Parallel Processing of the Semi-Lagrangian Scheme in GRAPES

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Outline

- Introduction of GRAPES project
- Introduction of GRAPES-global model
- Improvement of parallel processing on SL scheme.
  - S-L scheme in GRAPES
  - Improvement of S-L
  - Performance
- Some other performance issue
- Discussion
- Summary

GRAPES project

Purpose: develop the new national NWP operational systems of China.

Started in 2001.

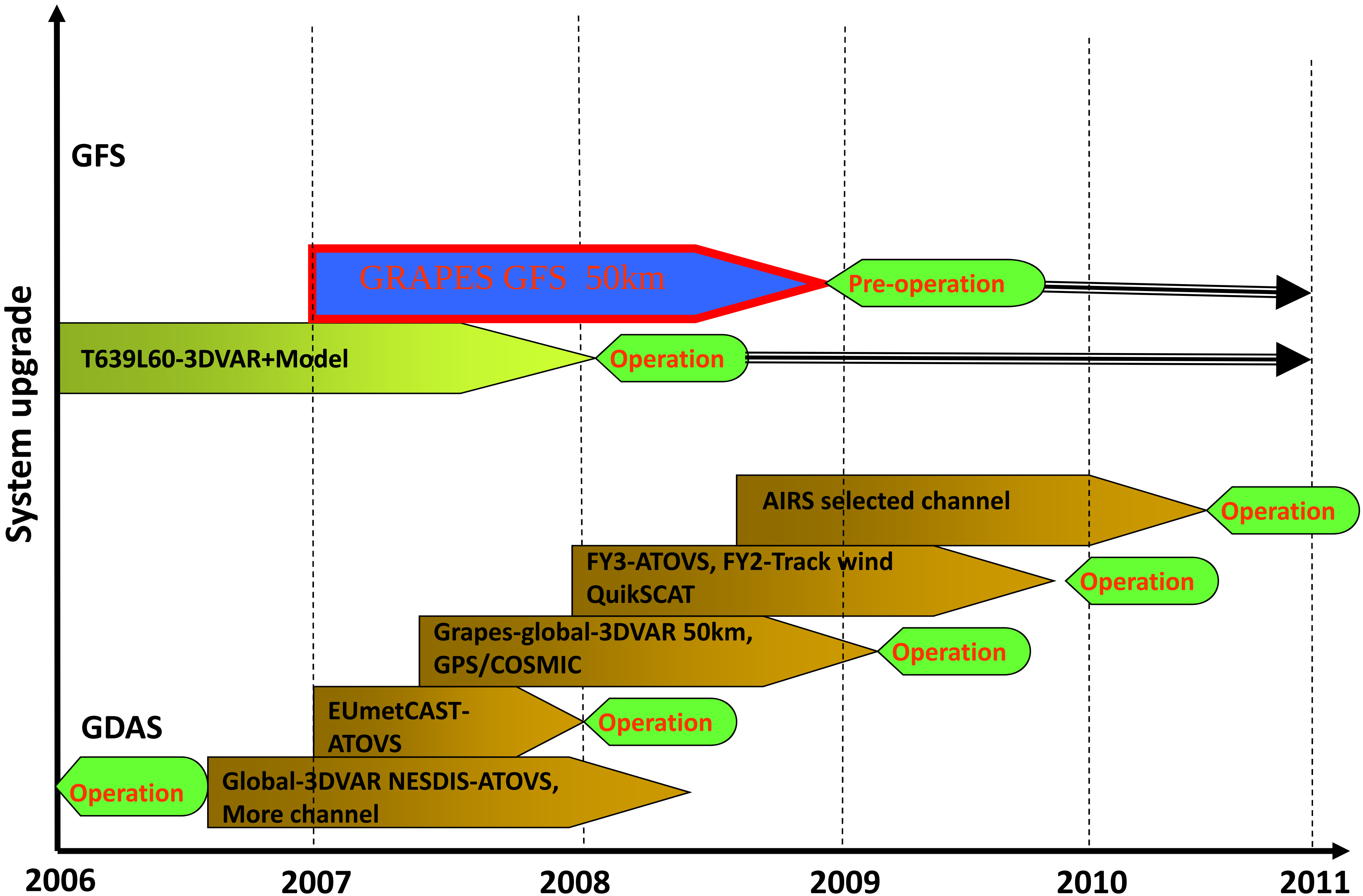
What have been done:

- Global forecast system
    - Global 3DV system (P level and model level)
    - GRAPES-global model(include its t-l & adj)
    - 4DV
    - Ensemble forecast system (SV)
- Limited area forecast system
    - 3DV system
    - GRAPES-meso model(include its t-l & adj)
    - 4DV
    - GRAPES-ruc
    - …

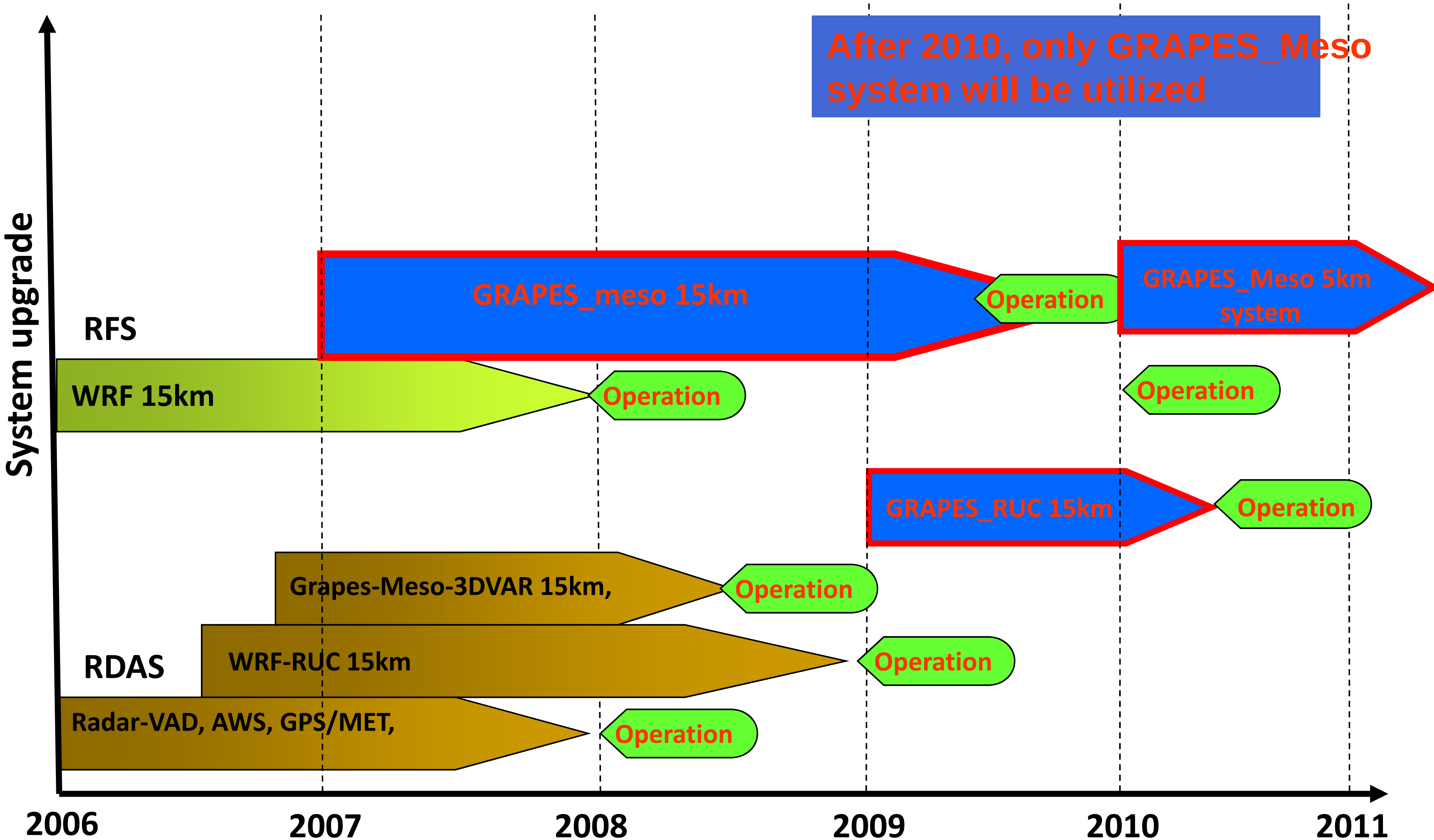
Current NWP Operational models in CMA

	Global Spectral Model (T_L639L60)	Meso Scale Model (GRAPES_Meso)	10day Ensemble (T_L213L31)	Typhoon deterministic & Ensemble forecast
Forecast range	Short- and Medium-range forecast	Rainfall forecast Short-range forecast	10day forecast	Typhoon forecast
Forecast domain	Global	East Asia (8340km x 5480km)	Global	
Horizontal resolution	T_L639(0.28125 deg)	15km	T213(0.5625 deg)	
Vertical levels / Top	60 0.1 hPa	31 10hPa	31 10 hPa	
Forecast Hours (Initial time)	240 hours (00、12 UTC)	72 hours (00, 12UTC)	240 hours (00、12 UTC) 15 members	120 hours (00, 06, 12, 18 UTC) 120 hours (00、12 UTC) 15 members
Initial Condition	Global Analysis (NCEP GSI)	GRAPES_3DVAR	NCEP SSI + Vortex relocation and Intensity adjustment with ensemble perturbations Perturbations are produced by Breeding-method	

CMA Global Forecast System

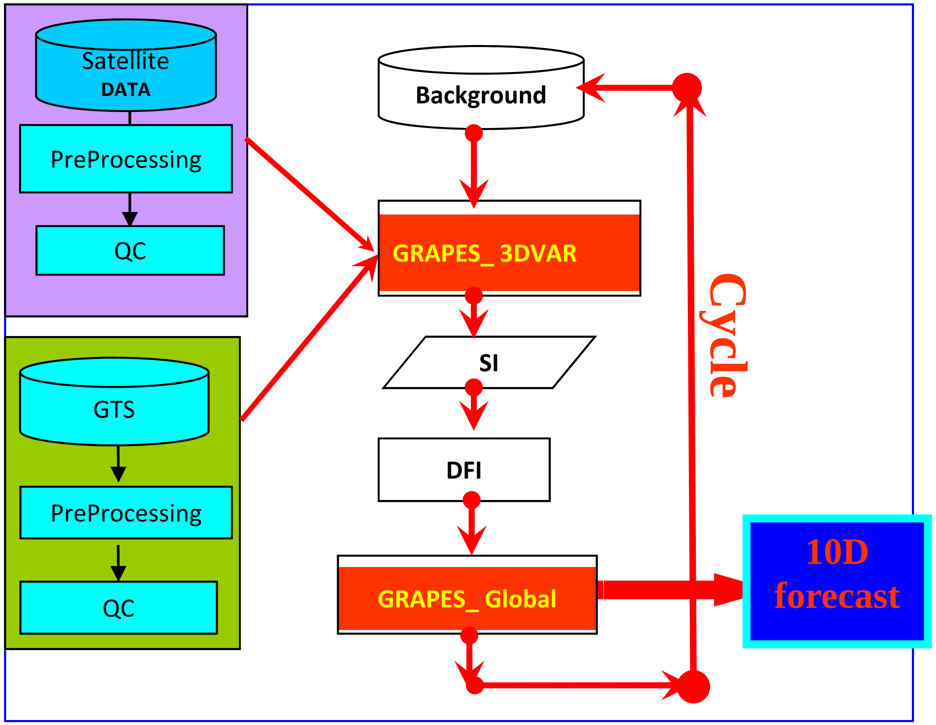


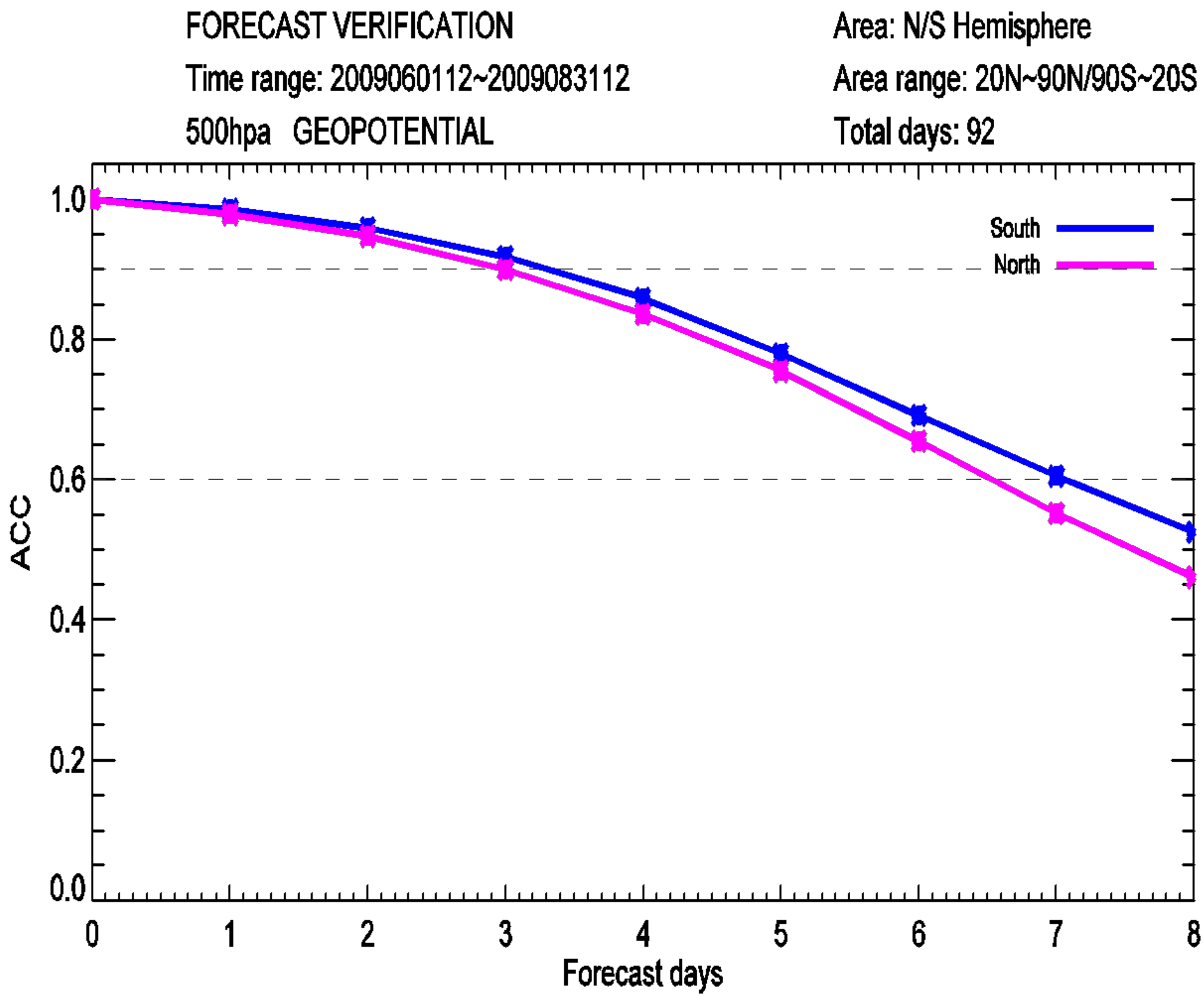
CMA Meso-scale Forecast System



GRAPES-GFS

- **GRAPES_GFS**:
  medium-range global forecast
  - **GRAPES_Global 50km L36 with model top at 10 hPa**
  - **GRAPES_3DVAR at 1.125 degree (global version)**
  - **6-hourly cycle**
  - **240 hour forecast (12UTC)**
  - GTS, NOAA15 amsua cha4-10;NOAA16 amsua cha4-11;NOAA16 amsub cha2-5;NOAA17 amsub cha2-5, METEOSAT-9 & MTSAT AMV




FORECAST VERIFICATION
Time range: 2009060112~2009083112
500hpa GEOPOTENTIAL
Area: N/S Hemisphere
Area range: 20N~90N/90S~20S
Total days: 92
South
North
ACC
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
Forecast days

Main features of GRAPES dynamics

- Fully compressible equations
- Height-based terrain-following coordinate
- Option of Hydrostatic and Non-hydrostatic
- Arakawa C lat-lon horizontal grid

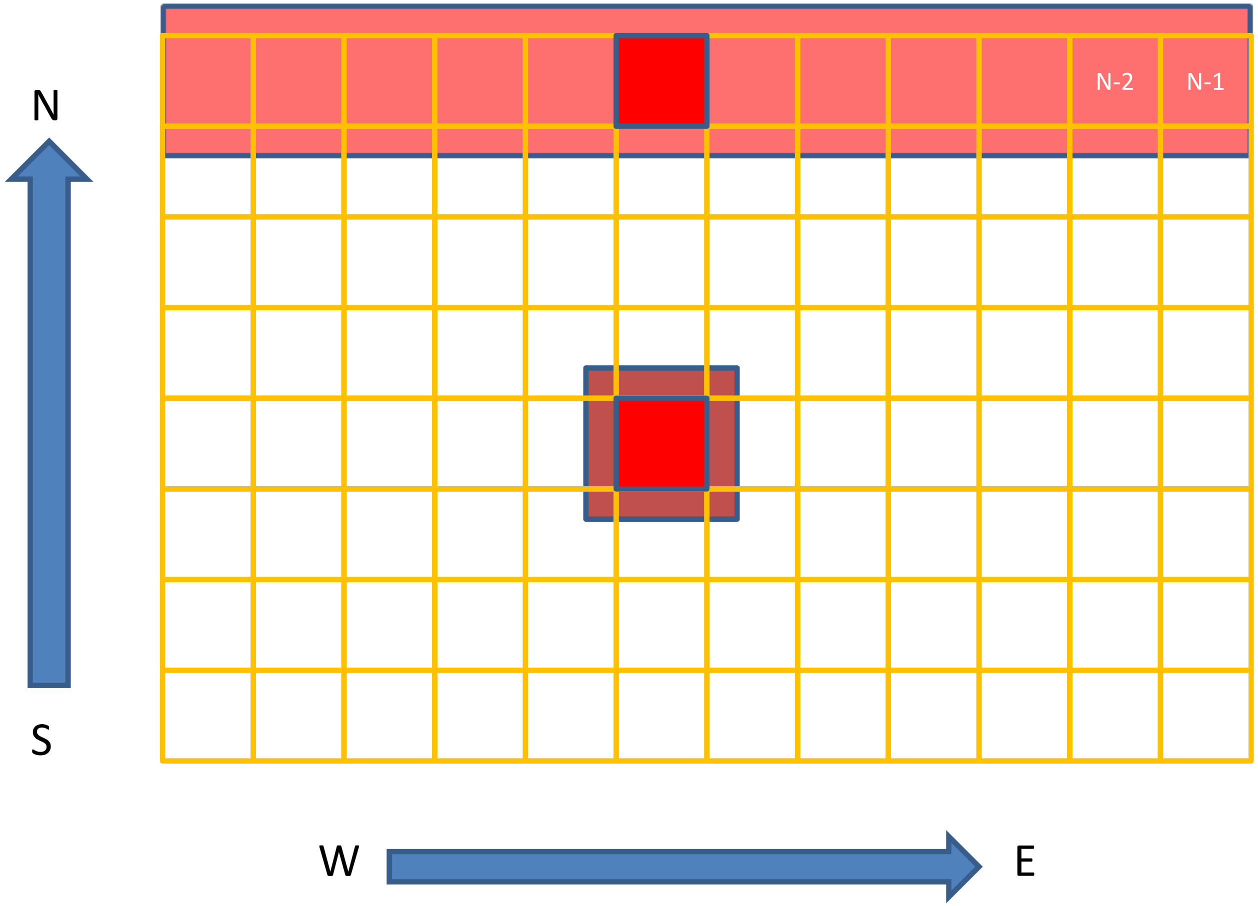
  Charney-Phillips vertical grid
- 2-time-level semi-implicit semi-Lagrangian (SISL) time-stepping
- QMSL for scalar advection
- GCR for Helmholtz Eq.
- 3D vector form of SISL formulation
- Spherical & polar effects of trajectory calculation
- Cascade interpolation
- Mass fixer
- Polar filter
- 4th order horizontal diffusion

Special for Global version

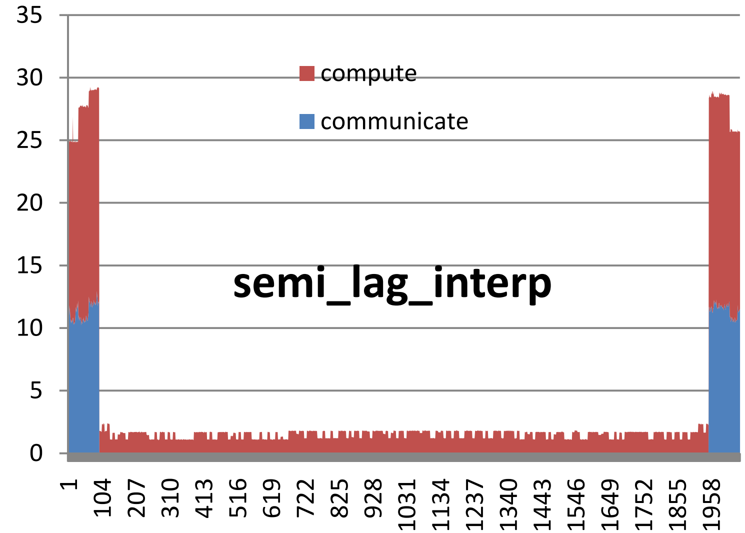
Parallel processing of GRAPERS-global

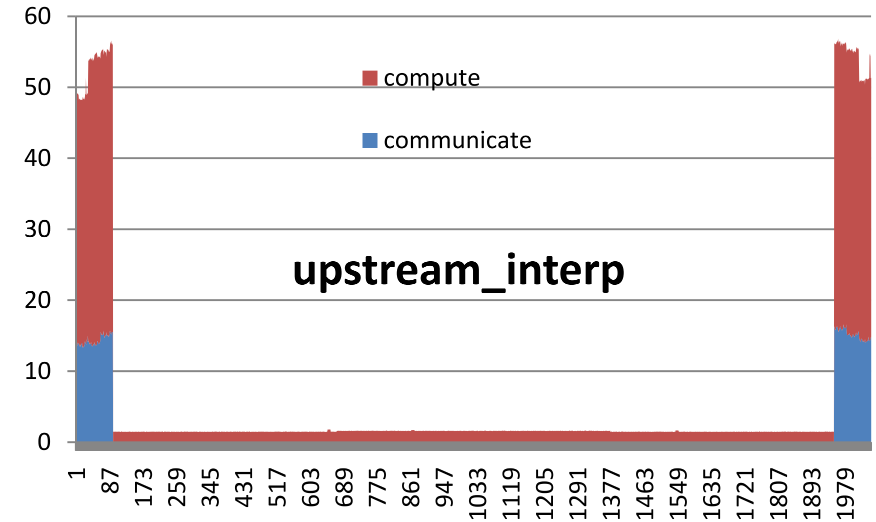
- “Standard” Lat-Lon domain decomposition with halo region overlapped between sub domains for data dependence
- Single I/O node
- Large halo region is required for semi-Lagrangian scheme, depend on the maximum wind speed. In GRAPES, there are six extra grid points on each side of sub domain and much bigger near the poles.

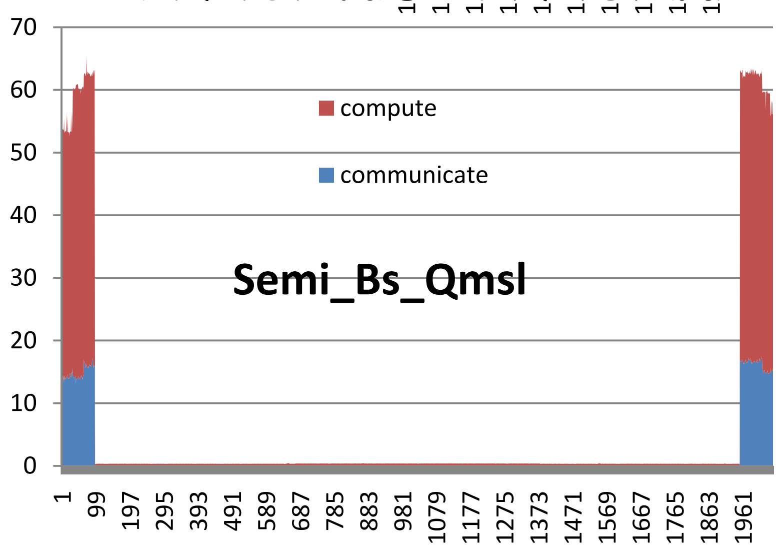
Domain decomposition & halo

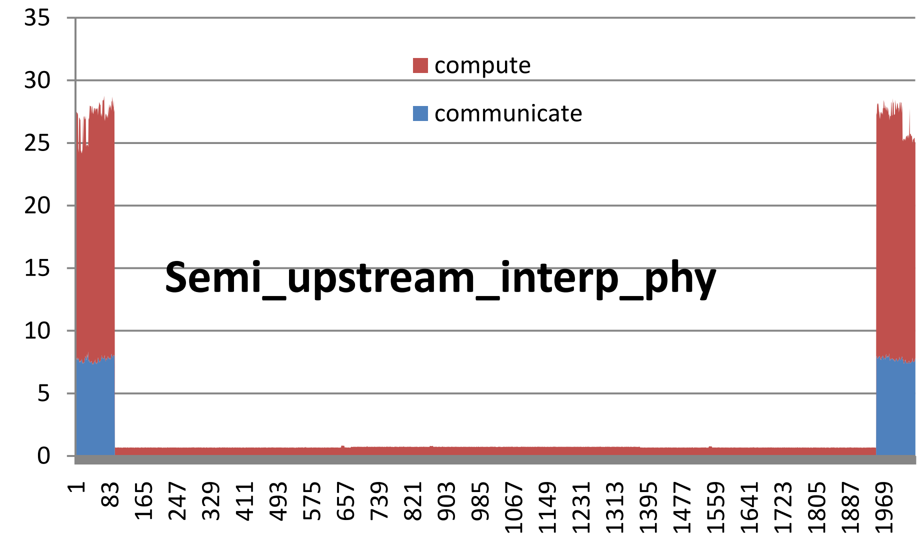


Timing of S-L related routines on 2048 core system









Disadvantage of big halo

- Inefficient use of memory.
- Increase the communication.
- Large memory requires higher memory bandwidth, decrease the performance of single node.

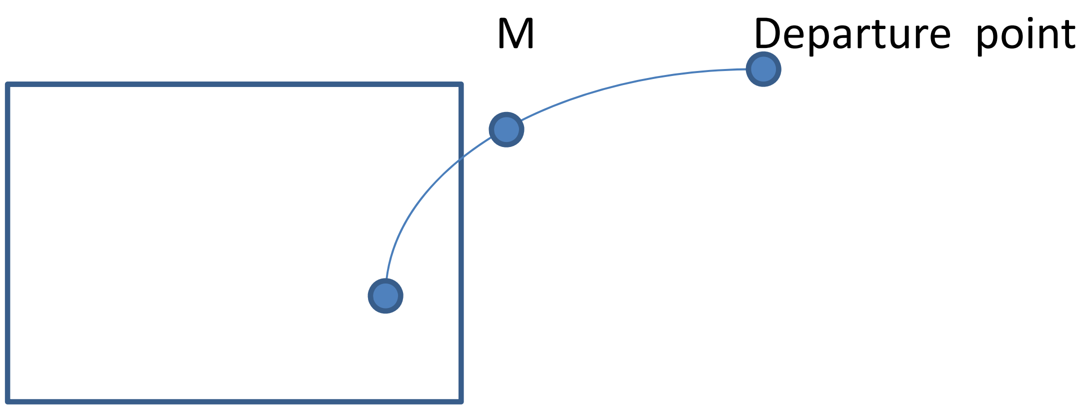
S-L scheme in GRAPES-global

- GRAPES use **2-time-level semi-Lagrangian scheme:**

$$\varphi(x_{grid}, t+\Delta t) = \varphi(x_{grid} - \delta x, t)$$

Departure point:

$$\delta x = \Delta t \times U(x_{grid} - \frac{\delta x}{2}, t + \frac{\Delta t}{2})$$



S-L scheme in GRAPES-global

- **Algrithem:**

A1 Compute $U(x_{grid}, t+\frac{\Delta t}{2})$ **by extrapolation t and t-Δt**

A2 Compute the mid-point by the wind at grid point: $\delta' x^{1}_{t+\Delta t/2} = \frac{\Delta t}{2} U(x_{grid}, t+\frac{\Delta t}{2})$

A3 Get the Wind at mid-point : $U(x_{grid} - \delta' x^{n}_{t+\Delta t/2}, t+\frac{\Delta t}{2})$

A4 Compute the mid-point by the wind at mid-point:

$$\delta' x^{n+1}_{t+\Delta t/2} = \frac{\Delta t}{2} U(x_{grid} - \delta' x^{\mathrm{n}}_{t+\Delta t/2}, t+\frac{\Delta t}{2})$$

A5 Repeat A3,A4

A6 Get the departure point: $\delta x = 2 \times \delta' x^{\mathrm{n+1}}_{t+\Delta t/2}$

A7 S-L interpolate

parallel processing of S-L

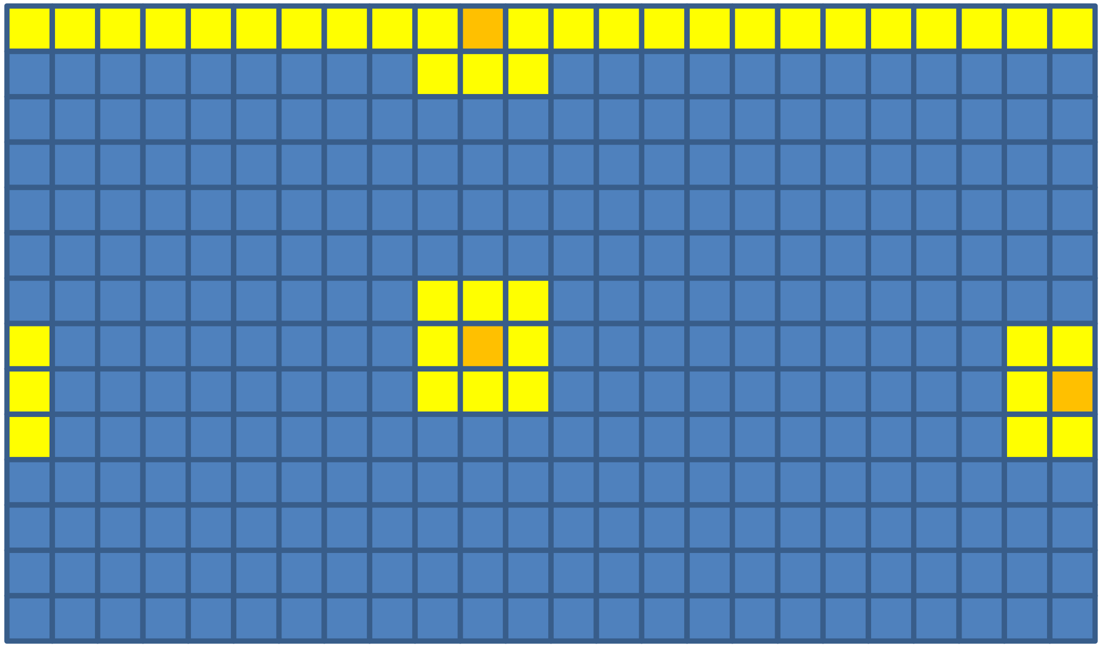
“communication on demand”

“ Instead of sending the data back, Send the results back”

Define neighbors (step1)

give each neighbor an index start form 1

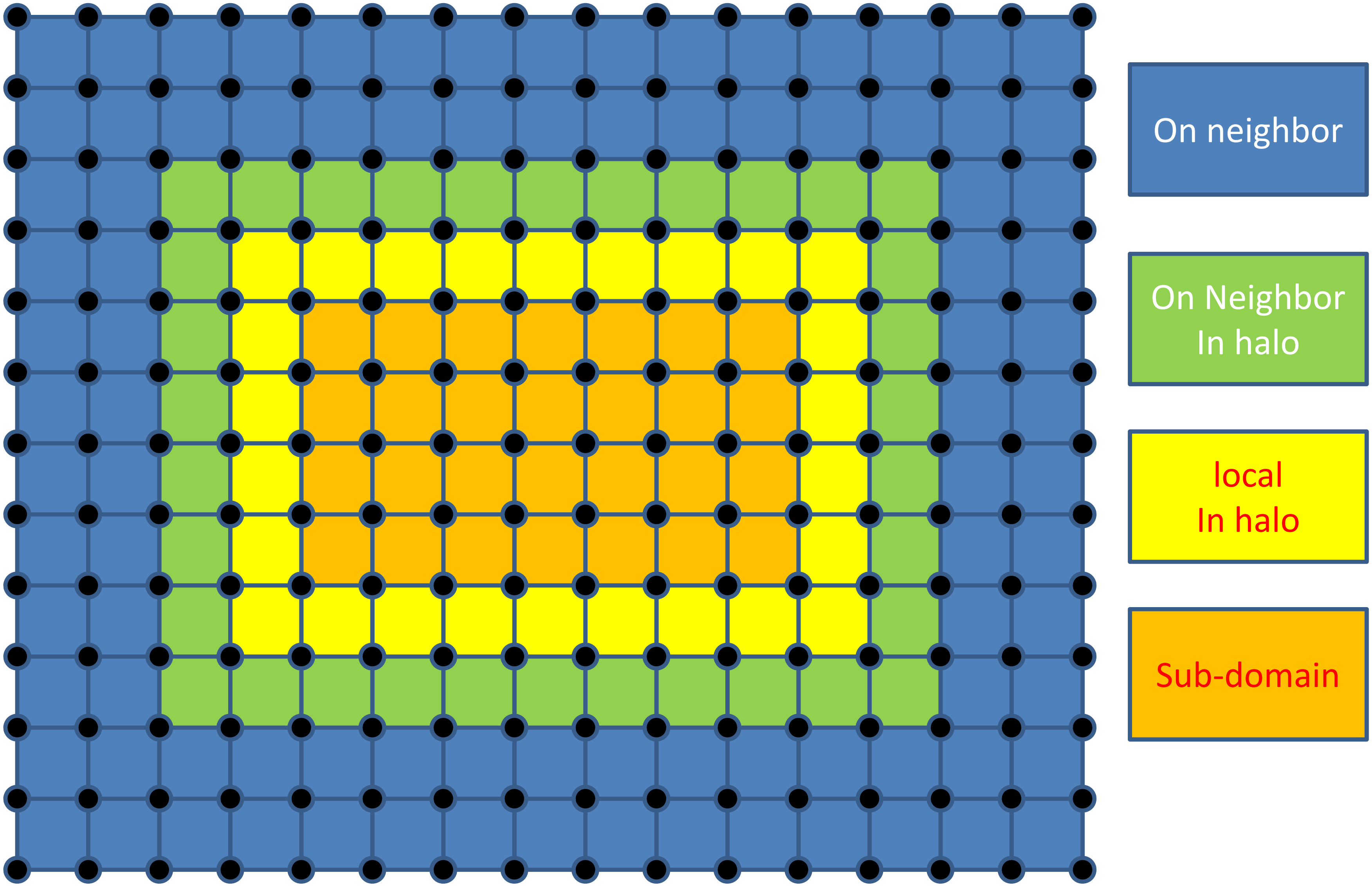
set a table (neighbor index <-> global index)



Parallel processing of S-L

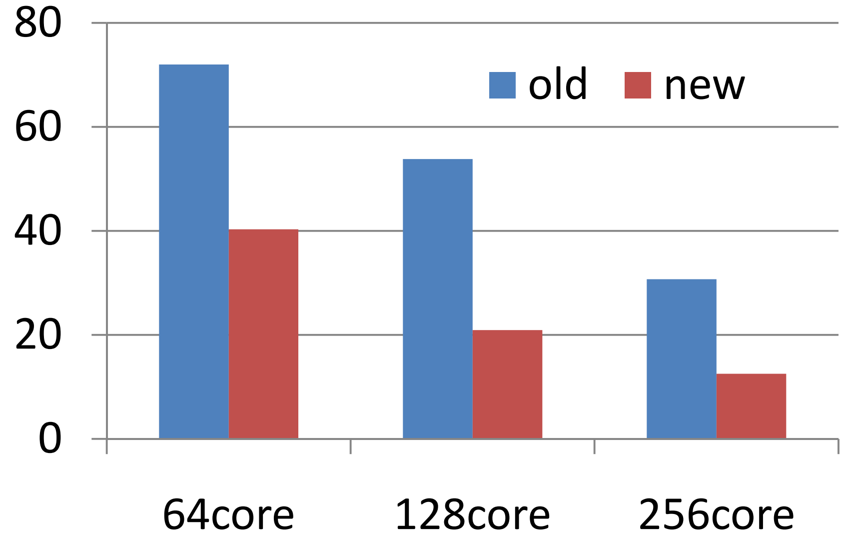
- Step2: compute wind of t+Δt/2
- Step3: compute mid-point position(in sub-domains)
- Step4: Set up position information table
  - if mid-point is outside, send the position to the neighbor
- Step5: interpolate the wind of mid-points
  - Start the asynchronous receive from my neighbors if needed
  - Interpolate the wind for my neighbors and asynchronous send to them if needed
  - Interpolate the wind for myself
  - Wait until communication finished
  - Place the received data, wind(sub-domain)
- Step6: repeat 3-5
- Step7: compute departure points position (in sub-domains)
- Step8: Set up position information table(like 4)
- Step9: interpolate the value of departure points (like 5)

Departure/ mid-points



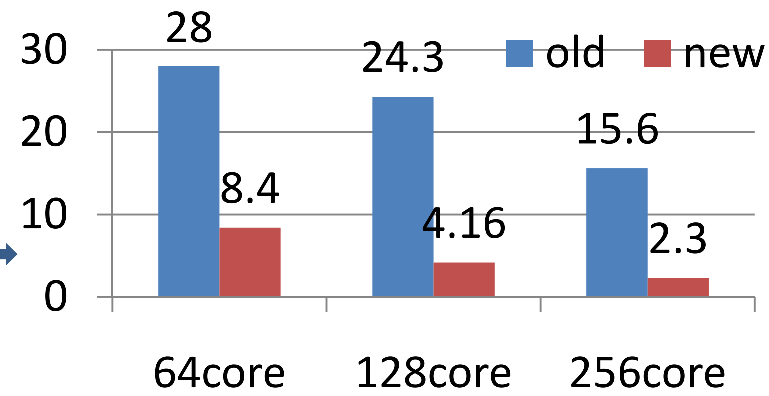
Time in computing departure point position

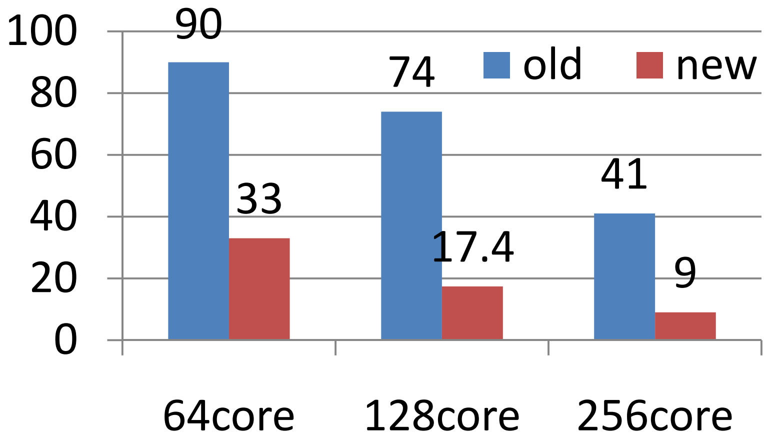
- GRAPES-global use C grid, 4 sets of departure point table are needed ： u,v,pi at full level and w at half level
- 0.5° resolution
- 24hr forecast,144 steps

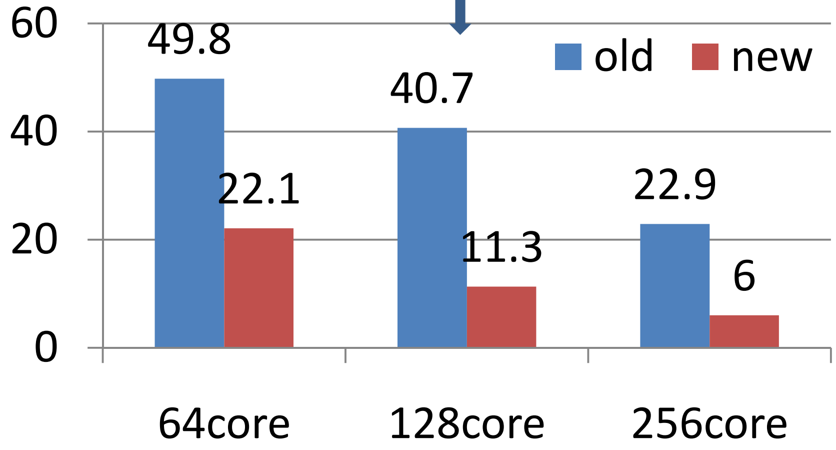


S-L Interpolation

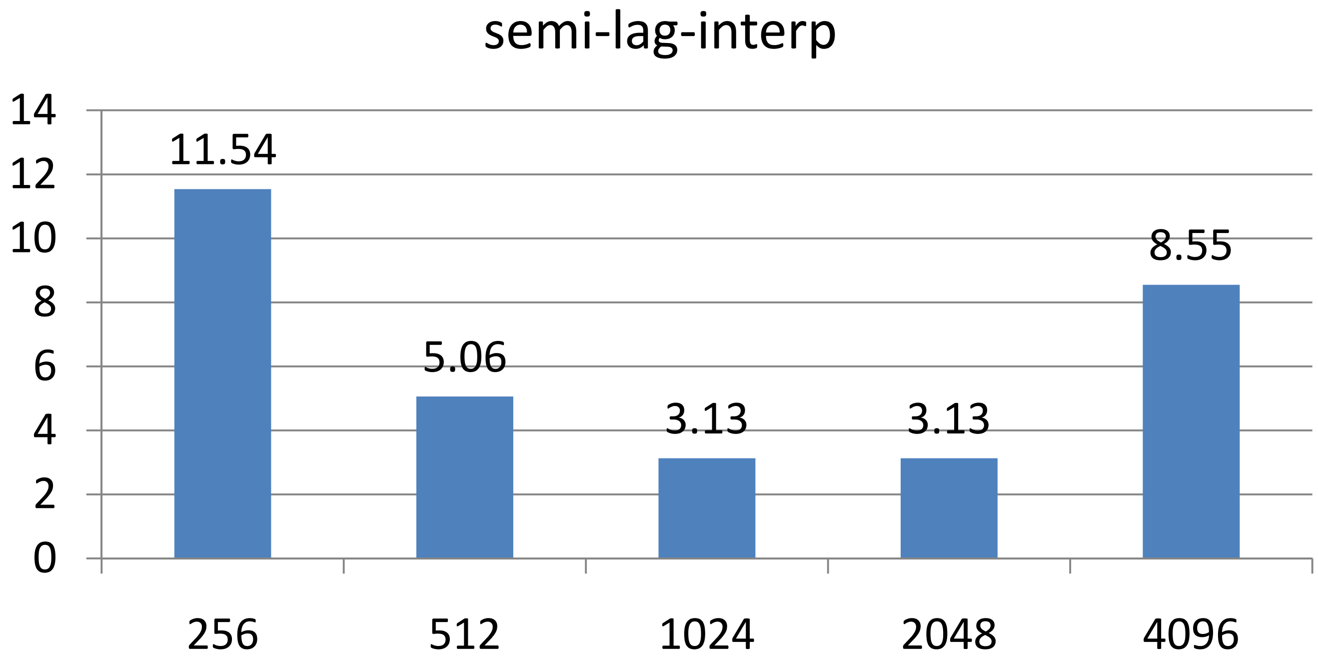
- Three S-L interpolation subroutines in grapes
  - semi-get-uptream
  - upstream-interp
  - semi-up-phy-interp







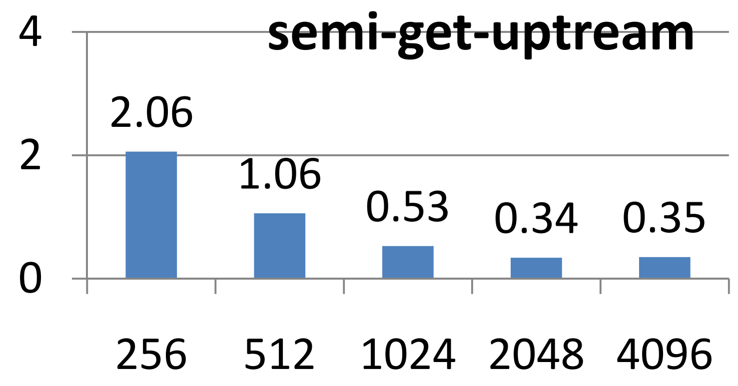
Scalability of setting departure points

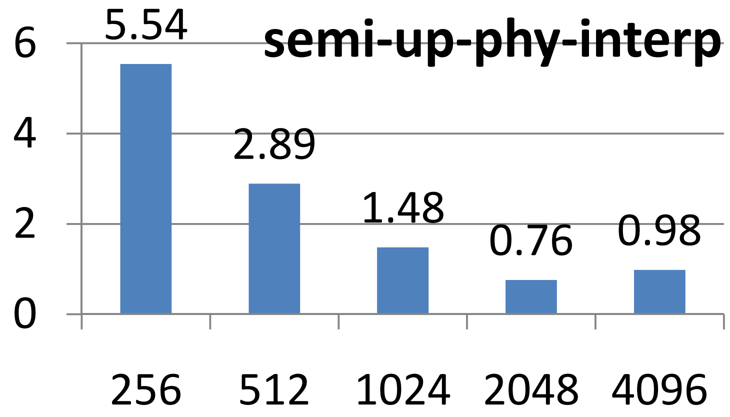


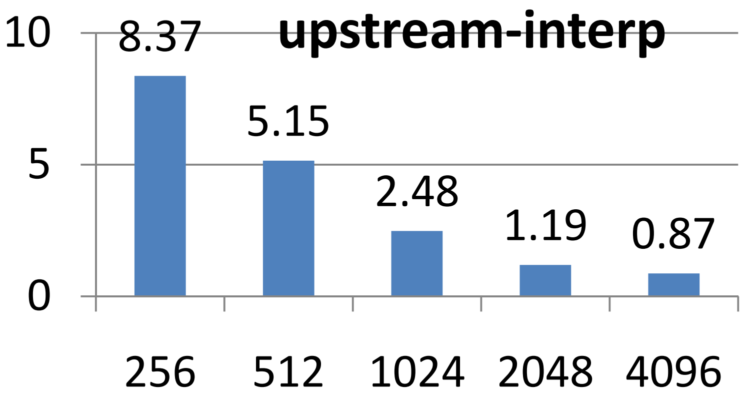
Total time of setting departure points in 32 steps at 0.25 °

S-L Interpolation

- Three S-L interpolation subroutines in grapes.
- 0.25°, 32steps

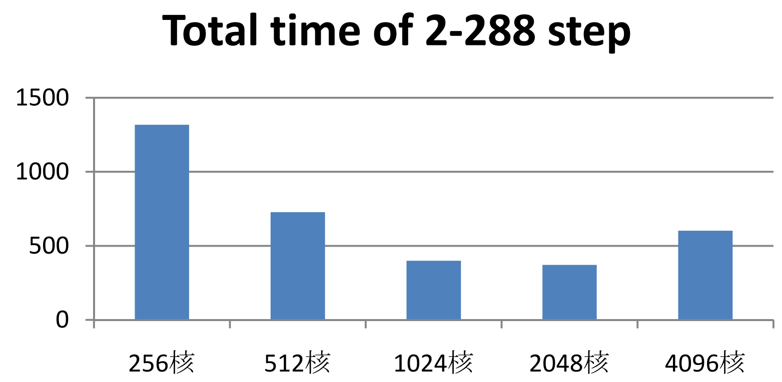


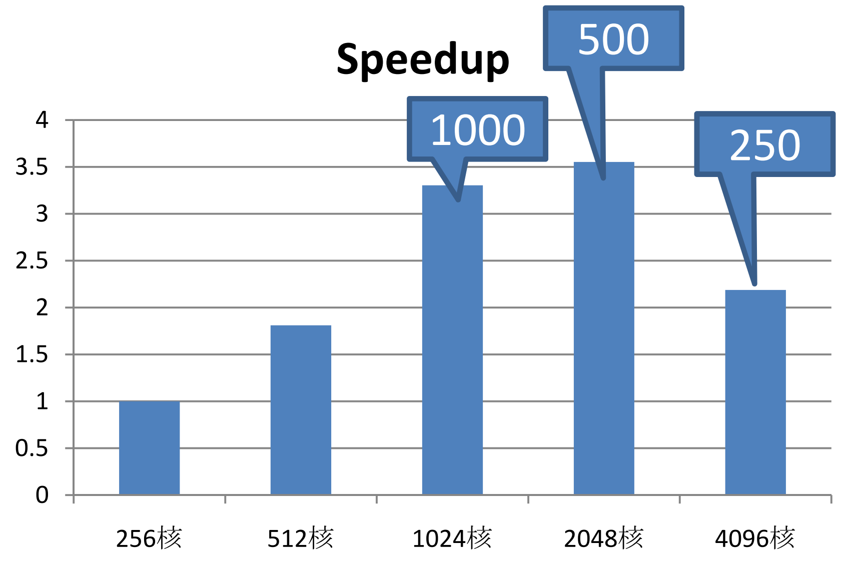




Performance of GRAPES-global(core)

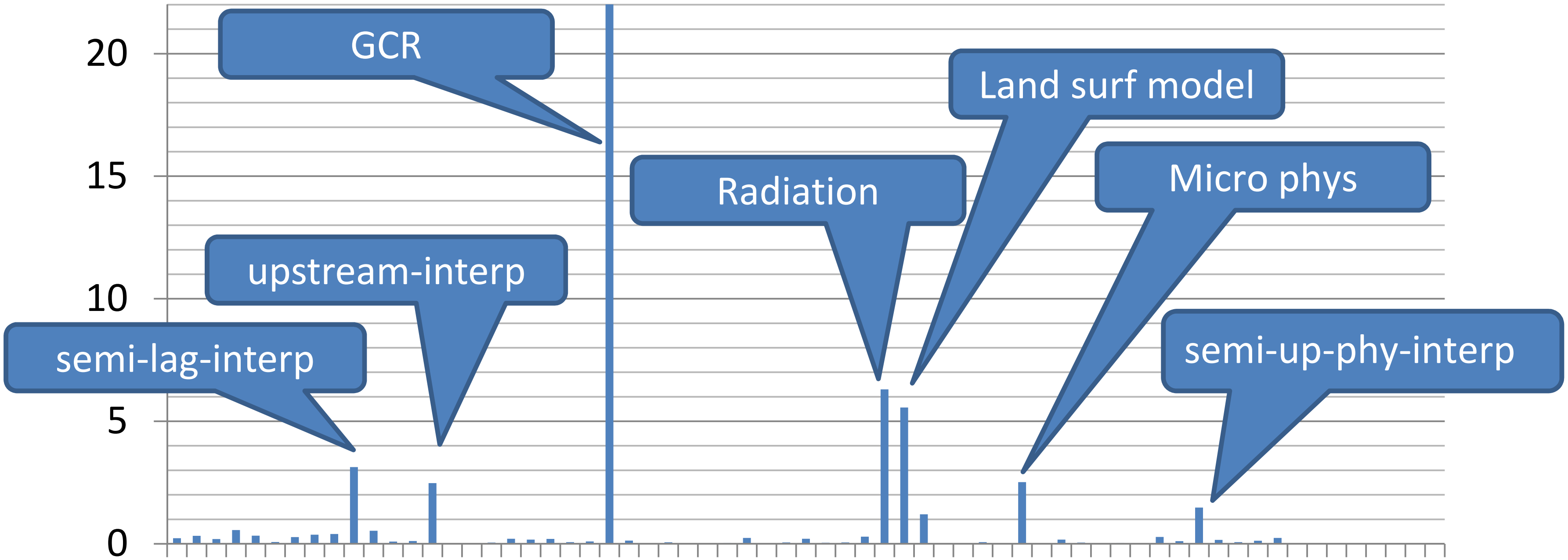
- Resolution: 0.25°
- Time step: 300s
- Forecast ： 24h
- Initialize, I/O are not included





GRAPES-global (core) performance

1024 tasks 0.25, 32steps



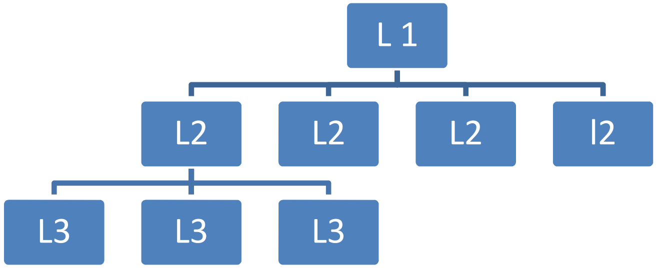
Break down Total time to 65 pieces

GRAPES-global I/O

- GRAPES use single node to perform I/O
- I/O time is dominated by distribution of data.
- Distribute the 3 D initial data (6G) layer by layer takes almost 1 hr. for 2048 mpi task
- Distribute the data by 3 D block takes about 200s for 2048 mpi tasks
- The time is increase super-linearly with amount of mpi tasks

Discussion and future work

- Further optimization:
  - Combine the u,v,pi,w together
  - Combine the different variable together
- Is the new method wins the old one?
  - Timing in the equator area
  - Do it in GRAPES-meso
- One-side communication?
  - In the stage of setup SL position information tab.
- Massively parallel
  - More neighbors
  - I/O



Summary

- S-L was improved for GRAPES-global.
- Large part of computation of GRAPES-global is consumed by the Helmholtz solver.
- I/O time is dominated by data distribution, not by disk operation
- OpenMP is needed

- Thank you