Evaluation and optimization of the I/O scalability of the (Open)IFS atmospheric model using XIOS

Xavier Yepes-Arbós
Mario C. Acosta

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Introduction

• Exascale supercomputers will allow Earth System Models (ESMs) to make simulations at an unprecedented level of horizontal resolution.
• But this has implications:
  • A huge amount of data will be generated that must be efficiently written into the storage system.
  • No more offline post-processing is affordable due to the size of the “raw” data.
  • A high cost of storage systems due to the huge data size.
Introduction

• Not much attention was paid on improving I/O of ESMs because it did not use to be an issue.

• This was the case of Numerical Weather Prediction (NWP) models such as IFS, where one of its output schemes uses sequential I/O.

• Sequential I/O is not scalable for such high resolution grids, and even less, for future exascale machines.
(Open) IFS overview

• The Integrated Forecasting System (IFS) is a global data assimilation and forecasting system which includes the modelling of the atmospheric composition developed by the European Centre for Medium-Range Weather Forecasts (ECMWF).

• It has two different output schemes:
  • The Météo-France (MF) I/O server which is fast and efficient from a computational point of view. It is only used at ECMWF, such its operational forecasts.
  • A sequential I/O scheme which is slow and inefficient from a computational point of view. It is used by non-ECMWF users, this is, in OpenIFS.

• OpenIFS is a free and simplified version of IFS available under a license.
Objective: Integrate XIOS

• The I/O issue is typically addressed by adopting scalable parallel I/O solutions.

• In the climate community, a widely I/O tool used is XIOS.

• The XML Input/Output Server (XIOS) is an asynchronous MPI parallel I/O server developed by the Institute Pierre Simon Laplace (IPSL).

• XIOS has the following features needed for climate modelling:
  • Output files are in netCDF format.
  • Written data is CMIP-compliant (CMORized).
  • It is able to post-process data online to generate diagnostics.
XIOS: Some technical features

• From a computational point of view, XIOS is thought to address:
  • The inefficient legacy read/write process.
  • The unmanageable size of “raw” data.

• By implementing:
  • Scalable parallel I/O.
  • Online post-processing.

• But it has been only tested for petascale supercomputers, so it is necessary to:
  • Stress different aspects such as memory consumption, MPI scalability, netCDF parallel I/O or data compression.
(Open)IFS-XIOS integration scheme

IFS process 0 -> IFS process 1 -> ... -> IFS process N-2 -> IFS process N-1

Library calls

IFS processes (IFS scope)

XIOS client 0 -> XIOS client 1 -> ... -> XIOS client N-2 -> XIOS client N-1

Asynchronous MPI

XIOS server 0 -> XIOS server M-1

System calls

System file (config. & output files)

output.nc -> iodef.xml
(Open) IFS-XIOS integration summary

• Scientific highlights:
  • Both grid-point and spectral fields are supported.
  • All surface and 3D fields can be output.
  • Different vertical levels are available: model, pressure, theta and PV levels.
  • No longer needed to set up the FullPos namelist (NAMFPC).
  • FullPos spectral fitting is available.
  • Physical tendencies and fluxes output (PEXTTRA fields) are also supported.

• Both XIOS 2.0 and 2.5 versions have been tested.
(Open)IFS-XIOS integration summary

• Highlights from the computational performance point of view:
  • In-depth benchmarking: the **overhead** of outputting data through XIOS is really **small** if using enough computational resources.
  • A profiling and performance analysis was done to detect potential bottlenecks.
  • Two different optimizations are available (switchable in the XIOS XML namelist):
    • Computation and communication overlap.
    • Sends from (Open)IFS to XIOS either in double or single precision.

• Different XIOS features available (listed only some of them):
  • Horizontal interpolations (from reduced Gaussian to rectangular Gaussian).
  • Arithmetic operations.
  • Time operations: average, maximum, minimum, etc.
  • **Lossless data compression** using gzip through HDF5.
Computational performance of IFS-XIOS

IFS-XIOS output scheme comparison
Cray XC40, Tco1279L137, multiple_file mode, 5-day forecast, 9.9 TB output

Execution time (seconds)

<table>
<thead>
<tr>
<th>Output scheme</th>
<th>Execution time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequential output</td>
<td>8974</td>
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<tr>
<td>MF I/O server</td>
<td>4187</td>
</tr>
<tr>
<td>IFS-FullPos</td>
<td>4138</td>
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<tr>
<td>XIOS</td>
<td>4521</td>
</tr>
<tr>
<td>IFS-FullPos-S.Trans.</td>
<td>4427</td>
</tr>
</tbody>
</table>
XIOS performance issue

XIOS computational resources usage
Cray XC40, three different configurations

Output size - Output frequency

- 24 GB - 3h
- 103 GB - 3h
- 2.4 TB - 1h
- 9.9 TB - 1h

XIOS nodes

0 5 10 15 20 25

1 2 8 20

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XIOS performance issue

IFS-XIOS parallel writing (HDF5 parallel I/O)
Cray XC40, 12 OSTs, Tco1279L137, one_file mode, 5-day forecast, 9.9 TB output
What about XIOS compression?

XIOS lossless compression (HDF5 - gzip) running Tco255L91
Cray XC40, compression level 6, 1 XIOS node (2 servers per node), 10-day forecast

- **Execution time (seconds)**
  - No compression: 1568
  - clwc, ciwc, cc fields: 1549
  - 16 3D fields: 1824
  - 16 3D fields (8 XIOS servers per node): 1555

- **Output size (GB)**
  - Time: 48, 39, 32
  - Output size: 50, 50, 32

[Graph showing the relationship between execution time and output size for different compression levels.]
What about XIOS compression?

XIOS lossless compression (HDF5 - gzip) running Tco511L91

Cray XC40, compression level 6, 2 XIOS nodes (1 server per node), 10-day forecast

![Graph showing execution time and output size for different compression levels.]

- No compression
- clwc, ciwc, cc fields
- 19 3D fields (8 XIOS servers per node)
What about XIOS compression?

XIOS lossless compression (HDF5 - gzip) running Tco1279L137
MN4, compression level 6, 20 XIOS nodes (2 servers per node), 5-day forecast

![Graph showing execution time and output size for different compression levels.]

- **Execution time (seconds)**
  - No compression: 5205 seconds
  - crwc, cswc, clwc, ciwc, cc fields: 5254 seconds
  - 37 3D fields: 13744 seconds
  - 37 3D fields (16 XIOS servers per node): 5719 seconds

- **Output size (TB)**
  - No compression: 4.6 TB
  - crwc, cswc, clwc, ciwc, cc fields: 8.8 TB
  - 37 3D fields: 0.8 TB
  - 37 3D fields (16 XIOS servers per node): 0.4 TB
Lossy compression filter for XIOS?

- The default lossless compression filter of HDF5 does not fit our needs:
  - If compression ratio is high, it takes too much time.
  - If it takes a reasonable amount of time, compression ratio is not enough.

- We want to explore if lossy compression is adequate for climate modelling. In particular, we would consider to use lossy compression in XIOS if it fulfills the following points:
  - Reach high compression ratios.
  - Enough compression speed to considerably mitigate the I/O overhead.
  - Keep high accuracy.

- In addition, it would be interesting to have OpenMP support as well as be integrated with HDF5 parallel I/O.
Open questions and collaboration opportunities

• What types of lossy compression are more suitable for climate modelling? Can we use same compression for all variables?

• In particular, we are interested in the SZ compressor from ANL. Do you think it is suitable for our needs?

• Thus, might there be a potential collaboration between ANL and BSC?

• The SZ compressor is already registered as a third-party filter of HDF5. We would like to explore with ANL if it is enough for XIOS, or we would need to develop a particular solution. Is it compatible with experimental HDF5 parallel I/O? And OpenMP?
Thank you

xavier.yepes@bsc.es