Universitatea
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Facultatea de
Automatică și
Calculatoare

Catedra de
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WRF ACCELERATION AND COUPLING WITH FLEXPART

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Topics

- WRF Overview
- Radiation Transfers
- CUDA Overview
- FLEXPART Overview
- Related Work
- CUDA Acceleration
- Results
- Future Work
- Conclusions

WRF THE WEATHER

RESEARCH

&

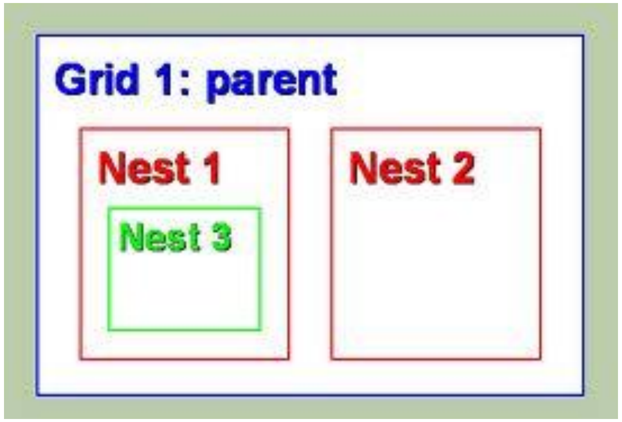
FORECASTING MODEL

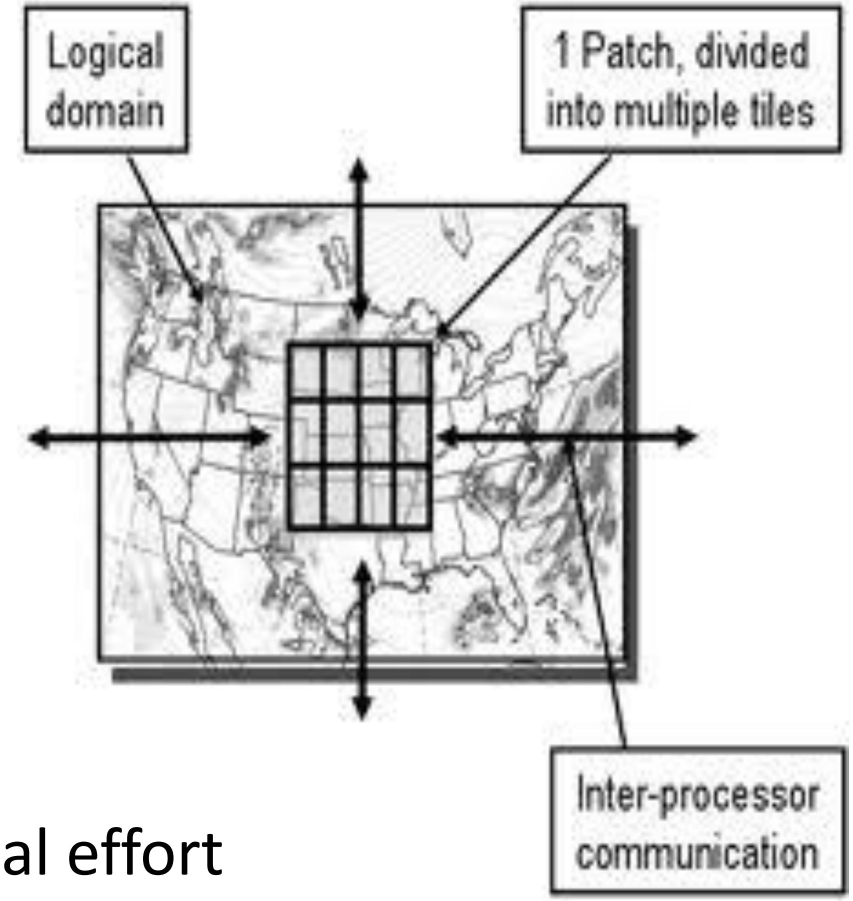
FLEXPART

WRF Overview

Weather Research and Forecasting Model

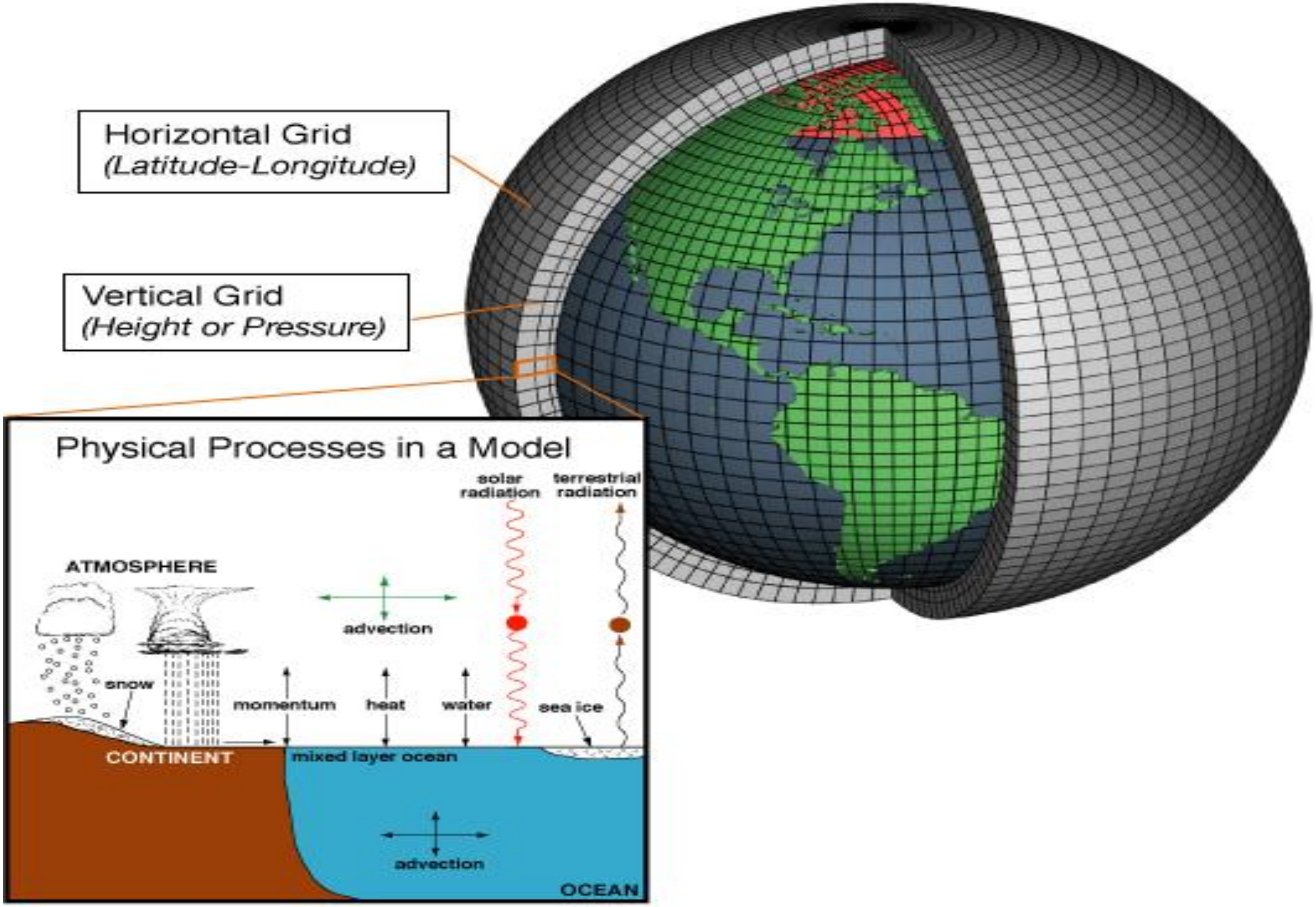
- Regional numeric model
- Scalability and efficiency
- MPI/OpenMP support
- NETCDF output




Logical domain
1 Patch, divided into multiple tiles
Inter-processor communication

- Nest-based computational effort

WRF Overview



WRF Radiation Transfers

Rapid Radiative Transfer Model (RRTM)

- **inirad():** computes the ozone mixing ratio distribution
- **setcoef():** input for the radiative transfer algorithm
- **mm5atm():** prepares atmospheric profiles
- **gasabs():** calculates gaseous optical depths
- **rtrn():** calculates the radiative transfer

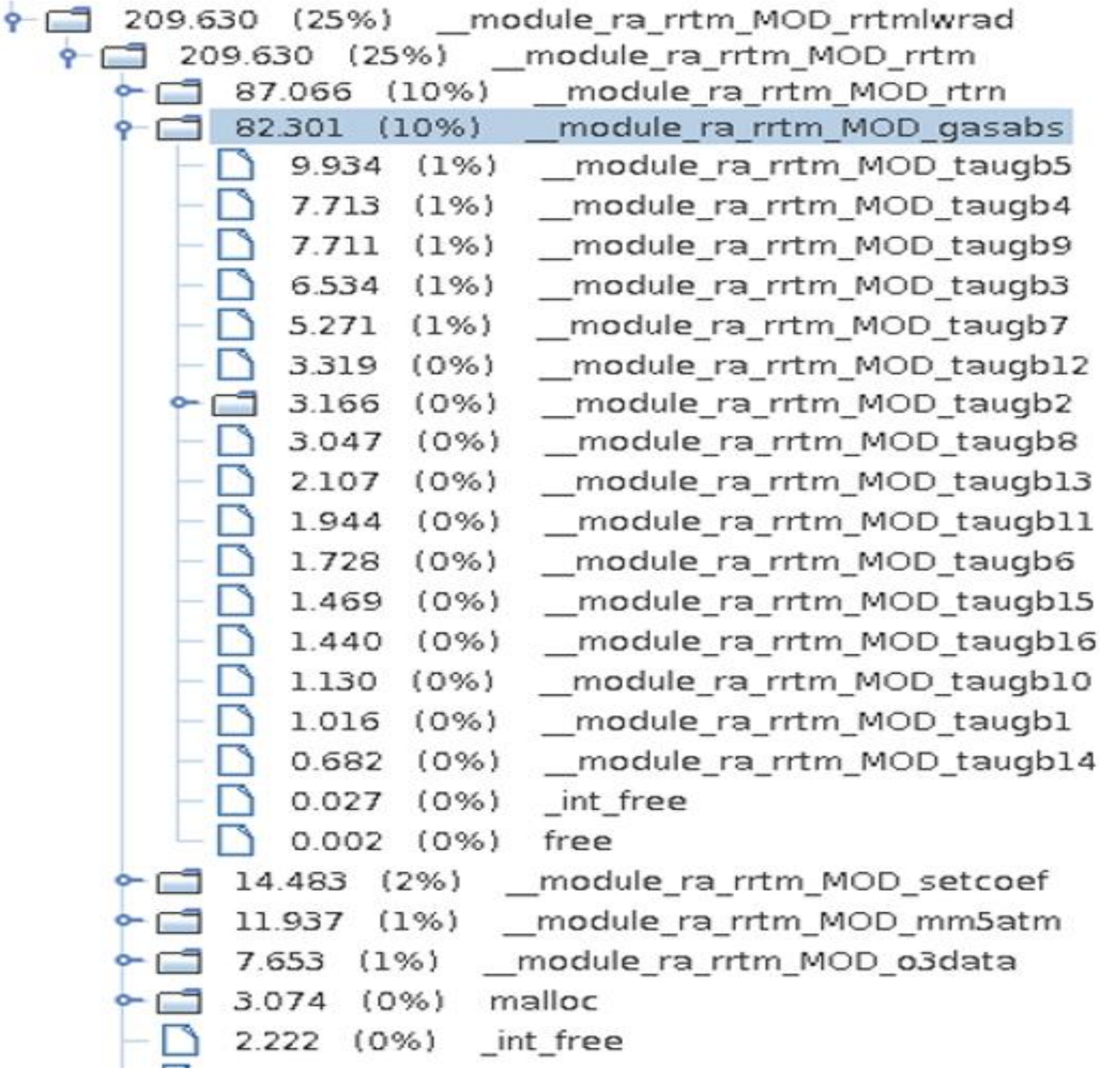
taugb1()

taugb2 ()

…

taugb16 ()

RRTM Call Graph



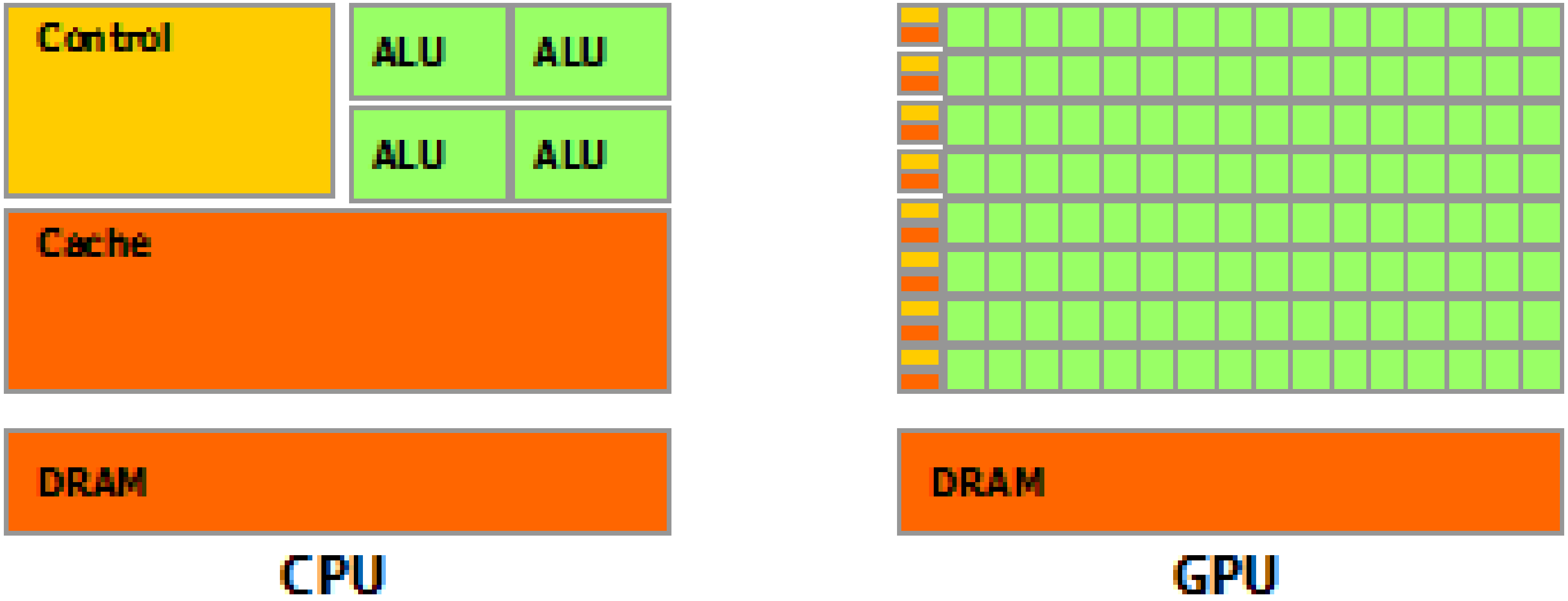
```
209.630  (25%)  __module_ra_rrtm_MOD_rrtmlwrad
  209.630  (25%)  __module_ra_rrtm_MOD_rrtm
    87.066  (10%)  __module_ra_rrtm_MOD_rtrn
    82.301  (10%)  __module_ra_rrtm_MOD_gasabs
        9.934  (1%)  __module_ra_rrtm_MOD_taugb5
        7.713  (1%)  __module_ra_rrtm_MOD_taugb4
        7.711  (1%)  __module_ra_rrtm_MOD_taugb9
        6.534  (1%)  __module_ra_rrtm_MOD_taugb3
        5.271  (1%)  __module_ra_rrtm_MOD_taugb7
        3.319  (0%)  __module_ra_rrtm_MOD_taugb12
        3.166  (0%)  __module_ra_rrtm_MOD_taugb2
        3.047  (0%)  __module_ra_rrtm_MOD_taugb8
        2.107  (0%)  __module_ra_rrtm_MOD_taugb13
        1.944  (0%)  __module_ra_rrtm_MOD_taugb11
        1.728  (0%)  __module_ra_rrtm_MOD_taugb6
        1.469  (0%)  __module_ra_rrtm_MOD_taugb15
        1.440  (0%)  __module_ra_rrtm_MOD_taugb16
        1.130  (0%)  __module_ra_rrtm_MOD_taugb10
        1.016  (0%)  __module_ra_rrtm_MOD_taugb1
        0.682  (0%)  __module_ra_rrtm_MOD_taugb14
        0.027  (0%)  _int_free
        0.002  (0%)  free
    14.483  (2%)  __module_ra_rrtm_MOD_setcoef
    11.937  (1%)  __module_ra_rrtm_MOD_mm5atm
    7.653  (1%)  __module_ra_rrtm_MOD_o3data
    3.074  (0%)  malloc
    2.222  (0%)  _int_free
```

CUDA Overview

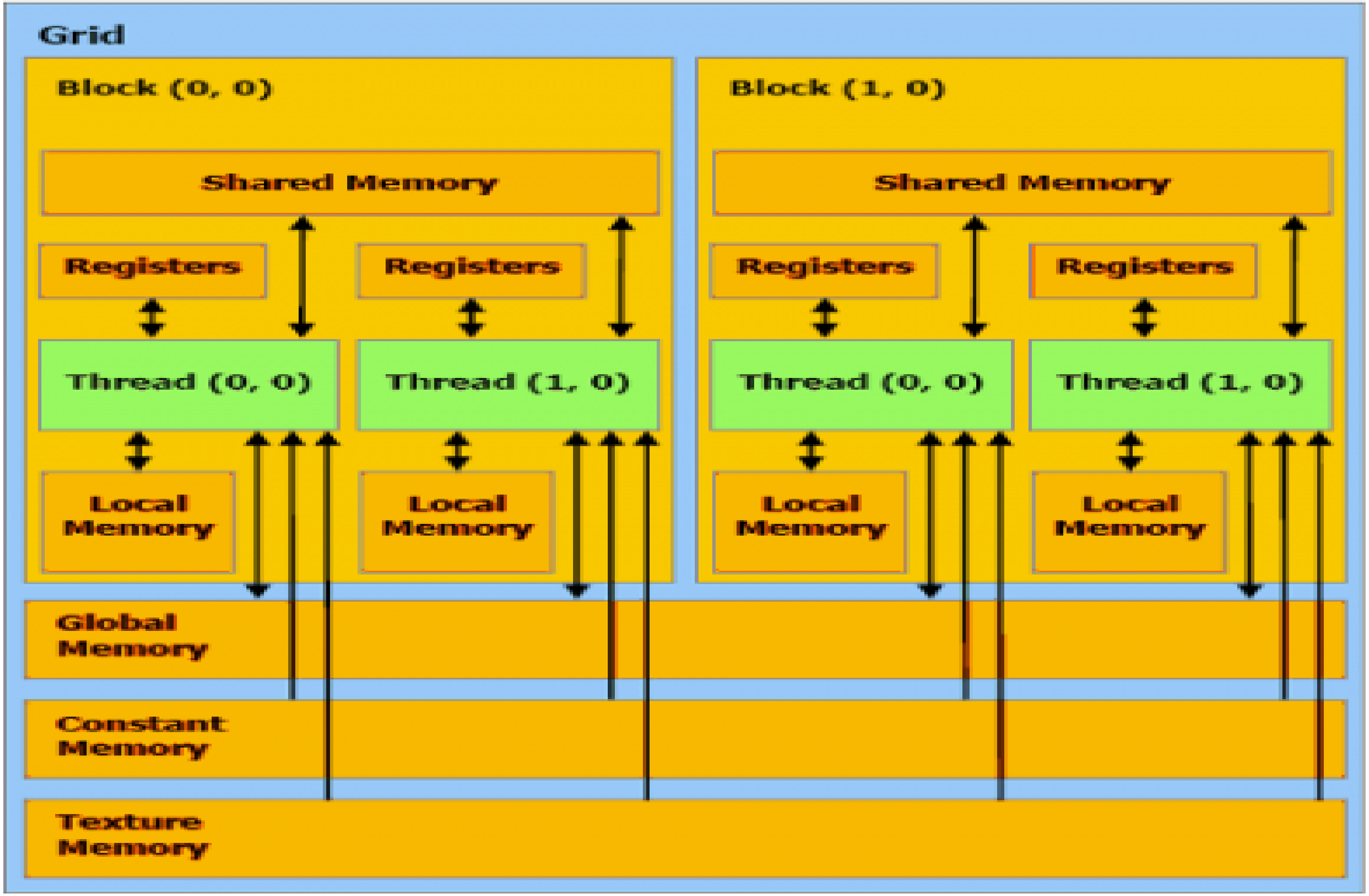
The GPU devotes more transistors to

data processing

(derived/inspired from graphics rendering)

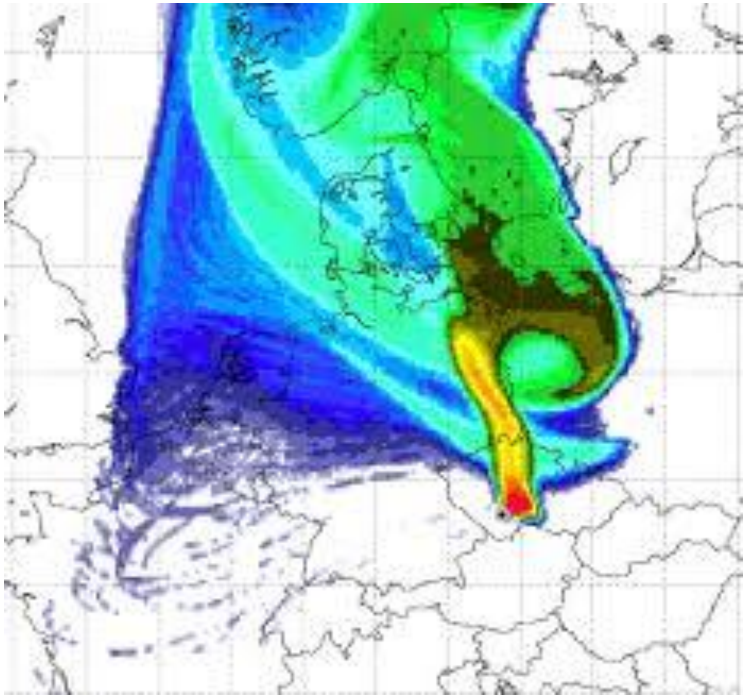


CUDA Memory Types

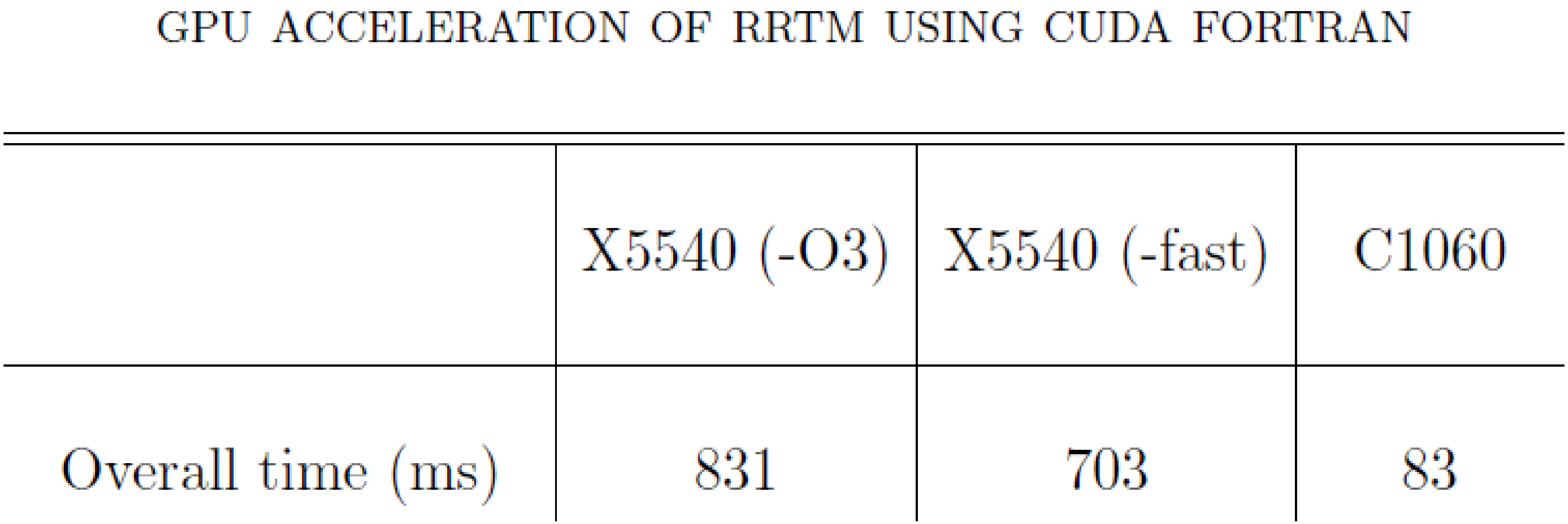


FLEXPART Overview

- Lagrangian particle dispersion model
- Originally designed for coupling with global weather models
- Forward/backward dispersion
- Radioactive decay, wet/dry deposition etc.
- Numerical parallelization for computation efficiency
- Netcdf format for output files



Related Work

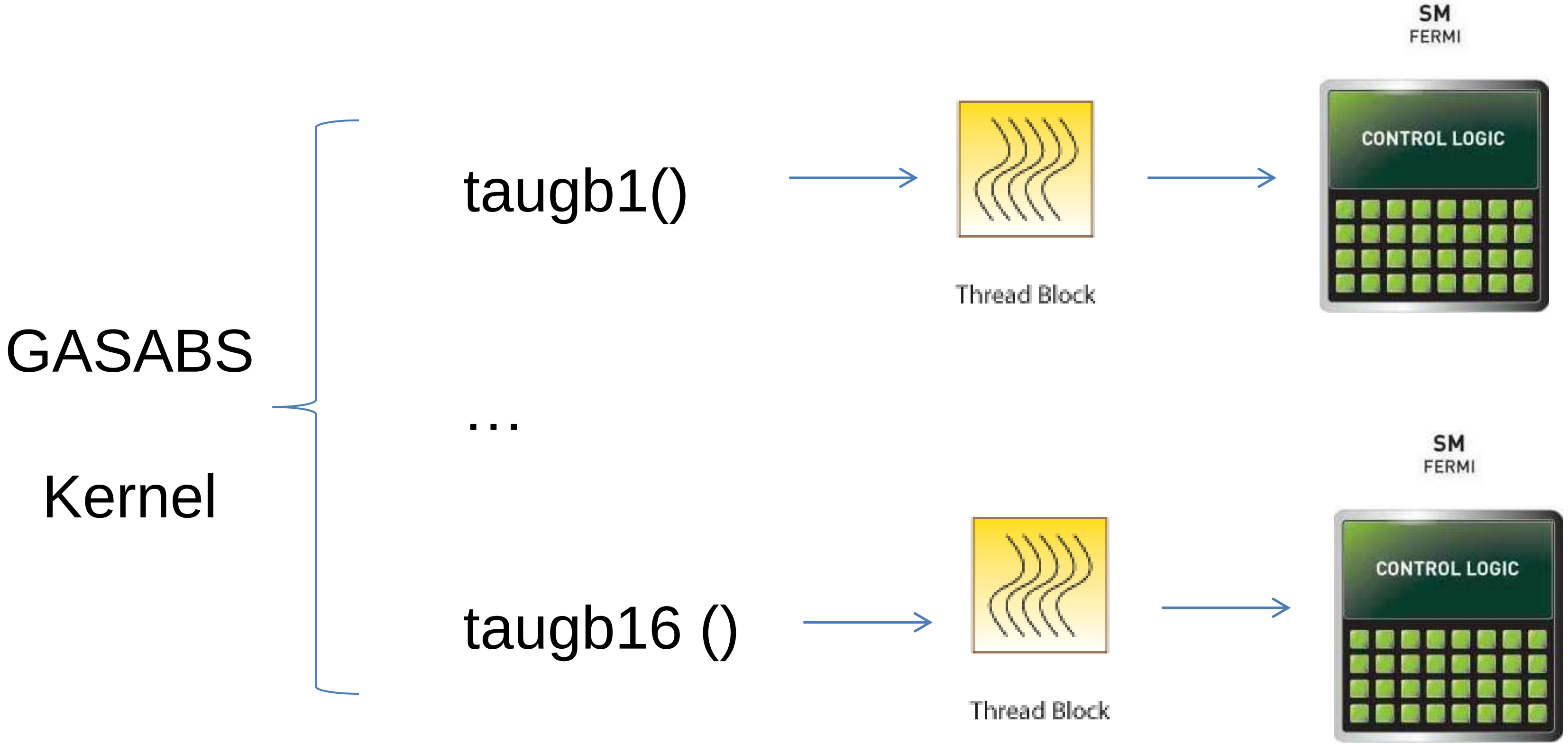


GPU ACCELERATION OF RRTM USING CUDA FORTRAN

	X5540 (-O3)	X5540 (-fast)	C1060
Overall time (ms)	831	703	83

- G.Reutsch, NVIDIA Corporation, GPU acceleration of the Long-wave Rapid Radiative Transfer Model in WRF using CUDA Fortran, 2011
- WRF speedup: 1.25

CUDA Acceleration



GASABS

Kernel

taugb1()

…

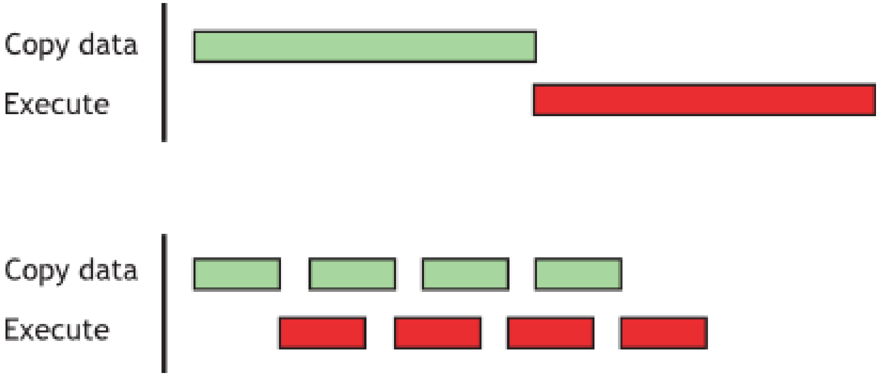
taugb16 ()

- 14 thread blocks
- 16 * NLAYERS threads / block
- 1 gasabs_gpu call for each 2D point in domain

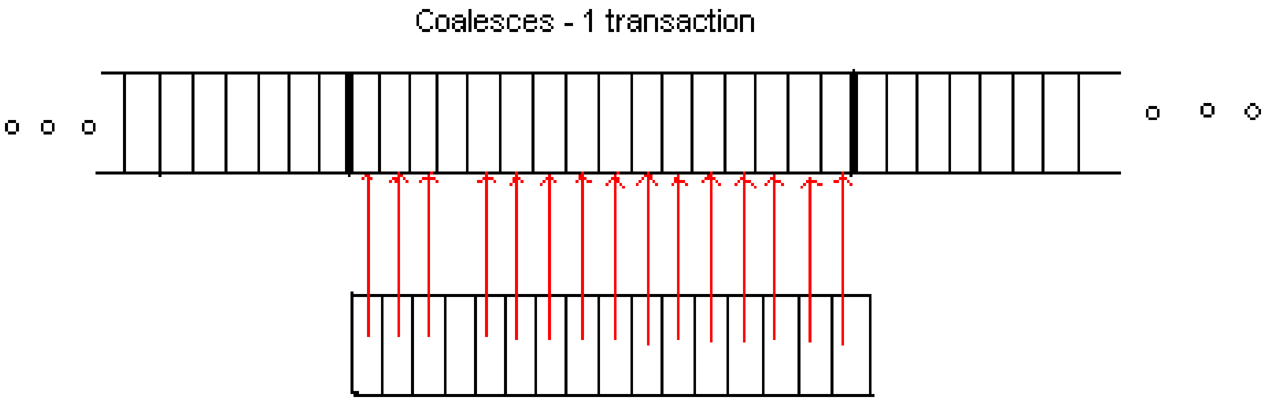
- 14 SMs / device
- 2 devices / node

CUDA Acceleration

- 1 CUDA stream for each CPU thread (OpenMP)
- CUDA streams uniformly spread across GPUs
- 1 MPI process per node
- Asynchronous cudaMemcpy
- Overlap data transfers and kernel execution



CUDA Acceleration



- Transposed some input arrays before sending them to GPU

  => coalesced accesses

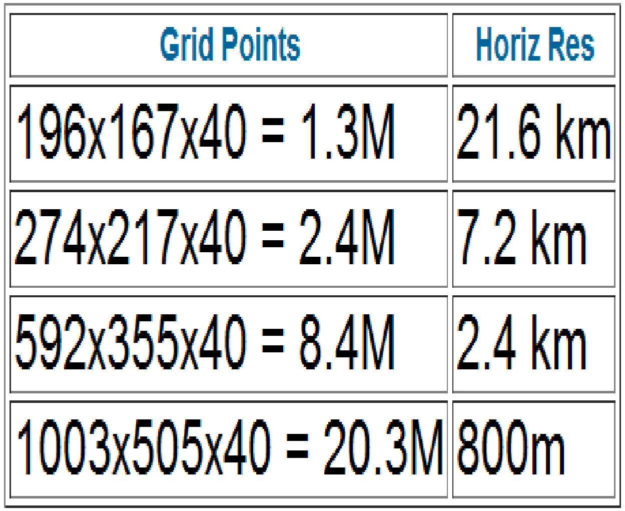
  => minimized global memory transactions

- Allocated memory on GPU only at first kernel call

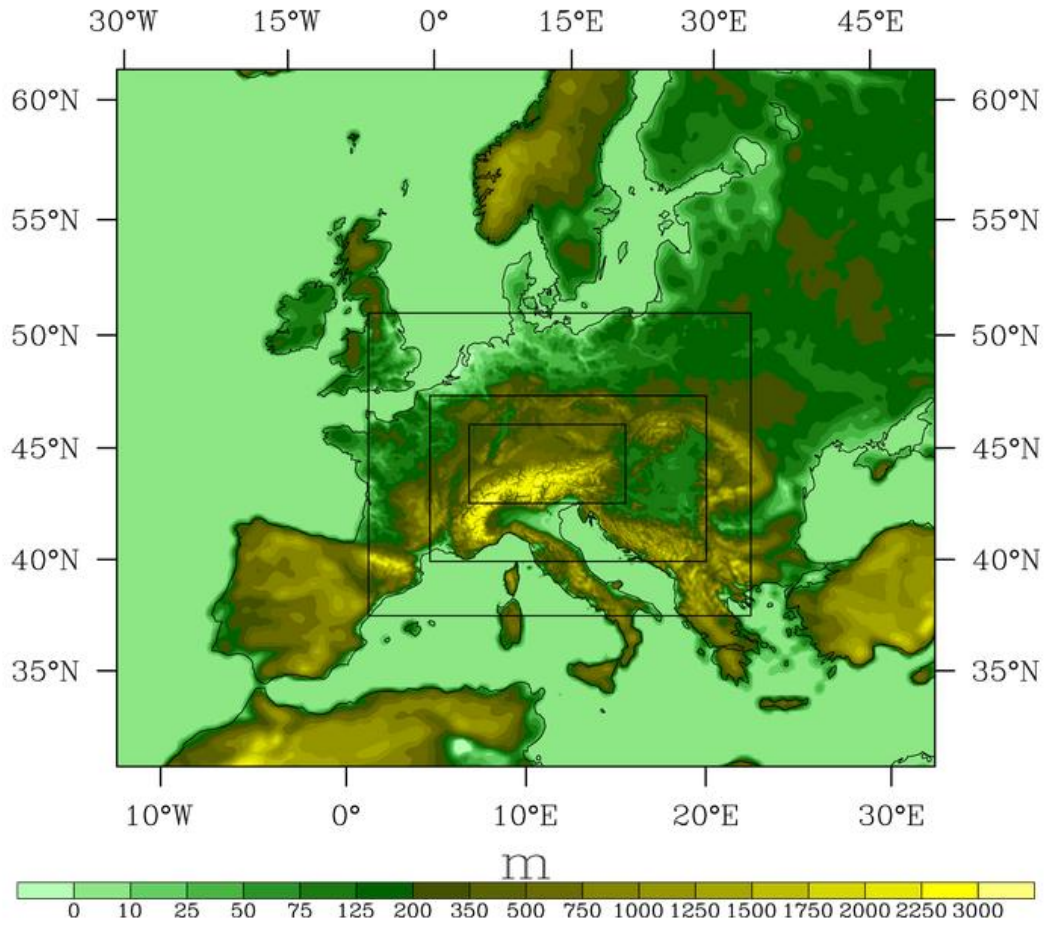
- Data transfers to/from GPU only when needed and in a minimum of transactions

Results (gfortran + nvcc)

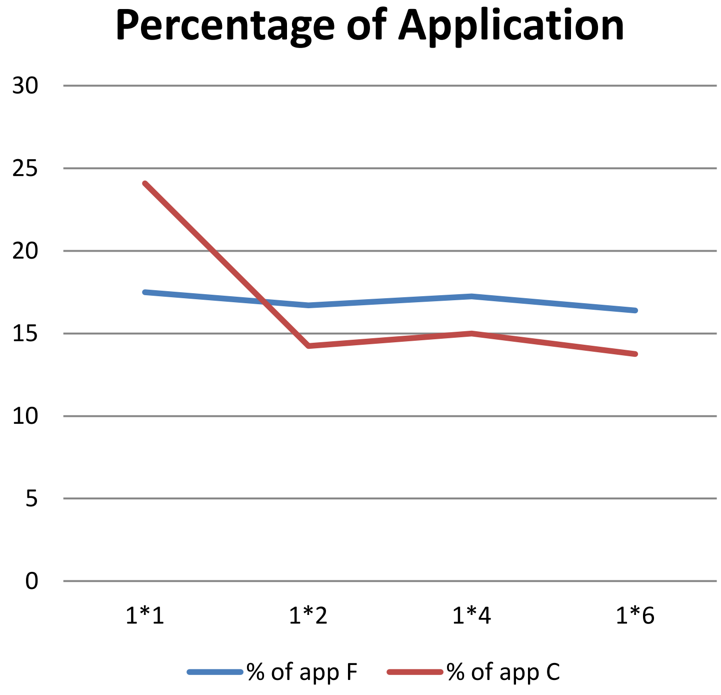
- Europe Benchmark
- 1h of simulation
- 1 domain



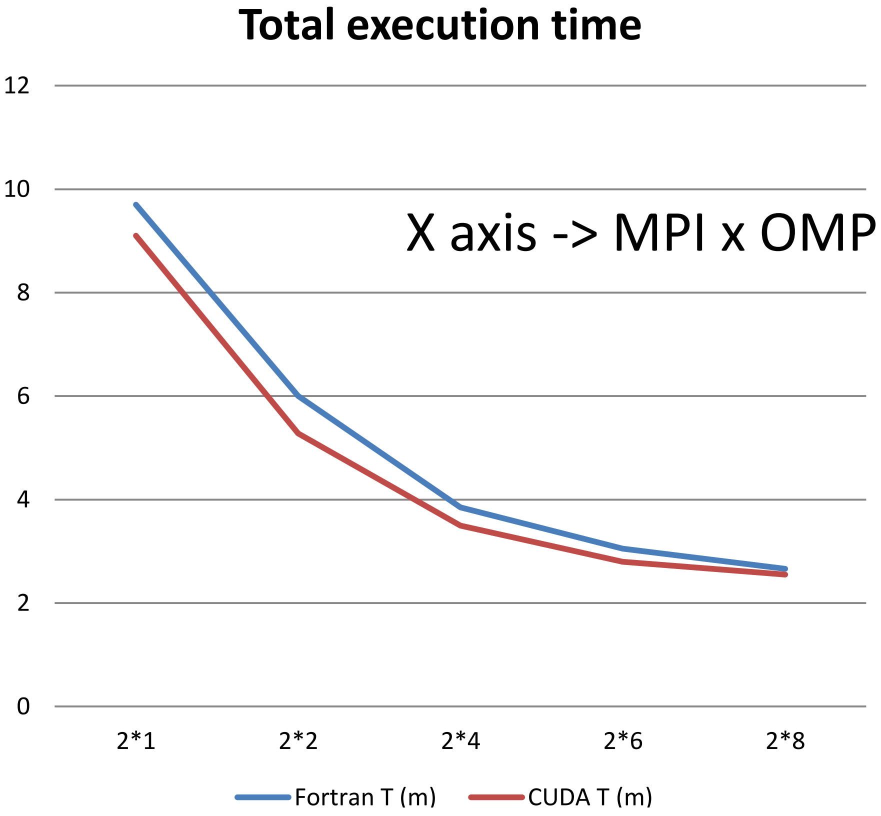
Grid Points	Horiz Res
196x167x40 = 1.3M	21.6 km
274x217x40 = 2.4M	7.2 km
592x355x40 = 8.4M	2.4 km
1003x505x40 = 20.3M	800m



Results (gfortran + nvcc)

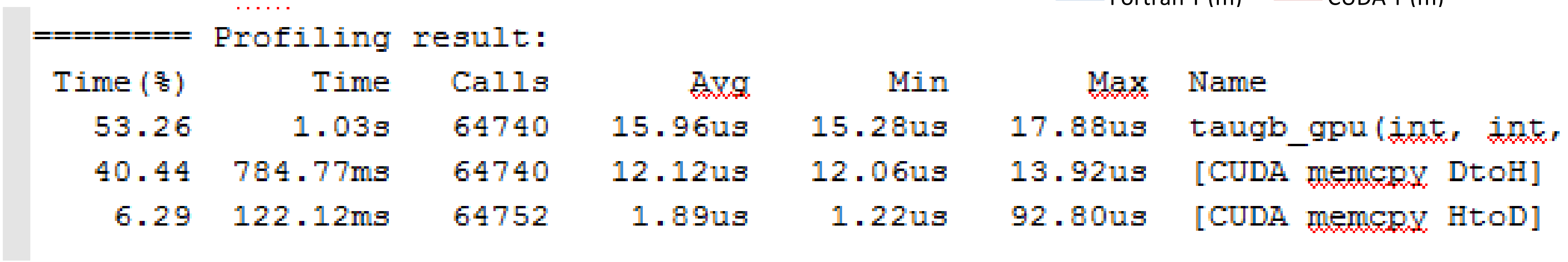


Percentage of Application



Total execution time

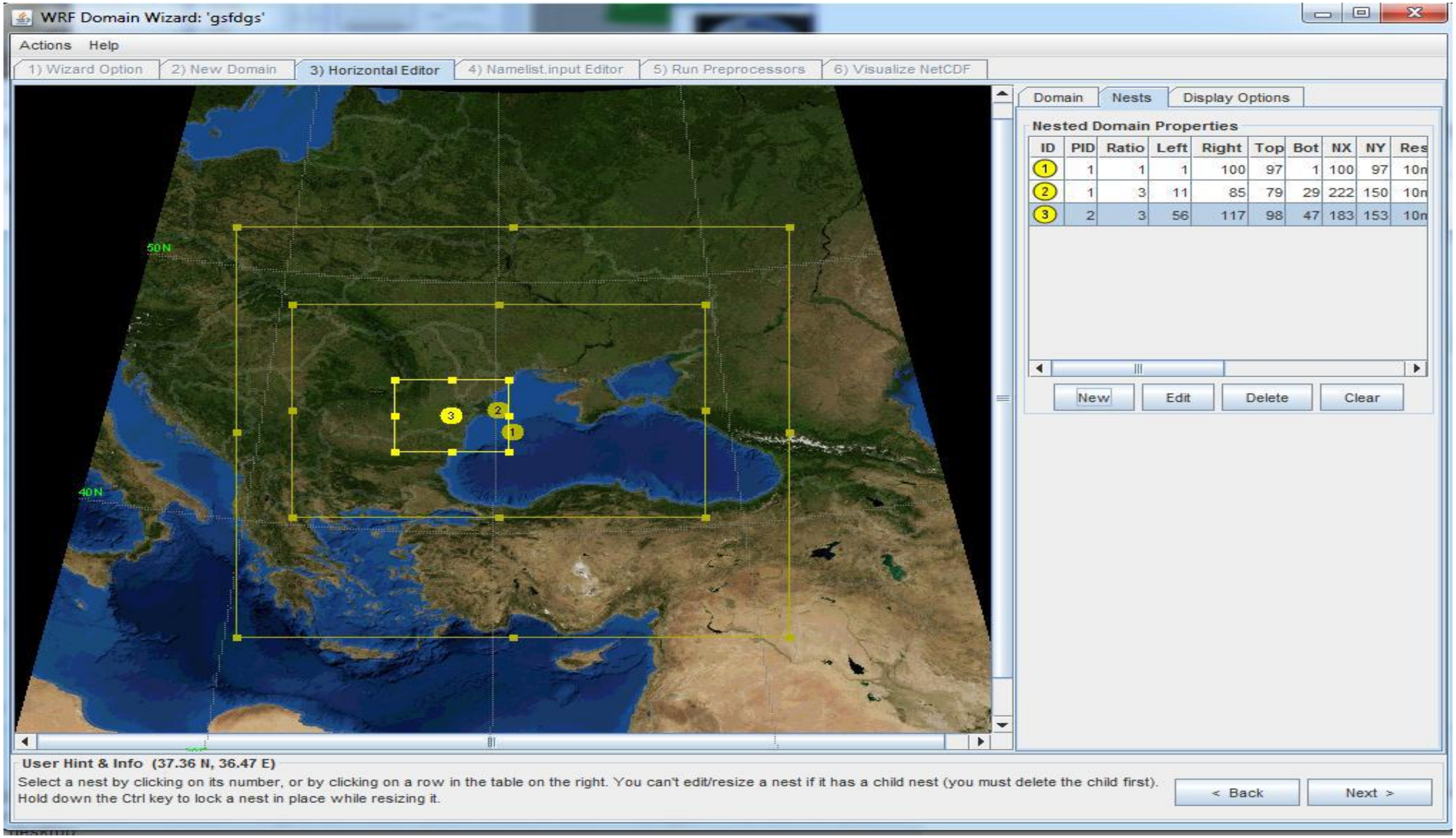
X axis -> MPI x OMP



```
======== Profiling result:
 Time(%)      Time    Calls       Avg       Min       Max  Name
   53.26     1.03s    64740   15.96us   15.28us   17.88us  taugb_gpu(int, int,
   40.44  784.77ms    64740   12.12us   12.06us   13.92us  [CUDA memcpy DtoH]
    6.29  122.12ms    64752    1.89us    1.22us   92.80us  [CUDA memcpy HtoD]
```

FLEXPART – WRF Coupling

Domain Generation – WRF Domain Wizard



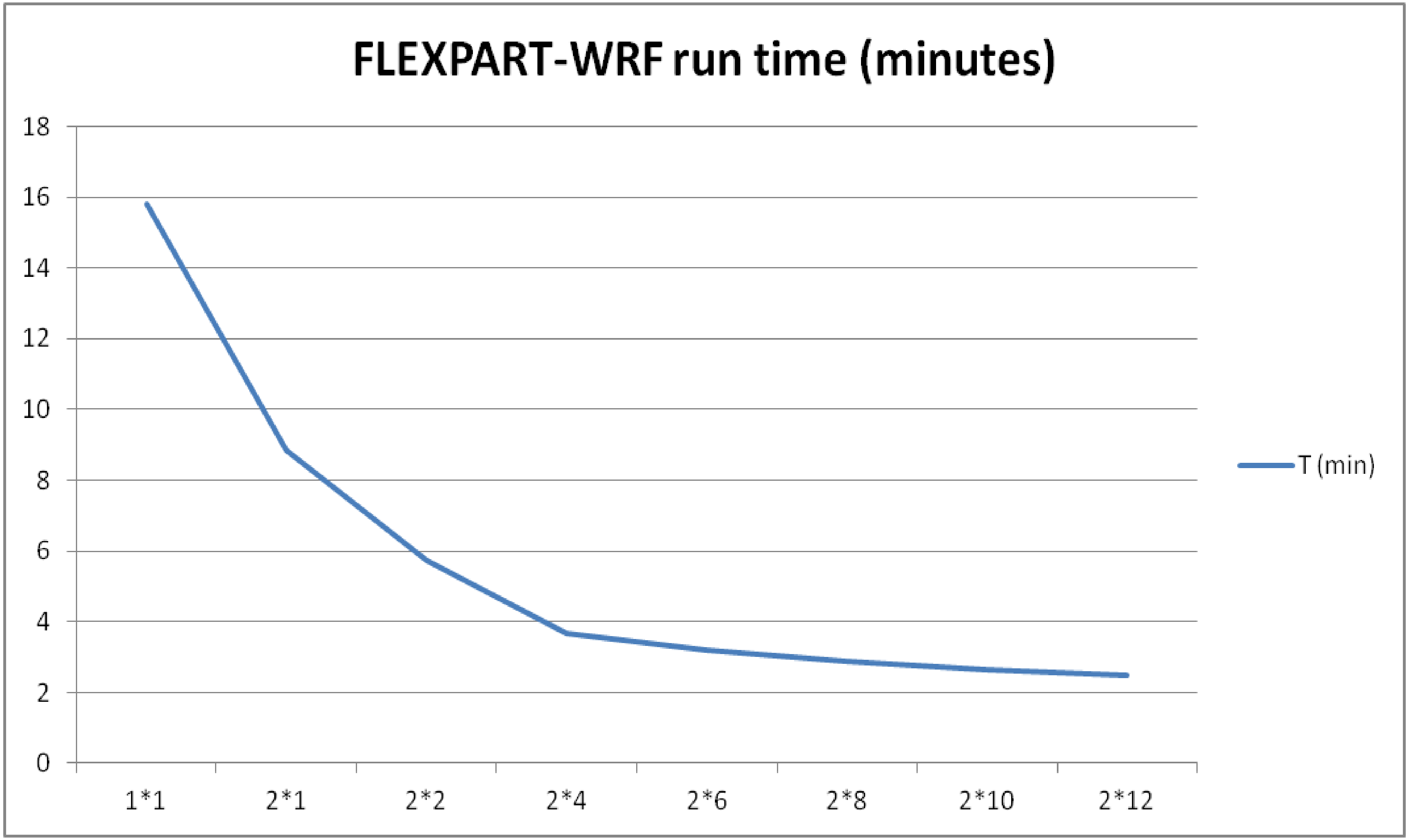
Nested Domain Properties

ID	PID	Ratio	Left	Right	Top	Bot	NX	NY	Res
1	1	1	1	100	97	1	100	97	10n
2	1	3	11	85	79	29	222	150	10n
3	2	3	56	117	98	47	183	153	10n

User Hint & Info (37.36 N, 36.47 E)

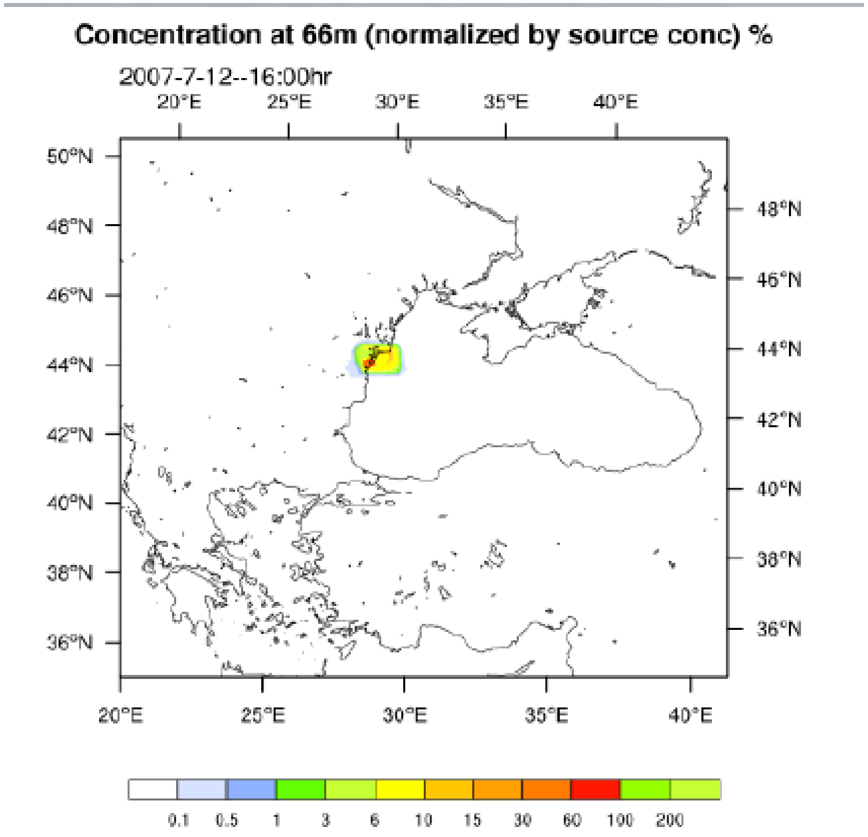
Select a nest by clicking on its number, or by clicking on a row in the table on the right. You can't edit/resize a nest if it has a child nest (you must delete the child first).
Hold down the Ctrl key to lock a nest in place while resizing it.

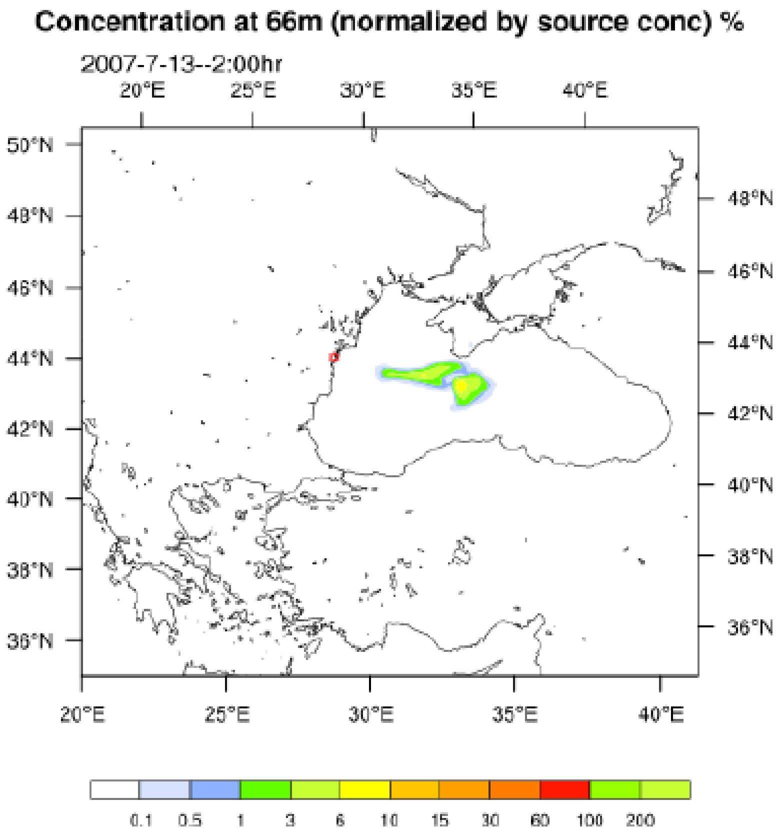
FLEXPART – WRF Coupling



FLEXPART – WRF Coupling

Particle concentrations – coupled run





Future GPU Acceleration

OpenACC
DIRECTIVES FOR ACCELERATORS

- Directive-based
- Multiple platforms supported (NVIDIA, AMD, Intel Xeon Phi, CRAY etc)
- v.2.0 (2014) – procedure calls

CPU-GPU transfers managed by the API

Conclusions

- Porting Fortran to CUDA C tends to result in better performance than using accelerator directives, but is very time consuming and prone to various implementation errors and vulnerabilities

- Overall WRF speedup of up to 1.1x
  - Gasabs() is only 10%-20% of WRF

- Upcoming accelerators and programming tools

- Scalability of last version of FLEXPART-WRF

Keywords

- WRF
- CUDA
- GPU
- RRTM
- Kernel
- Async

- FLEXPART
- Gfortran
- Domain
- OpenACC
- GASABS
- Speedup