An Update of HPC at the JMA

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## Current NWP models of NPD/JMA

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</tr>
<tr>
<td>Horizontal resolution</td>
<td>TL959(0.1875 deg)</td>
<td>TL479(0.375 deg)</td>
</tr>
<tr>
<td></td>
<td>5km</td>
<td>5km</td>
</tr>
<tr>
<td>Vertical levels / Top</td>
<td>100 0.01 hPa</td>
<td>100 0.01 hPa</td>
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<td></td>
<td>76 21.8km</td>
<td>76 21.8km</td>
</tr>
<tr>
<td>Forecast Hours (Initial time)</td>
<td>132 hours (00, 06, 18 UTC)</td>
<td>264 h (00, 12 UTC)</td>
</tr>
<tr>
<td></td>
<td>264 hours (12 UTC)</td>
<td>132 h (06, 18 UTC)*</td>
</tr>
<tr>
<td></td>
<td>39 hours (00, 03, 06, 09, 12, 15, 18, 21 UTC)</td>
<td>27 members</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39h 21 members</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6 hourly)</td>
</tr>
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<td>Initial Condition</td>
<td>Global Analysis (4D-Var)</td>
<td>Global Analysis with ensemble perturbations (SV, LETKF)</td>
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<tr>
<td></td>
<td>Meso-scale Analysis (4D-Var)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local Analysis (3D-Var)</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

* when a TC of TS intensity or higher is present or expected in the RSMC Tokyo - Typhoon Center’s area of responsibility (0°–60°N, 100°E–180°).
HPC PROCUREMENT
HPC procurement

• Requirements
  – Over 6x “effective” performance.
    • Not “theoretical (peak)” performance.
    • Evaluate by using benchmark test programs.
  – Restrictions on facilities (power).
    • Up to 4.4M Watts.

• Schedule
  – Request for information of materials ... Nov. 2014
  – Request for submission of comments ... Oct. 2015
  – Final RAPS release ... Feb. 2016
  – Contract award ... Apr. 2016
HPC procurement

• Benchmark Test
  – Programs
    – based on operational programs with next generation specs.
    • GA: Global 4D-Var(Inner:TL437)
    • GF: Global Forecast (TL1295)
    • GEPS: Global EPS (TL647)
    • MA: Meso 4D-Var(Inner:10km)
    • LA: Local 3D-Var(Inner:5km)
    • MF: Meso Forecast (asuca-5km)
    • LF: Local Forecast (asuca-2km)
  – Others ... required for storage.
    • MDTEST, IOR and original I/O benchmark program.
HPC procurement

- Rules for evaluation
  - Execute the combination of two benchmark programs (e.g. Global EPS + asuca-2km).
    - Since many programs flow simultaneously in operational use.
  - Run more than each determined number of copies within a limited time by using full nodes.
    - Required to load the I/O and network as well as CPU by using whole system.
    - The time limit and the determined number were set based on the performance of SR16000 and the requested level (6x).
      - “SR16000” is the 9th generation HPC, which was in operation since June 2012.
  - Code optimizations allowed within the some predefined rules.
    - Directives (e.g. OpenACC) is OK, but code conversion (e.g. from Fortran to CUDA) is NOT.
      - Unrealistic to convert all the operational codes during the migration period.

- Pros and Cons
  - Pros: Can acquire enough “weak scaling” HPC.
  - Cons: “Strong scaling” could not be evaluated
    - We set the time limit necessary for operation.
HPC procurement

• Result
  – Winner: HITACHI
    Inspire the Next
  • Supercomputer: CRAY
NEW HPC CONFIGURATION
Supercomputer System

- Supercomputer ... Cray XC50
  - Two independent systems.
    - Main System: Operational NWP
    - Subsystem: Backup and Development
  - Specifications

<table>
<thead>
<tr>
<th>Computational Node</th>
<th>CPU</th>
<th>Intel Xeon Platinum 8160 2.1GHz x2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of cores</td>
<td>24 x2</td>
</tr>
<tr>
<td></td>
<td>Peak Performance</td>
<td>3.2256 TFlops</td>
</tr>
<tr>
<td></td>
<td>Main Memory</td>
<td>96 GiB</td>
</tr>
<tr>
<td>Total</td>
<td>Num. of Nodes</td>
<td>2,816 (15 cabinets) x2</td>
</tr>
<tr>
<td></td>
<td>(ESM:2,741 MAMU:75)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peak Performance</td>
<td>9.083 PFlops x2</td>
</tr>
<tr>
<td></td>
<td>Main Memory</td>
<td>264TiB x2</td>
</tr>
<tr>
<td></td>
<td>Operating system</td>
<td>Cray Linux Environment</td>
</tr>
</tbody>
</table>
HPC Growth at JMA

22 times (peak performance)

Peak performance (KFLOPS)

100,000,000,000,000
100,000,000,000
100,000,000,000
10,000,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1

Year of implementation


IBM 704: 12 KFLOPS

HITAC 5020: 307 KFLOPS

HITAC 8800: 4.55 MFLOPS

HITAC M-200H: 23.8 MFLOPS

HITAC S-810: 630 MFLOPS

HITACHI S-3800: 32 GFLOPS

HITACHI SR8000: 768 GFLOPS

HITACHI SR11000: 27.5 TFLOPS

HITACHI SR16000: 847 TFLOPS

Cray XC50: 18 PFLOPS
Peak performance (Top 500)

- HPL performance of XC50
  - RMAX: 5,730.5 TFlops (62.8% of peak)
    - Ranked 25th and 26th in Top 500 (June 2018.)
  - Power: 1.354kW -> 4.232GFlops/W
    - Ranked 33rd and 34th in Green 500 (June 2018.)
Supercomputer System

- Storage for HPC ... DDN SFA14KXE
  - 3 sets for each Main system and Subsystem.
  - Filesystem: Lustre
  - Specifications (for 1 set).
    - OST ... (RAID6(8D+2P) x 28 + 10S ) x 2
      - 4TB 7,200rpm NL-SAS x 290 x 2
    - MDT ... RAID6 (4D+2P) x 2 + 2S
      - 900GB 10Krpm SAS x 14
  - Performance.
    - Total capacity : 4.8PB/system
      - 1.6PB for each set.
    - Total I/O throughput : 135GB/s/system
      - 45GB/s read/write for each set.
Effective performance

• Result of benchmark test
  – Prog1(GA:4DVar) and Prog4(LA:3DVar) achieved more than twice the performance of our requirement.
  – Prog2-2(GEPS:TL647) achieved almost same of our requirement.

Averaged performance : about 10 times
Strong scaling (Preliminary results)

**Runtimes**

GA: Global 4Dvar (Iter#:90) ...

- SR
- XC
- Limit for operational use

Lower is better

**Scaling**

GA: Global 4Dvar (Iter#:90) ...

- SR
- XC
- Ideal

**Runtimes**

GF: TL1295(132hour forecast) ...

- SR
- XC
- Limit for operational use

Lower is better

**Scaling**

GF: TL1295(132hour forecast) ...

- SR
- XC
- Ideal
Strong scaling (Preliminary results)

Runtimes

**Meso-Scale forecast (asuca-5km)**

- MF: asuca-5km (51 hour forecast) ... Runtimes
  - SR
  - XC
  - Limit for operational use

**Local forecast (asuca-2km)**

- LF: asuca-2km (10 hour forecast) ... Runtimes
  - SR
  - XC
  - Limit for operational use

Scaling

**Meso-Scale forecast (asuca-5km)**

- MF: asuca-5km (51 hour forecast) ... Scaling
  - SR
  - XC
  - Ideal

**Local forecast (asuca-2km)**

- LF: asuca-2km (10 hour forecast) ... Scaling
  - SR
  - XC
  - Ideal

Lower is better
MIGRATION
FROM SR TO XC
Difficulties of Migration

• From Hitachi SR series to Cray XC series
  – Brand new CPU (Big change since 2001 )
    • From IBM POWER to Intel Xeon.
  – Brand new compiler (Big change since the mid 1960’s )
    • From Hitachi compiler to Cray (or Intel) compiler.
  – Migration from “Hitachi Service Subroutine”
    • These are provided by Hitachi along with his compiler but not supported on Cray system.

• The number of programs to be migrated are increasing.
  – Over 1,300 operational programs.
    • Total lines of programs: ~6,000,000

• The number of staffs are also increasing.
  – Gap of knowledge and ability for porting.
  – Difficulty in sharing information.

• Supposed to be the biggest migration challenge of this century.
  – We introduced a small-scale Xeon “training” server in advance and accumulated know-how.
  – Also, by using “Redmine”, we shared information about bugs and tips of new system.
Schedule of Migration

• Before Jun. 2017
  – Porting test at Xeon “training” server
• Jun. 16 2017
  – Start using XC40 at U.S.A
• Aug. 1 2017
  – Start using XC50 (2 cabinets) at U.S.A
• Sep. 5 2017
  – Start using full XC50 (15 cabinets) at U.S.A
• Dec. 1 2017
  – Start using XC50 Main system set in the JMA site.
• Jun. 5 2018
  – Start XC50 operation.
Migration from SR to XC

• Basic Policy
  – Prohibit the upgrade of specifications at the time of migration.
    • In case that new bugs add in the upgrade, it would be difficult to isolate reasons from system.

• Result
  – Success in migration, and started in operation in June 5 2018.
  – However, some system trouble occurred during the migration period, and it was investigated and resolved with the vendors.
    • CPU, Memory and I/O...
Thrash out some issues

- **CPU issues**
  - After starting to use full XC50, trouble “calculation result does not reproduce” occurred with 3 CPUs.
  - 3 cases: case “O”, case “Ku” and case “Ka”
    - These cases were named each from the Initial of first discoverers.
  - JMA staffs identified troubled CPU and Hitachi exchanged it in all cases.
    - The exchanged CPU is investigating with the vendor side.

<table>
<thead>
<tr>
<th>Case</th>
<th>Detection date</th>
<th>Occurrence condition (program)</th>
<th>Error frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Nov. 2017</td>
<td>Various OpenMP parallel programs</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Ku</td>
<td>May. 2018</td>
<td>Only when using Cray compiler and Intel MKL in combination</td>
<td>100%</td>
</tr>
<tr>
<td>Ka</td>
<td>Jul. 2018</td>
<td>Only in a specific program (Global 4D-Var) (This case was confirmed by Cray when execute HPL.)</td>
<td>~50%</td>
</tr>
</tbody>
</table>
Thrash out some issues

• I/O issues
  – Execution delay
    • In node arrangement using Rank3 (inter-cabinet) communication, some MPI program was significantly delayed compared to normal.
      – It seems that communication from I/O and user program(MPI) were congested.
    • By optimizing the parameters around Lustre, the issue were almost eliminated.

Execution time of Ocean Assimilation using 16 nodes.
(Expected to finish in about 6 minutes.)

Red is neighbor

Neighor, but inter-cabinet placement

Inner-cabinet

Inter-cabinet
... Too slow!!

color = (max_vnode) – (min_vnode)
Thrash out some issues

• Memory issues 1
  – Memory leak
    • Due to a bug in CLE(6.0UP04), MemAvailable of ESM node decreased with each “aprun” command.

CLE: Operating system for ESM node.
ESM node: Kinds of computational node, run MPP programs via “aprun”.
aprun: Command to launch program for ESM nodes.
Thrash out some issues

• Memory issues 2
  – Memory Fragmentation
    • Execution delay occurred in programs using large hugepages.
      – Need periodic reboot even now.
        » Question to XC users ...
        • How often do you reboot your operational HPC?

Over 64MB is very small

Fragmentation progresses again…

Node reboot

Memory fragmentation status on xm_0_socket0 in July 2018
FUTURE PLAN
## NWP models of NPD/JMA in future (plan)

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<th>Global Spectral Model</th>
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<th>Global Ensemble</th>
<th>Meso-scale Ensemble</th>
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<tr>
<td>GSM</td>
<td>MSM</td>
<td>LFM</td>
<td>GEPS</td>
<td>MEPS</td>
<td></td>
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<td>Aviation forecast Disaster risk reduction</td>
<td>One-week forecast Typhoon forecast</td>
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<td>Japan and its surroundings (4080km x 3300km)</td>
<td>Japan and its surroundings (3160km x 2600km)</td>
<td>Global</td>
<td>Japan and its surroundings (4080km x 3300km)</td>
</tr>
<tr>
<td><strong>Horizontal resolution</strong></td>
<td>TL1295(0.1389 deg)</td>
<td>5km</td>
<td>2km</td>
<td>TL647(0.2778 deg)</td>
<td>5km</td>
</tr>
<tr>
<td><strong>Vertical levels / Top</strong></td>
<td>128 0.01 hPa</td>
<td>96 37km</td>
<td>76 21.8km</td>
<td>128 0.01 hPa</td>
<td>96 37km</td>
</tr>
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<td><strong>Forecast Hours (Initial time)</strong></td>
<td>132 hours (06, 18 UTC) 264 hours (00, 12 UTC)</td>
<td>51 hours (00, 12UTC) 39 hours (03, 06, 09, 15, 18, 21 UTC)</td>
<td>10 hours (00-23 UTC hourly)</td>
<td>264 h (00, 12 UTC) 132 h (06, 18 UTC)* 27 members</td>
<td>39h 21 members (00, 06, 12, 18 UTC)</td>
</tr>
<tr>
<td><strong>Initial Condition</strong></td>
<td>Global Analysis (LETKF/4D-Var hybrid)</td>
<td>Meso-scale Analysis (LETKF/4D-Var hybrid)</td>
<td>Local Analysis (3D-Var)</td>
<td>Global Analysis with ensemble perturbations (SV, LETKF)</td>
<td>Meso-scale Analysis with ensemble perturbations (SV)</td>
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Thank you for your attention.