Futurs du noyau dynamique
Future of dynamical cores

Mikhail Tolstykh,
Marchuk Institute of Numerical Mathematics RAS,
Hydrometcentre of Russia

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Tribute to Jean-Francois Geleyn
Jean-Francois Geleyn introduced me into the world of numerical weather prediction.

This had changed my scientific career dramatically.
Lessons from Jean-Francois

• Do not be afraid of doing something that nobody has tried.
• If somebody has done something, it probably can be done better.
• If you see a wall on your way, stop and think: the should be a way around.
• Implement your ideas efficiently (both algorithmically and in coding) (i.e. long time step)
A view on global NWP models

Based on the description in ‘Weather Prediction by Numerical Process’, by L.F. Richardson, 1922

http://mathsci.ucd.ie/~plynch/Publications/RFFF-WX-02-NoAbs.pdf
Courtesy of P.Lynch
## Current global NWP models

<table>
<thead>
<tr>
<th>Forecast Centre (Country)</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMWF (Europe)</td>
<td>Coupled O-A 0.25 TCo1279 L137 (~9km)</td>
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</tr>
<tr>
<td>Met Office (UK)</td>
<td>10km L70 7days</td>
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</tr>
<tr>
<td>Météo France (France)</td>
<td>~Tₜ1198c2.2 L105 (7km on W Europe to 36km)</td>
<td>~Tₜ1798c2.2 L105 (from 5km on W Europe to 24km)</td>
</tr>
<tr>
<td>DWD (Germany)</td>
<td>13 km L90 (6.5 km L60 for Europe)</td>
<td>13 km L120 (6.5 km L80 for N-Atlantic, Europe)</td>
</tr>
<tr>
<td>HMC (Russia)</td>
<td>0.24°x0.17° L51</td>
<td>0.1°x0.08° L104</td>
</tr>
<tr>
<td>NCEP (USA)</td>
<td>C768 L64 (13 km)</td>
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</tr>
<tr>
<td>Navy/FNMOC/NRL (USA)</td>
<td>T425L60</td>
<td>T681L60</td>
</tr>
<tr>
<td>CMC (Canada)</td>
<td>Yin-Yang (0.14°x0.14°) L84 coupled atm-ocean-ice</td>
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</tr>
<tr>
<td>CPTEC/INPE (Brazil)</td>
<td>20km L64</td>
<td>TBD</td>
</tr>
<tr>
<td>JMA (Japan)</td>
<td>TL959 L100</td>
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</tr>
<tr>
<td>CMA (China)</td>
<td>GRAPES(0.25, L90)</td>
<td>GRAPES(0.15, L90)</td>
</tr>
<tr>
<td>KMA (Korea)</td>
<td>12km L120</td>
<td></td>
</tr>
<tr>
<td>NCMRWF (India)</td>
<td>10kmL70</td>
<td></td>
</tr>
<tr>
<td>BoM (Australia)</td>
<td>12 km L120</td>
<td>12 km L120</td>
</tr>
</tbody>
</table>

### Horizontal resolution
- ~ 7-25 km

### Vertical resolution
- 50-137 levels

WGNE table
http://wgne.meteoinfo.ru/nwp-systems-wgne-table/wgne-table/
Future global models

• Resolution \( \sim 3-5 \text{ km} \)
• Nonhydrostatic
• Scalable at \( O(10^5 \text{ processor cores}) \)
• Include atmospheric composition models
  (Air mass conservation)
Question to solve 1

• Grid?
  - icosahedral (DWD)
  - cubed sphere (NCEP, UKMO)
  - Yin-Yang (ECCC)
  - reduced lat-lon (ECMWF)

Review by Staniforth, Thuburn, QJRMS 2012
No obvious winner so far
Question to solve 2

• Time integration scheme?
  - Horizontally explicit, vertically implicit
  - Semi-implicit

If the semi-implicit scheme is chosen, the solver should be local (i.e. multigrid)

The choice strongly affects scalability
Question to solve 3

• Advection:
  - Eulerian
  - Semi-Lagrangian

Arguments for both. Dominance of semi-Lagrangian advection disappears.
Question to solve 4

- Scalability: only local communications between processor cores are preferred. (1 remote operand~10 local operand~100 Flops). There are some exceptions for GPUs, XeonPhi.

- In dynamical core, preferably, local approximations. Examples: low-order finite differences, finite volumes (NCEP,...), finite elements (UKMO,...), discontinuous Galerkin method, spectral elements (NCAR, ...)
More questions

• Choice of equations set and prognostic variables
• Choice of vertical coordinate
• ...

There exist arguments for many choices
SLAV model

10-days operational medium range forecasts
0.225° in lon, 0.16°-0.24° in lat, 51 levs.

LETKF-based ensemble prediction system
0.9° in lon, 0.72° in lat, 96 levs, ongoing development.

Subseasonal and seasonal probabilistic forecast
(WMO S2S Prediction project)
1.4°x1.1°L28 currently,
0.9°x0.72°L96, by the end of this year.
Changes on ACC for 72hr forecast of H500 (left) and H250 (right) in 2012-2019 for SLAV (orange), ECMWF (red), UKMO (blue). Northern extratropics, 12 UTC run. Moving average over 12 months.

https://apps.ecmwf.int/wmolcdnv
SLAV strong scaling at Cray XC40 x86 Broadwell
3024x1513x126 grid, max. 6 OpenMP threads.
53% efficiency at 13608 cores, 64 % at 9072 cores

SLAV20 Intel Xeon Phi2
strong scaling (black line) in comparison with RHMC classic cluster (grey line).
Conclusions

• The model resolution increases as computing power grows
• It is more and more difficult to use this power
• Variety of options for each question
• Jean-Francois’s goal for computational efficiency remains unchanged