On the Convergence of HPC, Cloud and Data Analytics for Exascale Weather Forecasting

ECMWF Present and Future

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19th ECMWF Workshop on HPC in Meteorology

ECMWF

ECMWF's Forecasting Systems

Established in 1975, Intergovernmental Organisation

- 22 Member States | 12 Cooperation States
- 350+ staff

24/7 operational service

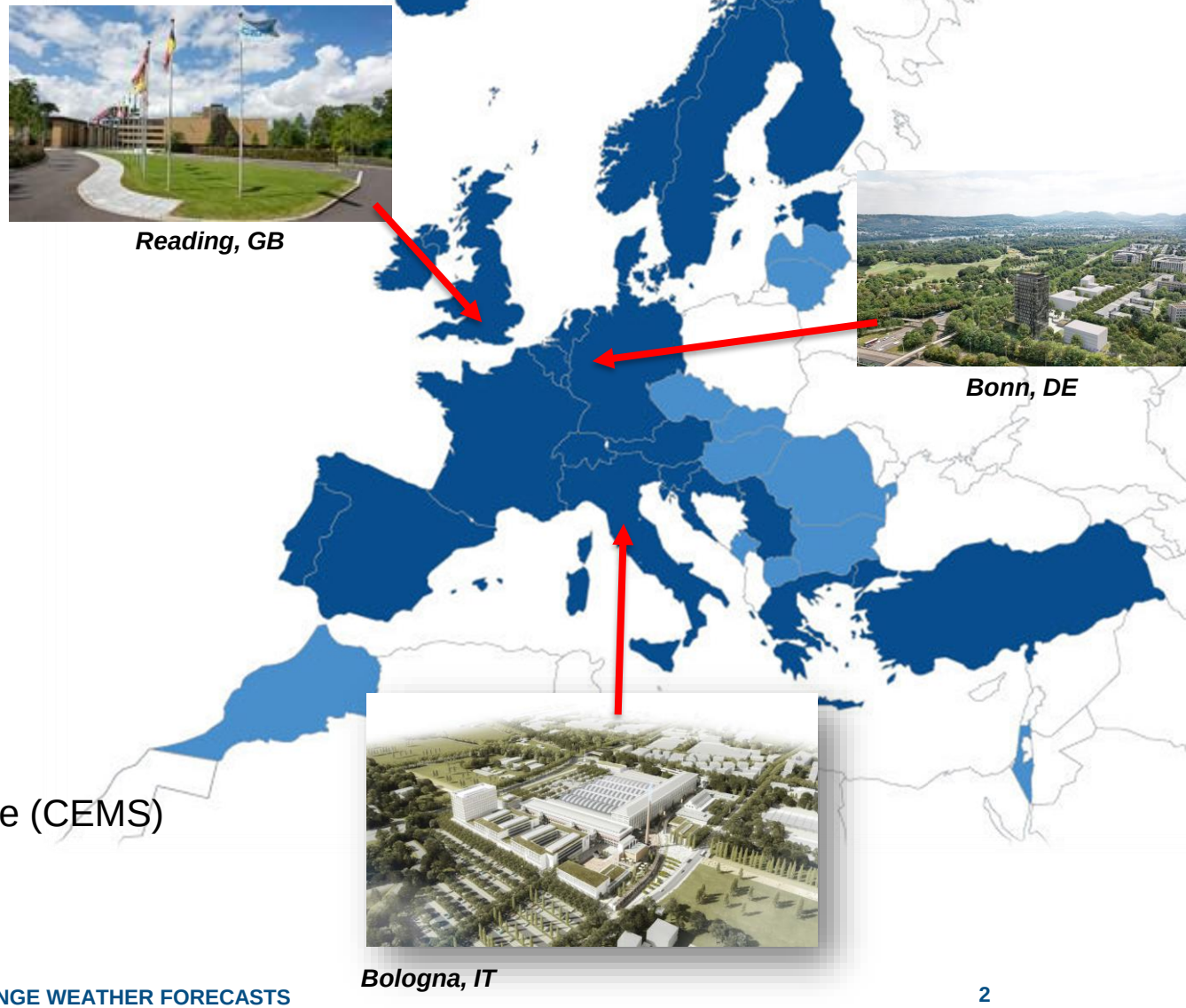
- Operational NWP – 4x HRES+ENS forecasts / day
- Supporting NWS (coupled models) and businesses

Research institution

- Experiments to continuously improve our models
- Reforecasts and Climate Reanalysis

Operate 2 EU Copernicus Services

- Climate Change Service (C3S)
- Atmosphere Monitoring Service (CAMS)
- Support Copernicus Emergency Management Service (CEMS)

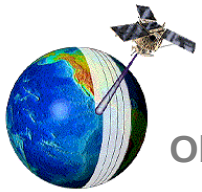


Reading, GB

Bonn, DE

Bologna, IT

ECMWF's Production Workflow



Global Observations

200M obs/day

120TiB/day

45TiB/day

~350 world destinations

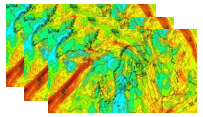
Acquisition → Earth System Model → Product Generation → Product Dissemination → Member States & Customers

Obs

Fields

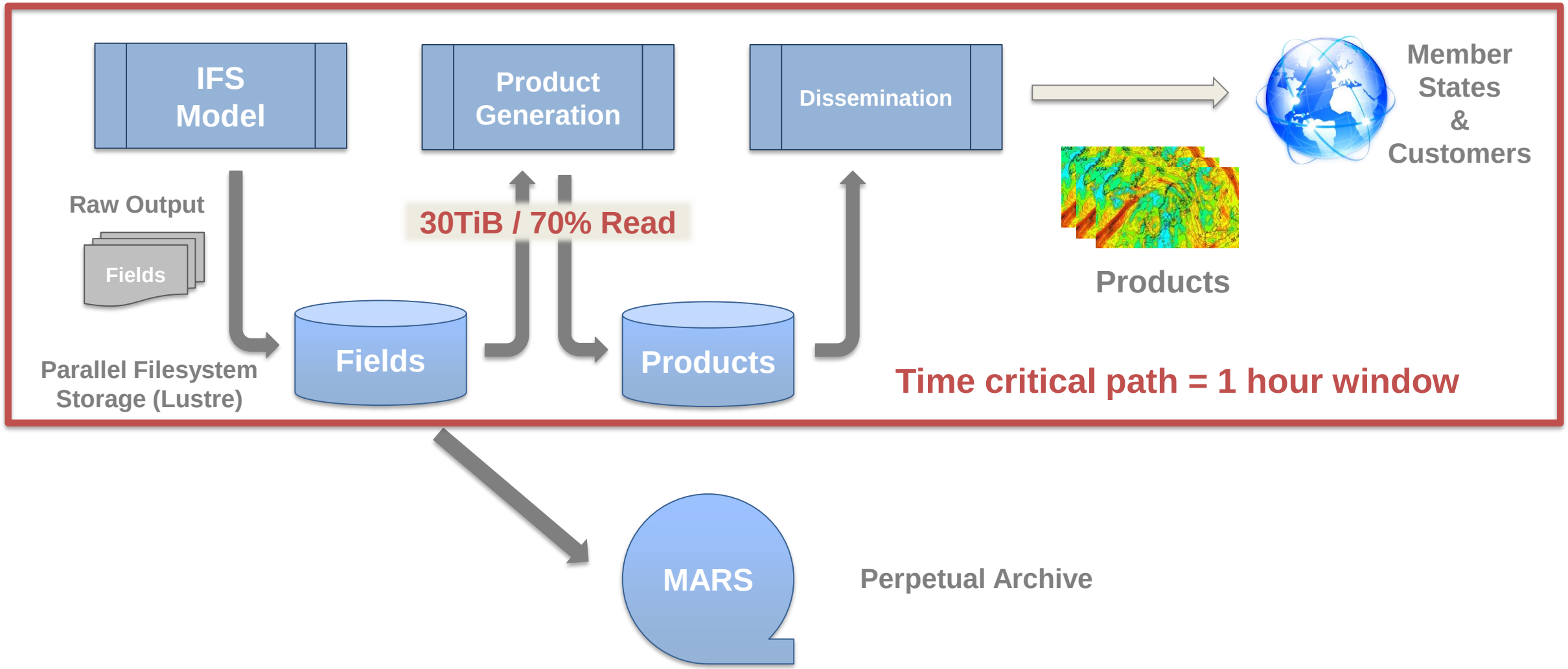
Archive

Perpetual Archive



Products

ECMWF's Production Workflow - Challenges



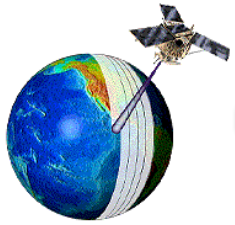
Effects of Product Generation using Parallel Filesystem

	IFS Model (No I/O)	IFS Model + I/O	IFS Model + I/O + PGen
Nodes	2440	2776	2926
Run time [s]	5765	6749	7260
Relative	-	**+ 17%**	**+ 26%**

Runtimes affected by the existence of another parallel job in the system:
Product Generation reading the data the model is writing
“Coupling” via the file system!

9Km 50 member ensemble
Broadwell nodes 2x18 cores
Cray XC40 Aries interconnect
Lustre FS IOR 90GiB/s

Storage View of Workflow



Observations

Acquisition

Product Dissemination

Member States & Customers

Acquire

Disseminate

Produce

Earth Sys Model

Storage Parallel FS

Archive

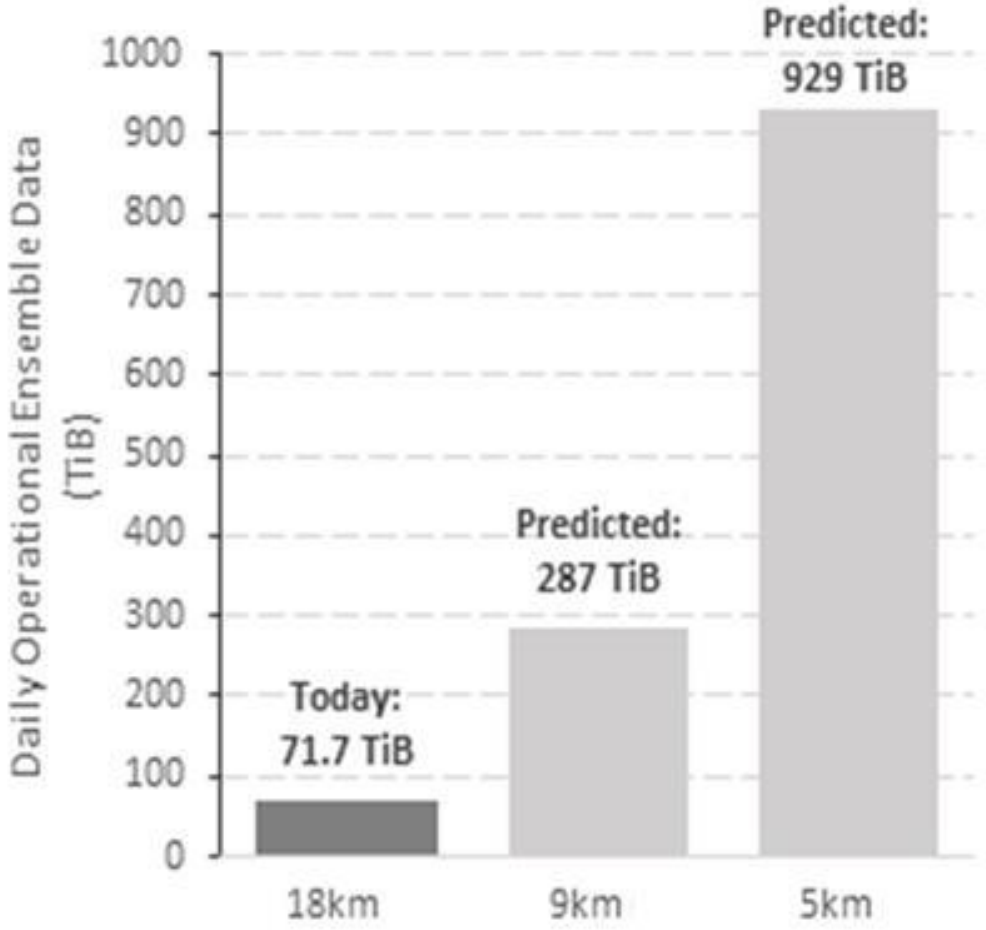
Modify

Product Generation

Perpetual Archive

Data is Central!

Data Growth – History and Projections



Model Output Projected Growth
40% compound yearly

Historical Growth of Disseminated Products

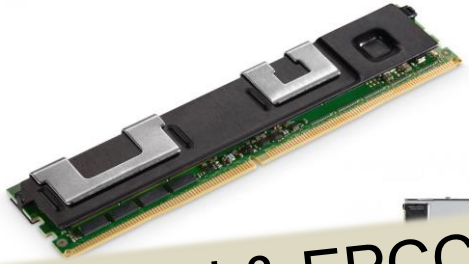
How large is a 1.25 km ensemble forecast?

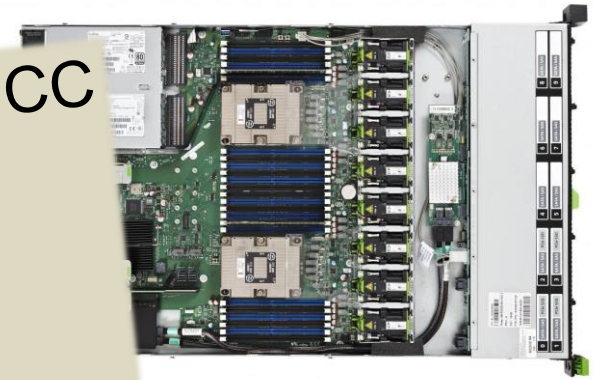
- **50-member ensemble forecast**
- ***Compressed* GRIB2 data @ 16bit & 24bit**
- **@ 9km O1280** **25 TiB**
- **Resolution @ 5km O1280 → O1999** **x 4**
- **Upgrade levels 137 → 200** **x 1.5**
- **Resolution @ 2.5km O1999 → O3999** **x 4**
- **Resolution @ 1.25km O3999 → O7999** **x 4**

25 TiB x 96 = 2400 TiB

FDB – Domain Specific Object Store

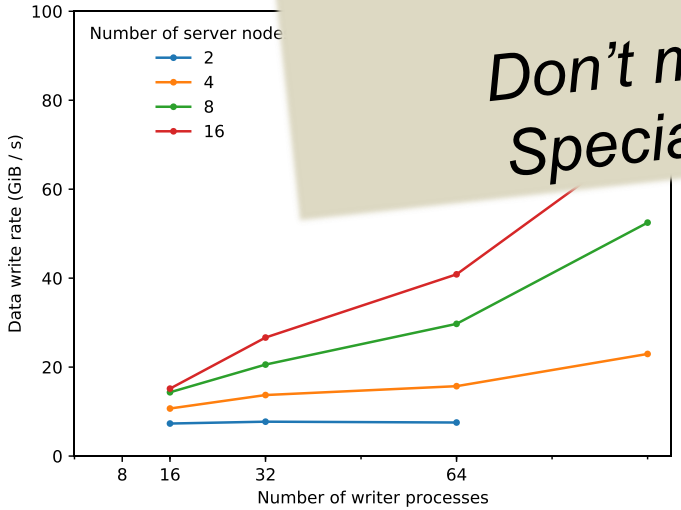
- **Domain specific (NWP) Distributed object store**
- Transactional, No synchronization
- Semantic / Scientific access to data
- Key-value store
- Support f

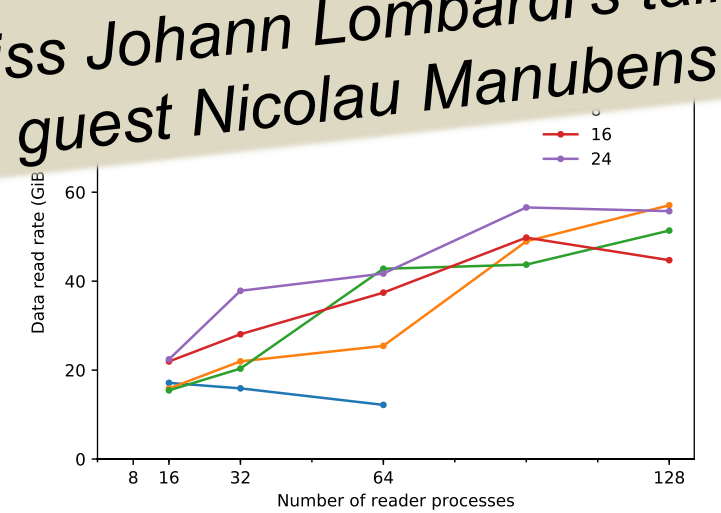




Currently developing an **FDB backend** with Intel & EPCC based on **DAOS & Optane**

Don't miss Johann Lombardi's talk on Friday
Special guest Nicolau Manubens (ECMWF)





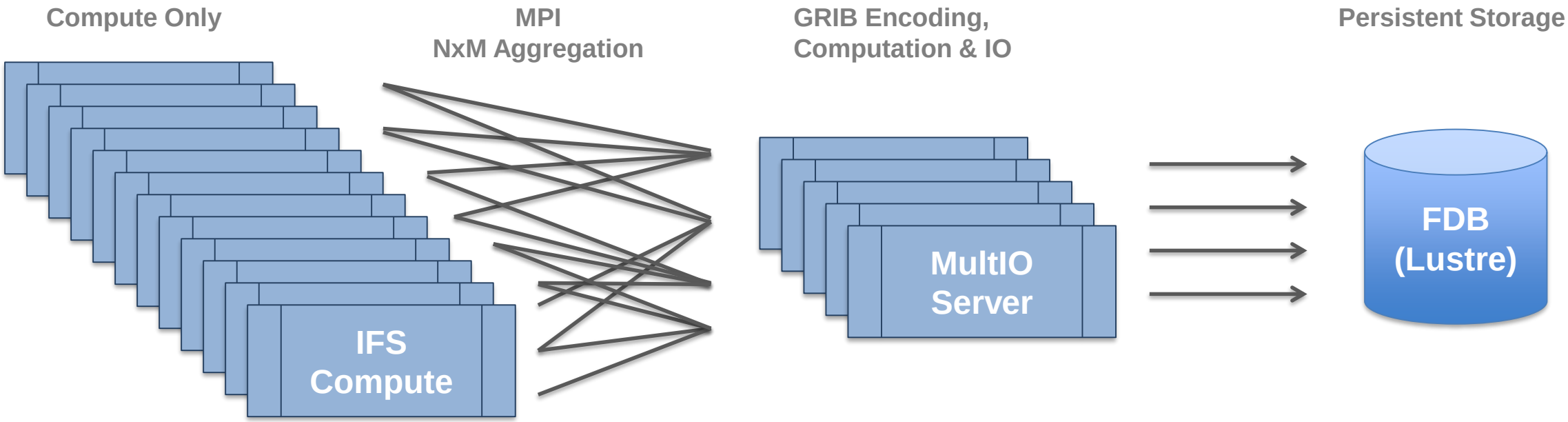
24 Nodes

- **3TiB NVMe DIMMs / Node**
- **Application data measured**
- **Full consistency semantics**

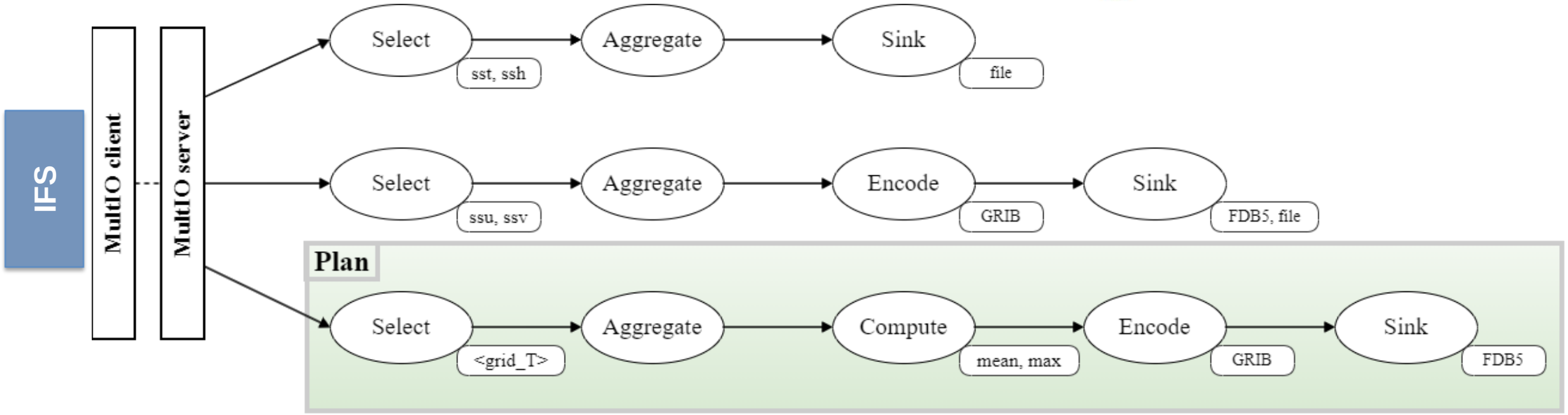
A High-Performance Distributed Object-Store for Exascale Numerical Weather Prediction and Climate
https://doi.org/10.1145/3324989.3325726

MultIO Server

- Currently under development
- Completed adaptation of NEMO v4 model

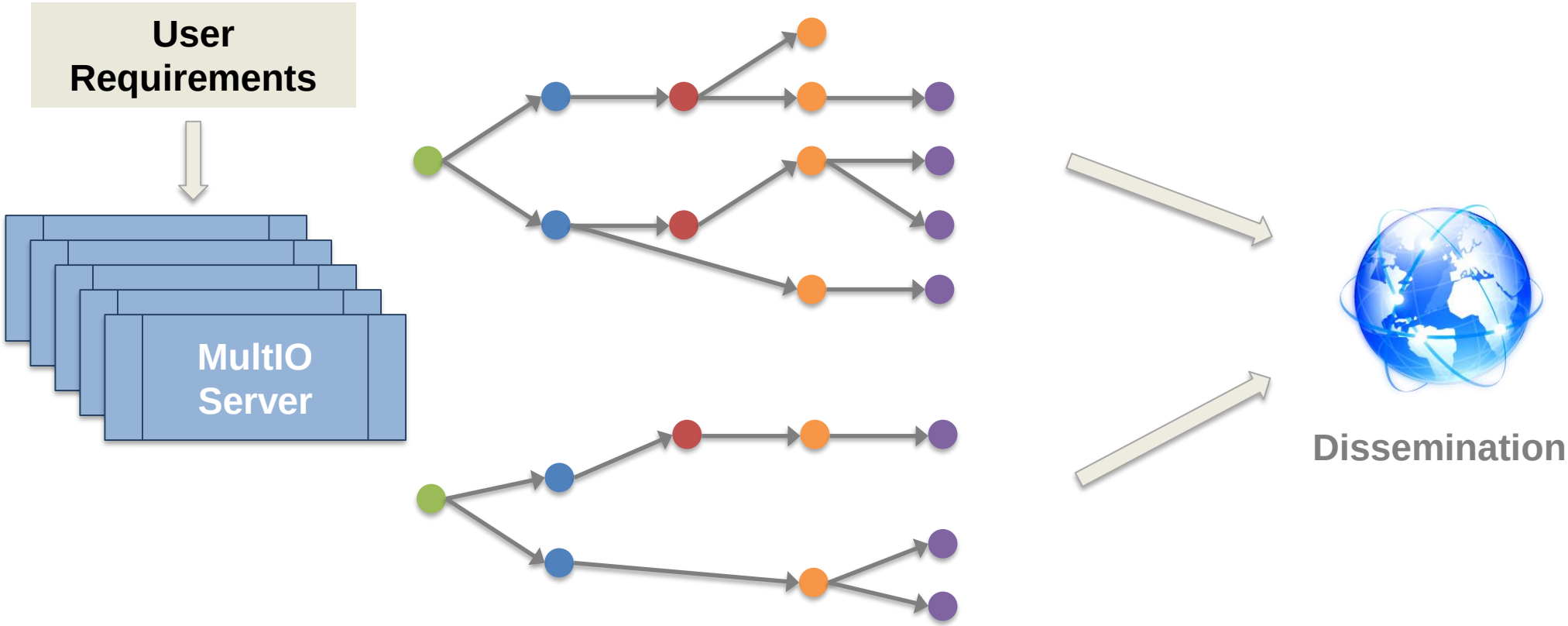


The MultIO Programmable Pipeline



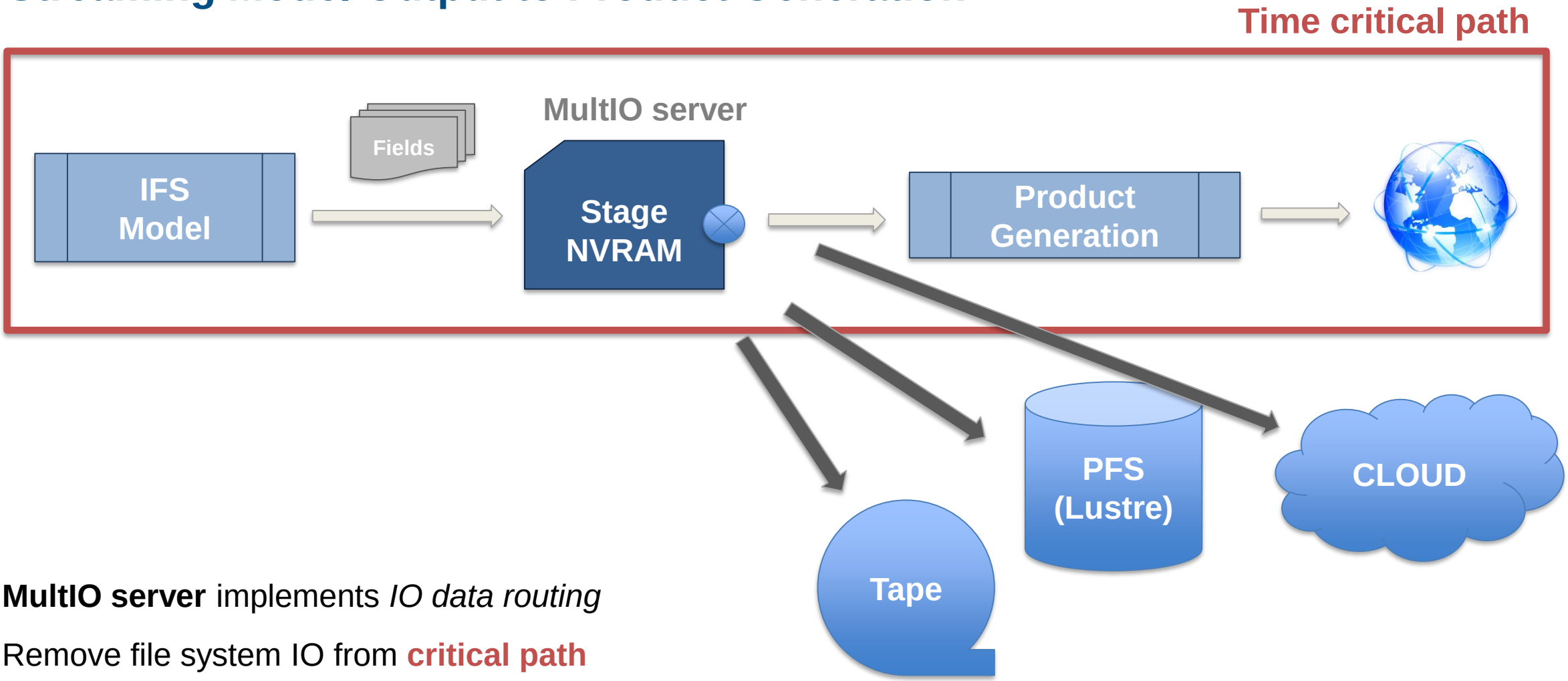
- A generic I/O-server, user-programmable pipeline of actions
- Messages that contain **Fields** are passed to the **Plans**
- Messages are ***routed*** along multiple pipelines
- Easily extendable to new domains & grids & models

On-the-Fly (or In-Place) Product Generation



All this in-memory, where the data is located

Streaming Model Output to Product Generation



MultIO server implements *IO data routing*

Remove file system IO from **critical path**

Product Generation **inside MultIO** with in-situ post-processing

Impacts of NVRAM on Data Access

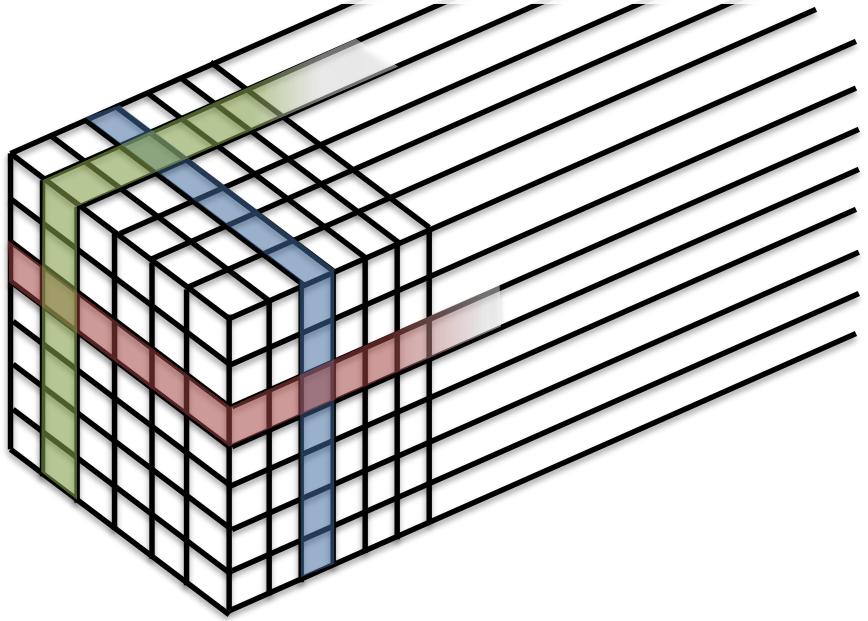
Byte Addressable Hypercubes (6D)

- Longitude (3600)
- Latitude (1800)
- Variables (~1000)
  - Atmospheric levels (~ 8 x 100)
  - Physical parameters (~200)
- Time steps (~100)
- Probabilistic perturbations (50)

@ double precision

- 16km **80 TiB**
- 9km **235 TiB**
- 5km **690 TiB**

Clients want to do **different** analytics across **multiple** axis



ECMWF Novel Data-Centric Workflows

Data Analytics / Machine Learning

Producer

Cloud

Consumer

- Bring **users** to the data
- Use data while it is **hot**
- Access using **scientifically meaningful metadata**

FDB
Data Hypercubes

PFS

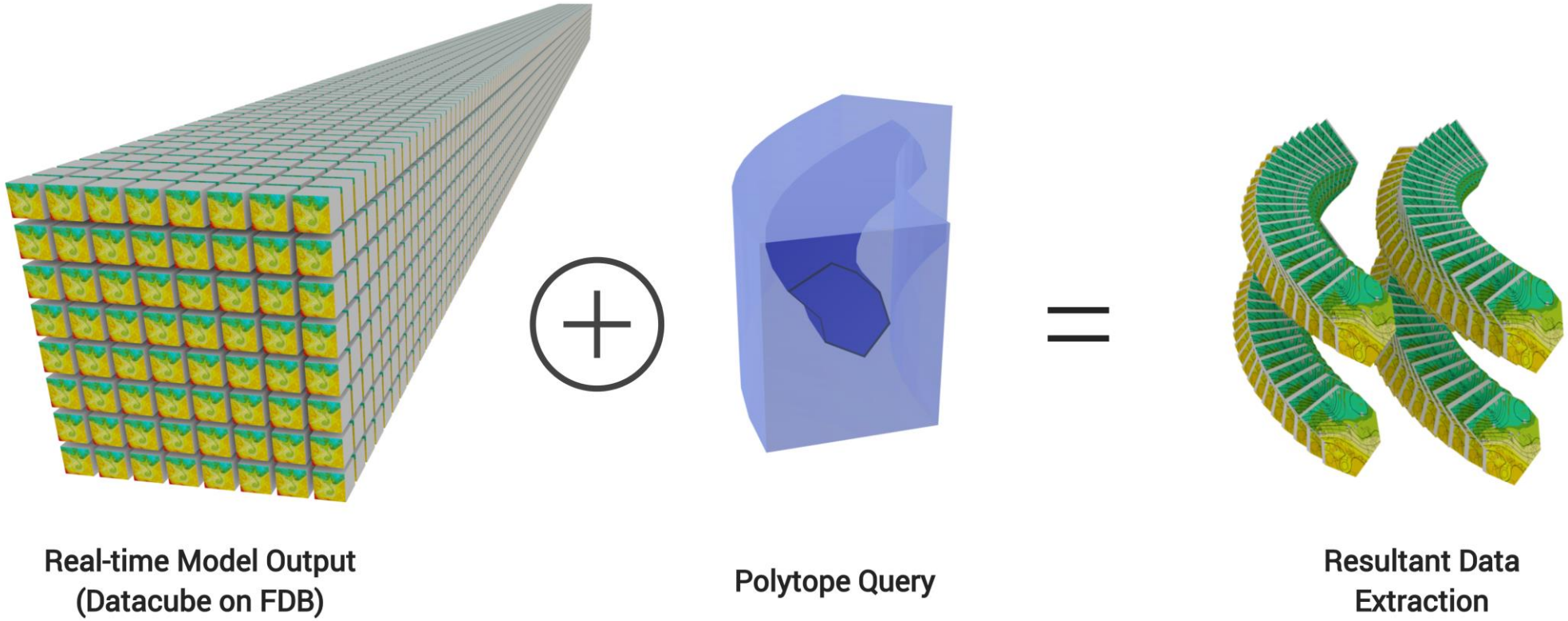
Archive

HDD

Tape

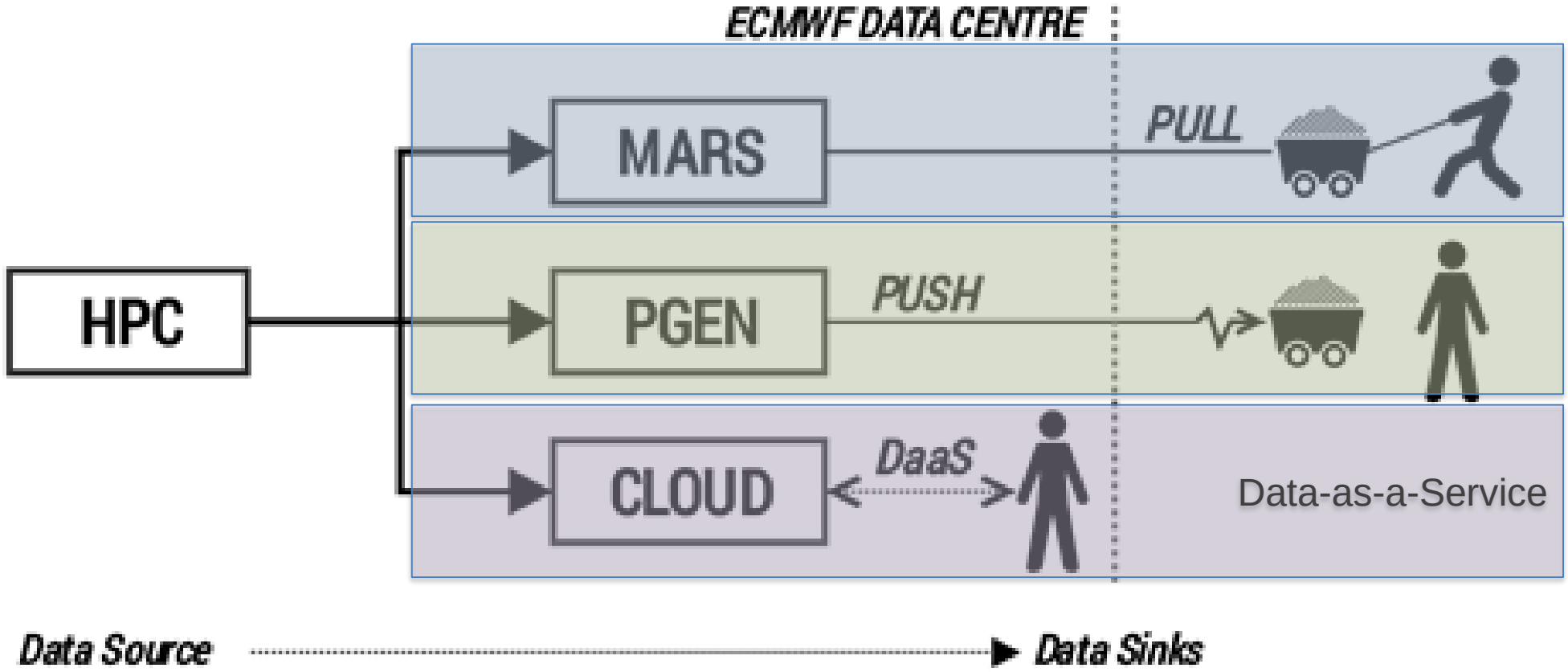
MARS

Datacube Access at Scale (~1 PiB)



Polytope (under development): http://polytope.ecmwf.int/openapi

Novel Data Flows – Multiple Pathways to Serve Data



Messages To Take Home

Ensemble data sets are growing quadratically to cubically in size. A challenge for time critical applications

Storage Class Memories *will change the way we use and analyze data*

ECMWF is adapting to ***data centric workflows*** *for Exascale weather forecasting, exploring* ***in-situ data analysis***

ECMWF is refactoring software stack end-to-end to enable Exascale datasets in Weather Forecasting

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