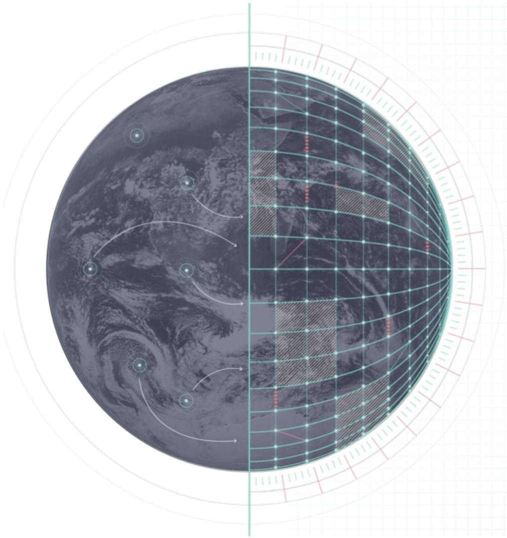
MultIO: A framework for message-driven data routing in high-resolution weather and climate modelling

20th ECMWF Workshop on HPC in Meteorology



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ECMWF’s Forecasting System

Established in 1975, Intergovernmental Organisation

- 23 Member States | 12 Cooperating States
- 450+ 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)

Destination Earth

- Operates the DestinE Digital Twin Engine (DTE)
- Operates two Digital Twins

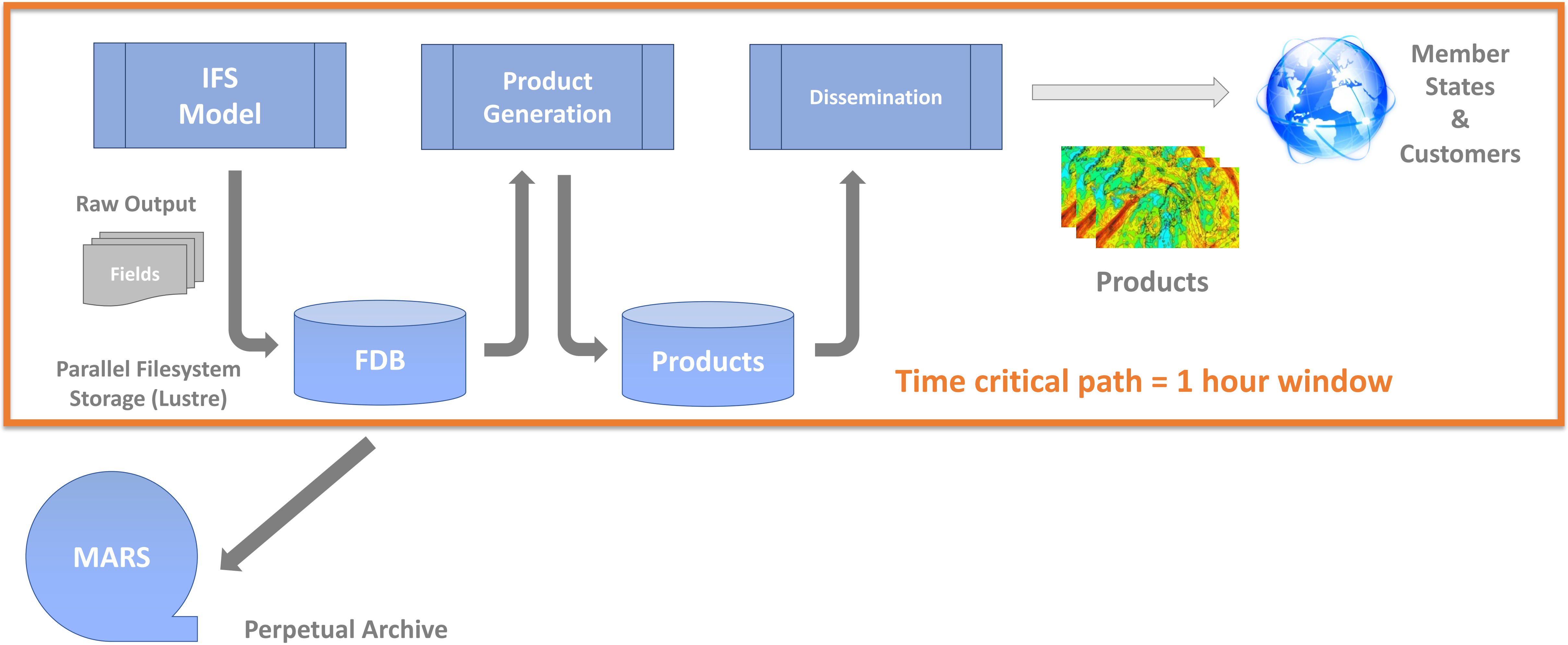
Reading
Bonn
Bologna

Reading, GB

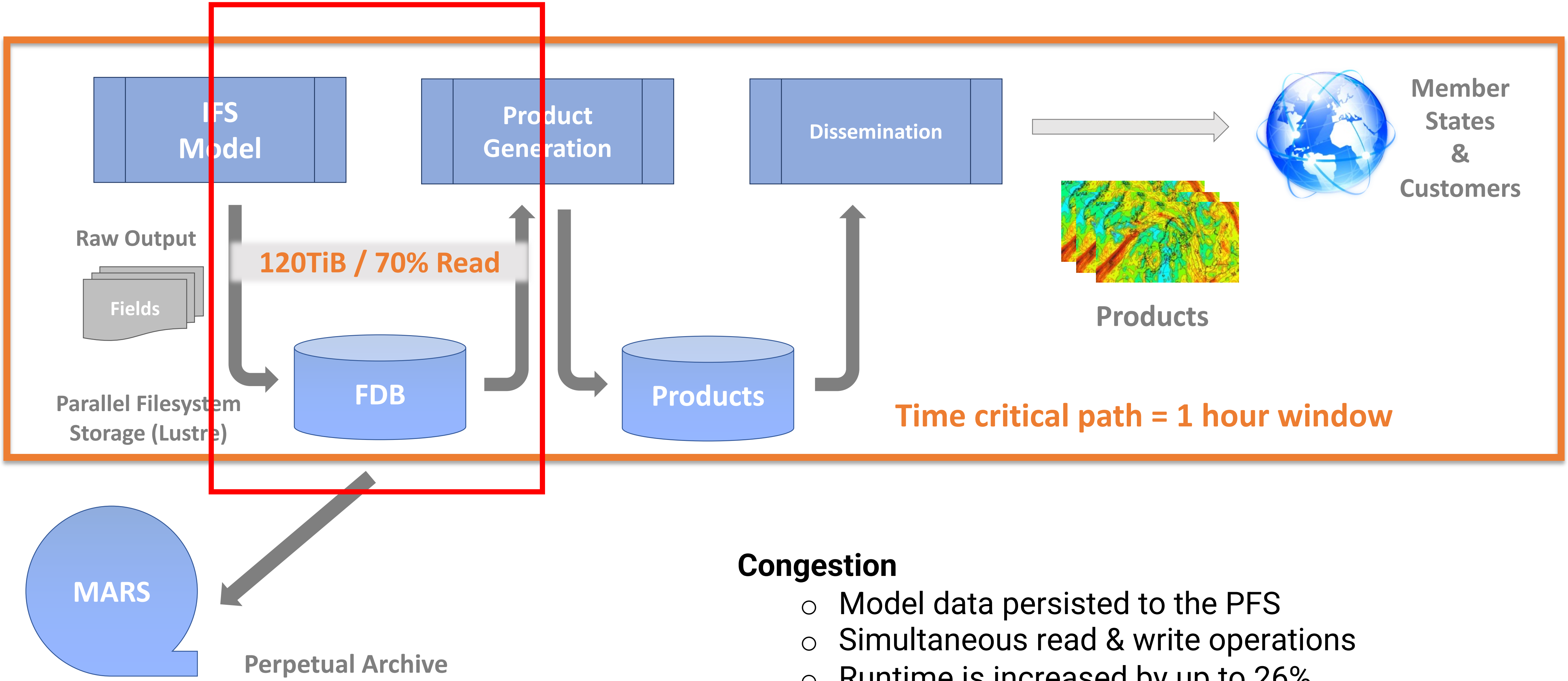
Bonn, DE

Bologna, IT

Use case 1 – ECMWF's production workflow



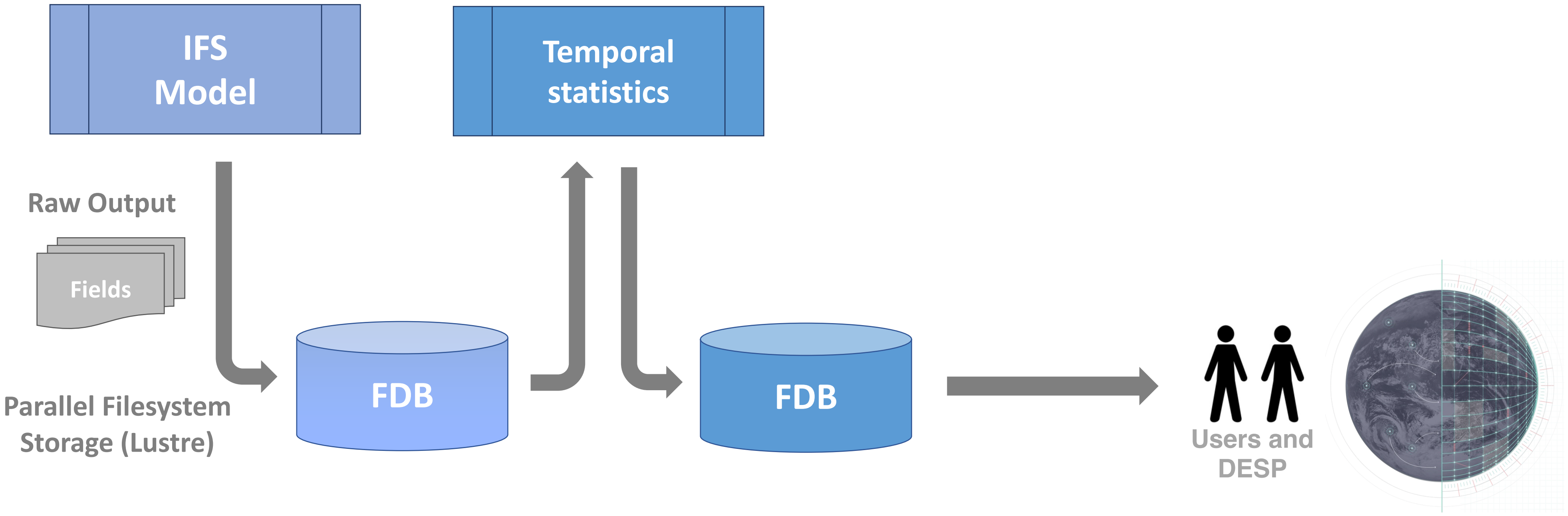
Use case 1 – ECMWF’s production workflow



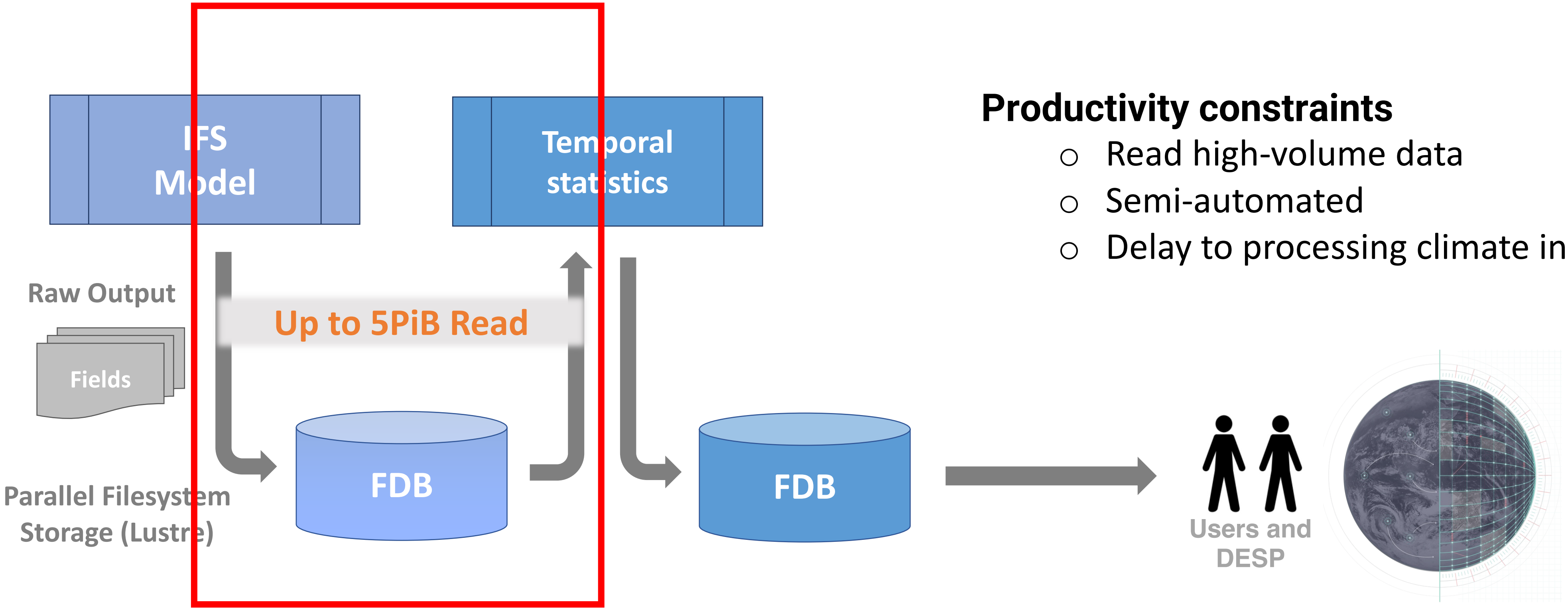
Congestion

- Model data persisted to the PFS
- Simultaneous read & write operations
- Runtime is increased by up to 26%

Use case 2 – High-resolution climate simulation



Use case 2 – High-resolution climate simulation

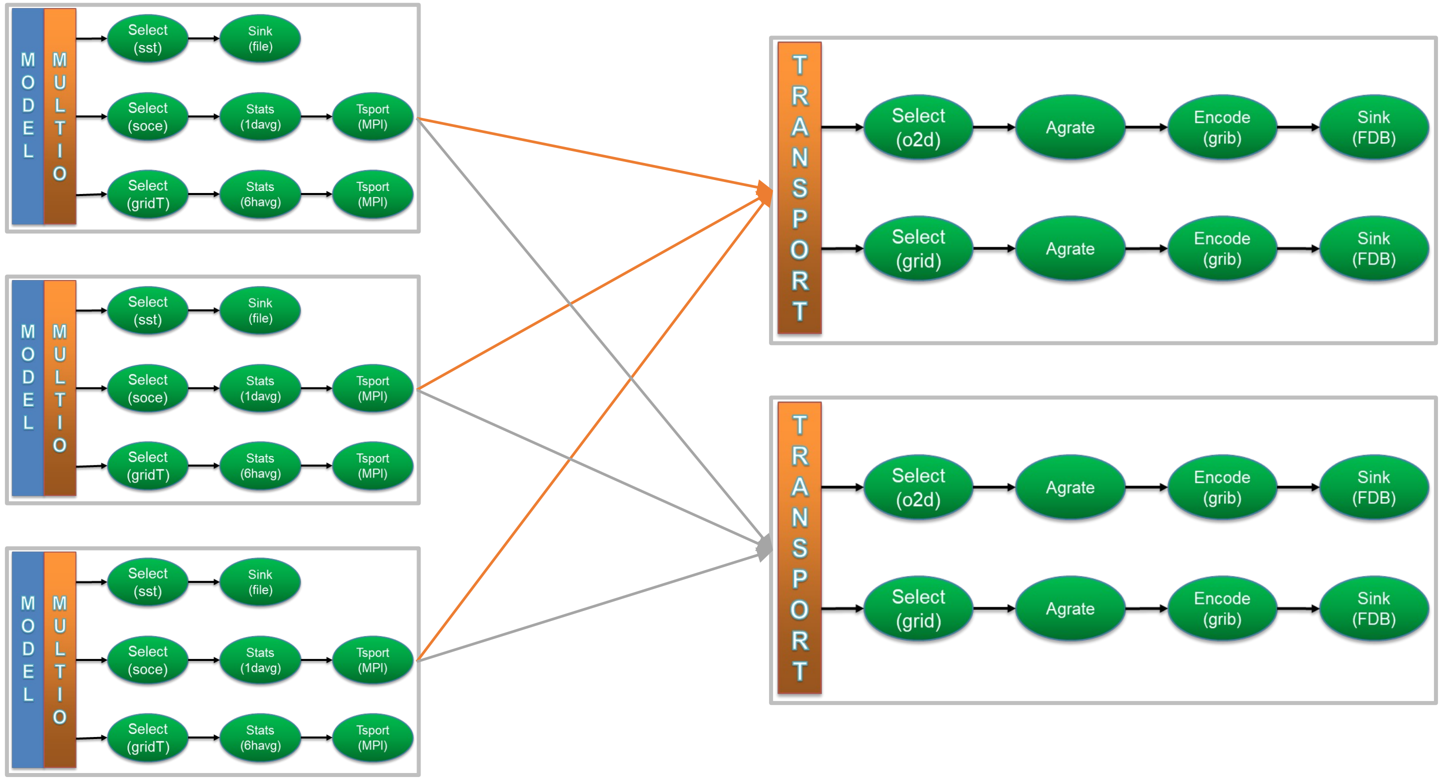


Productivity constraints

- Read high-volume data
- Semi-automated
- Delay to processing climate information

MultIO – high-level view

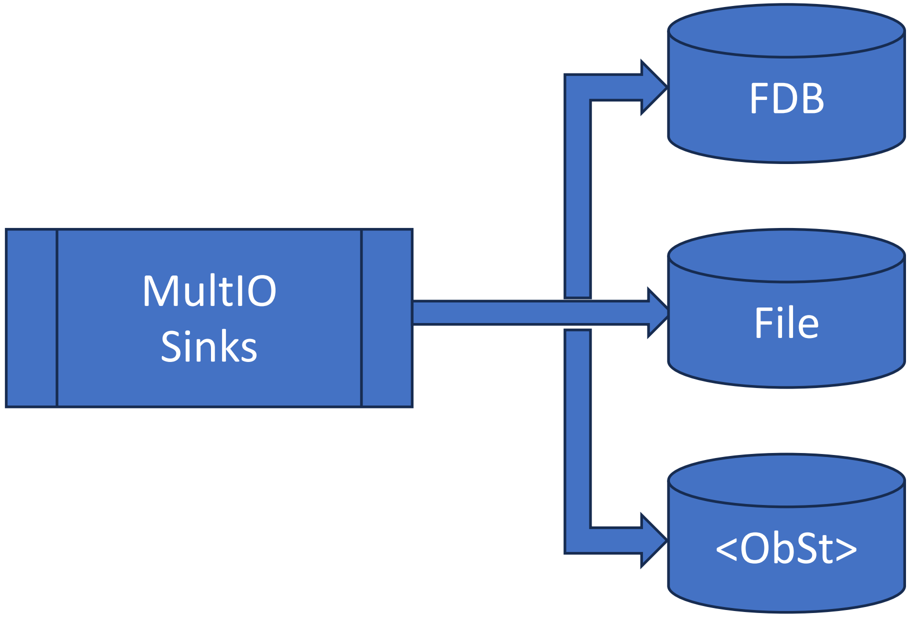
- **I/O-server functionality**
  - Asynchronous
  - Aggregate distributed fields
  - C/Fortran API
- **Processing pipelines**
  - In memory
  - User-programmable
  - Both partial/aggregated fields
  - User/pre-defined actions

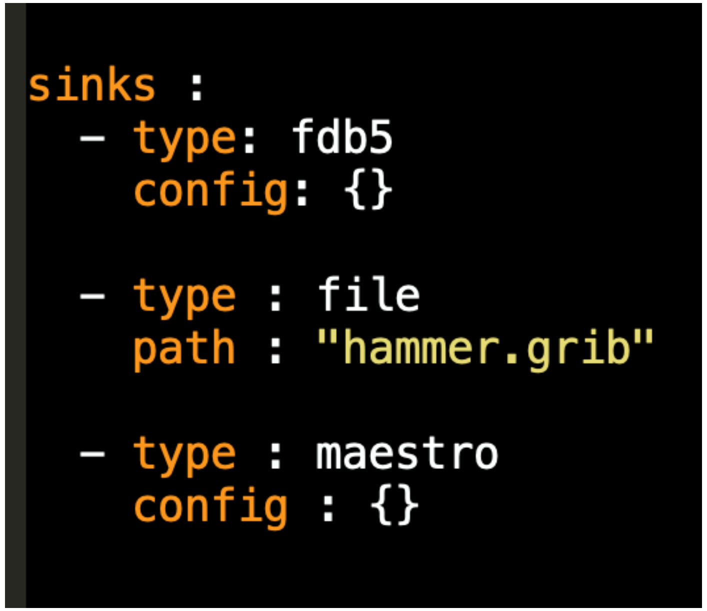


MultIO – a bit of history

🔀 **MultIO – Multiplexing I/O**

- Simultaneous output to multiple storage
- Ideal way to test novel storage technologies





```
sinks :
  - type: fdb5
    config: {}

  - type : file
    path : "hammer.grib"

  - type : maestro
    config : {}
```

MultIO – a bit of history

🔀 MultIO – Multiplexing I/O

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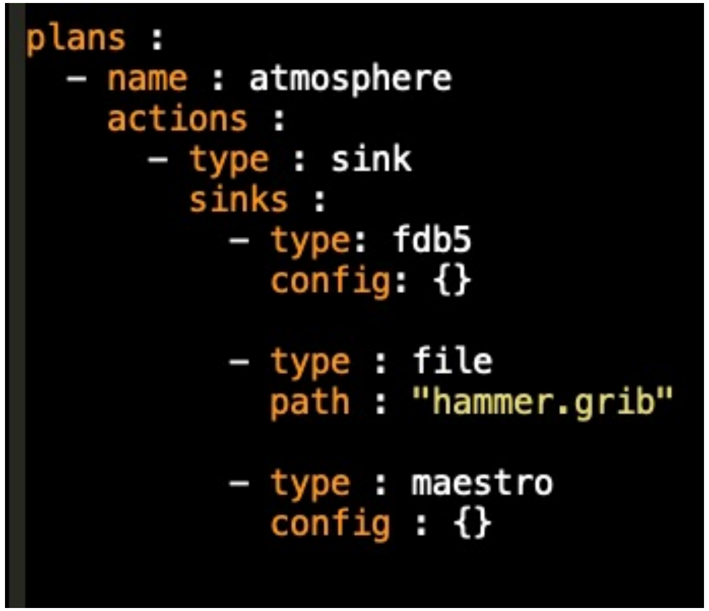
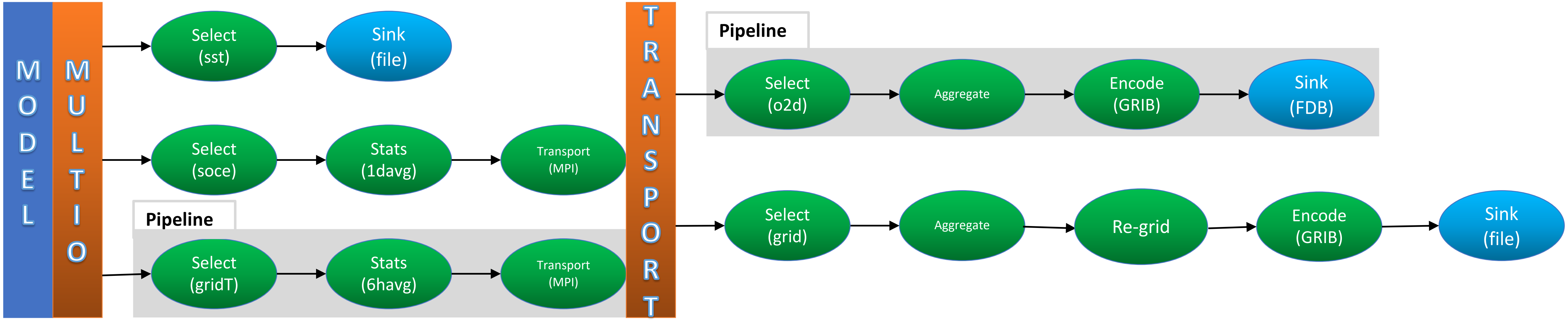
- Now a single action in the pipelines
- More than just I/O – on-the-fly post-processing with multiple pipelines

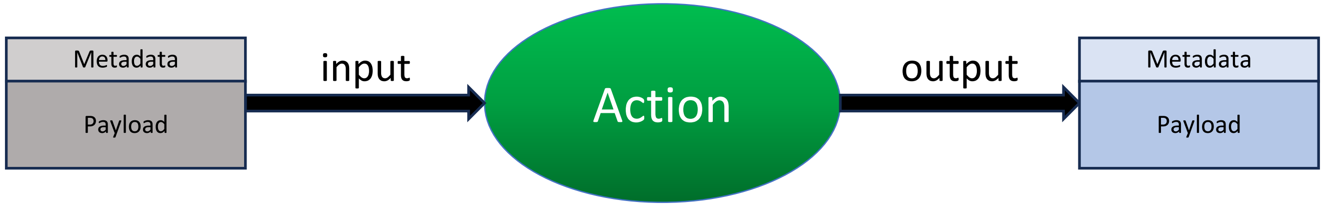


```
plans :
  - name : atmosphere
    actions :
      - type : sink
        sinks :
          - type: fdb5
            config: {}

          - type : file
            path : "hammer.grib"

          - type : maestro
            config : {}
```



Message-driven routing decisions

```
Metadata
date: 20210112 time: 1200 step: 24 parameter: T level: 0

Data payload
 - Field data (e.g. array of doubles)
 - GRIB2
 - Grid partition
```



Message

- Metadata, a unique description
- Payload

Contract

- Between message and action
- Decisions are based on
  - input message’s metadata
  - action’s default behaviour
  - action’s configuration
- Output message can be
  - same message
  - same payload, new metadata
  - new message
  - no message

Message-driven routing decisions

👱 **User-defined actions**

- The user in full control by defining the contract
- The user populates the metadata through the multio interface
- The user defines the action’s behaviour and implements it (conforming to multio’s action interface)

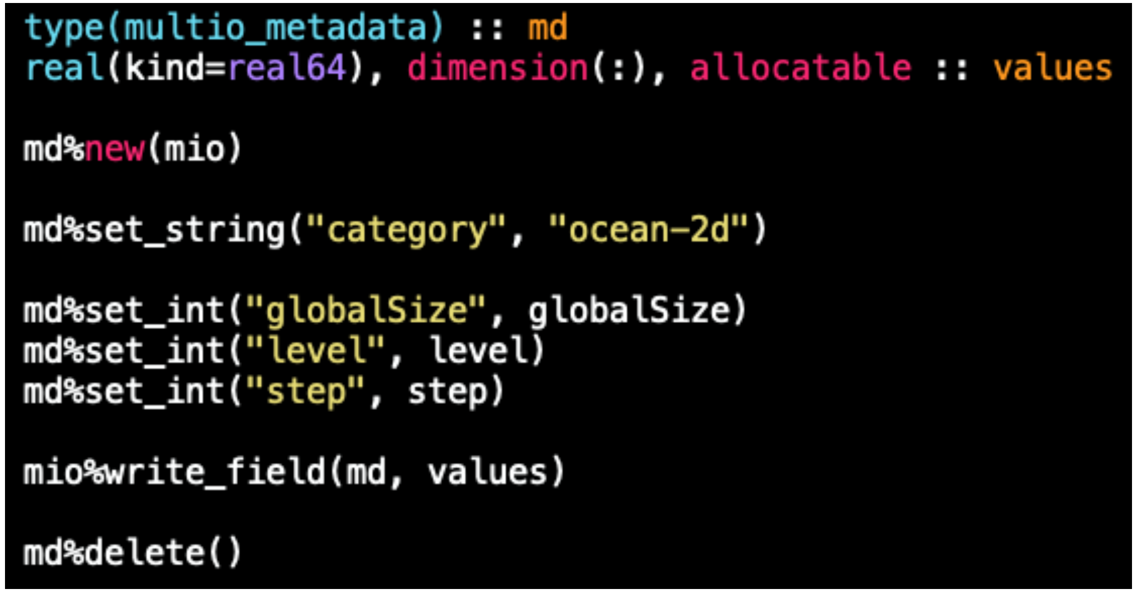
💻 **Pre-defined actions (shipped with multio)**

- The user need to be aware of the requirements on the metadata
- The user still populates the metadata through the multio interface

👨‍💻 **Both user-defined and pre-defined actions**

- The user need to be aware of metadata injected into the message by previous actions

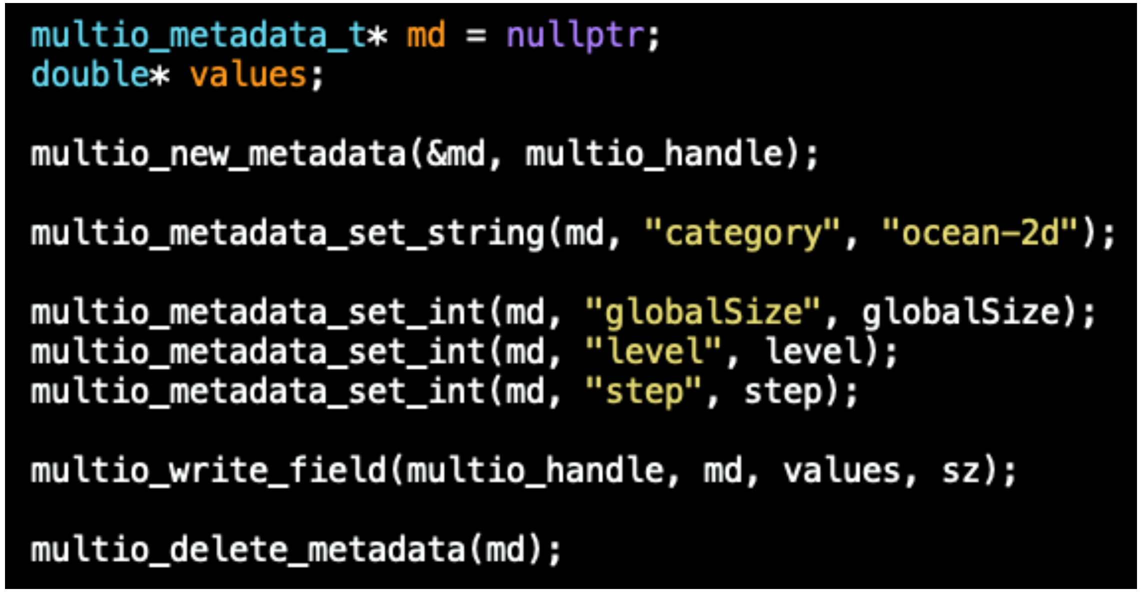
Pipeline interface



```fortran
type(multio_metadata) :: md
real(kind=real64), dimension(:), allocatable :: values

md%new(mio)

md%set_string("category", "ocean-2d")

md%set_int("globalSize", globalSize)
md%set_int("level", level)
md%set_int("step", step)

mio%write_field(md, values)

md%delete()
```

🧑‍💻 **Fortran/C API**

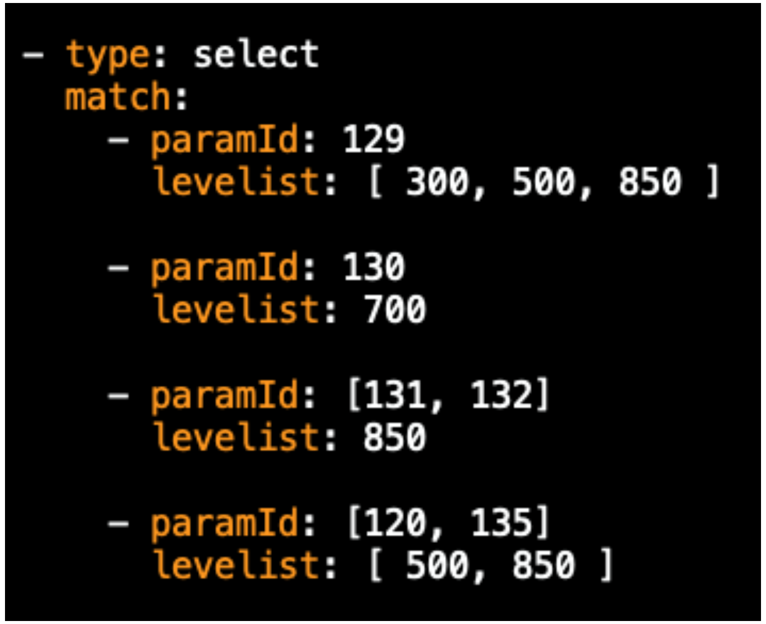
- Metadata is a key-value dictionary
- Create metadata handle
- Populate metadata
- Pass metadata + data
- Delete metadata handle



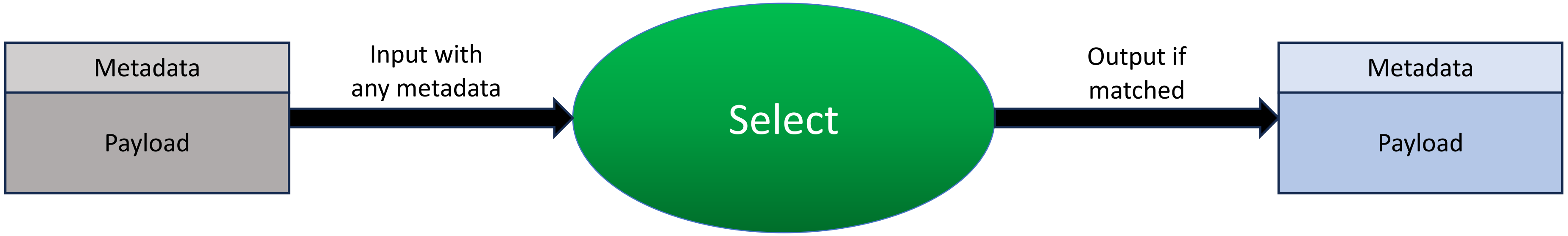
```c
multio_metadata_t* md = nullptr;
double* values;

multio_new_metadata(&md, multio_handle);

multio_metadata_set_string(md, "category", "ocean-2d");

multio_metadata_set_int(md, "globalSize", globalSize);
multio_metadata_set_int(md, "level", level);
multio_metadata_set_int(md, "step", step);

multio_write_field(multio_handle, md, values, sz);

multio_delete_metadata(md);
```

Pre-defined actions: Select

- Filter on metadata
- Never change the message
- Filter on any keys
- Both ‘and’ and ‘or’ supported



```
- type: select
  match:
    - paramId: 129
      levelist: [ 300, 500, 850 ]

    - paramId: 130
      levelist: 700

    - paramId: [131, 132]
      levelist: 850

    - paramId: [120, 135]
      levelist: [ 500, 850 ]
```



Metadata

Payload

Input with any metadata

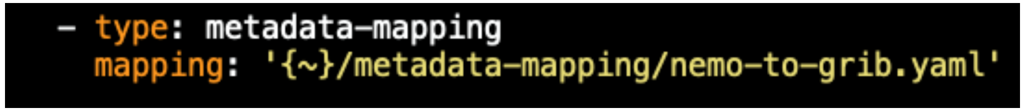
Select

Output if matched

Metadata

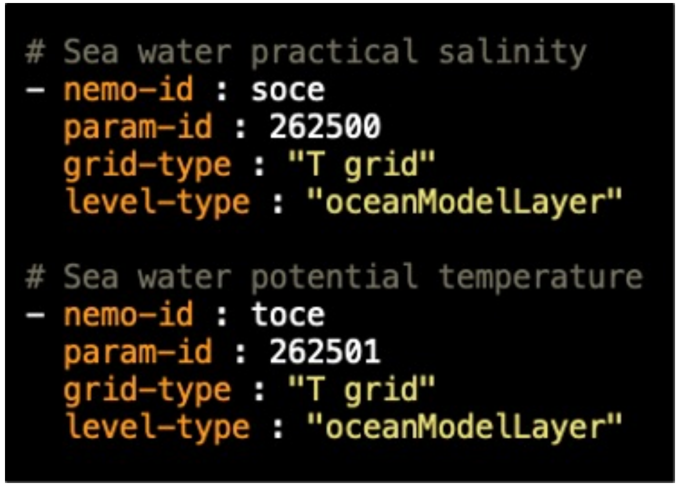
Payload

Pre-defined actions: MetadataMapping

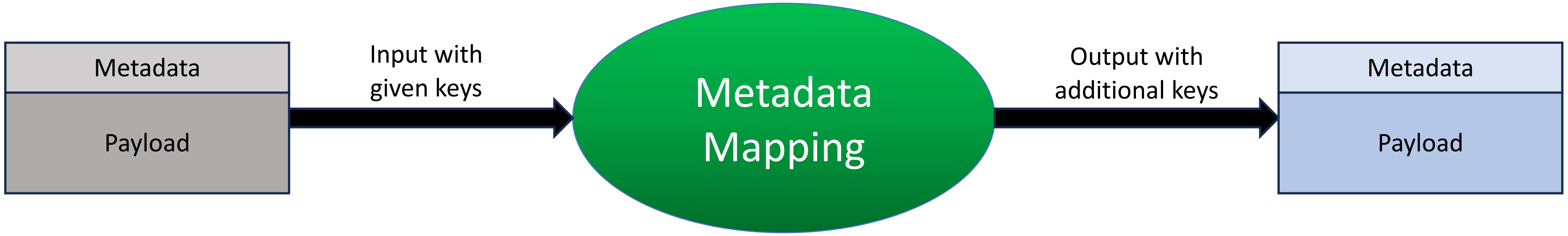


```
- type: metadata-mapping
  mapping: '{~}/metadata-mapping/nemo-to-grib.yaml'
```

- Inject additional metadata
- Never change the payload
- Always apply
- Require mapped-from metadata



```
# Sea water practical salinity
- nemo-id : soce
  param-id : 262500
  grid-type : "T grid"
  level-type : "oceanModelLayer"

# Sea water potential temperature
- nemo-id : toce
  param-id : 262501
  grid-type : "T grid"
  level-type : "oceanModelLayer"
```



Metadata

Payload

Input with given keys

Metadata Mapping

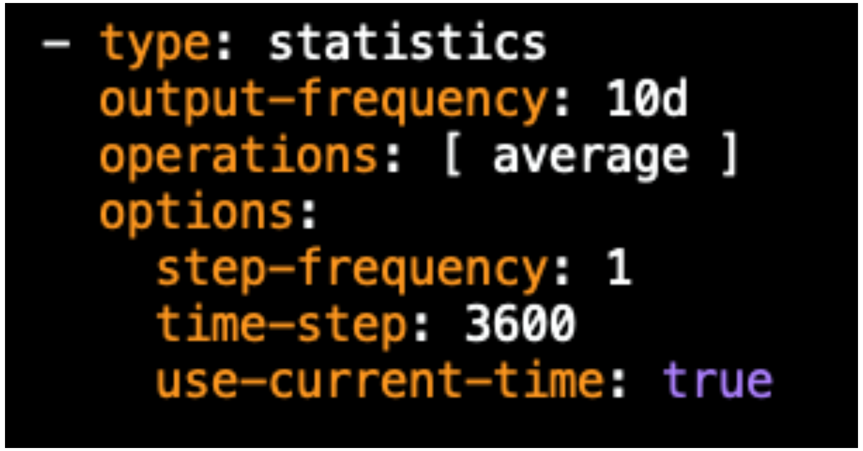
Output with additional keys

Metadata

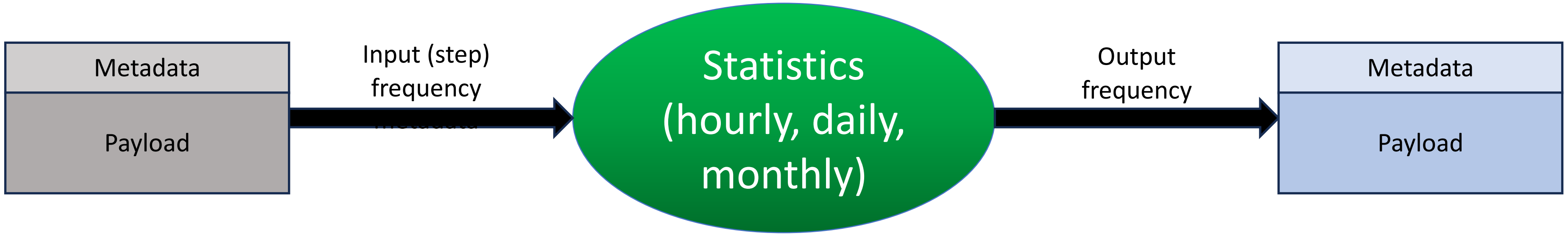
Payload

Pre-defined actions: Statistics

- Min/max
- Accumulate
- Average
- Flux average
- 🔨 Standard deviation
- 🔨 Synoptic means
- 🔨 Statistics restarts

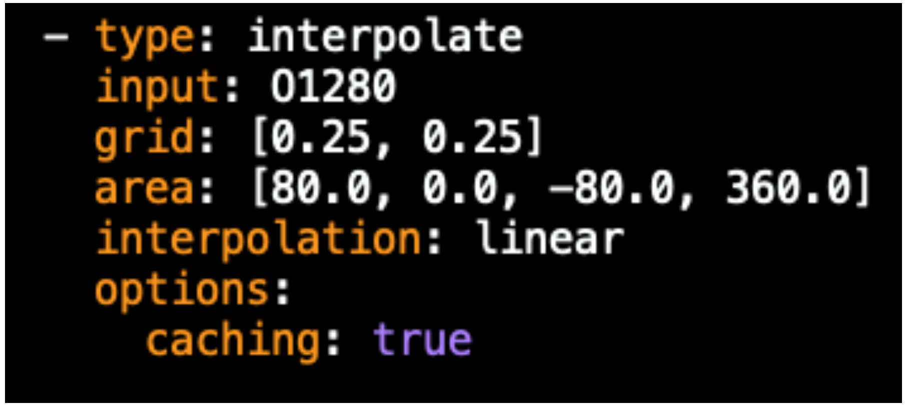


```
- type: statistics
  output-frequency: 10d
  operations: [ average ]
  options:
    step-frequency: 1
    time-step: 3600
    use-current-time: true
```

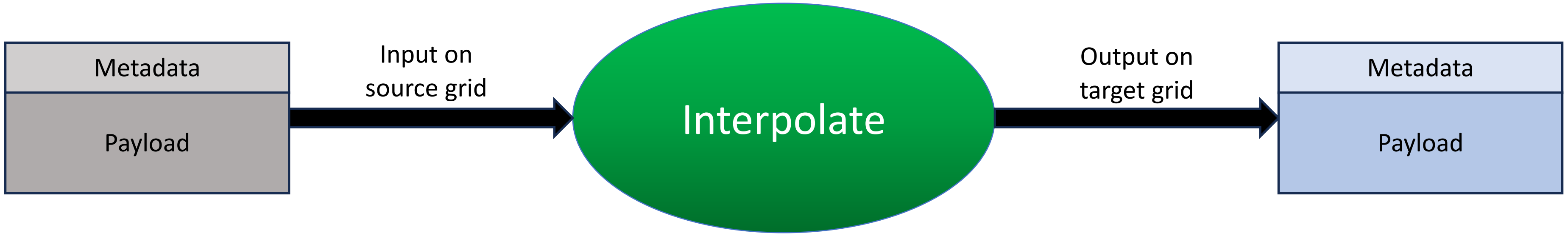


Pre-defined actions: Interpolate (re-grid)

- Uses the MIR library internally (github.com/ecmwf/mir)
- Interpolation between supported grids
- Cropping to rectangular domains
- Recent: support (e)ORCA ocean and HEALPix grids

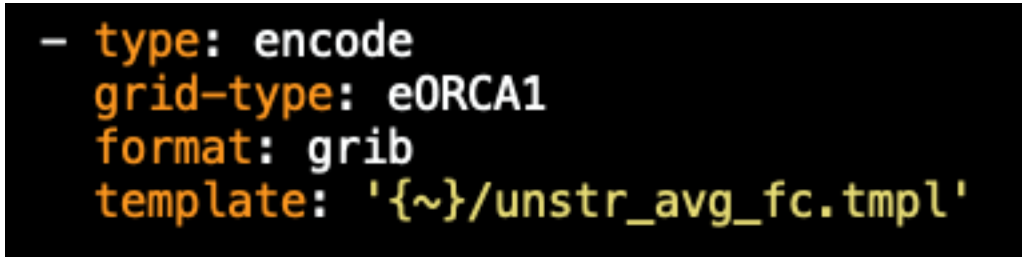


```yaml
- type: interpolate
  input: O1280
  grid: [0.25, 0.25]
  area: [80.0, 0.0, -80.0, 360.0]
  interpolation: linear
  options:
    caching: true
```

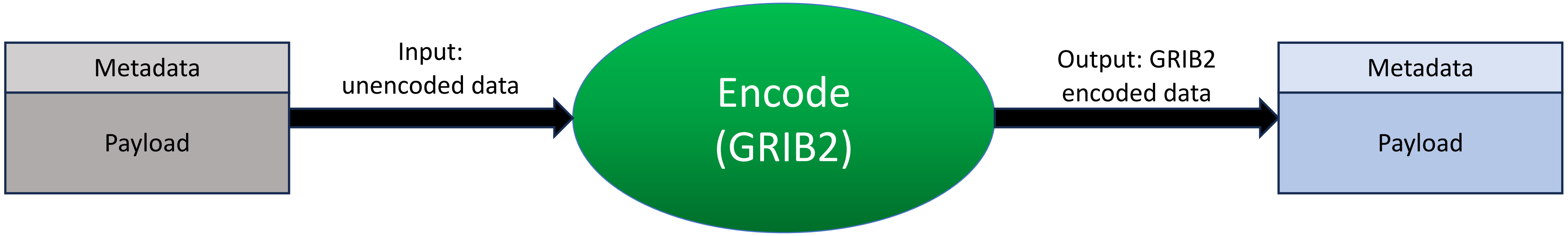


Pre-defined actions: Encode

- Uses eccodes internally (github.com/ecmwf/eccodes)
- Full GRIB2 support
- Some GRIB1 support (phasing out)



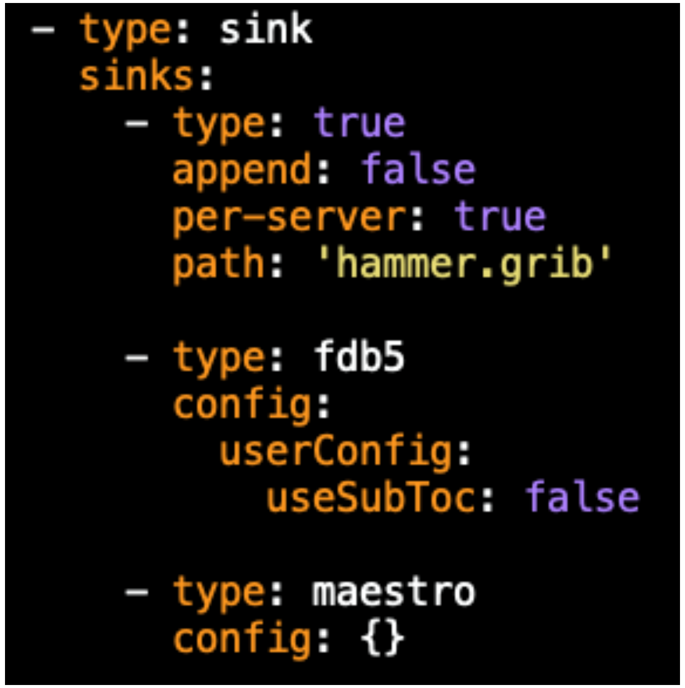
```
- type: encode
  grid-type: eORCA1
  format: grib
  template: '{~}/unstr_avg_fc.tmpl'
```



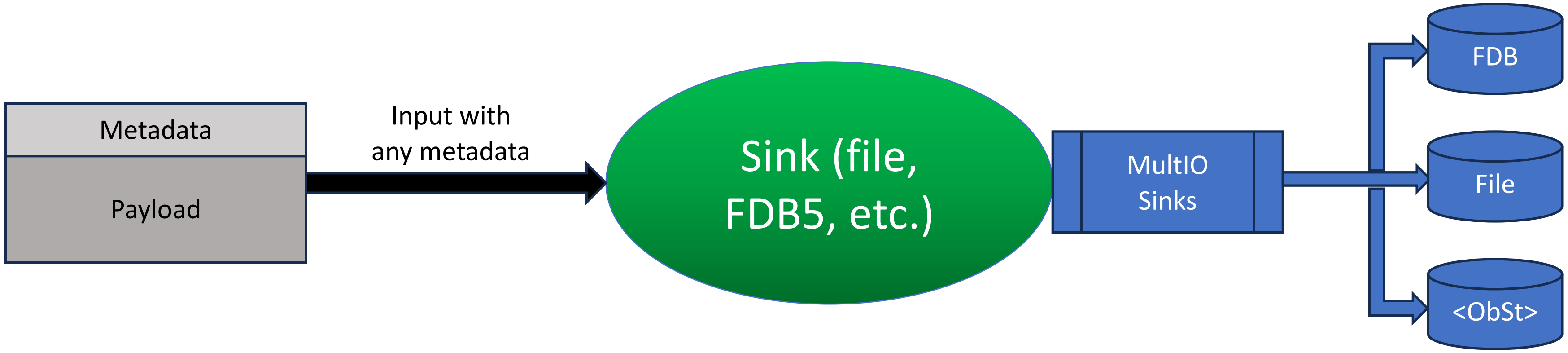
Pre-defined actions: Sink

MultIO sinks – Multiplexing I/O

- Simultaneous output to multiple storage
- Ideal way to test novel storage technologies
- Now a single action in the pipelines
- More than just I/O – on-the-fly post-processing with multiple pipelines

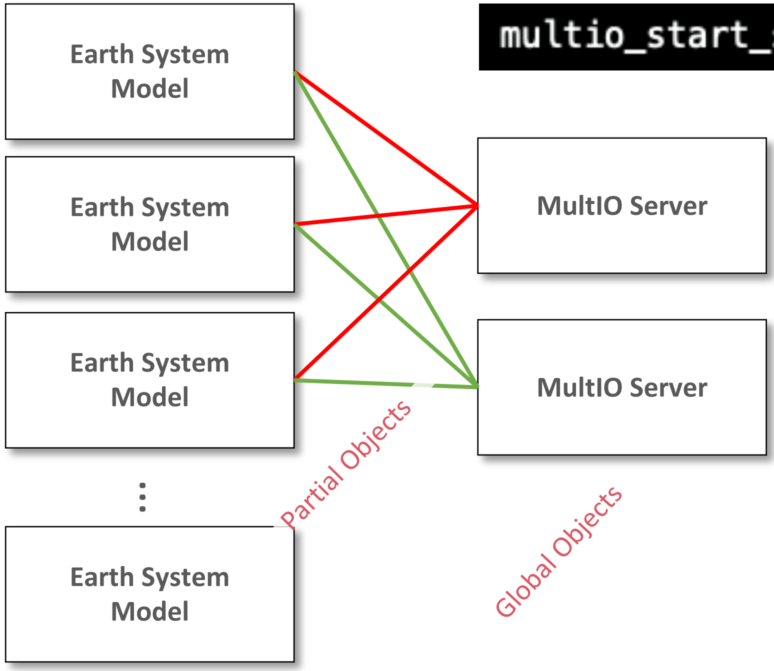


```
- type: sink
  sinks:
    - type: true
      append: false
      per-server: true
      path: 'hammer.grib'

    - type: fdb5
      config:
        userConfig:
          useSubToc: false

    - type: maestro
      config: {}
```



I/O-server additional interface

```
multio_start_server(mio_conf)
```



```
mio%open_connections()

mio%write_domain(md, domain_data)

mio%write_mask(md, zmask)

mio%close_connections()
```

🧑‍💻 **Additional API for distributed data**

- ○ Single API call for server
- ○ Transport-layer abstraction
- ○ Book-keeping for topology
- ○ Local-to-global index mapping
- ○ Land-sea mask information

Usage 1: Ocean re-analysis

⚡ **Release!**

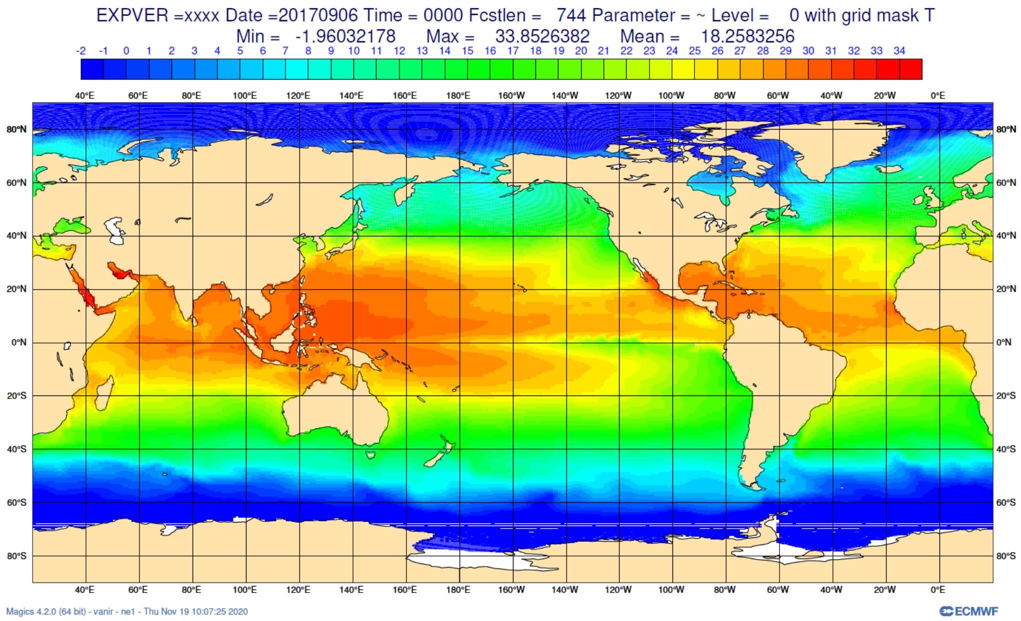
- ○ Version **2.0.1** for ORAS6 for production with NEMOv4 to begin in October/November

🌊 **GRIB2 ocean data in MARS**

- ○ Many new definitions for ocean
- ○ Support for (e)ORCA grids, curated and stored in atlas-io format (github.com/ecmwf/atlas-orca)

🌐 **NEMOv4 I/O-server & pipelines**

- ○ Compute hourly/daily/monthly statistics
- ○ Aggregation rules for (e)ORCA grids
- ○ Fully integrated in IFS operational toolchain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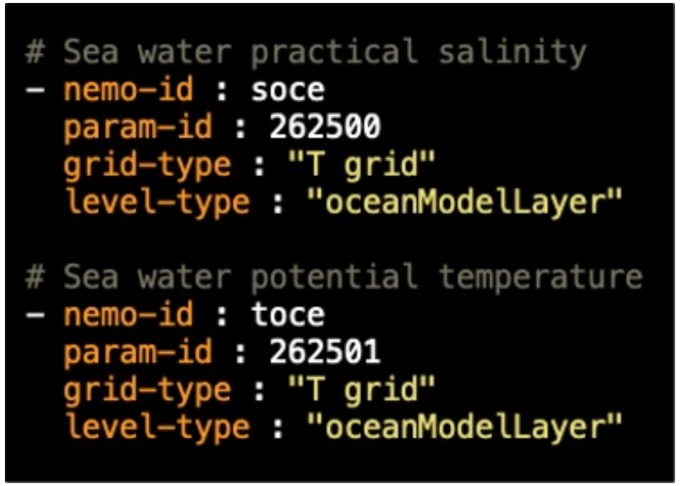
Min = -1.96032178 Max = 33.8526382 Mean = 18.2583256
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
40°E 60°E 80°E 100°E 120°E 140°E 160°E 180°E 160°W 140°W 120°W 100°W 80°W 60°W 40°W 20°W 0°E
80°N 60°N 40°N 20°N 0°N 20°S 40°S 60°S 80°S
Magics 4.2.0 (64 bit) - vanir - ne1 - Thu Nov 19 10:07:25 2020
ECMWF



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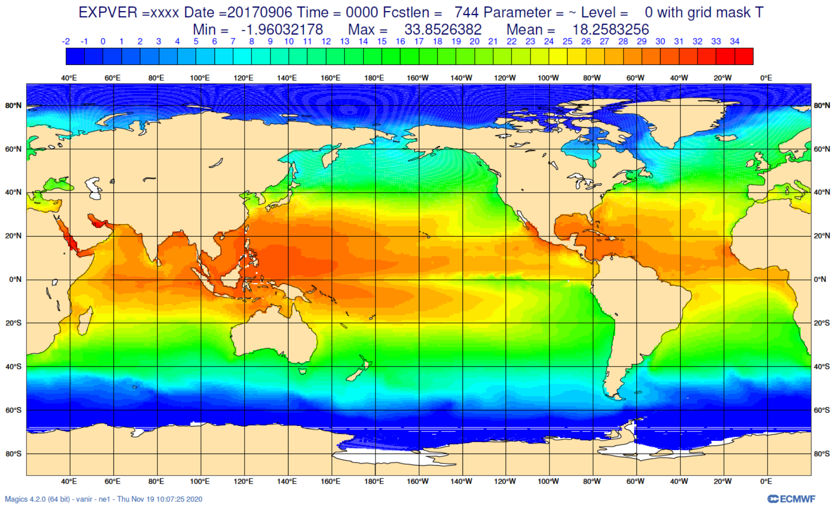
Usage 1: Ocean re-analysis

🎬 **Ocean6 re-analysis current production plans**

- ○ 6424 five-day assimilation loops
- ○ 11 ensemble members
- ○ 300 compute tasks per member
- ○ 20 I/O tasks per member



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Magics 4.2.0 (64 bit) - vanir - ne1 - Thu Nov 19 10:07:25 2020
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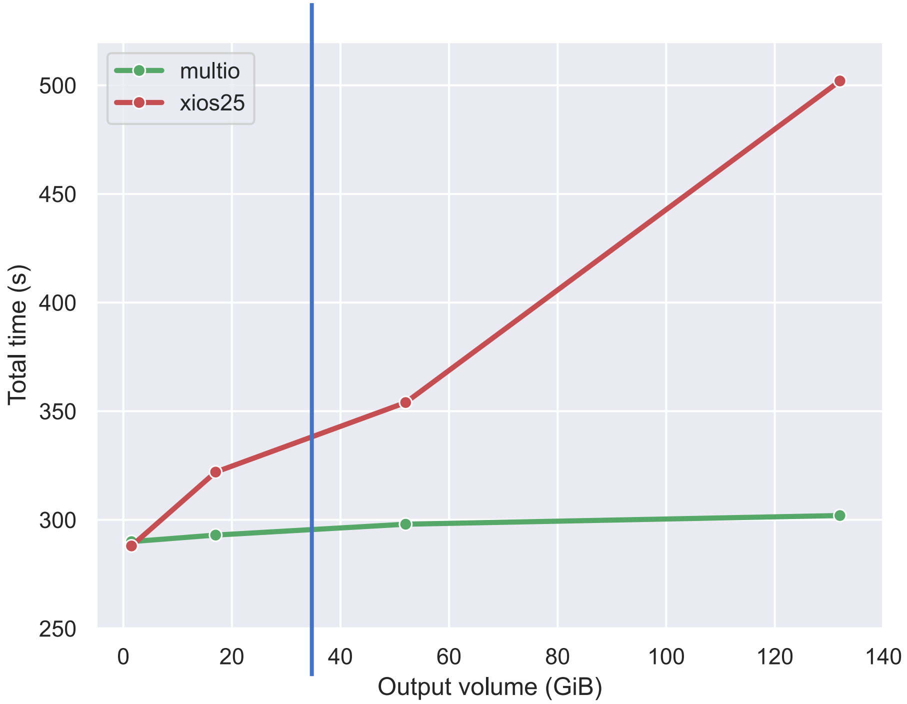
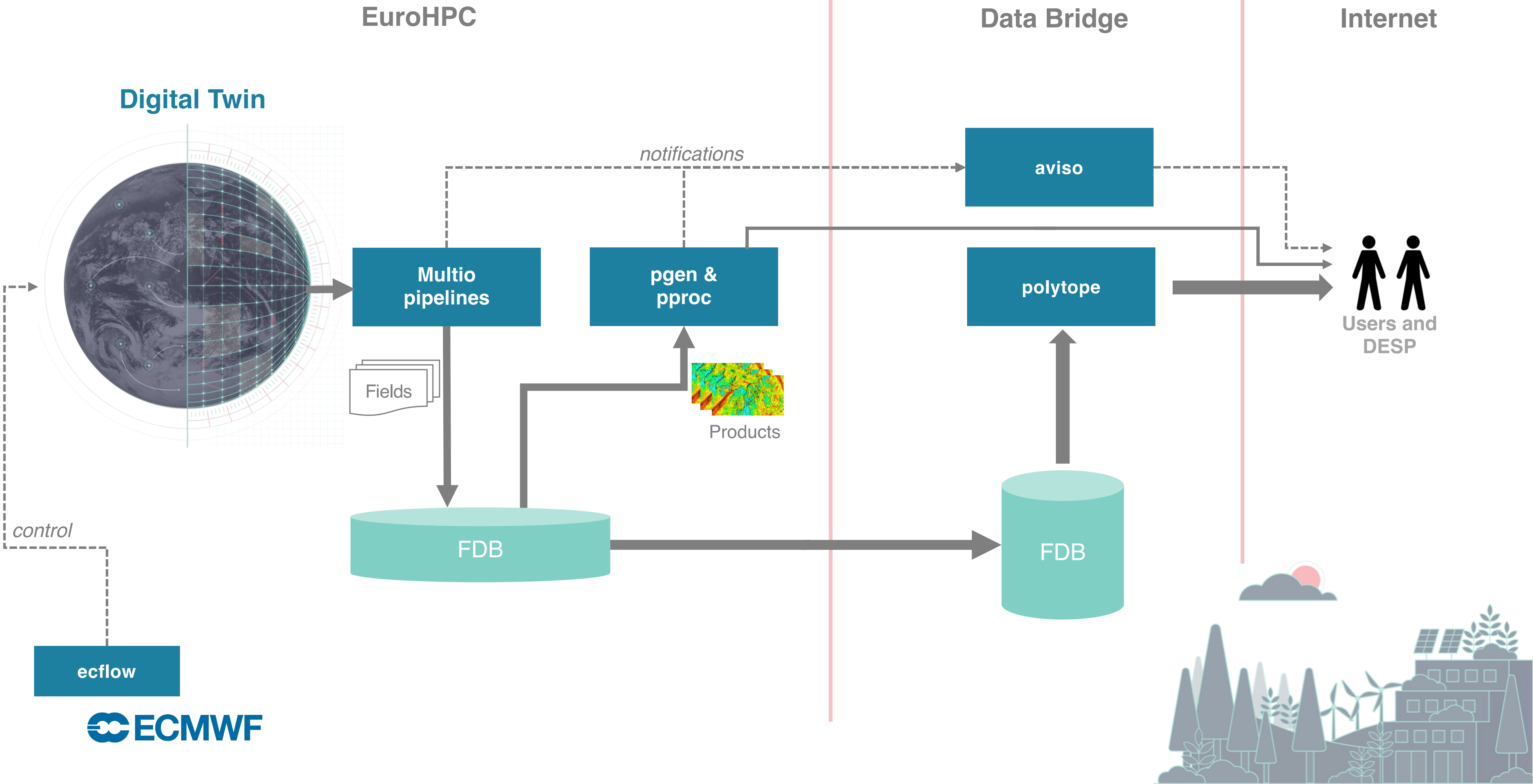
Comparison to xios 2.5 (best effort)



Usage 2: Destination Earth Phase 1 / NextGEMS



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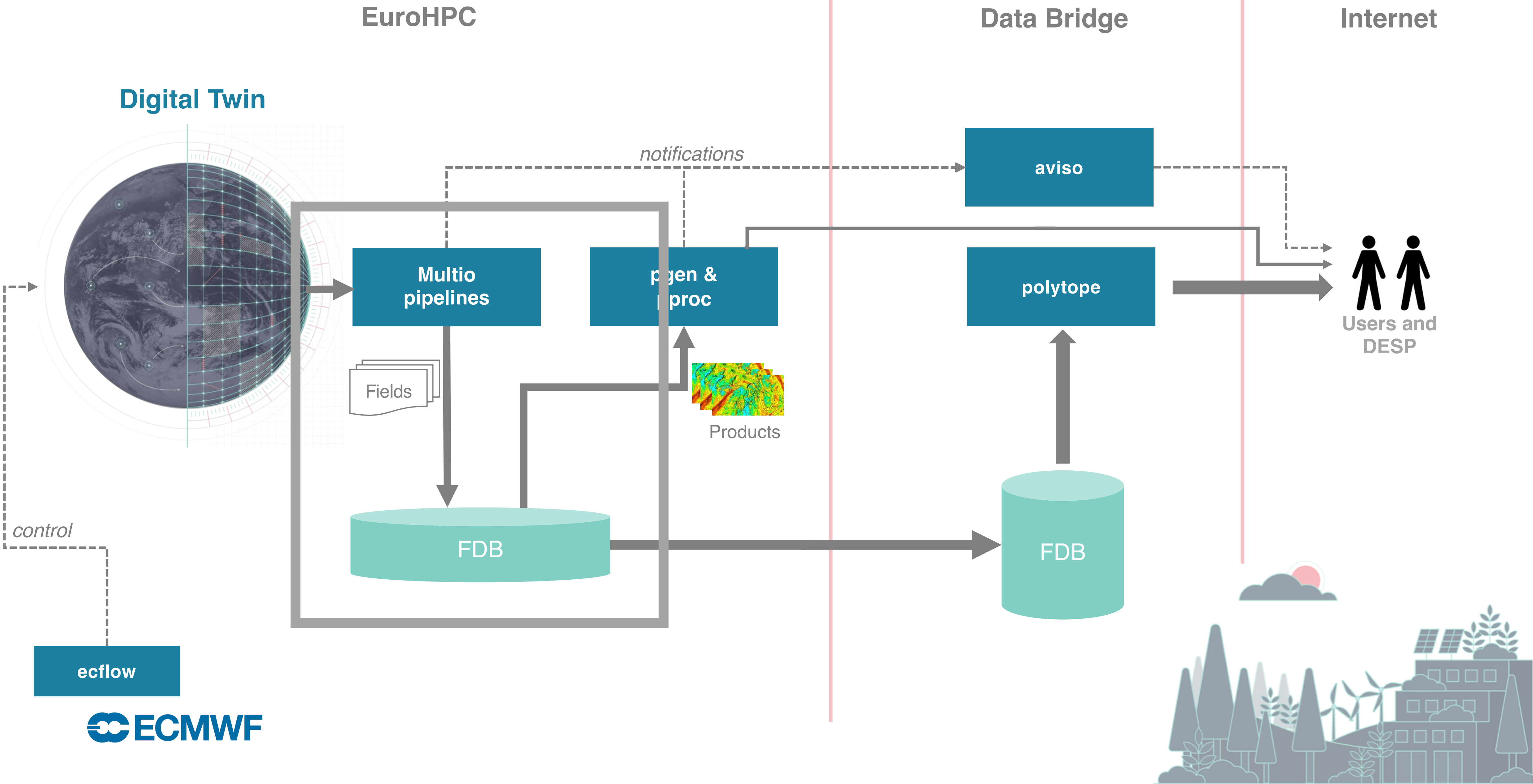

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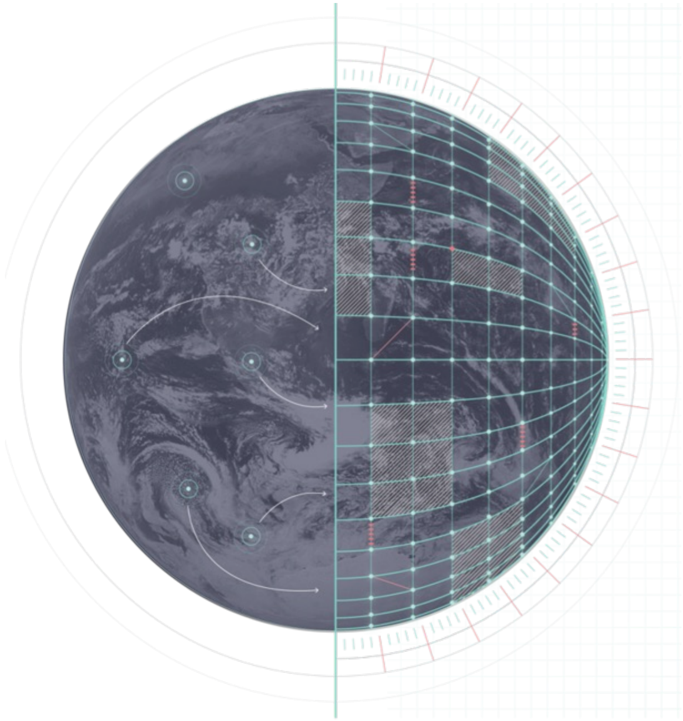
Usage 2: Destination Earth Phase 1 / NextGEMS

- **NextGEMS multi-year runs**
  - Coupled to NEMOv3 with no output
  - Post-processing pipeline for IFS
  - Statistics (monthly means)
  - Interpolation (re-gridding)
- **High-resolution DestinE climate runs**
  - Two coupled ocean-atmosphere models
    - IFS/NEMOv4
    - IFS/FESOMv2
  - I/O-server for both NEMOv4 and FESOMv2
  - Uniform output on HEALPix grids
  - Integrate output configuration



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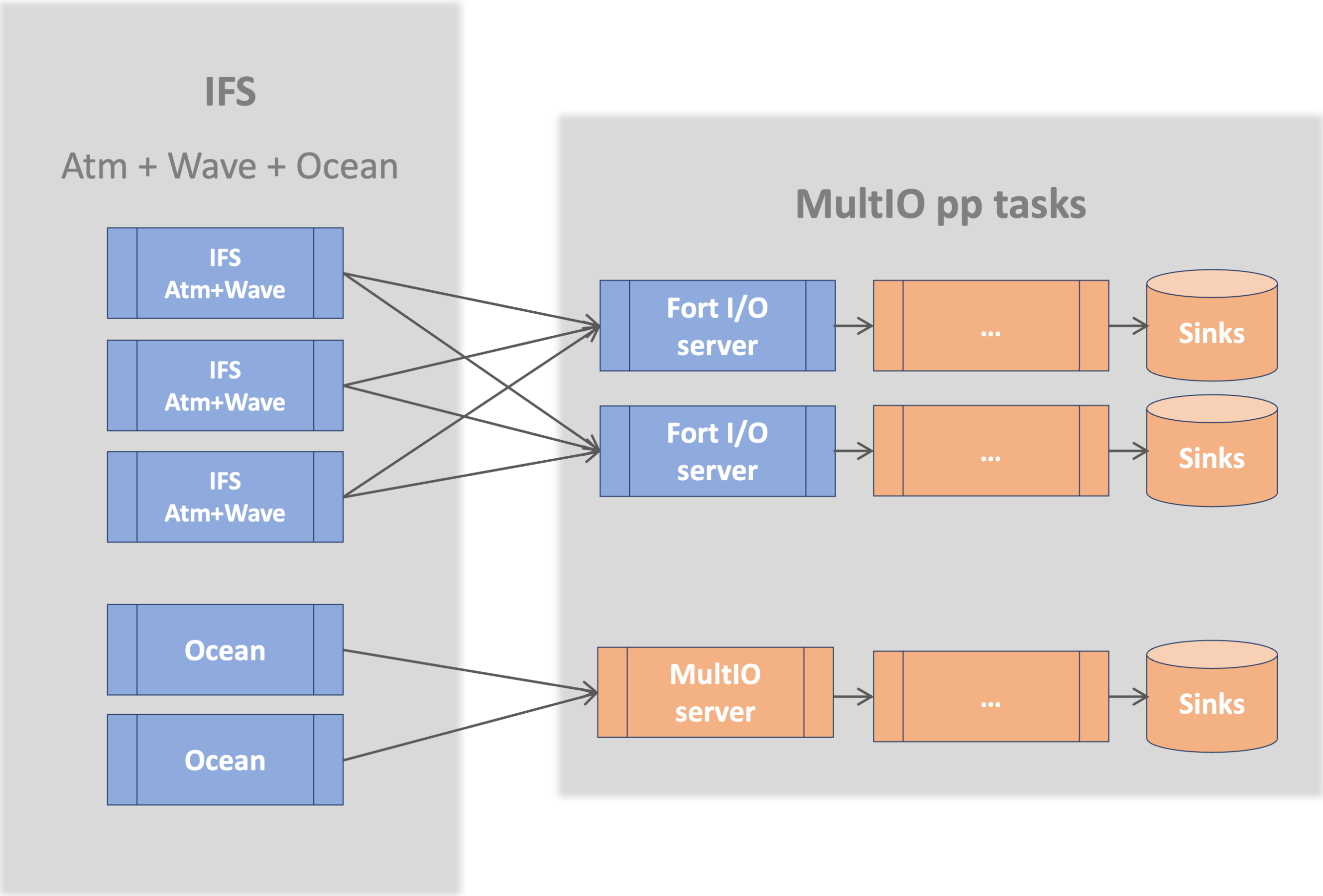
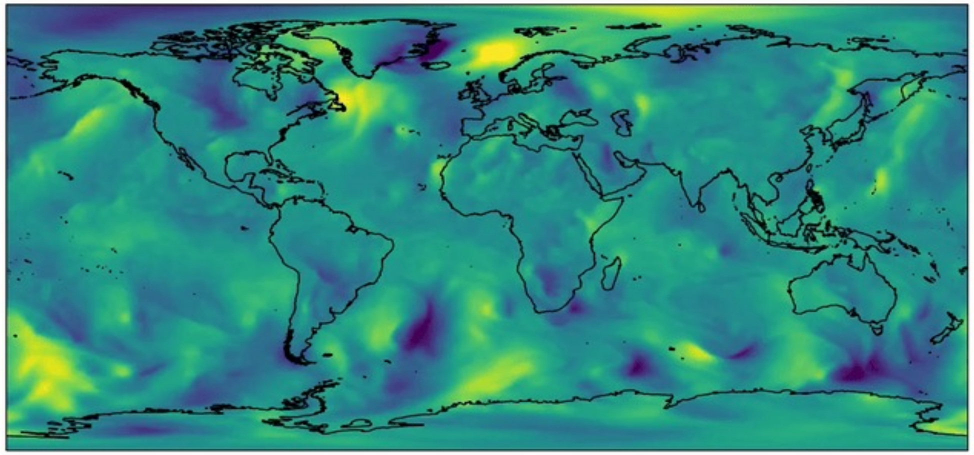
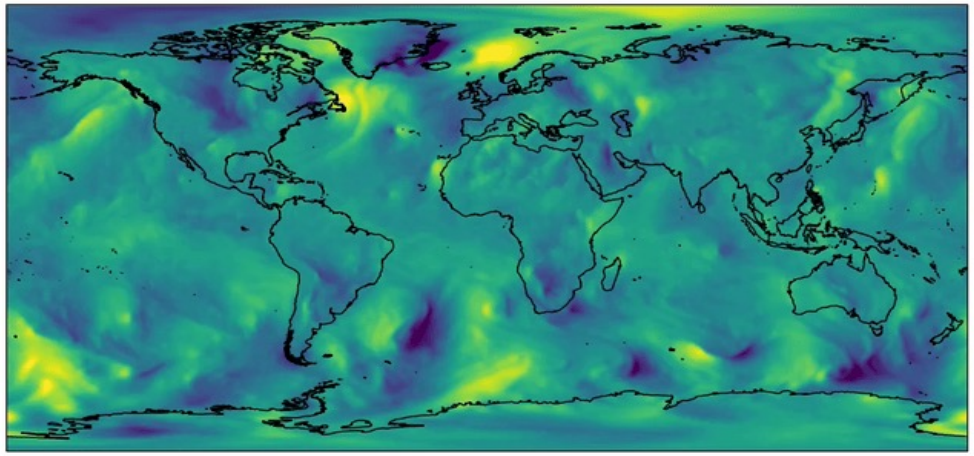


Current work and outlook



ML Model



The IFS

🤖 **Anticipation of AIFS**

- ○ Python interface for multio
- ○ Optimisations for more data to be processed

🌐 **Further developments for DestinE/operataions**

- ○ MultIO as I/O-server for IFS atmosphere and wave
- ○ Re-design GRIB2 encoding
- ○ Support of ERA6
  - Consolidate standard deviation
  - Consolidate synoptic means
  - Statistics checkpointing
- ○ More model-side post-processing (fullpos)

Messages to take home

*MultIO has programmable pipelines that allows **processing data closer to the model**, thus alleviating some of the burden on downstream users*

*MultIO provides an **asynchronous I/O-server** that will be first used in upcoming ECMWF's ocean re-analysis and Climate DT Phase 1 production*

*ECMWF is refactoring its IFS output and production stack to support **on-the-fly product generation** and MultIO as an I/O-server*