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NATIONAL WEATHER SERVICE

Model infrastructure development in UFS weather model

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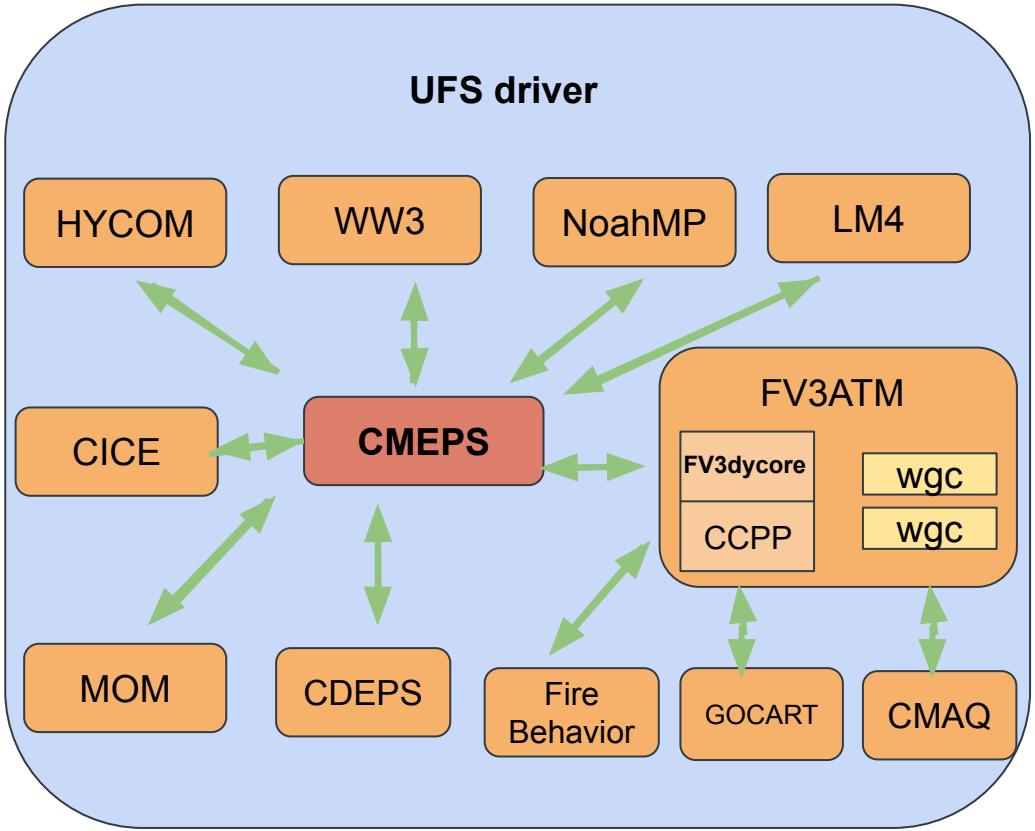
Overview

- UFS fully coupled capability overview
- Develop generic write grid component
- Computational performance
- Present and planned work

UFS: fully coupled earth modeling system

Fully Coupled UFS Weather Model Overview

- The UFS weather model is **open source** software supporting both **research and operational** developments. It contains:
  - **19 authoritative** repositories
  - **11 major flagship** model components
  - **Community mediator** and 11 **sharable** NUOPC caps
- **Model infrastructure** has been developed as the foundation to build the unified system:
  - Coupling is built upon **ESMF/NUOPC/FMS**
  - Coupling through direct exchange field **redistrition with interpolation** or **through mediator** where coupling fields are collected, accumulated and redistributed
  - Supports **GFSv17**, **GEFSv13**, **SFSv1**, **RRFSv1**, **AQMv7-8**, **HAFSv1-2**



Coupling Infrastructure Development

- CMEPS - Community Mediator for Earth Prediction Systems
  - Community development and testing helps ensure robustness across multiple applications
  - Feature rich, easily extensible
- FV3ATM: Atmosphere model with FV3 dycore with CCPP physics
  - Developed FV3ATM NUOPC cap
  - Integrated CCPP physics
  - Developed write grid component and inline post capability
  - Developed coupling capability with other earth model components
- CICE6 - Community Sea Ice Model
  - Replaced CICE5
  - Code refactor and modernization, new column ice physics package (icepack)
- MOM6 - Community ocean model
  - Enabled CMEPS compatibility
  - Added ocean lag and Mesh options

Coupling Infrastructure Development

- CMAQ - The Community Multiscale Air Quality Modeling System
  - Integrated into UFS as the air quality component model (AQM)
  - Used Fengsha windblown dust emission scheme
  - Upgrade to CMAQ 5.4
- GOCART - The Goddard Chemistry Aerosol Radiation and Transport
  - Integrated into UFS through new FV3atm run phases and GOCART NUOPC cap
  - two-way coupling FV3atm <--> GOCART
  - Introduced NASA's MAPL infrastructure into UFS
- WW3 - Wave Watch III
  - Developed a mesh based NUOPC cap
  - Developed the WW3 coupling capability on an unstructured triangular mesh
  - Implemented PIO capability for WW3 history and restart files in NetCDF format
- CDEPS - Community Data Models for Earth Predictive Systems
  - Feature rich, flexible data model replacement for any component
  - Leverages CMEPS for interoperability

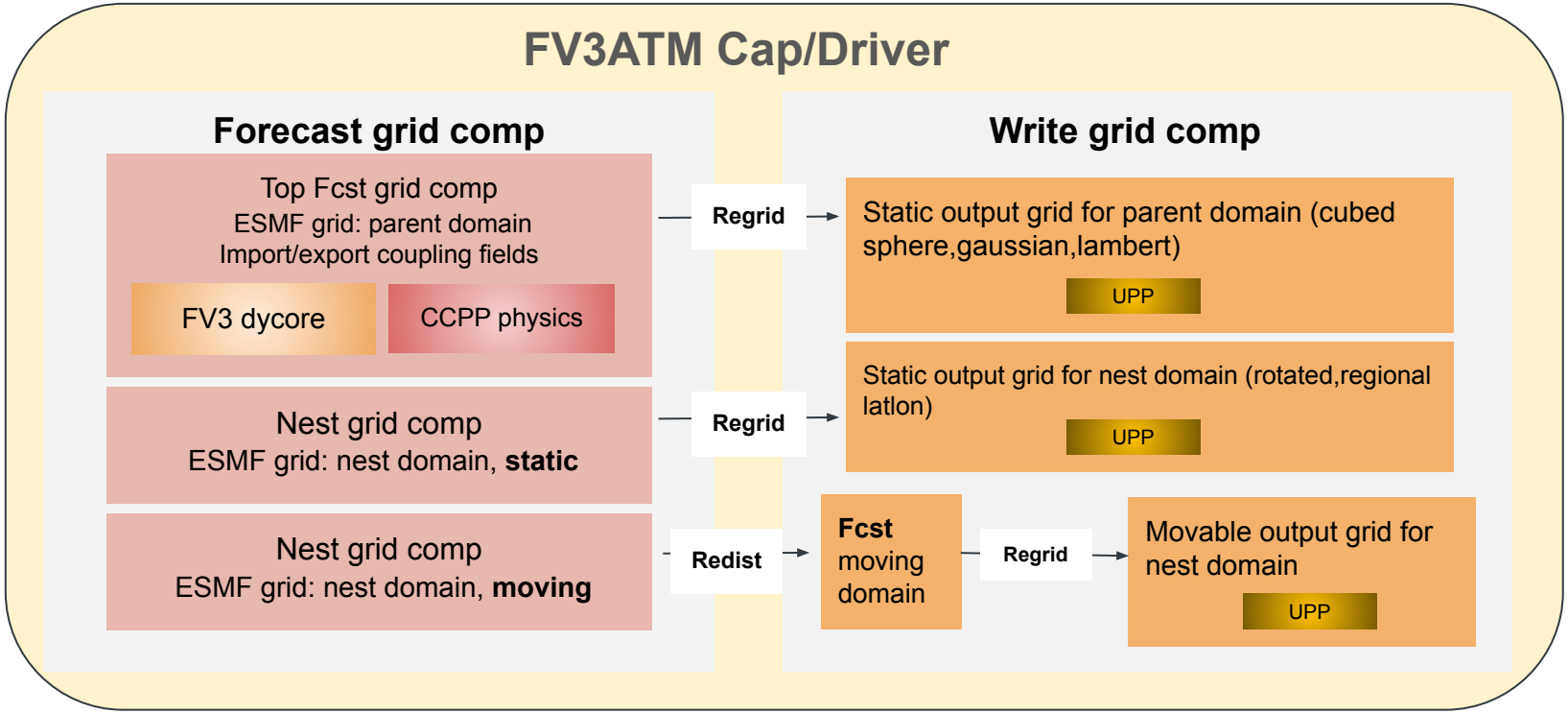
Coupling Infrastructure Development

- Noah-MP - The The community Noah land surface model with multiparameterization options
  - Developed an ESMF/NUOPC driver
  - Implement IO capability for Noah-MP modules
  - Two way coupling with UFS atmosphere
- LM4 - The GFDL land model 4
  - Developed LM4 NUOPC driver
  - Coupling with CDEPS data atmosphere
- Fire behavior model - The Community Fire Behavior Model
  - Developed a NUOPC cap to couple with UFS atmosphere grid component
  - A community model based on WRF-Fire modules

Documentation: Coupling Infrastructure Capability in UFS Weather Model, NOAA Office Note 519, 2024.

Develop generic write grid component

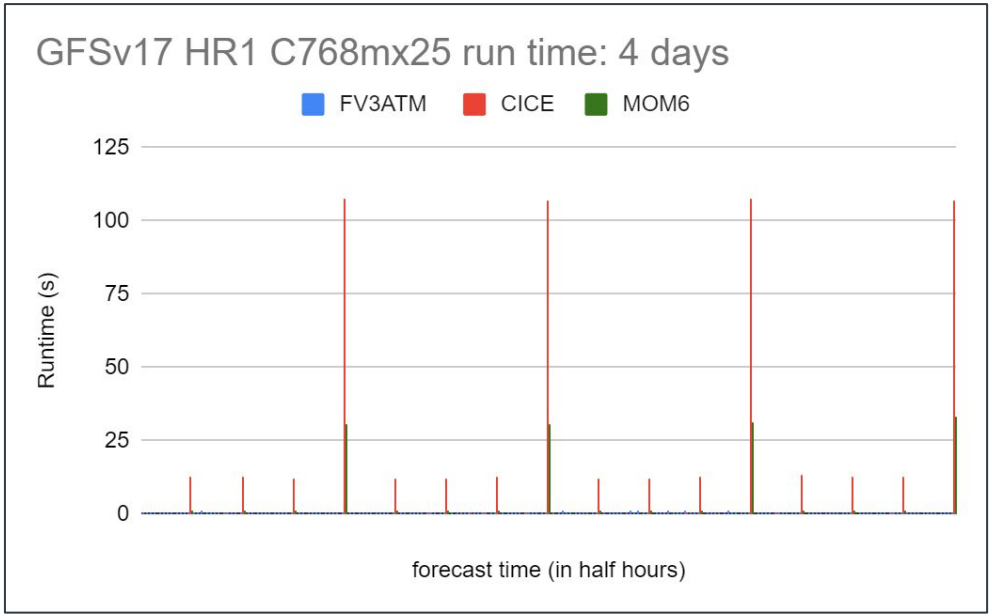
Asynchronous IO component in FV3ATM



UPP: unified Post processing
Fcst: forecast

IO bottleneck in UFS coupled configurations

- The IO bottleneck issue was found in the scalability analysis for GFSv17 HR1
- The atmosphere component (13km) is given a large number of MPI tasks (6528), ocean (25km) has 240 tasks and ice (25km) has 960 tasks.
- Load balance analysis is giving tasks to atm, ocean and ice so that they have comparable run time
- The atm has asynchronous IO so that forecast can continue without being held up by slow IO.
- Ocean and ice now only have sequential IO, when they are doing IO, the large number of atmosphere tasks are idle.
- Sequential ocean/ice IO becomes a bottleneck



Develop generic IO component

- Requirements for developing generic write grid component were collected
- Three design options were proposed and the NUOPC component implementation was selected.
- Initial testing was conducted to set up the NUOPC write component with CICE6
- Initial prototype for generalized NUOPC IO using NUOPC was implemented.
- Developing efficient generalized NUOPC IO prototype that can be applied to UFS model components.

```
# EARTH #
EARTH_component_list: MED ATM CHM OCN
ICE WAV ICEIO
EARTH_attributes::
  Verbosity = 0
::

# ICEIO #
ICEIO_model:                ufsio
ICEIO_petlist_bounds:       200 209
ICEIO_omp_num_threads:      1
ICEIO_attributes::
  Verbosity = 32529
  ConfigFile = ufsio.cice6.rc
::

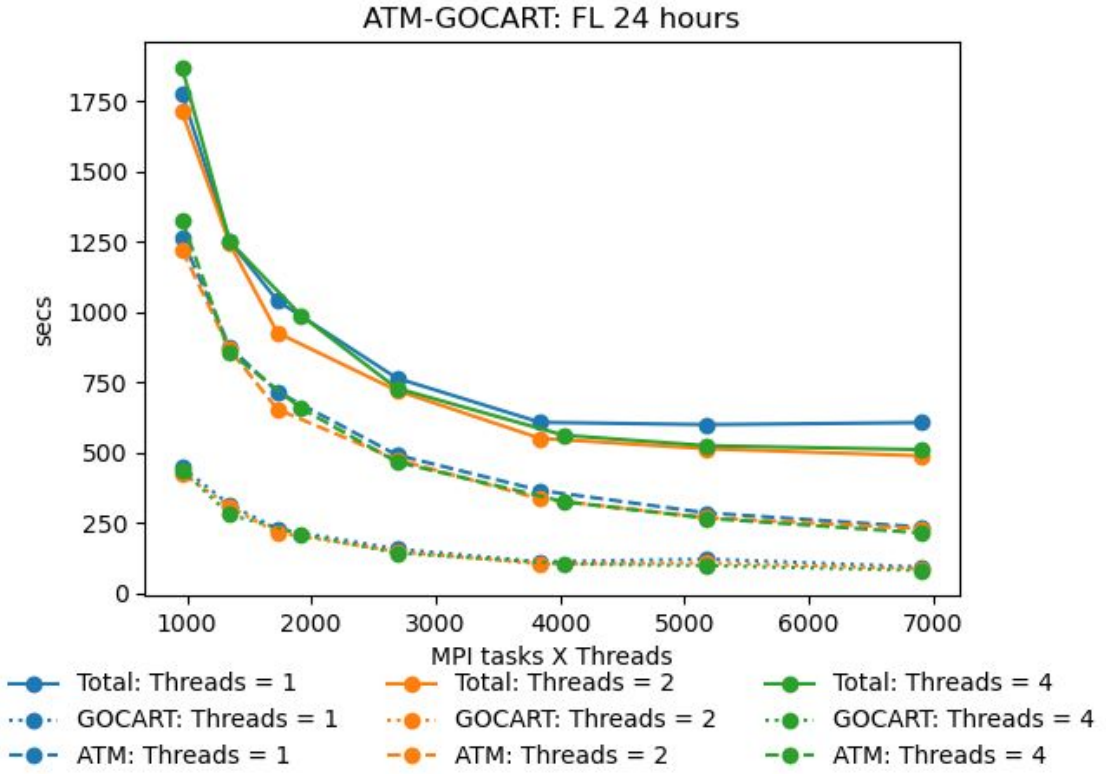
Run Sequence:

runSeq::
@43200    # 12h
  @@[coupling_interval_slow_sec]
    …
    OCN
    @@[coupling_interval_fast_sec]
      MED med_phases_prep_atm
      …
      ATM phase1
      ATM -> CHM
      CHM
      CHM -> ATM
      ATM phase2
      ICE
      WAV
      …
    @
    OCN -> MED :remapMethod=redist
    MED med_phases_post_ocn
    MED med_phases_restart_write
  @
  ICE -> ICEIO :remapMethod=redist
  ICEIO
@
::
```

Computational performance

GOCART threading capability

- Working with GEOS team on integrating and testing GOCART threading capability in UFS weather model coupled configurations
- Threading capability is working as shown in the 25km resolution C384L127 FV3ATM and GOCART coupled tests.
- The GOCART component scales well up to 4000 cores, after that increasing the number of cores has limited effect



New capabilities on FV3ATM write grid component

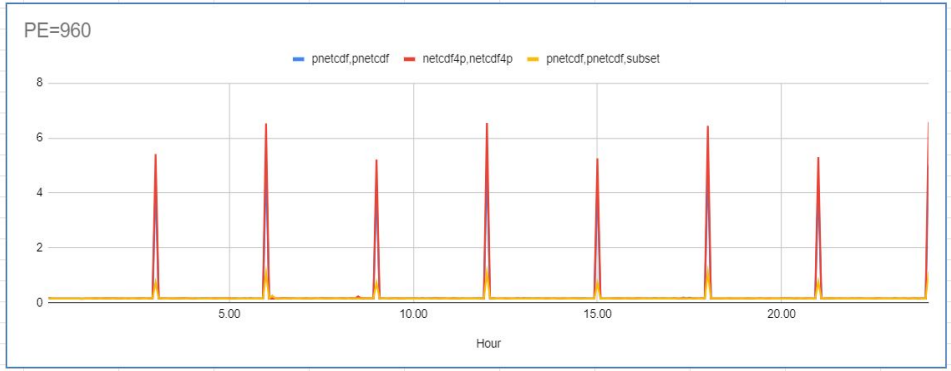
- **Write restart files**:
  - Create ESMF fields for restart fields required for UFS applications
  - Implement an ESMF bundle for each restart file
  - Use ESMF connectors to directly distribute the data from forecast grid components to write grid components
  - Extend the capability for HAFS moving nest applications
  - **Writing time comparable to FMS IO2**, saving 15s for each writing on forecast side in C768 fv3atm configuration
- Write out both Gaussian grid and cubed sphere grid history files at the same time

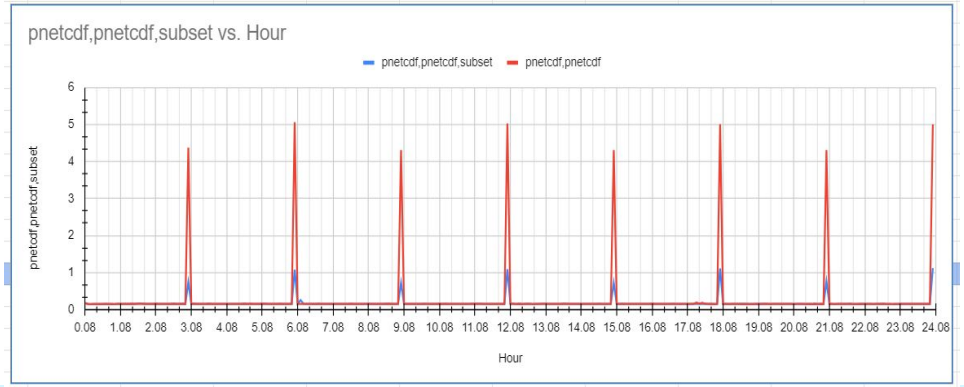
FV3ATM C768 restart writing time on write grid component

File names	fv_core.res.nc	fv_srf_wnd.res.nc	fv_tracer.res.nc	phy_data.nc	sfc_data.nc
Writing time (s)	3.5	0.1	4.2	3.7	2.3

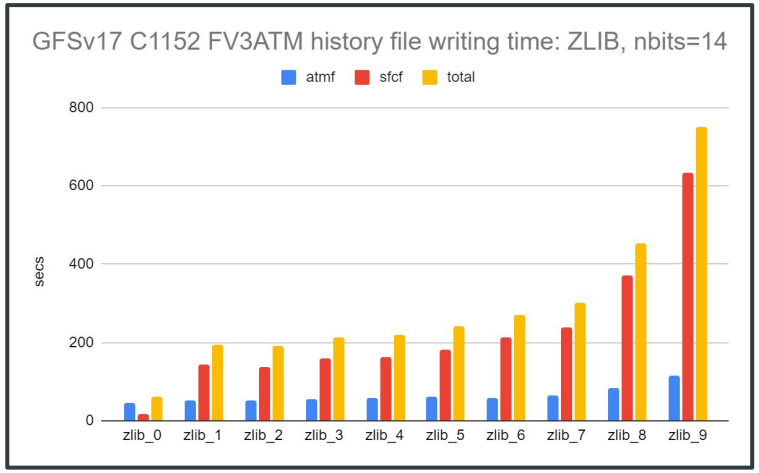
Using PIO to write CICE history and restart files

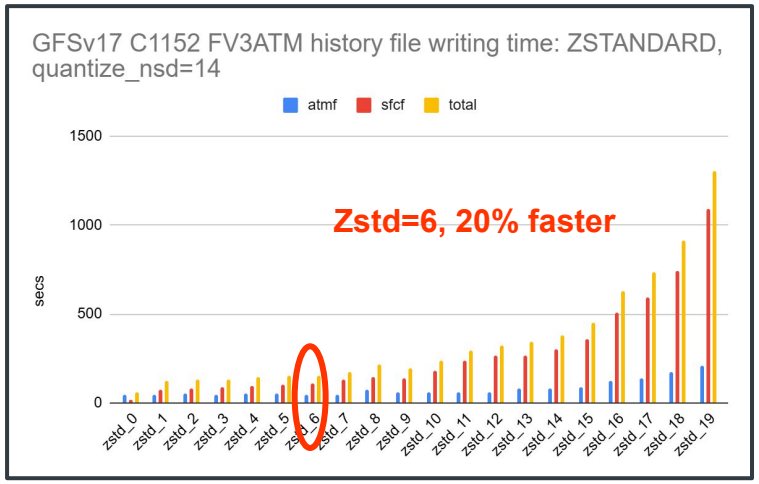
- Utilize new namelist I/O configuration options added to CICE v6.5.1
- Switches from the netcdf (serial) CICE_IO API to PIO
- Netcdf and PIO error checking is added
- Test the CICE output in 0.25 degree cice coupled configurations
- CICE restart file writing time is reduced to less than 5 secs.

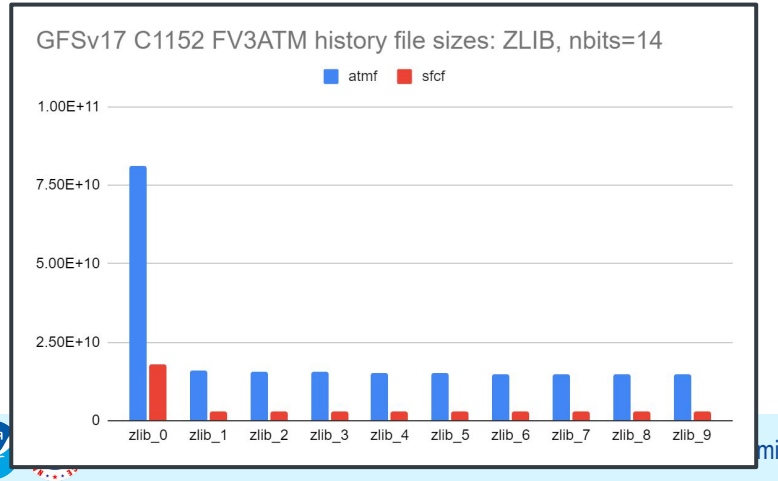


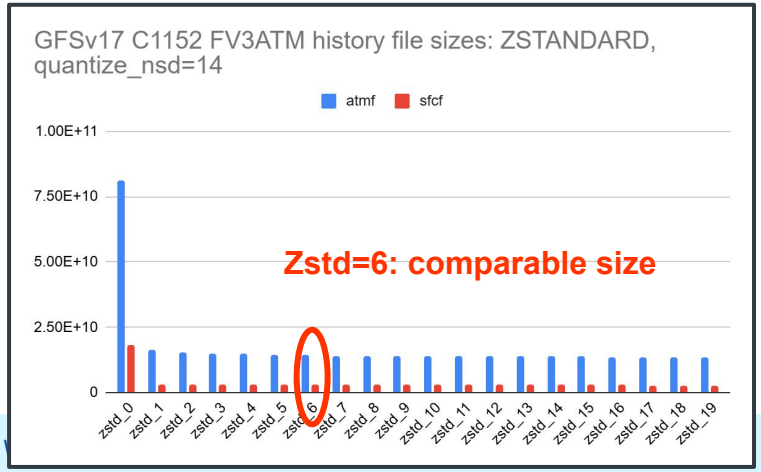


Using zstandard netcdf library in FV3ATM (conti.)









GFSv17 scalability analysis

- Monitoring GFSv17 HR1 - HR4 prototypes computational performance
- Confirm the model can run within the required operational window (~7mins)

Test case: (in HPSS)																
Goal (mins/day)	6.4			Goal reached (Y/N)				GFSv17								
Test #	Platform	total number of nodes	tasks per node	total wallclock time (s) and s/day	Forecast length (hr)	Restart frequency (hr)	ESMF managed threading (Y/N)	Mixed mode fms (Y/N)	ATM (forecast tasks: layout)	ATM io tasks: wrt_group * wrt tasks per group	ATM history output frequency	ATM total tasks/threads/nodes	GOCART On/Off, if on, NH3/NO3an*/NI on or off	MOM6 history output frequency	MOM6 total tasks/threads/nodes	CICE history output frequency	CICE6 total tasks/thread odes
George's test 1	wcoss2	251		12700 (610 s/day)	474		n		24x24	11:04	1h	3456/1	off	?	440/1	?	
HR1 - 32BIT	wcoss2	55	42	23063 (1441s/d)	384	384	N	Y	16x12	24	3hr	1408/3/34	off	3hr	220/3/5.2	3hr	012(
HR1	wcoss2	55	42	29160 (1822s/d)	384	384	N	N (all 64 bit)	16x12	24	3hr	1408/3/34	off	3hr	220/3/5.2	3hr	012(
GWV test2	wcoss2	321	32	1446s/2day	48	24	n	y	36x36	10 64	1h	10272/4/321	0ff	24	880/4	24	960/4
	wcoss2	321	32	7899 (8.2m/d)	384	24	n	y	36x36	10 64	1h to 12(	10272/4/321	0ff	24	880//4	24	960/4
	hercules	222	40	4138 413/day	240	24	n	y	36x36	10 64	1h to 12(	8888/2/222	off	24	220/2		240/2
GWV test 4/25/2	wcoss2	234	32	7036 (439/d)	390	24	n	32bit	32x32	10 64	1h to 12(	6144	off	?	220	?	
GWV test 5/2/23	wcoss2	234	32	6845 (421s/d)	390	24	n	32bit	32x32	10 64	6 (only d	6144	off	?	220	?	
Test1	wcoss2	368	32	6162, (385s/d)	384	24	n	Y	32x48	10x64	1h(126),	9856/4/308	off	6hr	480	6hr	
Test2	wcoss2	173	32	1473s, run:1082, 9r	48	24	n	Y	24x24	10x64	1hr	4096/4/128	off	6hr	480	6hr	
Test3	wcoss2	368	32	1194s, run 654, 5.5r	48	24	n	Y	32x48	10x64	1hr	9856/4/308	off	6hr	480	6hr	
Test4	wcoss2	393	32	1868s, run 1047, 8.7	48	24	n	Y	32x48	15x64	1hr	9856/4/308	off	6hr	960	6hr	
Test5	wcoss2	253	32	1242s, run 822, 6.8	48	24	n	Y	32x32	8x64	1hr	6656/4/208	off	6hr	480	6hr	
Test 6	wcoss2	238	32	1177s, run 821, 6.8	48	24	n	Y	32x32	8x64	1hr	6656/4/208	off	6hr	480	6hr	
Test 7	wcoss2	231	32	1530s, run 1219, 10	48	24	n	Y	32x32	8x64	1hr	6656/4/208	off	6hr	480	6hr	
Test 8	wcoss2	236	32	6784s, 424s/d	384	24	n	Y	32x32	8x64	1hr	6656/4/208	off	6hr	480	6hr	

Future work:

- **Develop generic write grid component:**
  - Work with ESMF team to develop a prototype NUOPC write component
    - Simple prototype that can satisfy the requirements
    - Simplify the run sequence to support different output files at random output time
  - Additional code needs to be provided to UFS model components
    - Communicate with authoritative component model managers
    - Implement the generic NUOPC write component in MOM6
    - Evaluate and benchmark the computational performance
- **Computational Optimization for the coupled configuration:**
  - Improve WW-III IO performance
- **Performance testing:**
  - Continue developing the coupled configuration load balance tools
  - Continue benchmarking and profiling the to-be-implemented operational model computational performance

Thank you!