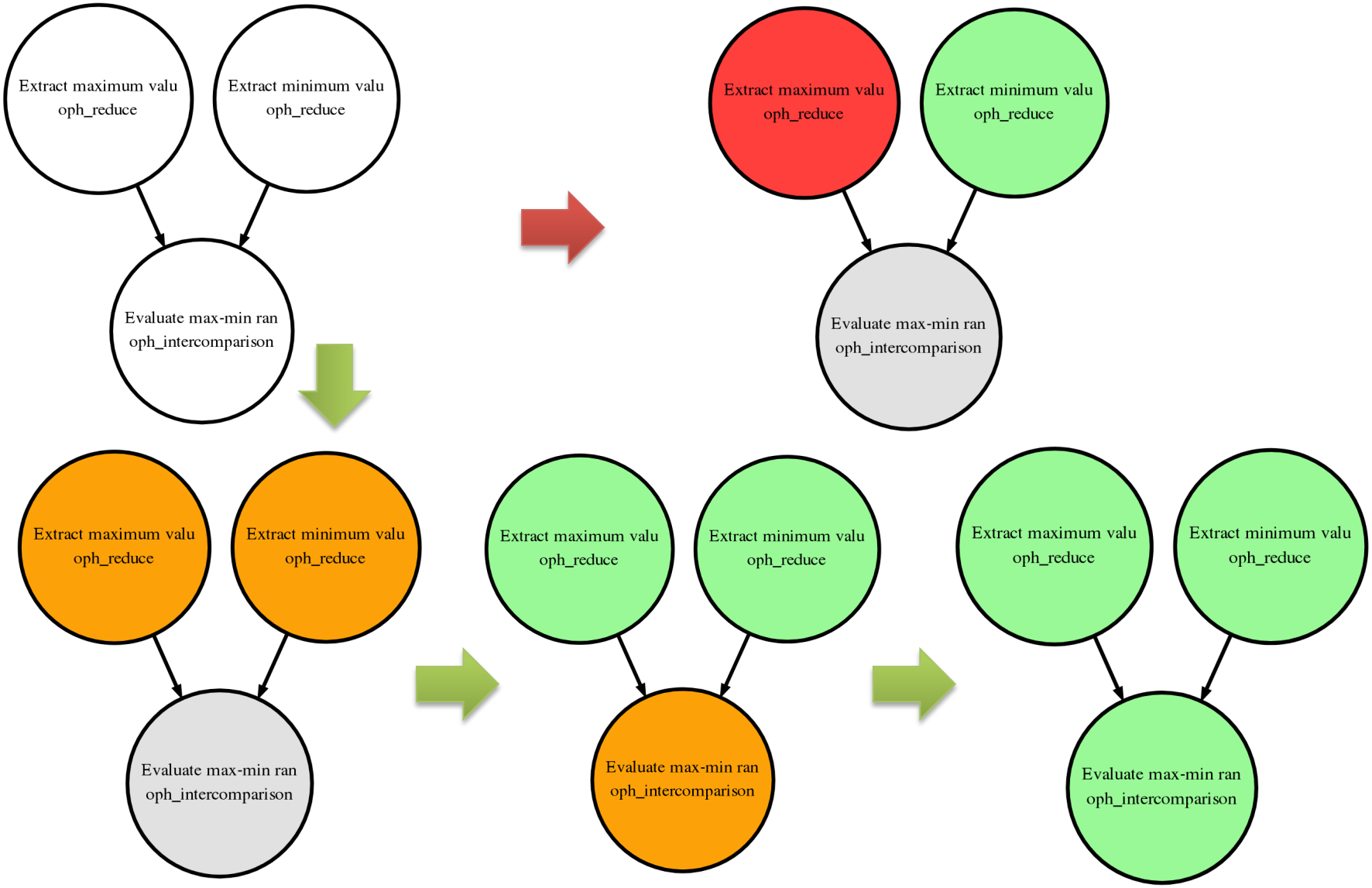
Support different **I/O servers**

Native I/O server with **parallel execution engine**

Multiple **storage systems** supported

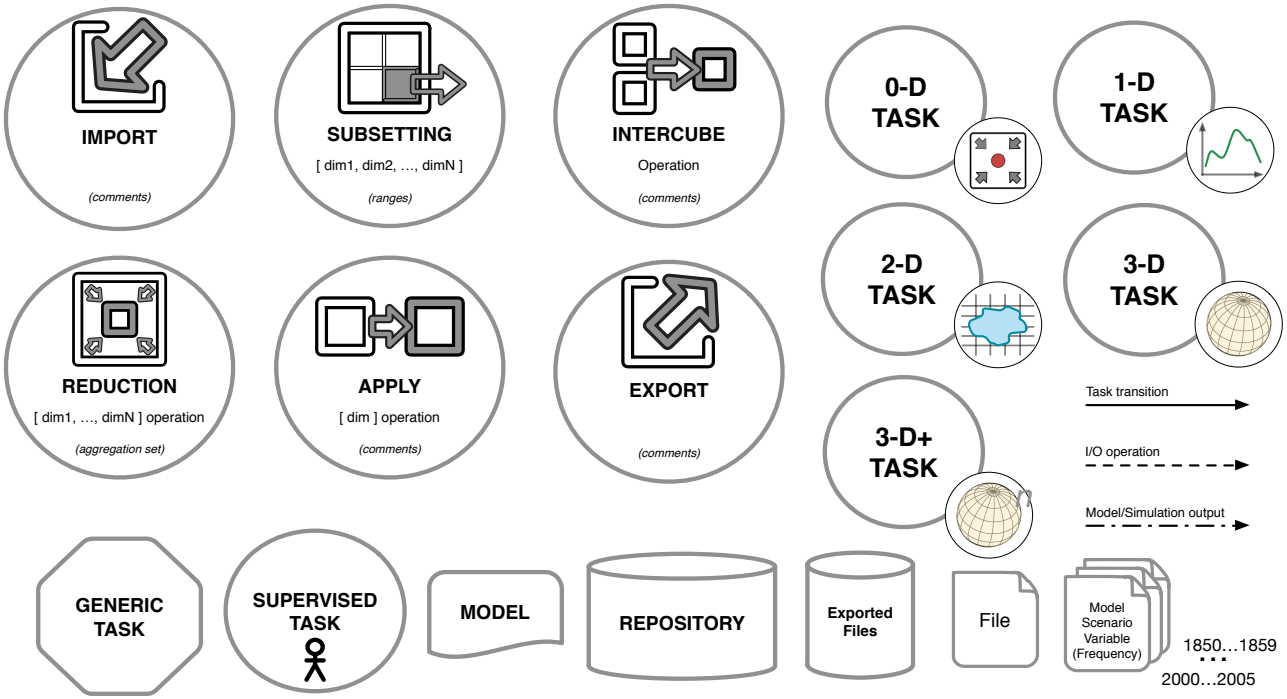


Workflow support



From a user experiment to a scientific workflow

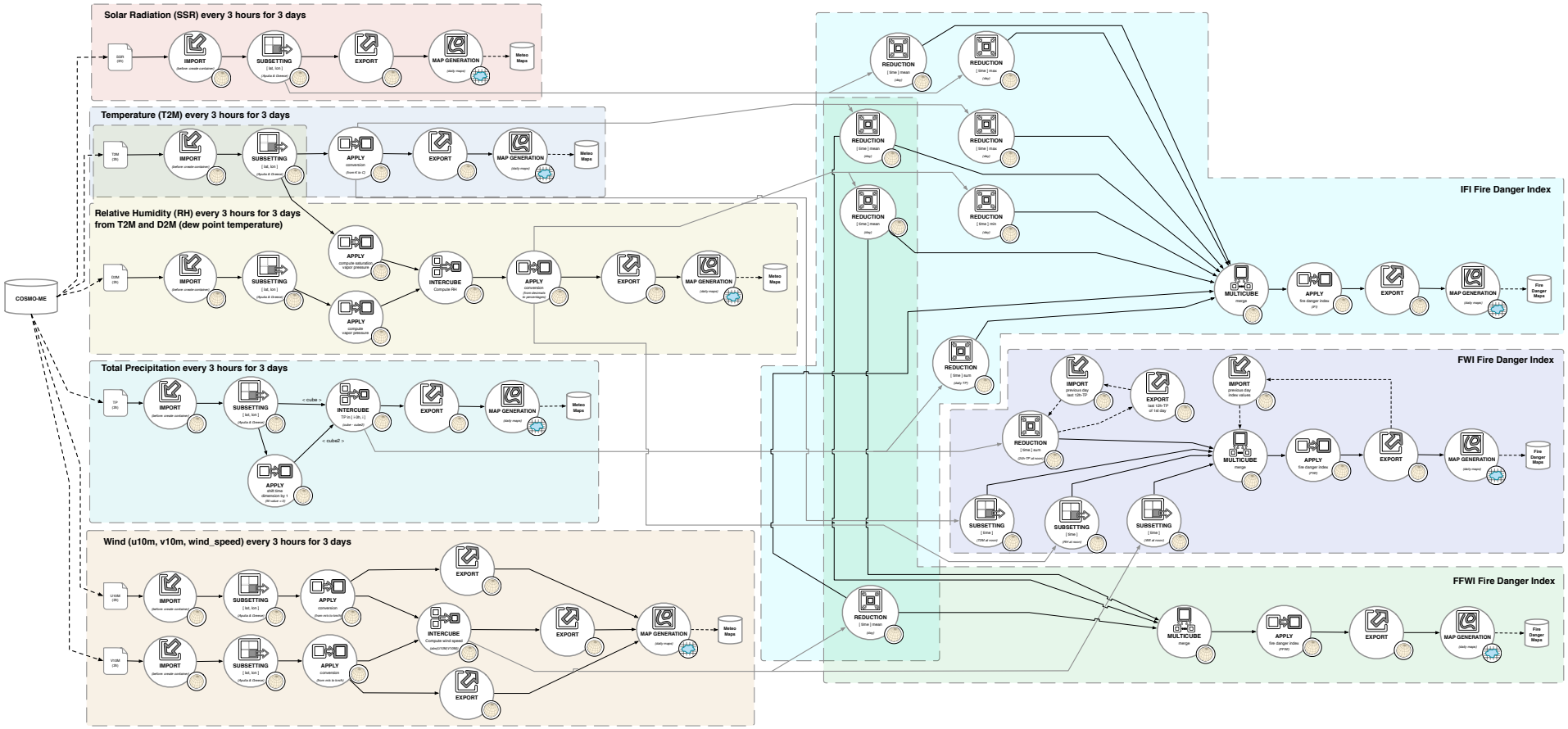
- ✔ *A Data Analytics Workflow Modelling Language (DAWML) has been defined*
- ✔ ***Extensible** schema jointly defined with application-domain scientists*
- ✔ *The schema allows the definition of **abstract** workflows*



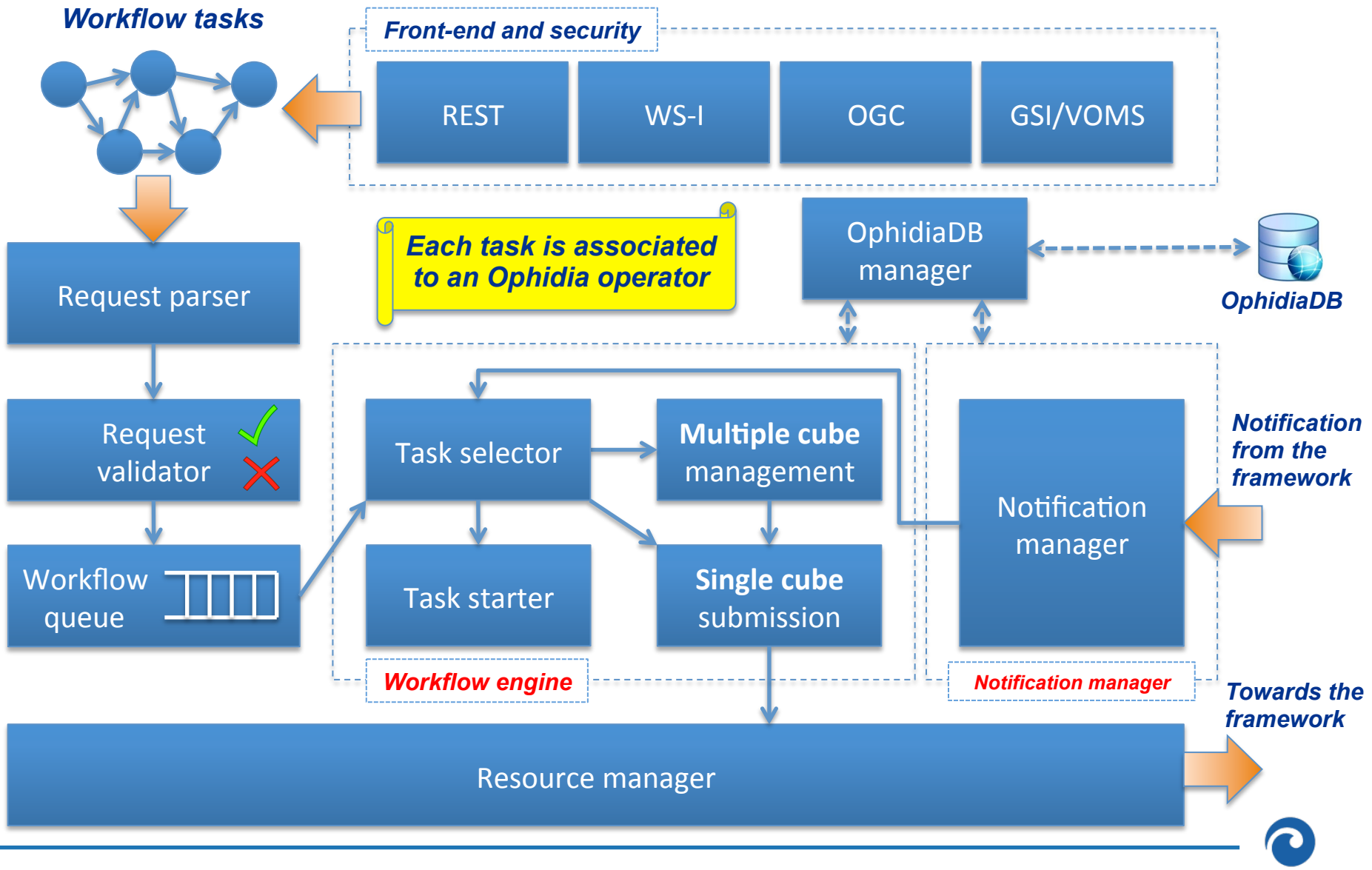
C. Palazzo, A. Mariello, S. Fiore, A. D'Anca, D. Elia, Dean N. Williams, G. Aloisio, "A workflow-enabled big data analytics software stack for escience", HPCS 2015: 545-552

Workflow example II: fire danger analysis

OFIDIA main objective is to build a **cross-border operational fire danger prevention infrastructure** that advances the ability of regional stakeholders across Apulia and Ioannina Regions to **detect** and **fight forest wildfires**

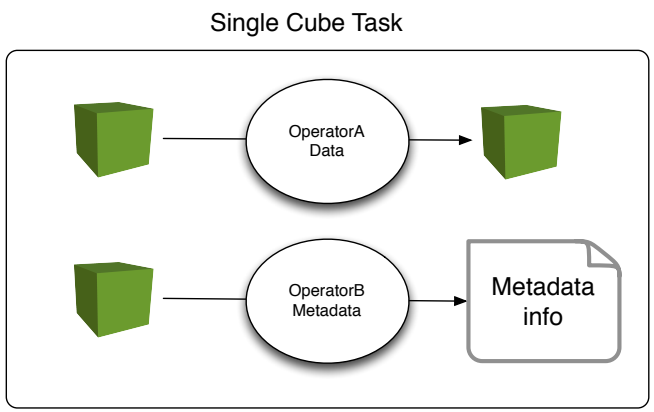


Architecture 2.0: Ophidia Server & Workflow support



Single Cube Task

Execution of a data/metadata operator through a single declarative statement



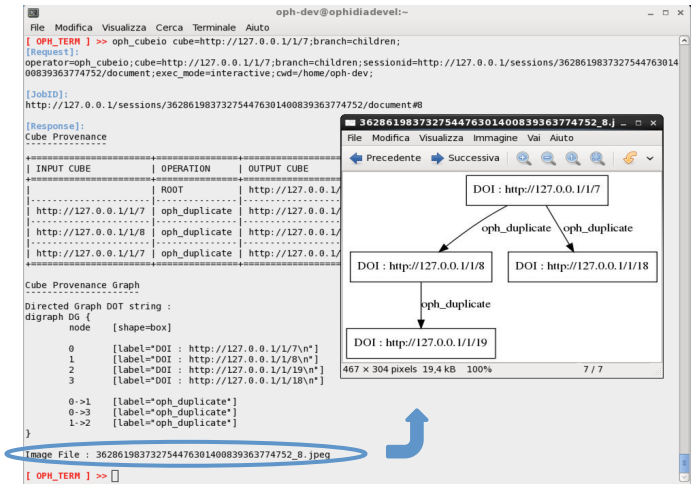

```
[ OPH_TERM ] >> oph_list level=3
[Request]:
operator=oph_list;level=3;sessionid=http://127.0.0.1/sessions/2348699147308869342414016277505283 97/document;exec_mode=interactive;cwd=/home/oph-dev;

[JobID]:
http://127.0.0.1/sessions/2348699147308869342414016277505283 97/document#6

[Response]:
Ophidia Filesystem
```

T	PATH	DATACUBE DOI	MEASURE	LEVEL	SOURCE
c	/home/oph-dev/cmip5	http://127.0.0.1/9/58	tas	0	/home/oph-dev/Scrivania/tas_historical_CMCC-CM/r1i1p1/tas_hist.nc
c	/home/oph-dev/cmip5	http://127.0.0.1/9/59	tas	1	http://127.0.0.1/9/58
c	/home/oph-dev/cmip5	http://127.0.0.1/9/60	tas	2	http://127.0.0.1/9/59
c	/home/oph-dev/cmip5	http://127.0.0.1/9/61	tas	3	http://127.0.0.1/9/60
c	/home/oph-dev/cmip5	http://127.0.0.1/9/62	tas	4	http://127.0.0.1/9/61
c	/home/oph-dev/cmip5	http://127.0.0.1/9/63	tas	1	http://127.0.0.1/9/58
c	/home/oph-dev/cmip5	http://127.0.0.1/9/64	tas	2	http://127.0.0.1/9/63
c	/home/oph-dev/cmip5	http://127.0.0.1/9/65	tas	3	http://127.0.0.1/9/64
c	/home/oph-dev/cmip5	http://127.0.0.1/9/66	tas	4	http://127.0.0.1/9/65
c	/home/oph-dev/cmip5	http://127.0.0.1/9/67	tas	0	/home/oph-dev/Scrivania/tas_rcp85_CMCC-CM/r1i1p1/tas_rcp85.nc
c	/home/oph-dev/cmip5	http://127.0.0.1/9/68	tas	1	http://127.0.0.1/9/58
c	/home/oph-dev/cmip5	http://127.0.0.1/9/69	tas	2	http://127.0.0.1/9/68
c	/home/oph-dev/cmip5	http://127.0.0.1/9/70	tas	3	http://127.0.0.1/9/69
c	/home/oph-dev/cmip5	http://127.0.0.1/9/71	tas	1	http://127.0.0.1/9/67
c	/home/oph-dev/cmip5	http://127.0.0.1/9/72	tas	2	http://127.0.0.1/9/71
c	/home/oph-dev/cmip5	http://127.0.0.1/9/73	tas	3	http://127.0.0.1/9/72
c	/home/oph-dev/cmip5	http://127.0.0.1/9/74	tas	1	http://127.0.0.1/9/58

oph_list level=3



oph_cubeio cube=DOI;branch=children

```
[ OPH_TERM ] >> oph_explorecube cube=http://127.0.0.1/9/67;limit_filter=10;show_id=yes;show_index=yes;subset_dims=time;subset_filter=281:282;
[Request]:
operator=oph_explorecube;cube=http://127.0.0.1/9/67;limit_filter=10;show_id=yes;show_index=yes;subset_dims=time;subset_filter=281:282;session:
3252568383844140163837823593 0/document;exec_mode=interactive;cwd=/home/oph-dev;

[JobID]:
http://127.0.0.1/sessions/1953418325256838384414016383782359 30/document#6

[Response]:
tas
```

ID	lat	INDEX OF lat	lon	INDEX OF lon	tas
1	-89.427084	1	0.000000	1	224.7158966064
2	-89.427084	1	0.750000	2	224.7295684814
3	-89.427084	1	1.500000	3	224.7412872314
4	-89.427084	1	2.250000	4	224.7490997314
5	-89.427084	1	3.000000	5	224.7569122314
6	-89.427084	1	3.750000	6	224.7666778564
7	-89.427084	1	4.500000	7	224.7744903564
8	-89.427084	1	5.250000	8	224.7842559814
9	-89.427084	1	6.000000	9	224.7940216064
10	-89.427084	1	6.750000	10	224.8018341064

```
Summary
Selected 10 rows out of 115200
```

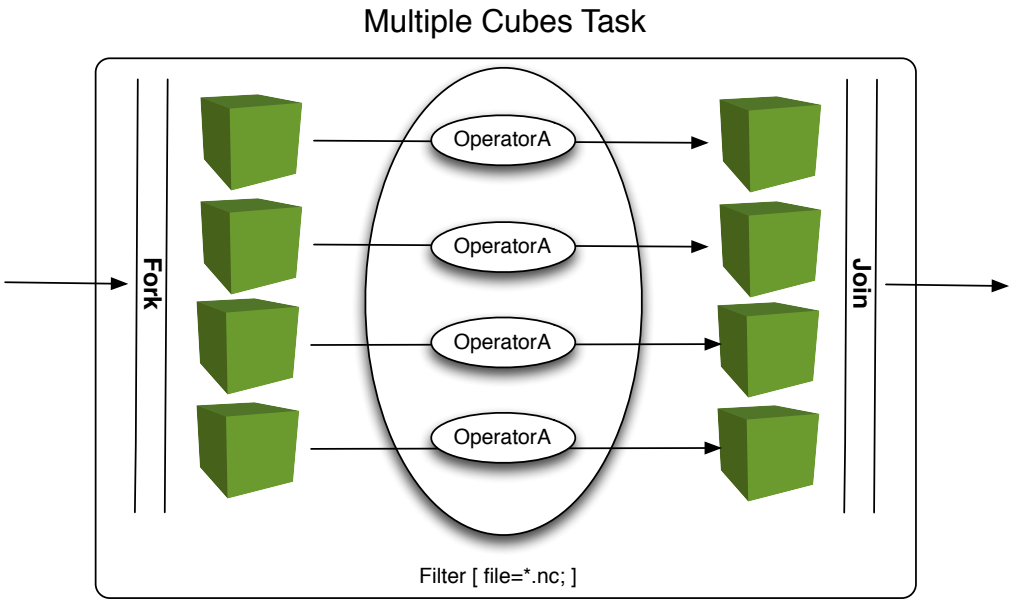
oph_explorecube cube=DOI.

Multiple cubes task

*Execution of the **same data operator** over a **group of data cubes** through a **single declarative statement***

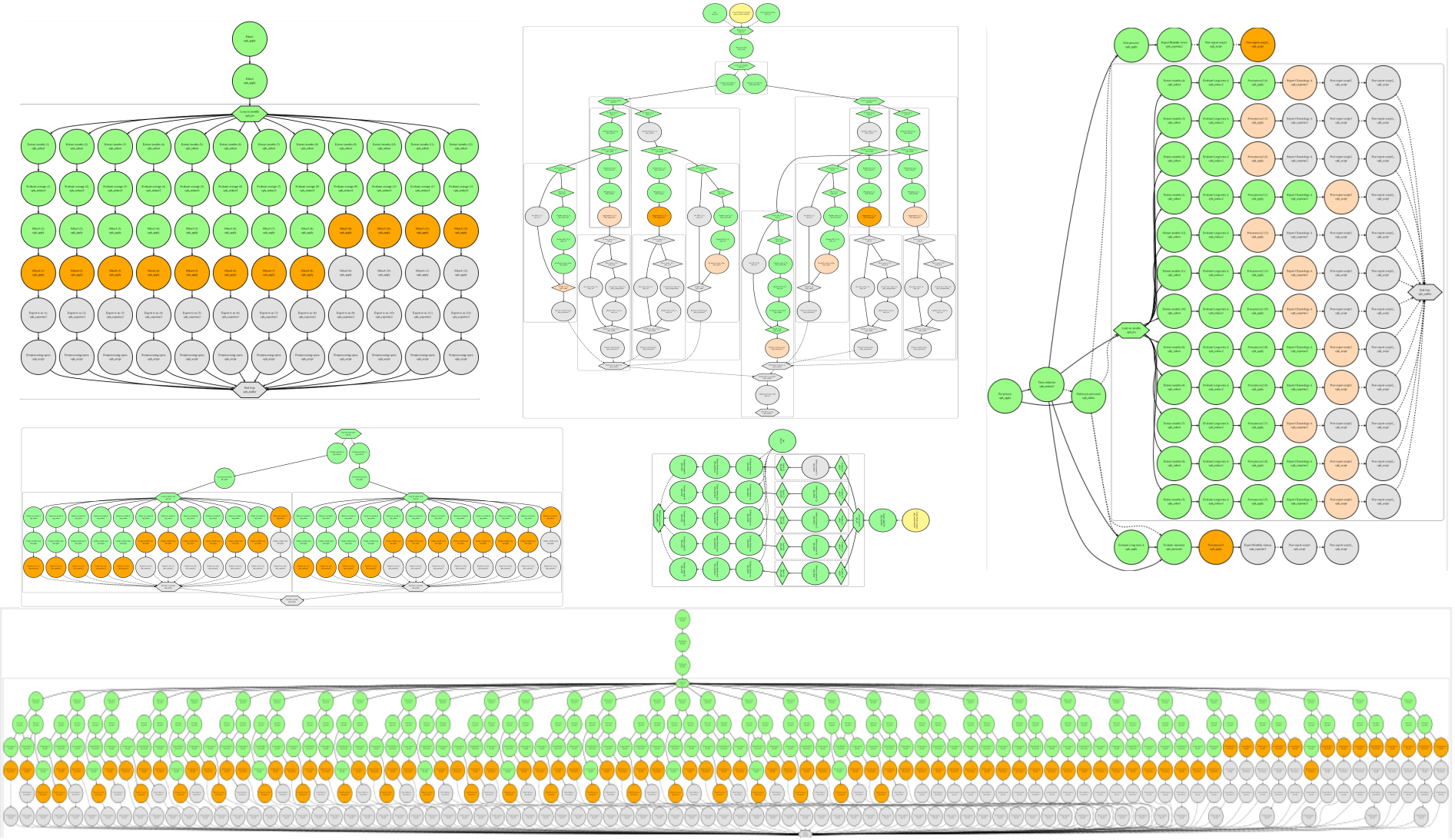
Multiple cubes tasks can be used:

- *to import a large number of datasets into the Ophidia platform*
- *to process a large set of data cubes with similar properties*



*Data cubes to be processed by a multiple cubes operator can be selected by applying a set of **filters***

Analytics workflows support and interfaces



Analytics workflows support and interfaces

Workflow Management

This group includes a number of flow control operators that could be used within an Ophidia workflow to implement complex data processing in batch mode. In particular, they implement several advanced features: setting of run-time variables, iterative and parallel interface, selection interface, interactive workflows, interleaving workflows, etc.

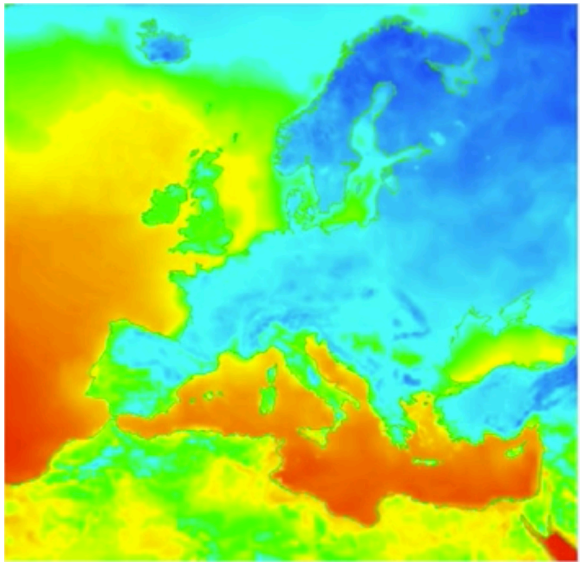
NAME	DESCRIPTION
OPH_ELSE	Start the last sub-block of a selection block "if".
OPH_ELSEIF	Start a new sub-block of a selection block "if".
OPH_ENDFOR	Close a loop "for".
OPH_ENDIF	Close a selection block "if".
OPH_FOR	Implement a loop "for".
OPH_IF	Open a "if" selection block.
OPH_INPUT	It sends commands or data to an interactive task.
OPH_SET	Set a parameter in the workflow environment.
OPH_WAIT	Wait until an event occurs.

Workflow I: climate indicators processing

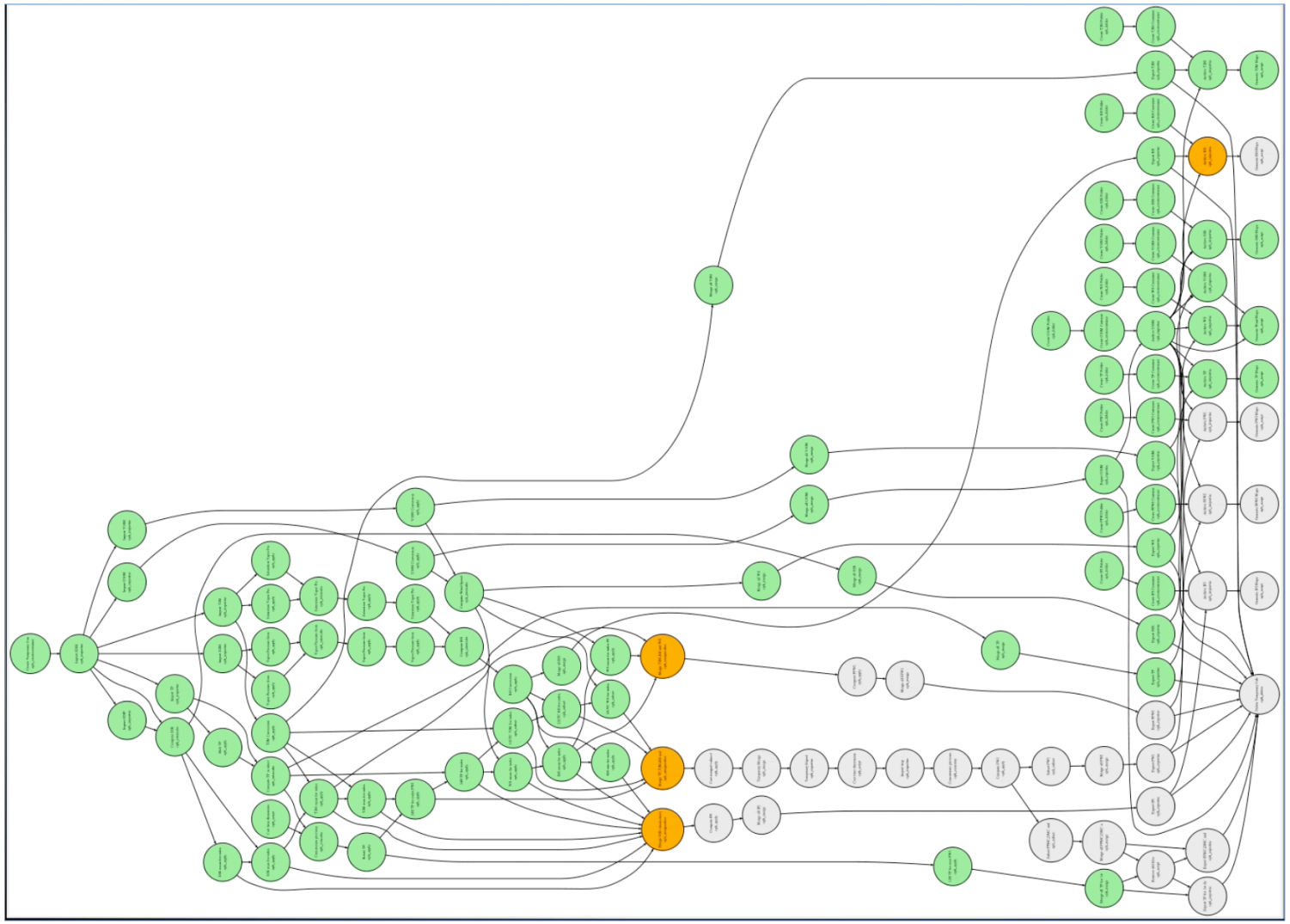
- *In the CLIPC project, processing chains for data analysis are being implemented with Ophidia to compute **climate indicators***

- ***First set of indicators** includes: TNn, **TNx**, TXn, **TXx***
  - *Input files: 12GBs (TasMin & TasMax)*
    - *TNx = max of the min temperatures*
    - *TXx = max of the max temperatures*

- ***Parallel approach***
  - *Inter-parallelism & Intra-parallelism*



Workflow example II: fire danger analysis Runtime Execution



https://www.youtube.com/watch?v=vxbYF1Zhpuc&feature=youtu.be

Workflow example III: multi-model analytics
Cloud-enabled, distributed multi-model analytics experiment

2016 IEEE International Conference on Big Data (Big Data)

Distributed and cloud-based multi-model analytics experiments on large volumes of climate change data in the Earth System Grid Federation eco-system

S. Fiore[1], M. Plóciennik[2], C. Doutriaux[3], C. Palazzo[1], J. Boutte[3], T. Żok[2], D. Elia[1], M. Owsiak[2], A. D'Anca[1], Z. Shaheen[3], R. Bruno[4], M Fargetta[4], M. Caballer[5], G. Moltó[5], I. Blanquer[5], R. Barbera[4,6], M. David[7], G. Donvito[4], D. N. Williams[3], V. Anantharaj[8], D. Salomoni[4], and G. Aloisio[1,9]

[1]Euro-Mediterranean Center on Climate Change Foundation (CMCC), Italy
[2]Poznan Supercomputing and Networking Center (PSNC), Poland
[3]Lawrence Livermore National Laboratory (LLNL), California, USA
[4]Italian National Institute of Nuclear Physics (INFN), Italy
[5]Universitat Politècnica de València (UPV), Spain
[6] University of Catania, Italy
[7]Laboratório de Instrumentação e Fisica Experimental de Particulas (LIP), Portugal
[8]Oak Ridge National Laboratory (ORNL), Tennessee, USA
[9]University of Salento, Italy

***Abstract*—A case study on *climate models intercomparison data analysis* addressing several classes of multi-model experiments is being implemented in the context of the EU H2020 INDIGO-DataCloud project. Such experiments require the availability of large amount of data (multi-terabyte order) related to the output of several climate models simulations as well as the exploitation of scientific data management tools for large-scale data analytics. More specifically, the paper discusses in detail a use case on precipitation trend analysis in terms of requirements, architectural design solution, and infrastructural implementation. The experiment has been tested and validated on CMIP5 datasets, in the context of a large scale distributed testbed across EU and US involving three ESGF sites (LLNL, ORNL, and CMCC) and one central orchestrator site (PSNC).**

Keywords-big analytics, workflow management, cloud computing, ESGF, INDIGO-DataCloud

I. Introduction

The increased models resolution in the development of comprehensive Earth System Models is rapidly leading to very large climate simulations output that pose significant scientific data management challenges in terms of data sharing, processing, analysis, visualization, preservation, curation, and archiving [1-3].

In this domain, large scale global experiments for climate model intercomparison (CMIP) have led to the development of the Earth System Grid Federation (ESGF [4-5]), a federated data infrastructure involving a large set of data providers/modelling centers around the globe, which includes the European contribution - regarding the ENES [6] community – through the IS-ENES project.

From an infrastructural standpoint, ESGF provides a production-level support for search & discovery, browsing and access to climate simulation data and observational data products. ESGF has been serving the Coupled Model Intercomparison Project Phase 5 (CMIP5) experiment, providing access to 2.5PB of data for the Intergovernmental Panel on Climate Change (IPCC) [7] Assessment Reports 5 [8], based on consistent metadata catalogues. More precisely, the Coupled Model Intercomparison Project (CMIP) has been established by the Working Group on Coupled Modelling [9] (WGCM) under the World Climate Research Programme [10] (WCRP).

It provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyse General Circulation Models (GCMs) in a systematic fashion, a process that serves to facilitate models improvement.

CMIP5 has promoted a standard set of model simulations in order to:

- evaluate how realistic the models are in simulating the recent past;
- provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond); and
- understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle.

In such a context, running a multi-model data analysis experiment is very challenging, as it requires the availability of large amount of data (multi-terabyte order) related to multiple climate models simulations as well as scientific data management tools for large-scale data analytics.

The remainder of this work is organized as it follows. Section II provides the current workflow for the multi-model climate data analysis in the CMIP context, whereas Section III presents the paradigm shift needed to address such large-

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Big Data Challenges, Research, and Technologies in the Earth and Planetary Sciences

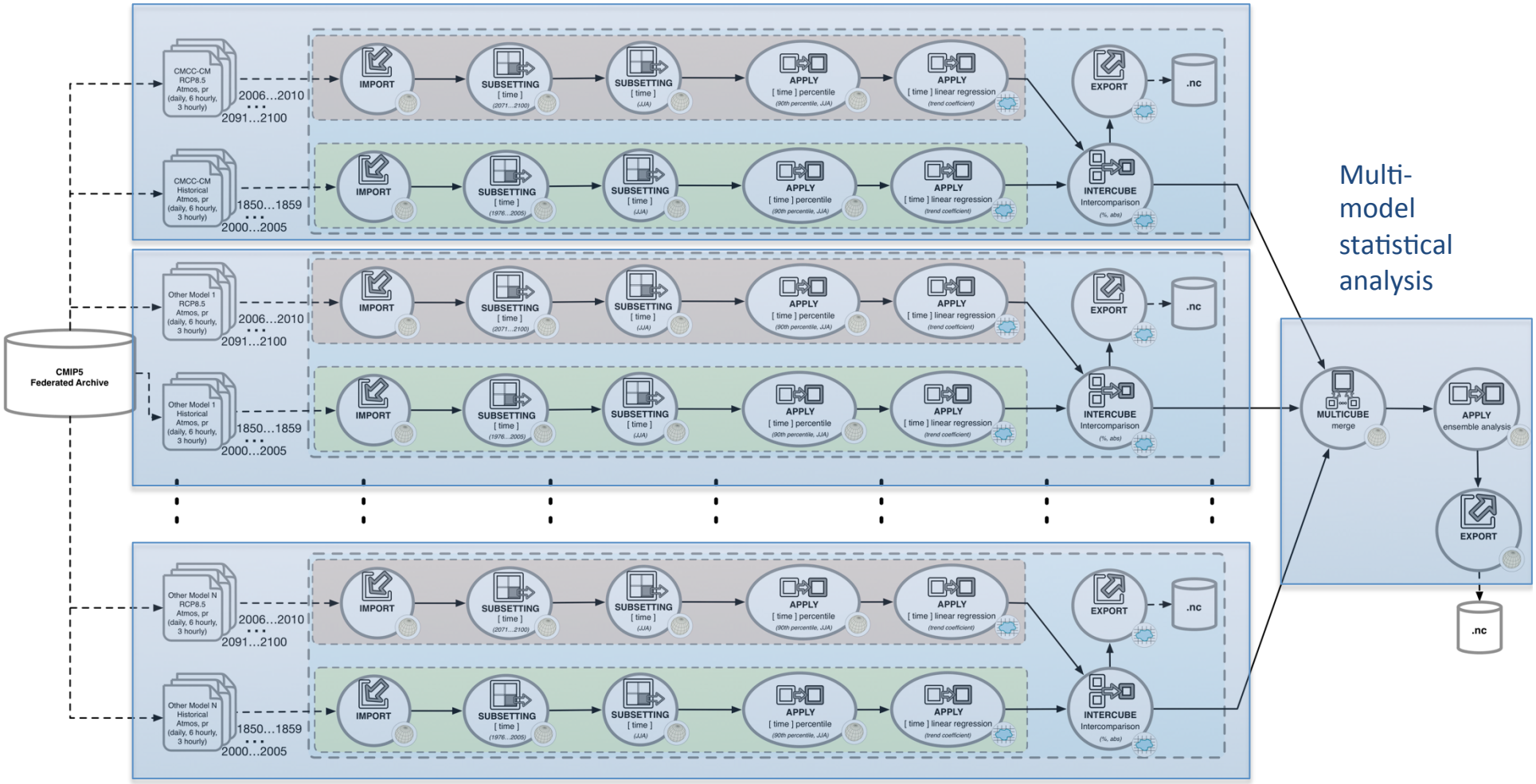
A workshop to be held Monday December 5th at the 2016 IEEE International Big Data Conference

- *A first experiment across sites was demonstrated at the 1st INDIGO Review, November 2016 in Bologna*
- *Strong synergy with the ESGF CWT Roadmap*
- *International collaboration across the Atlantic*

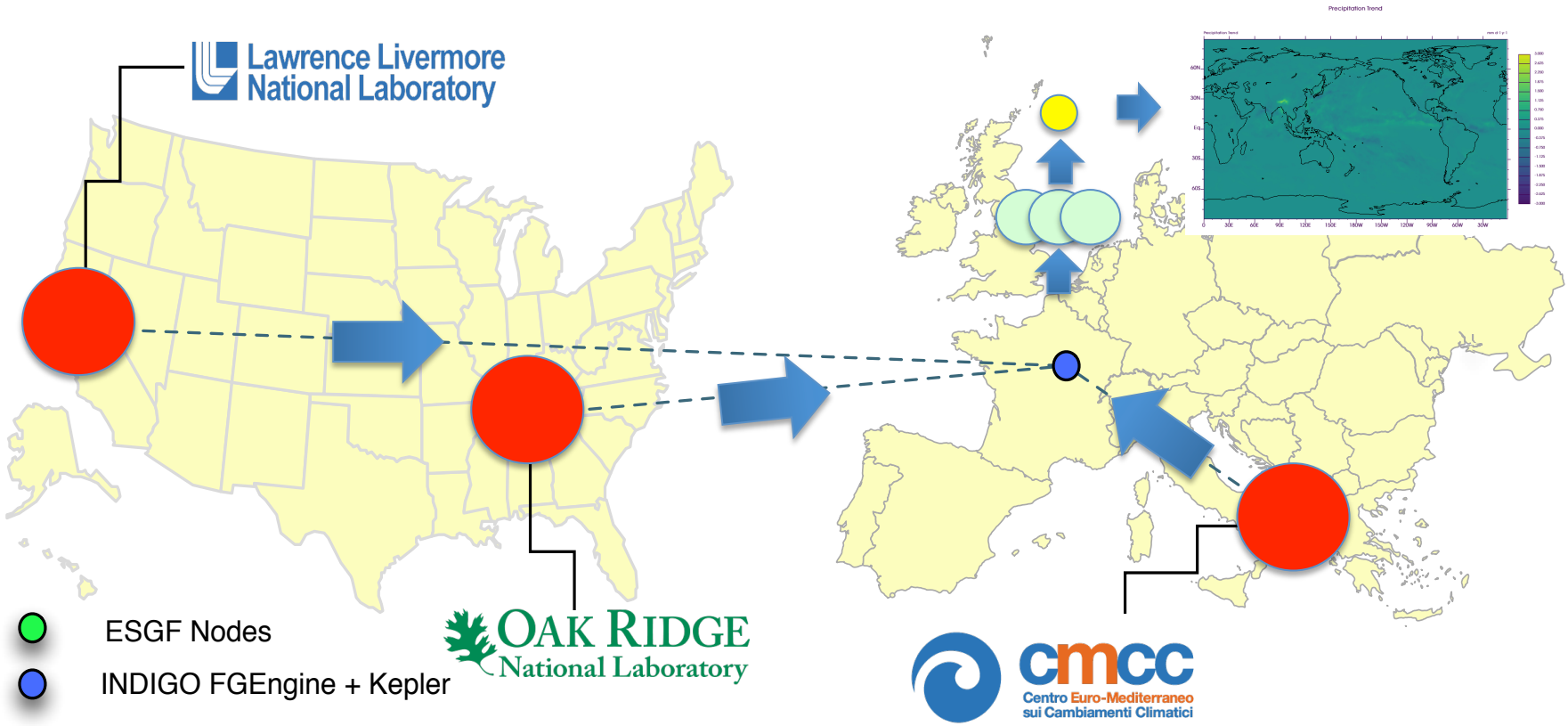
S. Fiore, M. Plóciennik, et al.: Distributed and cloud-based multi-model analytics experiments on large volumes of climate change data in the Earth System Grid Federation eco-system. BigData 2016: 2911-2918

High-level view of the multi-model „precipitation trend analysis" experiment

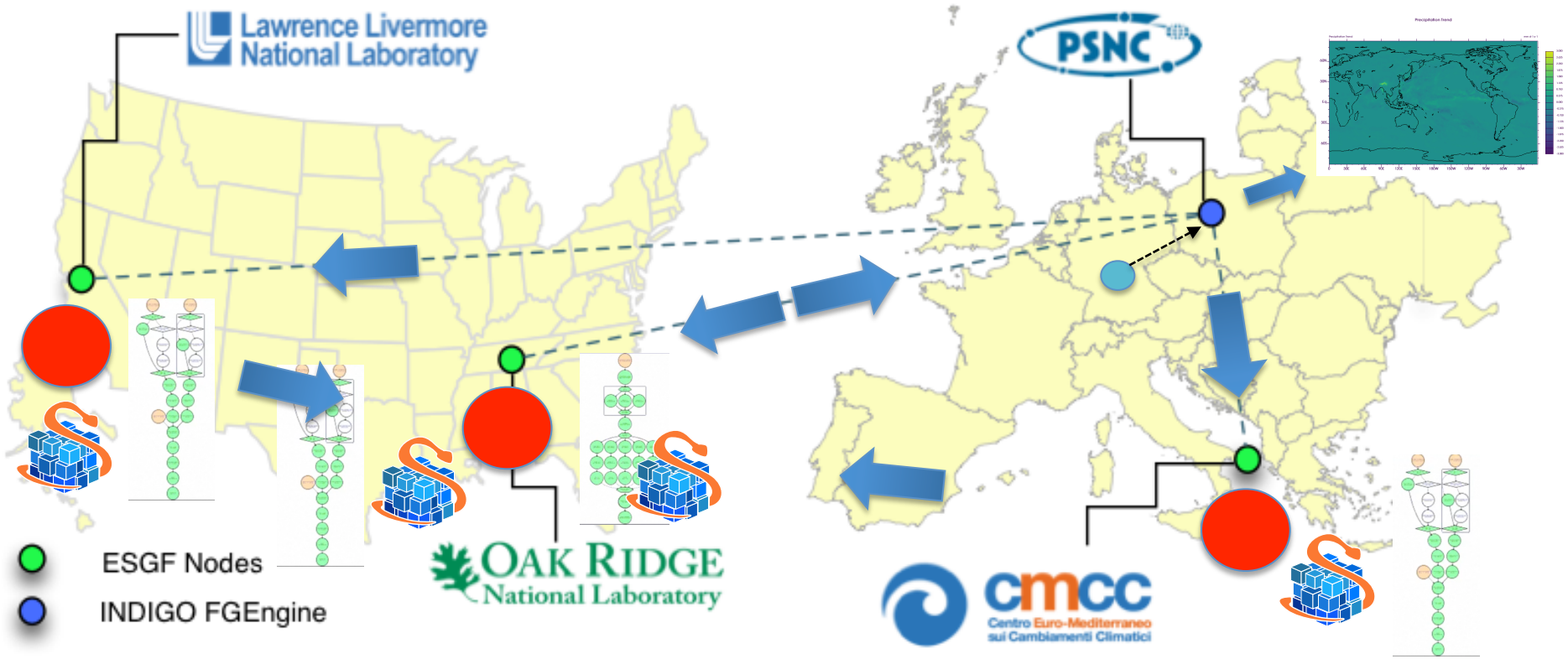
Single model precipitation trend analysis



CMIP5 scientific data analysis workflow in ESGF



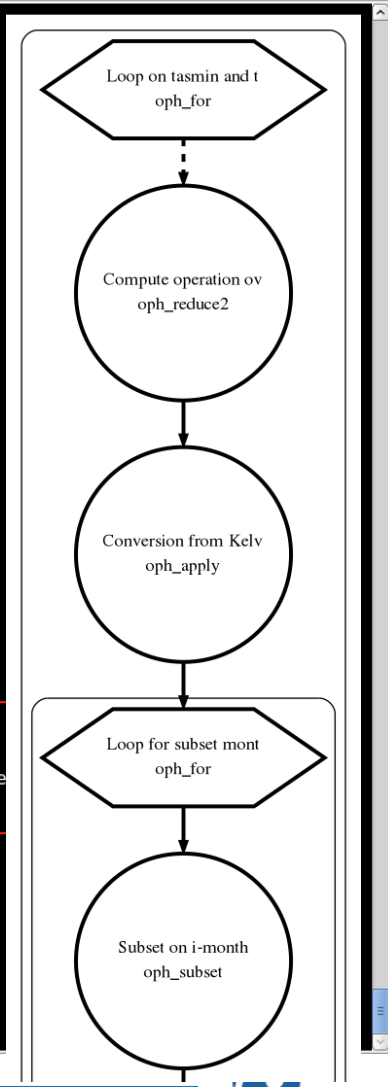
The paradigm shift proposed & exploited in INDIGO-DataCloud



Behind the scene: workflow JSON representation

ophrpm@ophidiarpm:~/workflow

```
"tasks": [
    {
        "name": "Loop on tasmin and tasmax cubes",
        "operator": "oph_for",
        "arguments": [ "name=cube","counter=1:2", "values=${1}|${2}", "parallel=yes" ]
    },
        {
                "name": "Compute operation over time",
                "operator": "oph_reduce2",
                "arguments": [
                        "cube=@{cube}",
                        "dim=time",
                        "concept_level=M",
                        "midnight=00",
                        "operation=$3",
                        "container=tmp"
                ],
                "dependencies": [
                        { "task": "Loop on tasmin and tasmax cubes" }
                ]
        },
        {
                "name": "Conversion from Kelvin to Celsius degrees",
                "operator": "oph_apply",
                "arguments": [
                        "query=oph_sum_scalar('oph_float','oph_float',measure,-273.15)"
                ],
                "dependencies": [{
                        "task": "Compute operation over time",
                        "type": "single"
                }]
        },
        {
                "name": "Loop for subset months",
                "operator": "oph_for",
                "arguments": [ "name=index","counter=1:12", "values=Jan|Feb|Mar|Apr|May|Jun|Jul|Aug|Sep|Oct|N
                "dependencies": [ { "task":"Conversion from Kelvin to Celsius degrees", "type": "single" } ]
        },
                {
                        "name": "Subset on i-month",
                        "operator": "oph_subset",
                        "arguments": [
                                "subset_dims=time",
                                "subset_filter=&index:12:end"
                        ],
                        "dependencies": [
--More--(65%)
```



***Youtube video**: https://www.youtube.com/watch?v=PTZkw60YCNU*

Workflow submission

ophrpm@ophidiarpm:~/devel/oph-client/res | ophrpm@ophidiarpm:~/workflow

```
[37..6380] >>
[37..6380] >> ./Tind_loop.json http://193.204.199.174/ophidia/29/2046 http://193.204.199.174/ophidia/30/2047 max
[JobID]:
http://193.204.199.174/ophidia/sessions/376699238311302232511449455166146380/experiment?247#3144

[37..6380] >> view 247
[247] ./Tind_loop.json http://193.204.199.174/ophidia/29/2046 http://193.204.199.174/ophidia/30/2047 max [http://193.204.199.174/ophidia/sessions/376699238311302
232511449455166146380/experiment?247#3144]

[Response]:
Workflow Status
---------------

OPH_STATUS_COMPLETED

Workflow Progress
-----------------

+==========================+======================+
| NUMBER OF COMPLETED TASKS | TOTAL NUMBER OF TASKS |
+==========================+======================+
| 82                       | 82                   |
+==========================+======================+

Workflow Task List
------------------

+==========================================================+======================+========+=======+===========+============================+=====+=============+
| OPH JOB ID                                               | SESSION CODE         | WORKFL | MARKE | PARENT MA | TASK NAME                  | TYP | EXIT STATUS |
|                                                          |                      | OW ID  | R ID  | RKER ID   |                            | E   |             |
+==========================================================+======================+========+=======+===========+============================+=====+=============+
| http://193.204.199.174/ophidia/sessions/37669923831130   | 37669923831130223251 | 247    | 3145  | 3144      | Loop on tasmin and tasmax  | SIM | OPH_STATUS_ |
| 22325114494551661463 80/experiment?247#3145              | 1449455166146380     |        |       |           | cubes                      | PLE | COMPLETED   |
|----------------------------------------------------------|----------------------|--------|-------|-----------|----------------------------|-----|-------------|
| http://193.204.199.174/ophidia/sessions/37669923831130   | 37669923831130223251 | 247    | 3146  | 3144      | Compute operation over ti  | SIM | OPH_STATUS_ |
| 22325114494551661463 80/experiment?247#3146              | 1449455166146380     |        |       |           | me (1)                     | PLE | COMPLETED   |
|----------------------------------------------------------|----------------------|--------|-------|-----------|----------------------------|-----|-------------|
| http://193.204.199.174/ophidia/sessions/37669923831130   | 37669923831130223251 | 247    | 3147  | 3144      | Compute operation over ti  | SIM | OPH_STATUS_ |
| 22325114494551661463 80/experiment?247#3147              | 1449455166146380     |        |       |           | me (2)                     | PLE | COMPLETED   |
|----------------------------------------------------------|----------------------|--------|-------|-----------|----------------------------|-----|-------------|
| http://193.204.199.174/ophidia/sessions/37669923831130   | 37669923831130223251 | 247    | 3148  | 3144      | Conversion from Kelvin to  | SIM | OPH_STATUS_ |
| 22325114494551661463 80/experiment?247#3148              | 1449455166146380     |        |       |           | Celsius degrees (1)        | PLE | COMPLETED   |
|----------------------------------------------------------|----------------------|--------|-------|-----------|----------------------------|-----|-------------|
| http://193.204.199.174/ophidia/sessions/37669923831130   | 37669923831130223251 | 247    | 3149  | 3144      | Conversion from Kelvin to  | SIM | OPH_STATUS_ |
| 22325114494551661463 80/experiment?247#3149              | 1449455166146380     |        |       |           | Celsius degrees (2)        | PLE | COMPLETED   |
|----------------------------------------------------------|----------------------|--------|-------|-----------|----------------------------|-----|-------------|
```

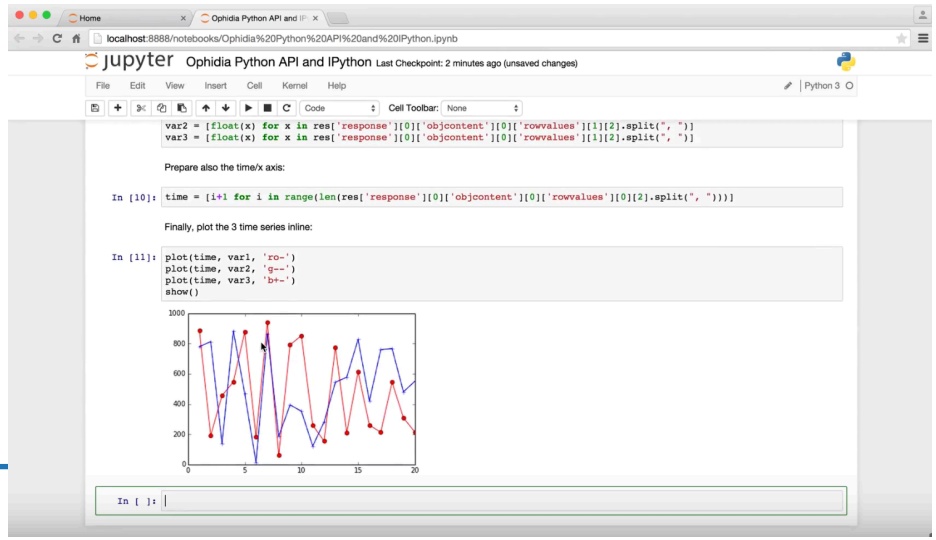
Programmatic access through the PyOphidia class

- ✓ **PyOphidia** provides a Python interface to submit commands to the Ophidia Server and to retrieve/deserialize the results
- ✓ Two classes implemented:
  - ✓ **Client class**: connect to the server, navigate into the ophidia file system, submit workflows, manage sessions, etc.
  - ✓ **Cube class**: manipulate cubes (reduce, subset, operations between cubes, intercomparison, etc.), get information on cubes (schema, dimensions, metadata, etc.)

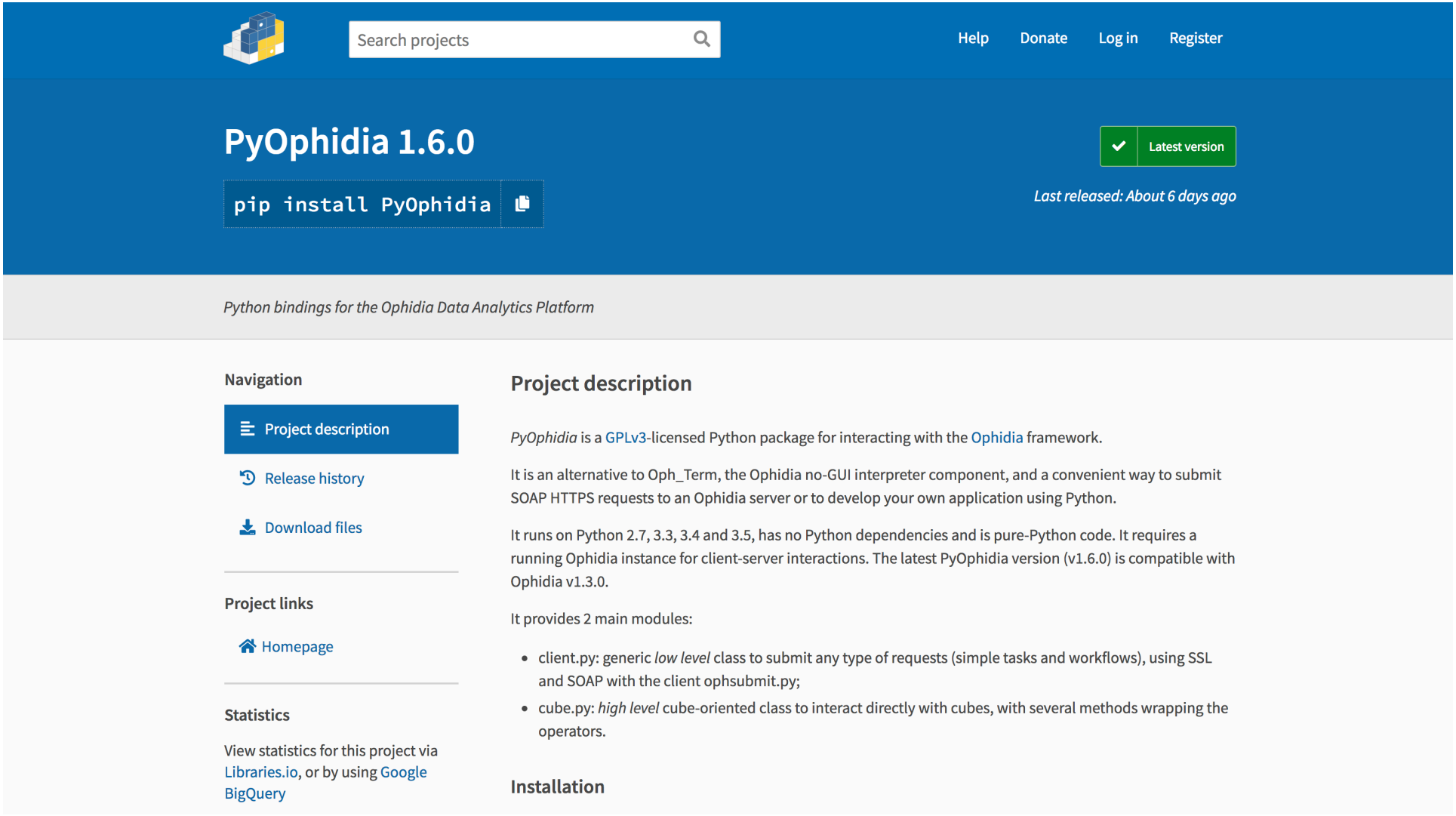
```
class Cube():
    """Cube(container='-', cwd=None, exp_dim='auto', host_partition='auto', imp_dim='auto', measure=None, src_path=None, cdd=None, compressed='no',
            exp_concept_level='c', filesystem='auto', grid='-', imp_concept_level='c', import_metadata='no', check_compliance='no', offset=0,
            ioserver='mysql_table', ncores=1, ndb=1, ndbms=1, nfrag=0, nhost=0, subset_dims='none', subset_filter='all', time_filter='yes'
            subset_type='index', exec_mode='sync', base_time='1900-01-01 00:00:00', calendar='standard', hierarchy='oph_base', leap_month=2,
            leap_year=0, month_lengths='31,28,31,30,31,30,31,31,30,31,30,31', run='yes', units='d', vocabulary='-', description='-', schedule=0,
            pid=None, check_grid='no', display=False) -> obj
         or Cube(pid=None) -> obj

    Attributes:
        pid: cube PID
        creation_date: creation date of the cube
        measure: name of the variable imported into the cube
        measure_type: measure data type
        level: number of operations between the original imported cube and the actual cube
        nfragments: total number of fragments
        source_file: parent of the actual cube
        hostxcube: number of hosts associated with the cube
        dbmsxhost: number of DBMS instances on each host
        dbxdbms: number of databases for each DBMS
        fragxdb: number of fragments for each database
        rowsxfrag: number of rows for each fragment
        elementsxrow: number of elements for each row
        compressed: 'yes' for a compressed cube, 'no' otherwise
        size: size of the cube
        nelements: total number of elements
        dim_info: list of dict with information on each cube dimension

    Class Attributes:
        client: instance of class Client through which it is possible to submit all requests
```



PyOphidia release



https://pypi.org/project/PyOphidia/

PyOphidia applications: Jupyter notebooks

Import PyOphidia and connect to server instance

In [ ]:
```
from PyOphidia import cube, client
cube.Cube.setclient(read_env=True)
```

Import data and extract a single time series

In [ ]:
```
mycube = cube.Cube.importnc(src_path='/public/data/tos_01_2001-2002.nc',measure='tos',imp_dim='time',ncores=5)
mycube2 = mycube.subset2(subset_dims="lat|lon",subset_filter="0:1|0:1",ncores=5)
data = mycube2.export_array()
```

Plot time series

In [ ]:
```
import matplotlib.pyplot as plt
y = data['measure'][0]['values'][0][:]
x = data['dimension'][2]['values'][:]
plt.figure(figsize=(11, 3), dpi=100)
plt.plot(x, y)

plt.ylabel(data['measure'][0]['name'] + " (degK)")
plt.xlabel("Days since 2001/01/01")
plt.title('Sea Surface Temperature (point 0.5, 1)')
plt.show()
```

Convert from Kelvin to Celsius degrees

In [ ]:
```
mycube3 = mycube2.apply(query="oph_sum_scalar('OPH_FLOAT','OPH_FLOAT',measure,-273.15)",description="celsius")
data = mycube3.export_array()
```

Plot time series

In [ ]:
```
y = data['measure'][0]['values'][0][:]
x = data['dimension'][2]['values'][:]
plt.figure(figsize=(11, 3), dpi=100)
plt.plot(x, y)

plt.ylabel(data['measure'][0]['name'] + " (degC)")
plt.xlabel("Days since 2001/01/01")
plt.title('Sea Surface Temperature (point 0.5, 1)')
plt.show()
```

Native Ophidia I/O server

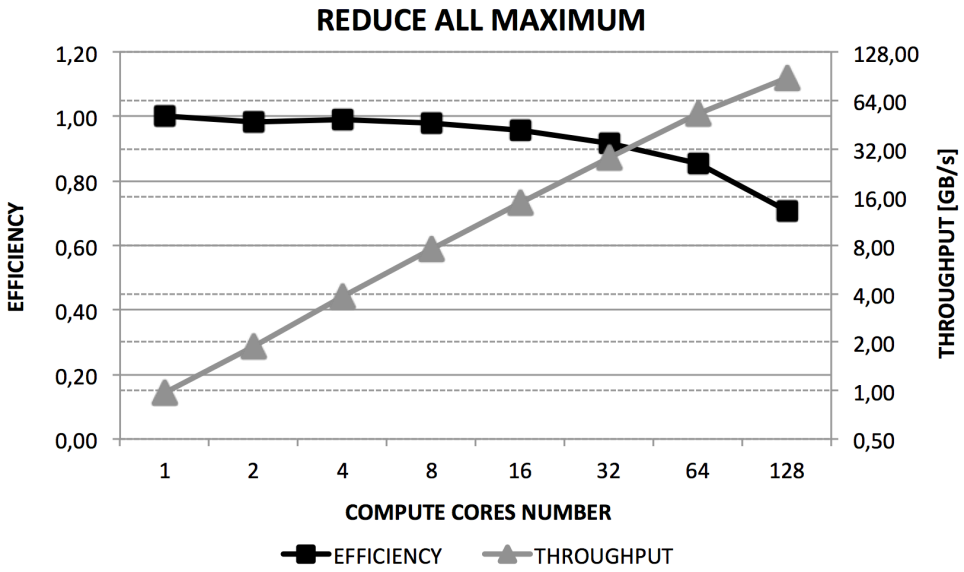
The I/O server provides a native solution for the scientific domain applications. The requirements for the Ophidia I/O server are:

- run **data analytics tasks in-memory** taking advantage of the lower latency
- **binary array-oriented engine** to efficiently process scientific multidimensional data
- interact directly with the storage layer to **exploit data locality**
- exploit **parallelism at the array-level**
- **NoSQL approach** based on key-value store providing a **declarative query language** (SQL-like)
- guarantee extensibility and interoperability of the I/O server to **support multiple storage back-ends**

Experimental results (in-memory I/O server)

Execution time is measured by scaling up the number of parallel tasks
Two metrics are evaluated:

- efficiency (speedup/computational resources)
- throughput (data processed/time unit)



CORES NUMBER	EXECUTION TIME [s]	EFFICIENCY	THROUGHPUT [GB/s]
1	388,50	1,00	0,97
2	197,51	0,98	1,90
4	97,96	0,99	3,83
8	49,52	0,98	7,57
16	25,39	0,96	14,77
32	13,22	0,92	28,36
64	7,11	0,85	52,72
128	**4,29**	0,71	87,47

3D dataset, 375GB, 2.1M time series, 24K elements each (50 Billions elements)
8 nodes, 16 cores each, 128 cores in total
Max computation over time dimension, 2D result (map)

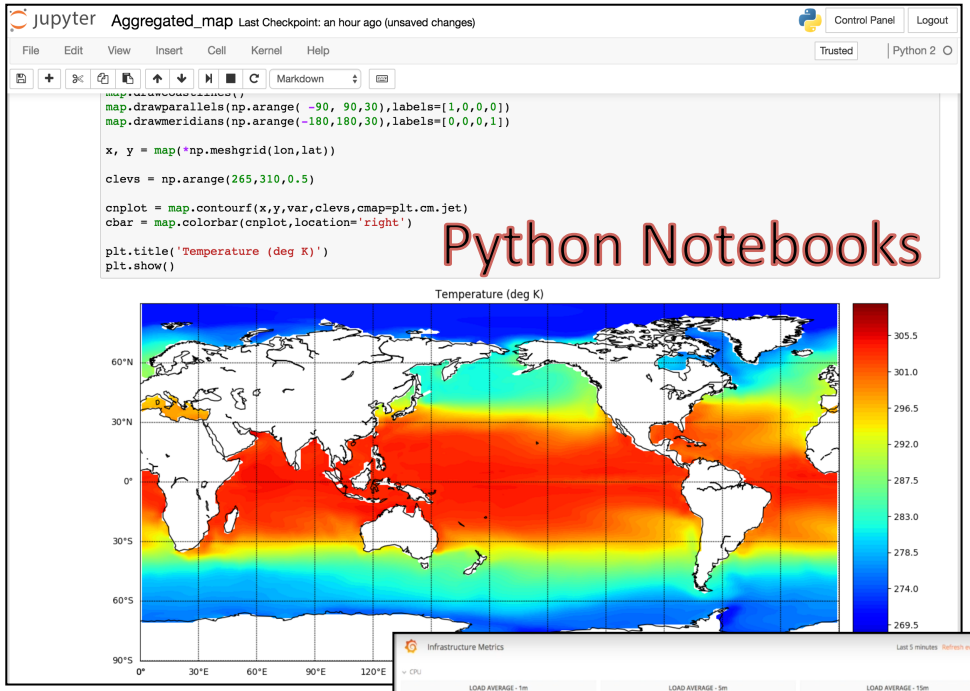
With 128 cores it is around 30x faster than MySQL I/O engine!
Full benchmark is ongoing on the Athena Cluster at CMCC SCC

ECASLab in the EOSC-hub context

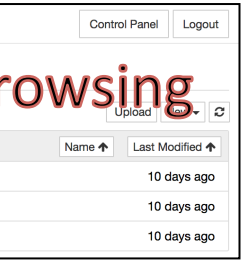
ECASLab: a user-oriented environment for data analysis and visualization

- ✔ ***ECASLab*** *is an integrated scientific environment for scientific data management*
- ✔ *It provides a ready-to-use multi-node* ***ECAS (ENES Climate Analytics Service)*** *to perform data analytics on scientific datasets*
- ✔ *Currently setup at at CMCC (Italy) and DKRZ (Germany)*
- ✔ *It integrates data,* ***analysis and visualization tools*** *in a user-friendly environment accessible with light-weight clients (i.e. a desktop bash-like client and a web GUI)*
- ✔ *It exposes a* ***JupyterHub*** *service to create, execute and share Jupyter notebooks (Python-based) supporting live-code and visualization*
- ✔ *File system navigation, file editing, upload and download supported via web*
- ✔ *Released on May 2017, with an initial set of services:*
  - ✔ *Simple quick start & registration form available*
  - ✔ *JupyterHub, OPeNDAP/THREDDS/IDV, ECAS Terminal*
  - ✔ *Monitoring system based on Grafana*
  - ✔ *Besides PyOphidia Several Python libraries available for analysis & visualization*
  - ✔ *Workflow IDE (alpha release)*

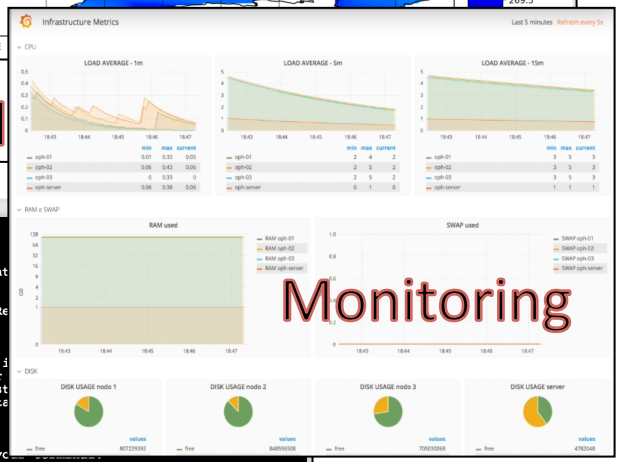
ECASLab in a nutshell



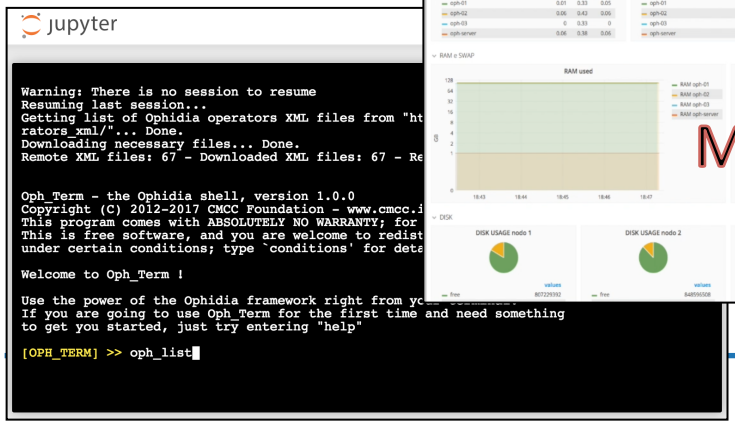
Python Notebooks



Files browsing



Monitoring



ECAS Terminal

Quick Start

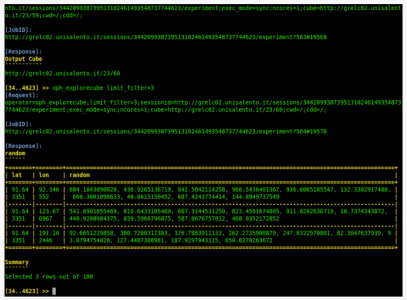
OphidiaLab provides two different ways to get access to its scientific eco-system: JupyterHub and Ophidia client.

Jupyter supports interactive data science and scientific computing.
OphidiaLab includes a JupyterHub installation and, thanks to the Jupyter Notebooks, scientists can create and share documents that contain live code, equations, visualizations and explanatory text.

The JupyterHub interface is available here*.

After you login, open "Quick Start.ipynb" notebook available under the *quickstart/* folder in your home to get started with OphidiaLab environment capabilities.

**Please note that for security reasons, the access to our JupyterHub instance is restricted to authorised users only and needs an additional step after the registration process.*



QuickStart

The Ophidia Terminal is a robust, comprehensive, and user-friendly Ophidia client, developed with characteristics similar to the bash shell present in almost all Unix-like environments.
Please have a look at the online available documentation to learn more about the basic functionalities of the Ophidia terminal as well as some advanced features useful for more skilled users.
Two short guides (basic, advanced) in pdf format are also available.
Several examples of real-world usage of the terminal are also available on the Ophidia website tutorial section.
The latest client RPM for CentOS7 is available here.
The related DEB package can be downloaded from here.

Once installed you can simply run:

/usr/local/ophidia/oph-terminal/bin/oph_term -H ophidialab.cmcc.it -u <username> -p <password> -P 11732

ECASLab: Jupyter user local folder

ECASLab: Jupyter notebooks

jupyter Time_series_extraction (read only)

Control Panel | Logout

File Edit View Insert Cell Kernel Help | Not Trusted | Python 2

Markdown

Import PyOphidia and connect to server instance

In [ ]:
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cube.Cube.setclient(read_env=True)
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Import data and extract a single time series

In [ ]:
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In [ ]:
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In [ ]:
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Plot time series

In [ ]:
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x = data['dimension'][2]['values'][:]
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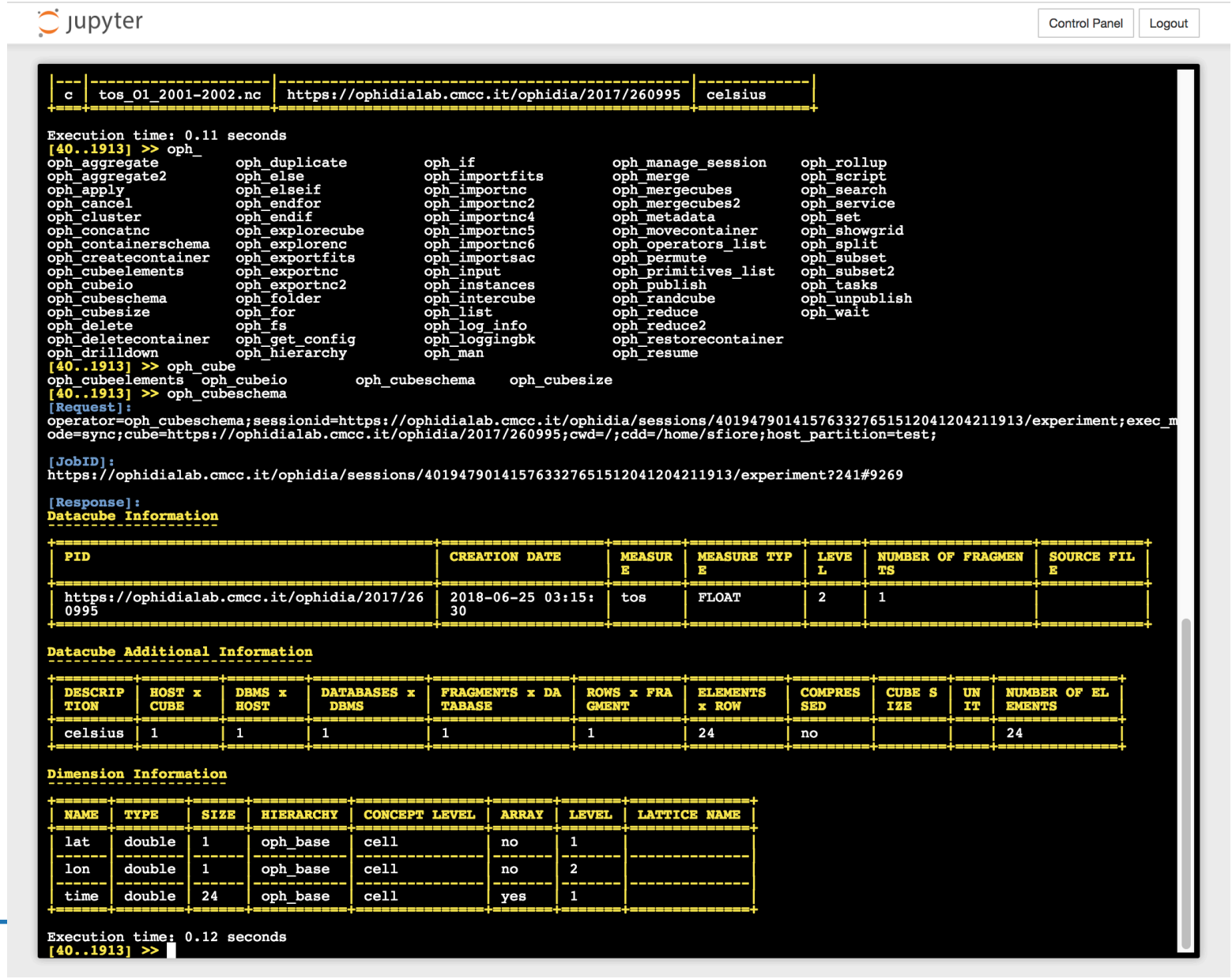
plt.plot(x, y)

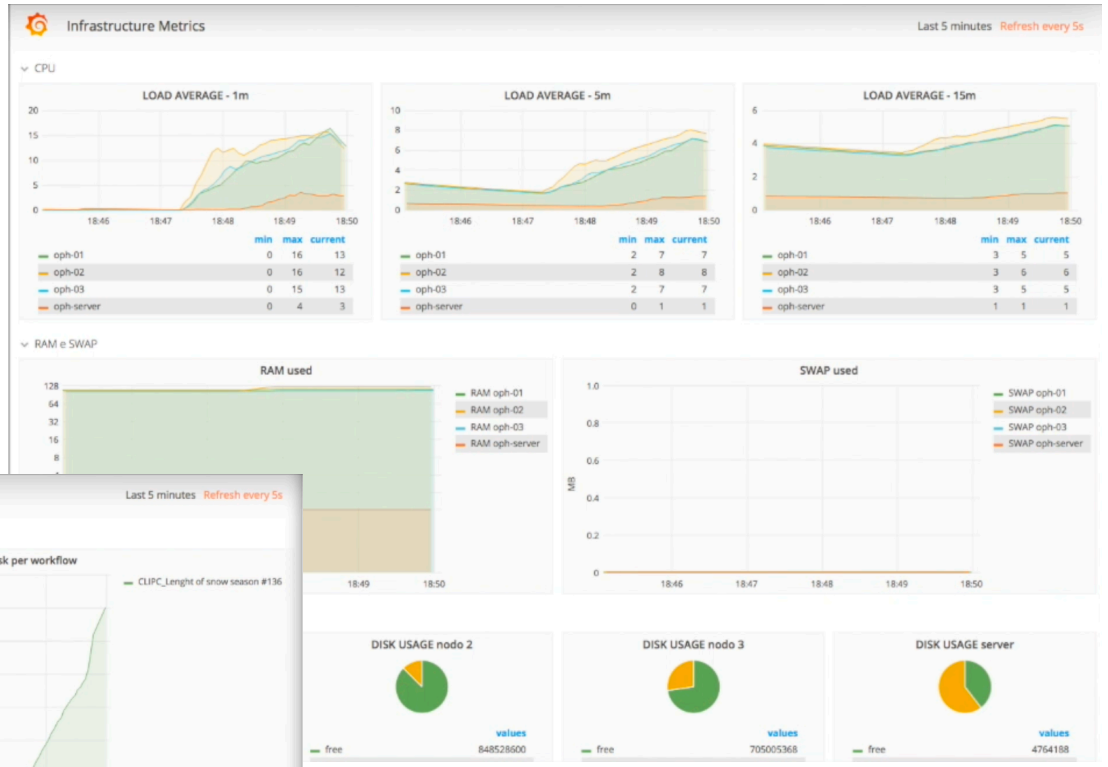
plt.ylabel(data['measure'][0]['name'] + " (degC)")
```

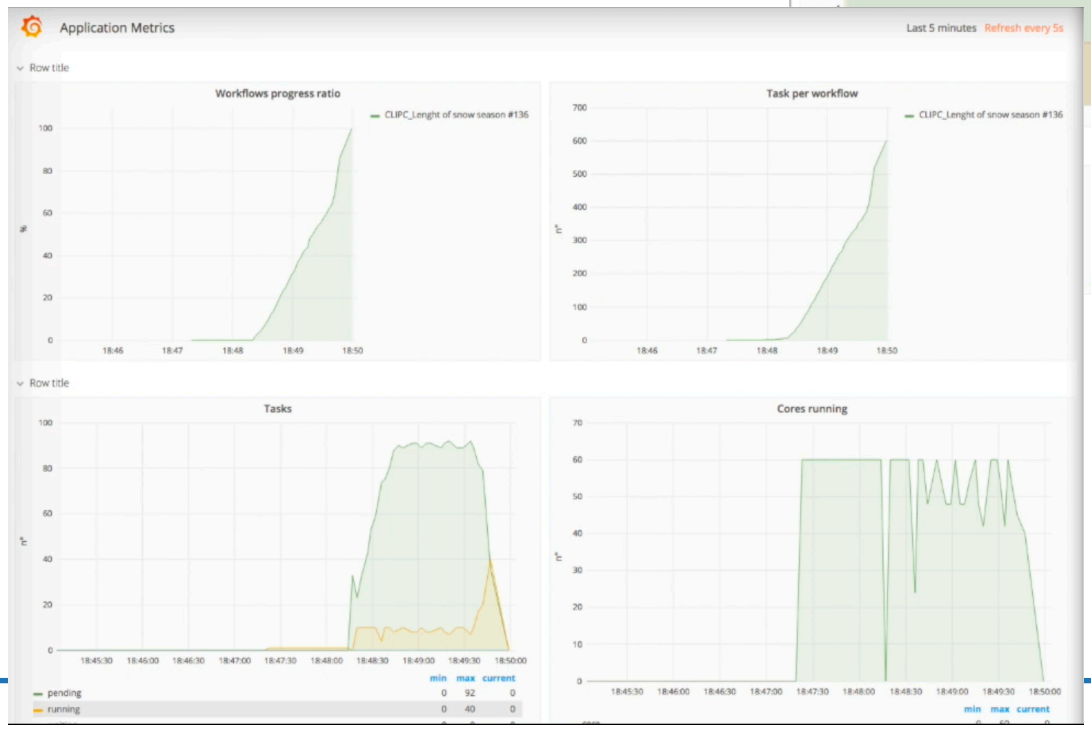
ECASLab: ECAS Terminal (from Jupyter)



ECASLab: Grafana monitoring interface

- ✓ Based on grafana
- ✓ It provides real-time monitoring of the ECAS cluster
- ✓ Used internally by admins



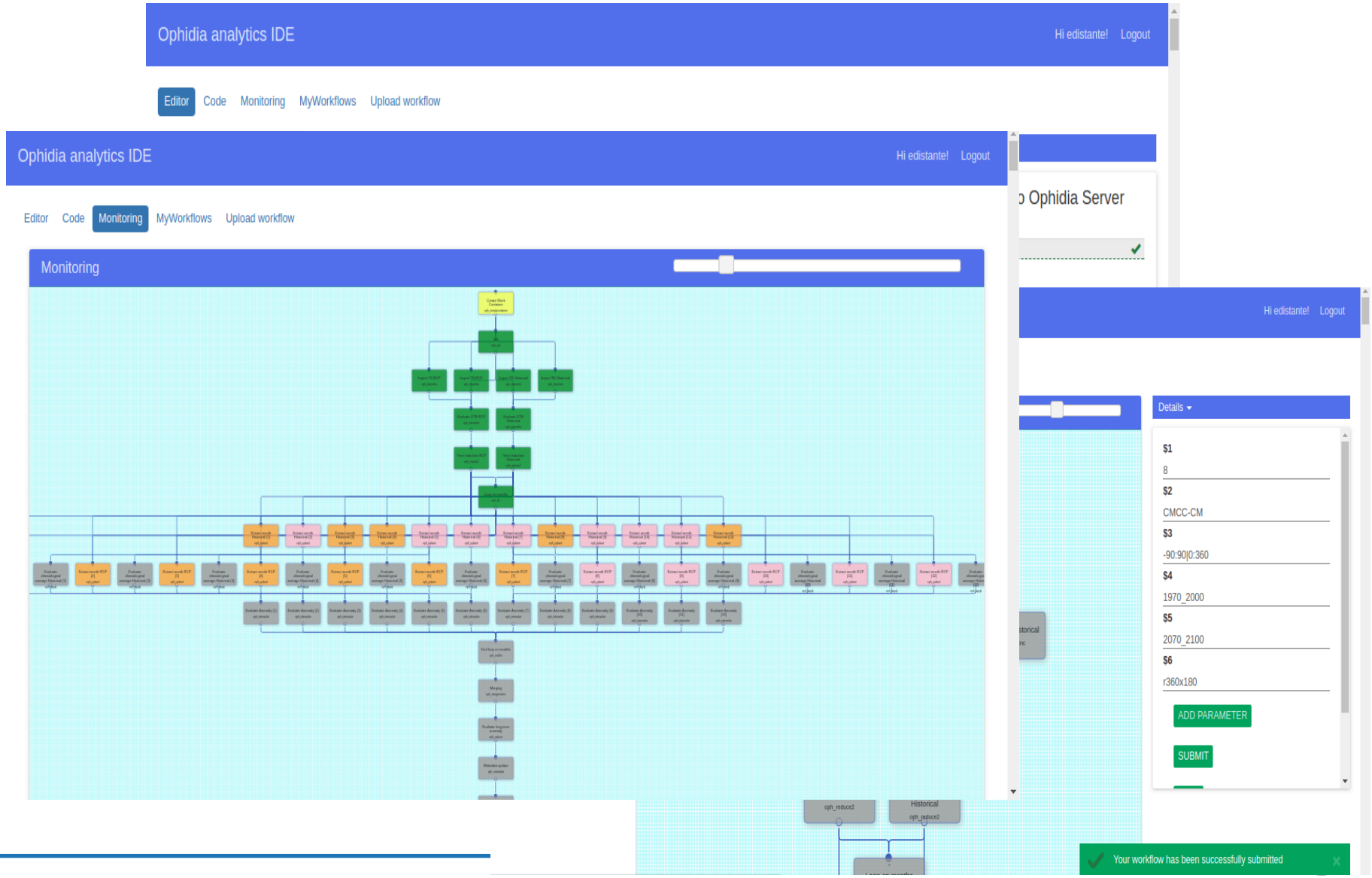


- ✓ It also supports application-level monitoring (for wf)

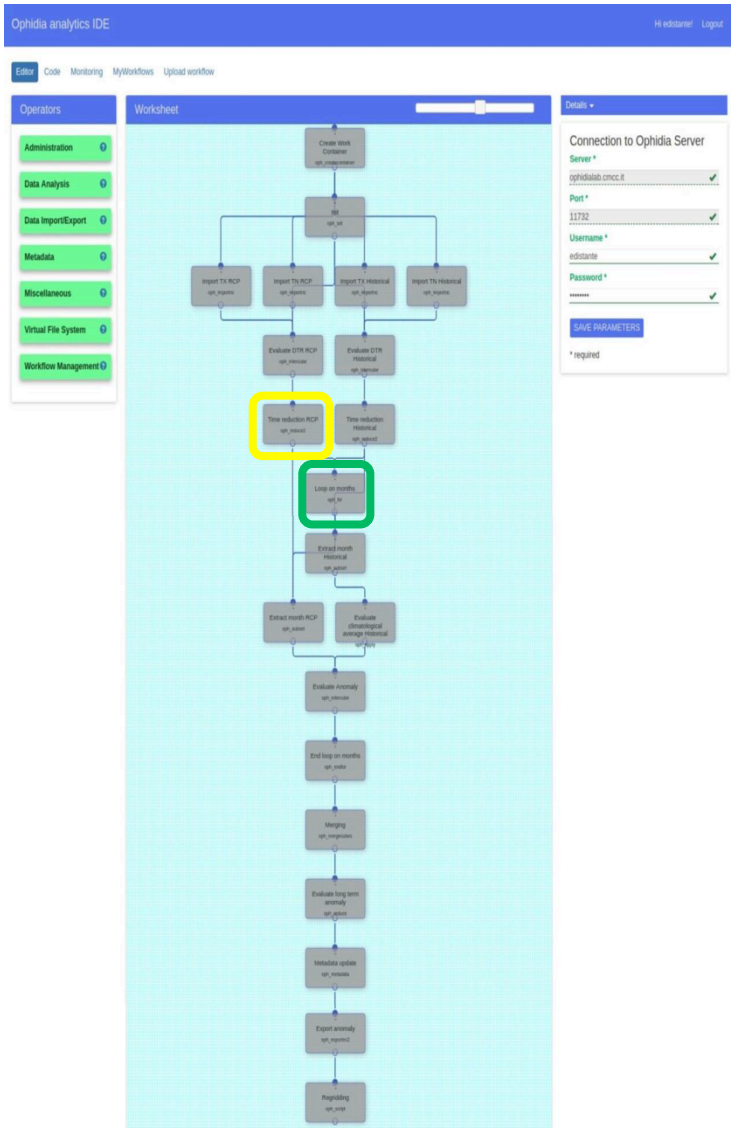
Looking forward

Workflow IDE and Server-side machine learning

ECASLab and the analytics workflow IDE



Easy and automated generation of JSON code




```
{
        "name": "dtr anomaly",
        "author": "CMCC",
        "abstract": "This workflow computes the anomaly of DTR (Diurnal Temperature Range) index with respect to past values. It works on two input files (tasmin/tasmax variable): $1 is
ncores, $2 is the model, $3 is spatial filter (lat|lon ranges), $4 is the first time filter (historical), $5 is the second time filter (scenario), $6 is the grid of output map using the
format r<lon>x<lat> (e.g. r360x180), i.e. a global regular lon/lat grid (this parameter is optional and by default the lon/lat grid of input file is adopted).",
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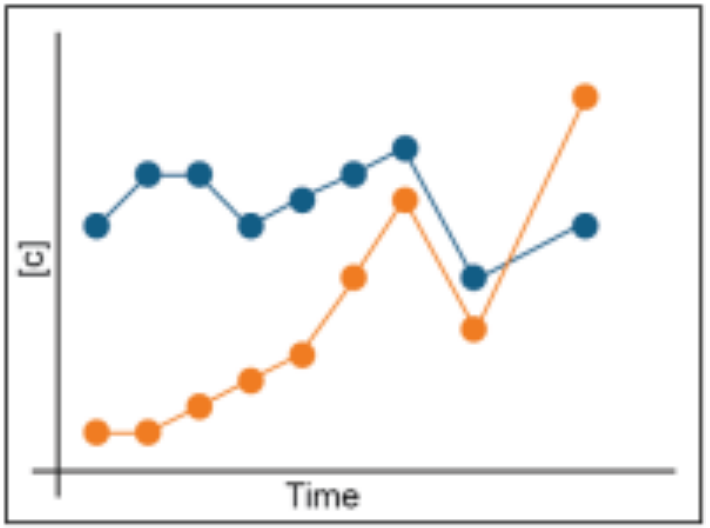
```

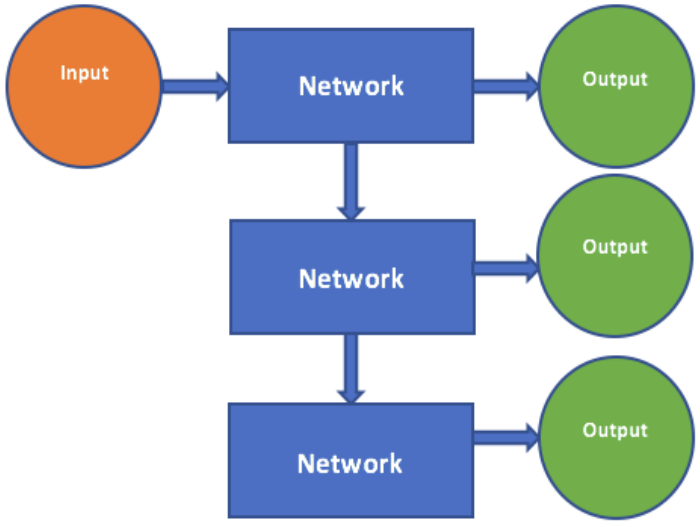
OPH_REDUCE2

OPH_FOR

Long Short-Term Memory Network for Time Series Prediction

- We modeled the time series as a supervised learning problem, that is, as a sequence of inputs and outputs.
- At each stage, the network receives as input the *n* values in the past from a time *t*. The output is *h* nodes representing the values in the future.
- The goal of the network is to learn the mapping from the input to the output.
- Hopefully, the LSTM is able to capture some kind of temporal dependence in order to get better predictions.





Ophidia Primitives For LSTM: Training

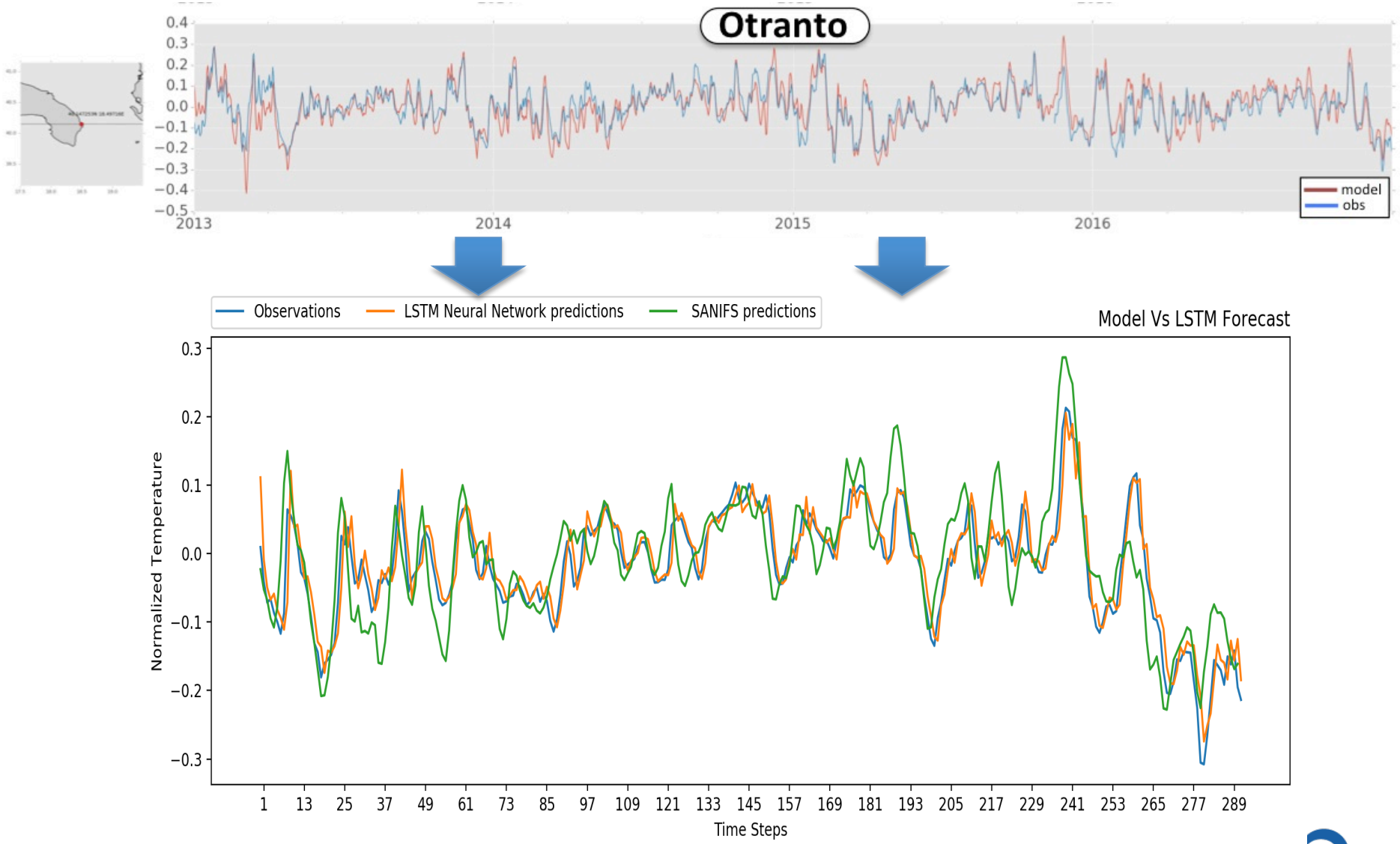
- The algorithm has been divided in two phases: one for training and one for test/prediction.
- The primitive for the **training** task:

```
oph_lstm(input_OPH_TYPE, output_OPH_TYPE, measure,
dim_in, dim_out, n_h_layers, n_h_neurons, [dropout],
[learning_rate], [unrolled_len], [minibatch_size],
[max_epoch])
```

- It can be run in a SQL statement or in the OPH_APPLY operator.
- After the training phase, the resulting neural network with updated parameters is saved as a binary array in a datacube. It can then be reused in the test phase.
- The primitive for the **test/prediction**:

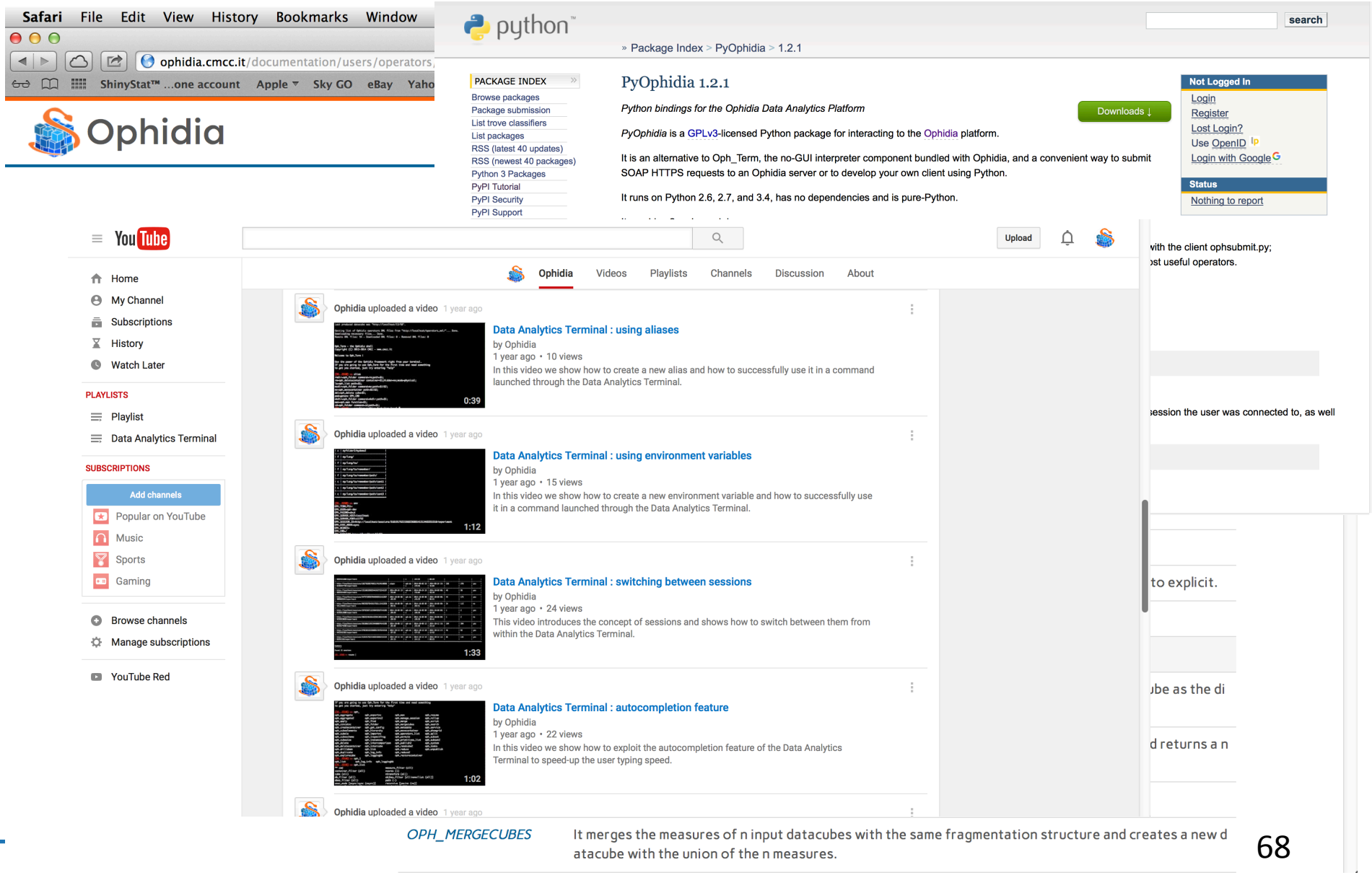
```
oph_lstm_predict(input_OPH_TYPE, output_OPH_TYPE,
measure_a, measure_b, test)
```

LSTM for the SANIFS Use Case



Useful resources and final remarks

Ophidia documentation and social/multimedia content



Useful Resources

- *Website: https://ophidia.cmcc.it*
- *Doc : http://ophidia.cmcc.it/documentation*
- *The Ophidia code is available on GitHub under GPLv3 license at https://github.com/OphidiaBigData*
- *RPMs are also available for CentOS6 at the following repo: http://download.ophidia.cmcc.it/rpm*
- *Youtube Channel https://www.youtube.com/user/OphidiaBigData/*
- *A Virtual Machine Image (OVA format) is also available at https://download.ophidia.cmcc.it/vmi_desktop/ to get started in a few minutes with Ophidia*

Publications

[11] S. Fiore, C. Palazzo, A. D'Anca, D. Elia, E. Londero, C. Knapic, S. Monna, N. M. Marcucci, F. Aguilar, M. Płóciennik, J. E. M. De Lucas, G. Aloisio, "Big Data Analytics on Large-Scale Scientific Datasets in the INDIGO-DataCloud Project". In Proceedings of the ACM International Conference on Computing Frontiers (CF '17), May 15-17, 2017, Siena, Italy, pp. 343-348

[10] A. D'Anca, C. Palazzo, D. Elia, S. Fiore, I. Bistinas, K. Böttcher, V. Bennett, G. Aloisio, "On the Use of In-memory Analytics Workflows to Compute eScience Indicators from Large Climate Datasets," 2017 17th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGRID), Madrid, May 14-17, 2017, pp. 1035-1043.

[9] S. Fiore, M. Plóciennik, C. M. Doutriaux, C. Palazzo, J. Boutte, T. Zok, D. Elia, M. Owsiak, A. D'Anca, Z. Shaheen, R. Bruno, M. Fargetta, M. Caballer, G. Moltó, I. Blanquer, R. Barbera, M. David, G. Donvito, D. N. Williams, V. Anantharaj, D. Salomoni, G. Aloisio, "Distributed and cloud-based multi-model analytics experiments on large volumes of climate change data in the earth system grid federation eco-system". In Big Data (Big Data), 2016 IEEE International Conference on. IEEE, 2016. p. 2911-2918.

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[7] D. Elia, S. Fiore, A. D'Anca, C. Palazzo, I. Foster, D. N. Williams, G. Aloisio, "An in-memory based framework for scientific data analytics". In Proceedings of the ACM International Conference on Computing Frontiers (CF '16), May 16-19, 2016, Como, Italy, pp. 424-429

[6] C. Palazzo, A. Mariello, S. Fiore, A. D'Anca, D. Elia, D. N. Williams, G. Aloisio, "A Workflow-Enabled Big Data Analytics Software Stack for eScience", The Second International Symposium on Big Data Principles, Architectures & Applications (BDAA 2015), HPCS 2015, Amsterdam, The Netherlands, July 20-24, 2015, pp. 545-552

[5] S. Fiore, M. Mancini, D. Elia, P. Nassisi, F. V. Brasileiro, I. Blanquer, I. A. A. Rufino, A.C. Seijmonsbergen, C. O. Galvao, V. P. Canhos, A. Mariello, C. Palazzo, A. Nuzzo, A. D'Anca, G. Aloisio, "Big data analytics for climate change and biodiversity in the EUBrazilCC federated cloud infrastructure", Workshop on Analytics Platforms for the Cloud, In Proceedings of the 12th ACM International Conference on Computing Frontiers (CF '15), May 18th, 2015, Ischia, Italy. Article 52, 8 pages.

[4] S. Fiore, A. D'Anca, D. Elia, C. Palazzo, I. Foster, D. Williams, G. Aloisio, "Ophidia: A Full Software Stack for Scientific Data Analytics", proc. of the 2014 International Conference on High Performance Computing & Simulation (HPCS 2014), July 21 – 25, 2014, Bologna, Italy, pp. 343-350, ISBN: 978-1-4799-5311-0

[3] S. Fiore, C. Palazzo, A. D'Anca, I. T. Foster, D. N. Williams, G. Aloisio, "A big data analytics framework for scientific data management", IEEE BigData Conference 2013: 1-8

[2] S. Fiore, A. D'Anca, C. Palazzo, I. T. Foster, D. N. Williams, G. Aloisio, "Ophidia: Toward Big Data Analytics for eScience", ICCS 2013, June 5-7, 2013 Barcelona, Spain, ICCS, volume 18 of Procedia Computer Science, page 2376-2385. Elsevier, 2013

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Conclusions

- ✔ ***ECAS*** *represents the community evolution of Ophidia and is a key thematic service in the context of the* ***EOSC-hub***
- ✔ ***OLAP approach*** *for big data – multidimensional data model*
- ✔ *Multiple use cases for data analysis in* ***different domains*** *have been implemented*
- ✔ *It provides access via* ***CLI*** *(end-users) and* ***API*** *(devel users)*
- ✔ *Programmatic access via* ***C*** *and* ***Python APIs***
- ✔ *Several deployment scenarios tested in* ***cloud*** *and* ***HPC*** *environments*
- ✔ *Strong* ***workflow support*** *and* ***in-memory analytics***
- ✔ ***Programmable interface to develop machine learning algorithms***
  - ✔ ***Preliminary results on this topic are promising***

Do you want to join?

*That's an **open source** project aiming at becoming a **community effort***

Feel free to get in touch with us

sandro.fiore@cmcc.it

Thanks

http://ophidia.cmcc.it

@OphidiaBigData

www.youtube.com/user/OphidiaBigData