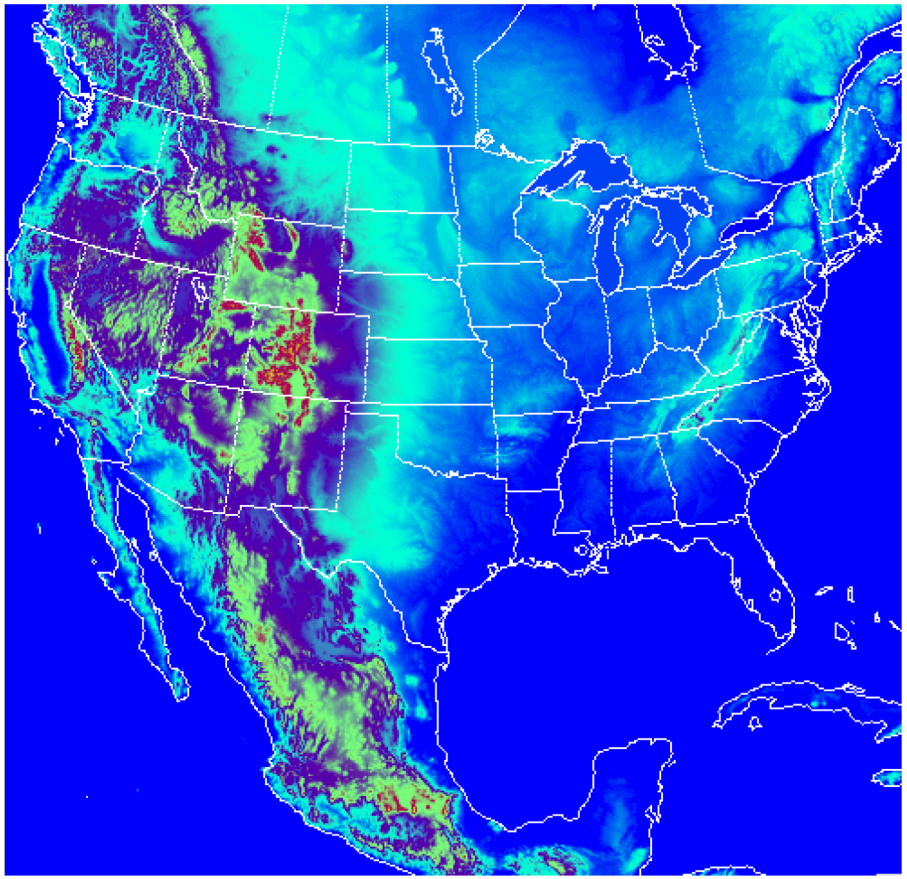
WRF Computation

Dave Gill

- Parallelism in WRF
  - Why is it required
  - What is “scaling”
- OpenMP and MPI
- Halos
- Domain Decomposition
  - Reasonable, max, min, bad
  - Dimensions and decomposition
  - Coarse grid vs nest grid
- Where is all of this information
  - Using rsl files

WRF v4, 1500x1500x50, 3 km, CONUS Suite

- 50 vertical levels
- No cumulus
- Hybrid vertical activated
- Moist theta
- 18 s dt
- 6 minute simulation
- 10 hour spin-up, then restart
- No I/O included in timing
- Single radiation time step
- 18 non-radiation time steps



Parallelism:

Execution of processes are carried out simultaneously

Without parallelism, all of the work is handled by a single processor

Why is Parallelism Required

- When we decompose the WRF domain into smaller pieces, we distribute work to additional processors
- Since less work is performed by each individual processor, the elapsed time to complete the computational task for each processor is reduced
- The aggregated parallel job completes in less elapsed time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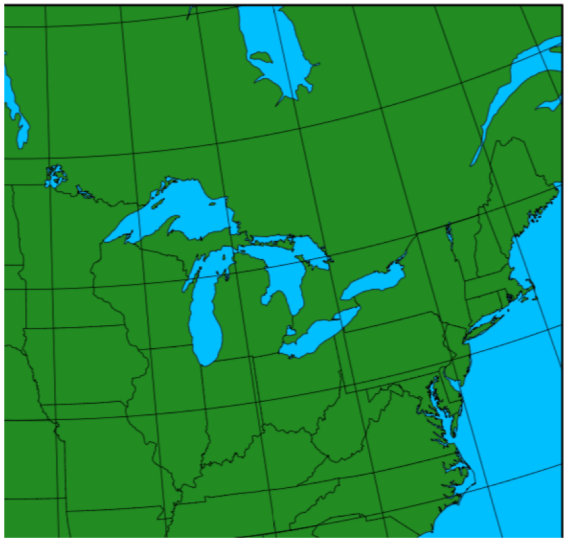


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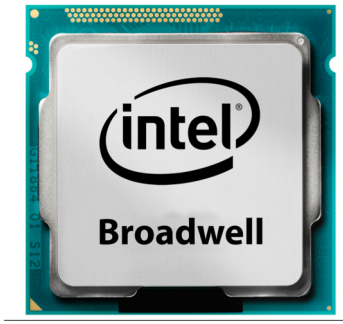
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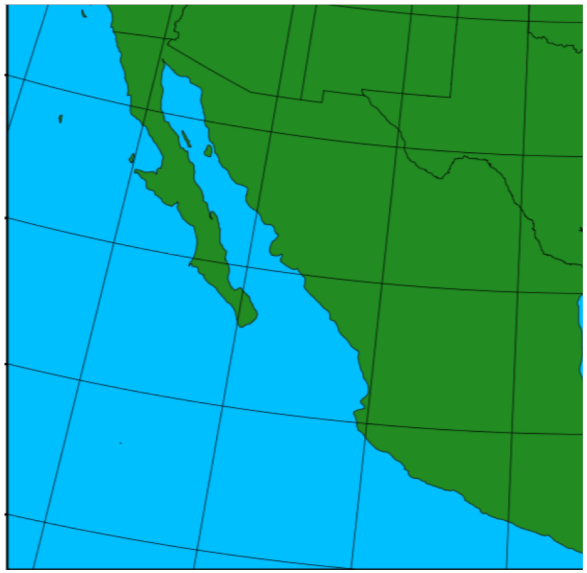

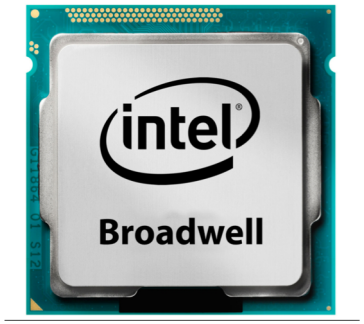
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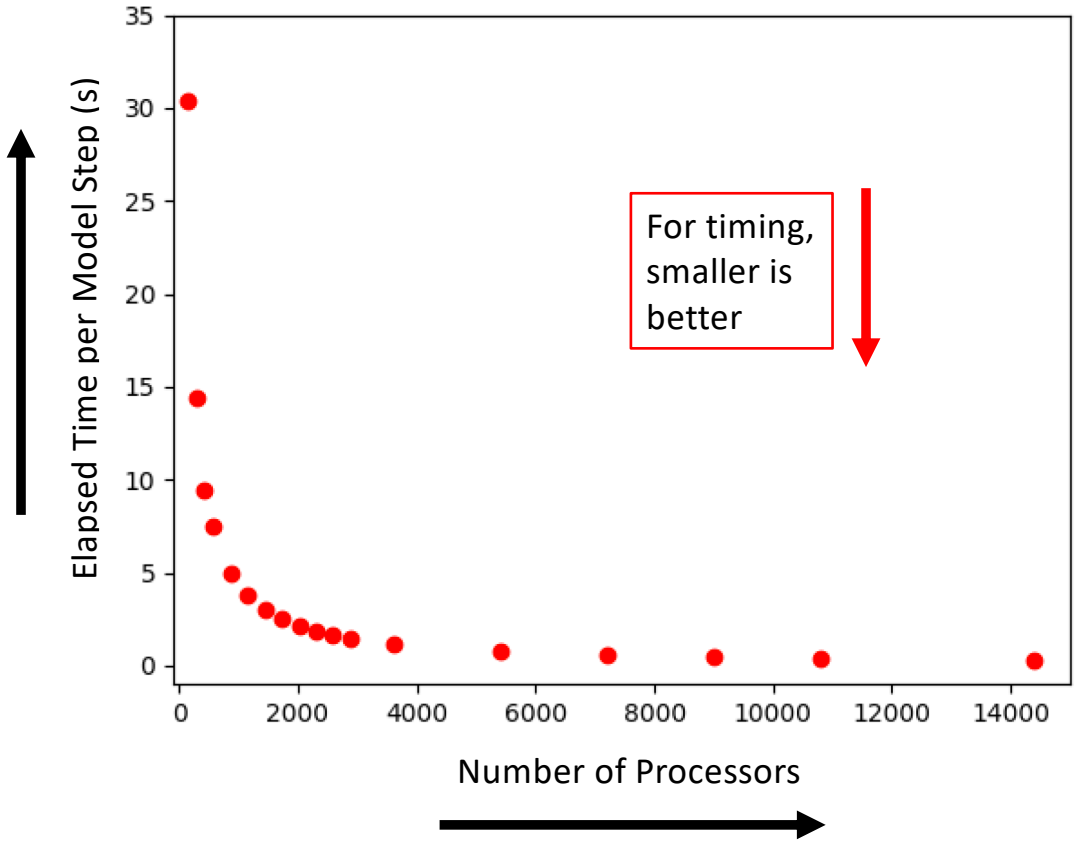
What is “scaling”

- The ability of the WRF model to handle these additional processors is a measure of how well the WRF model scales
- On a supercomputer, the most efficient usage of additional processors tends to be by using full or nearly full nodes
- With perfect scaling
  - Twice as many nodes = 2x faster = 1/2 of the original time
  - 3x as many nodes = 3x faster = 1/3 of the original time
  - *n*x as many nodes = *n*x faster = 1/*n* of the original time
- Raw scaling plots look like hyperbolas

What is “scaling”

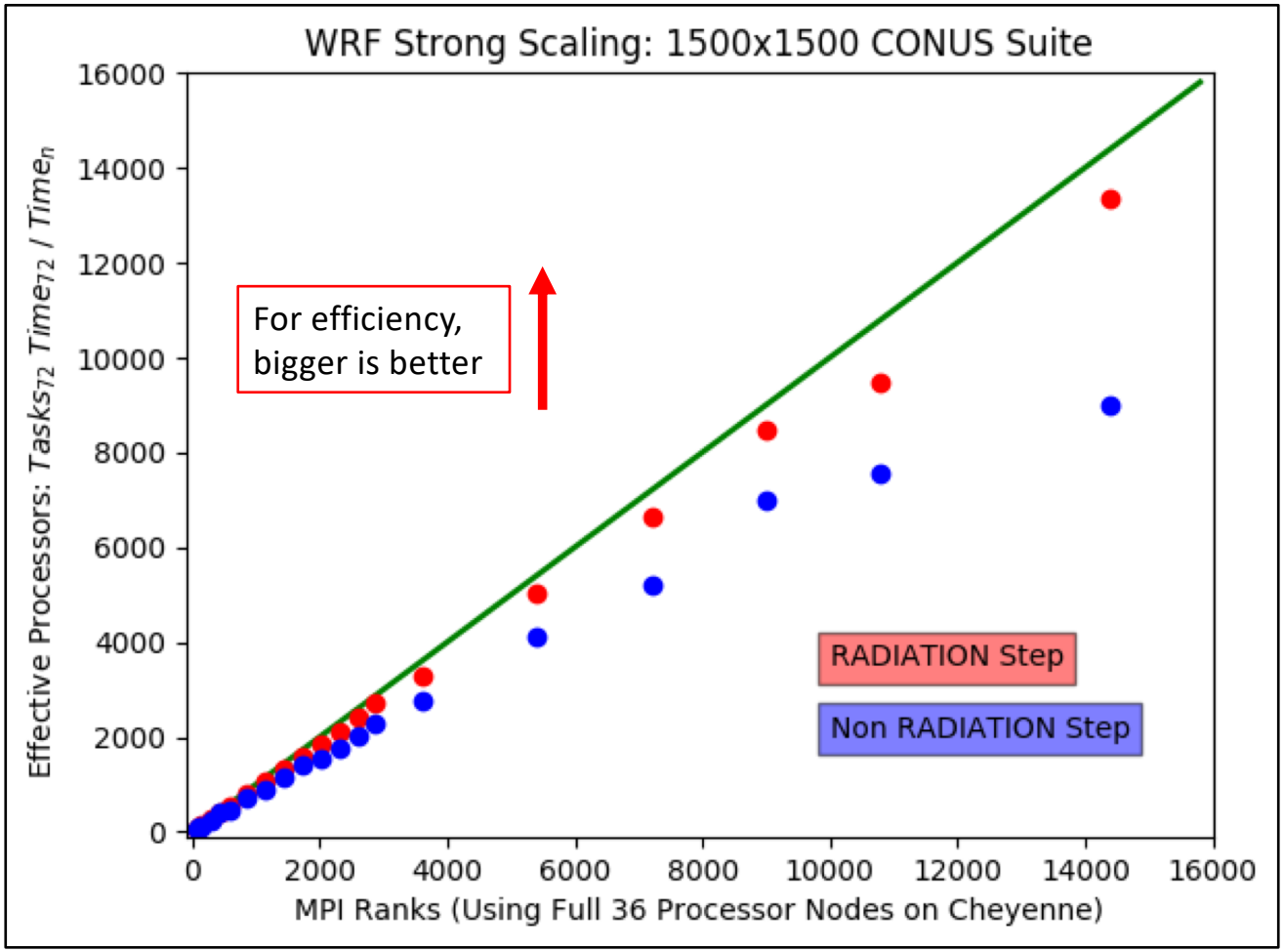


- While the information is accurate, this presentation of the timing data is not easy to interpret
- Scaling plots are typically recast with an easy comparison against a known value (100% efficient) or a fixed quantity (such as Days of Simulation per Elapsed Day of Computation)

WRF v4, 1500x1500x50, 3 km, CONUS Suite

Base scaling using 72 processors

2 full nodes on cheyenne



WRF v4, 1500x1500x50, 3 km, CONUS Suite

MPI Ranks	I-Dim	J-Dim	Radiation (s)	Non Rad (s)	Days / Day	Scaling Rad	Scaling NonRad
72	188	167	55.30796	8.63828	1.35284964	1	1
108	167	125	37.42179	5.93252	1.98206299	0.98530758	0.970726324
144	125	125	30.35208	6.99176	1.92971713	0.91110659	0.617747177
288	94	84	14.4129	2.56148	4.80432774	0.95934822	0.843094617
432	84	63	9.47383	1.53414	7.73159676	0.97299543	0.938449772
576	63	63	7.45682	1.33647	9.23785158	0.92713717	0.807938076
864	56	47	4.9866	0.886827	13.8802748	0.92427639	0.81172164
1152	47	42	3.75109	0.686984	18.1196878	0.92153147	0.785888027
1440	42	38	2.98979	0.53509	23.0603669	0.92494724	0.807180101
1728	42	32	2.5313	0.442302	27.6412012	0.91040111	0.813761487
2016	36	32	2.15486	0.398824	31.3355417	0.91666479	0.773549235
2304	32	32	1.87563	0.352528	35.6549881	0.92148971	0.765744139
2592	32	28	1.65853	0.307171	40.6957251	0.92632164	0.781168216
2880	32	25	1.46797	0.269931	46.1852403	0.9419123	0.800045197
3600	25	25	1.20596	0.225149	55.687883	0.91724369	0.767338962
5400	21	20	0.79517	0.150944	83.5784193	0.9273985	0.763045014
7200	19	17	0.59816	0.119898	107.319039	0.92463488	0.720469065
9000	17	15	0.47138	0.0891089	141.358285	0.93865603	0.775525677
10800	15	14	0.41968	0.0825039	154.876666	0.87857352	0.698009831
14400	13	13	0.29857	0.06929	195.189659	0.92621429	0.623342474

What is “scaling”

- We have a fixed-sized problem that we want to solve: WRF model with a particular set of parameters
- Look at the measure of the effectiveness of increasing the number of processors on this fixed-size problem
- Referred to as strong scaling
- Basically, if I use more processors, does this model finish in less time

OpenMP (Shared) and MPI (Distributed)

- Modern supercomputers have large processor counts

- Cheyenne:
  - 145,152 processor cores
  - 4,032 nodes
  - 36 cores/node

An SGI ICE XA Cluster, the Cheyenne supercomputer features 145,152 Intel Xeon processor cores in 4,032 dual-socket nodes (36 cores/node) and 313 TB of total memory.

Cheyenne's login nodes give users access to the GLADE shared-disk resource and the High Performance Storage System (HPSS).

- Two types of parallelism
  - Between nodes (MPI) – distributed memory
  - Within nodes (OpenMP) – shared memory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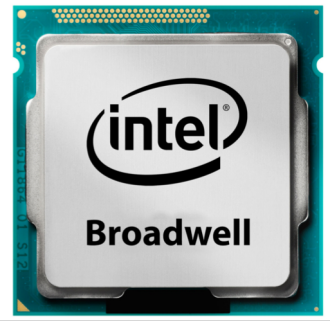
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With shared memory processing, the domain is split among the run-time available OpenMP threads

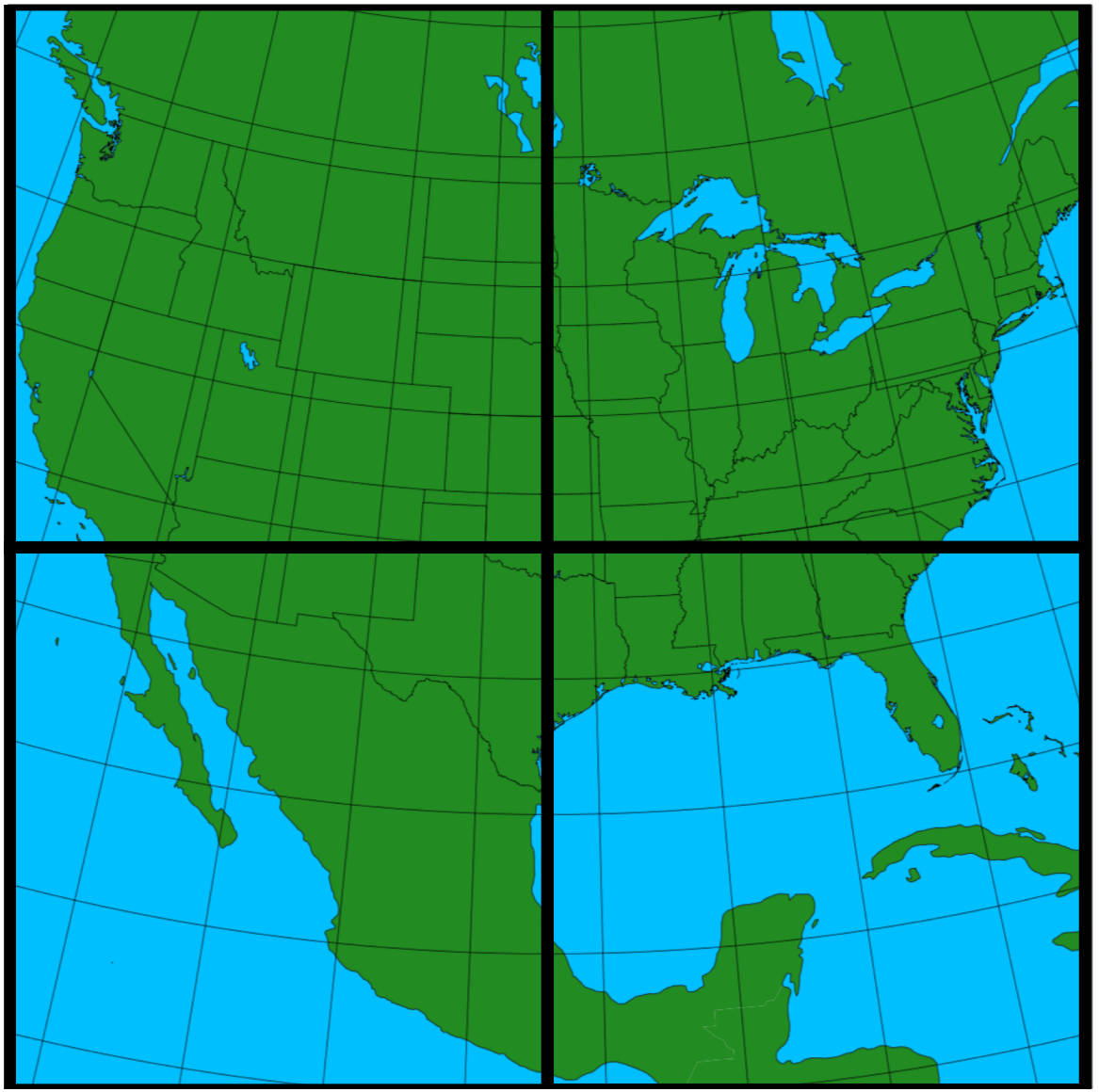
For WRF, for small processor counts, this is effective

With larger WRF jobs, the number of OpenMP threads is not sufficient to run the model

Distributed memory processing is required for larger jobs

Using OpenMP Threading in WRF – Single Node

- The WRF model supports OpenMP threading
- Following is a 150x150 benchmark case (same geophysical size as 1500x1500, just using 30-km resolution instead of 3-km resolution)
- Has CU activated
- Running on a single node of Cheyenne, from 1 – 36 cores
- Two tile strategies: XY and Y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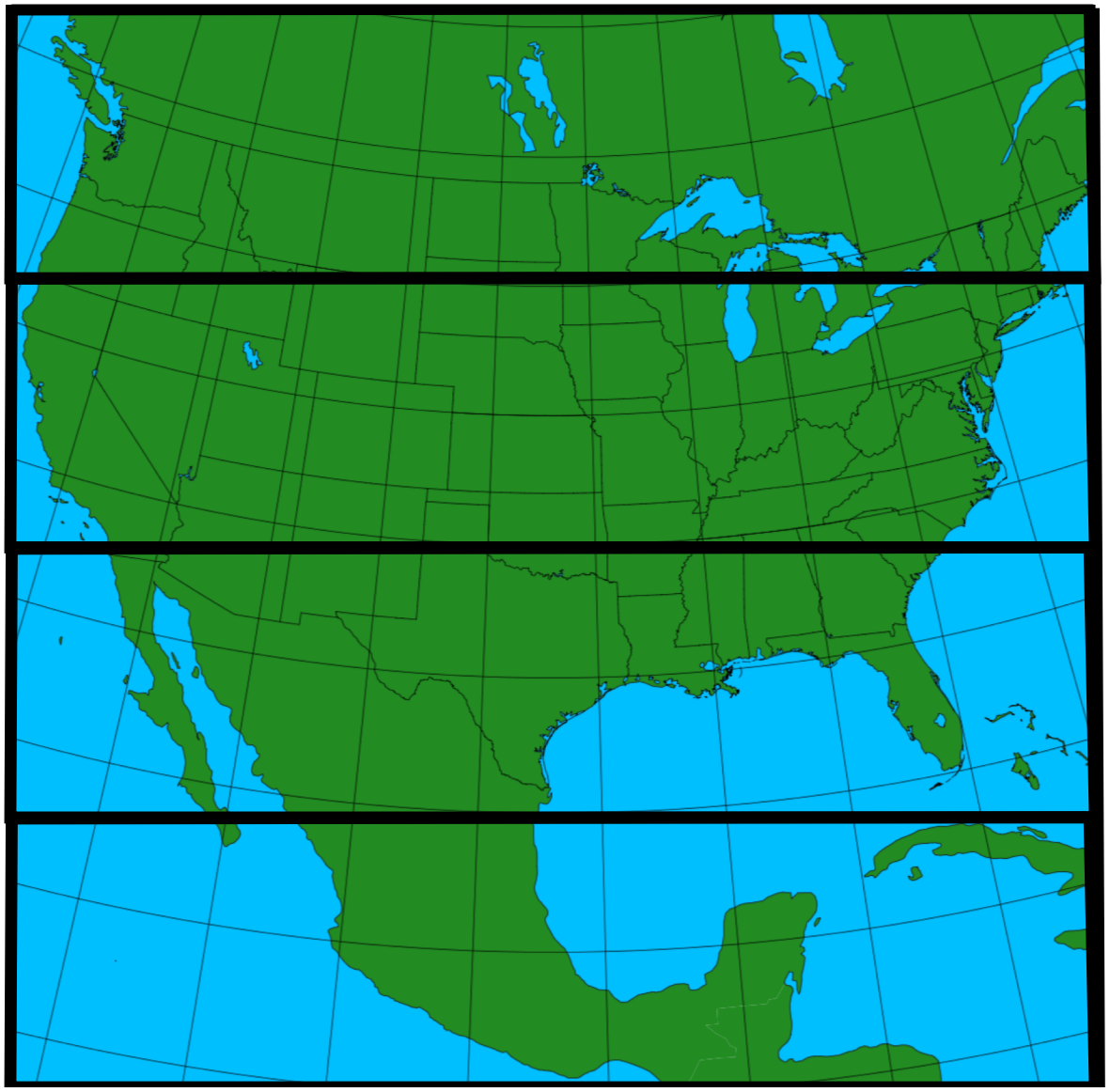
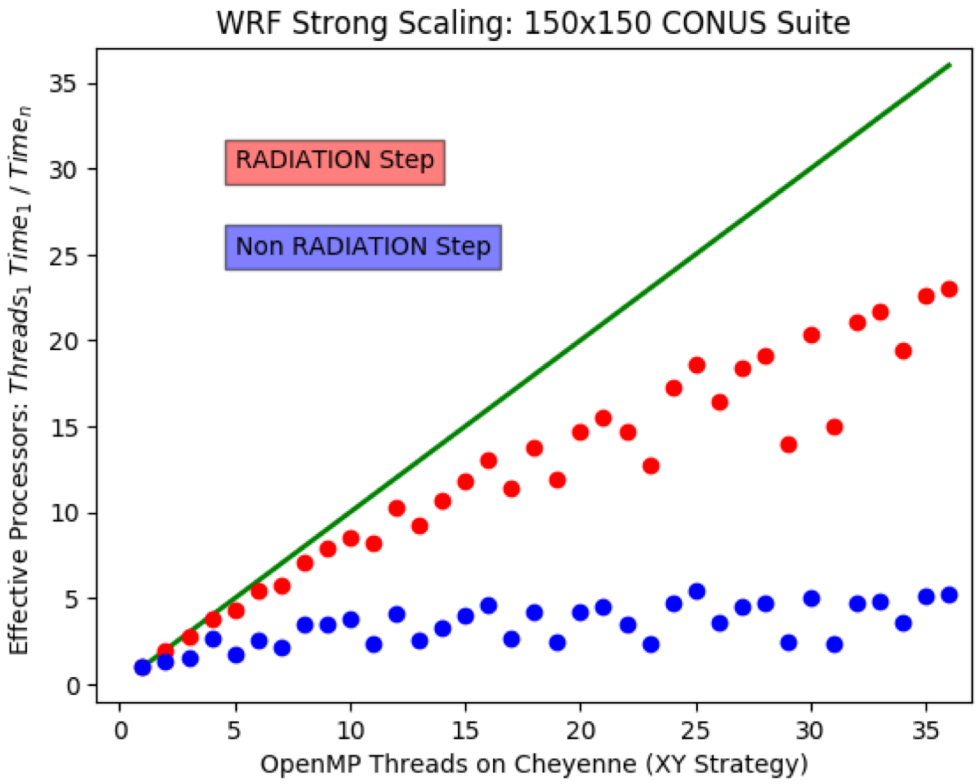
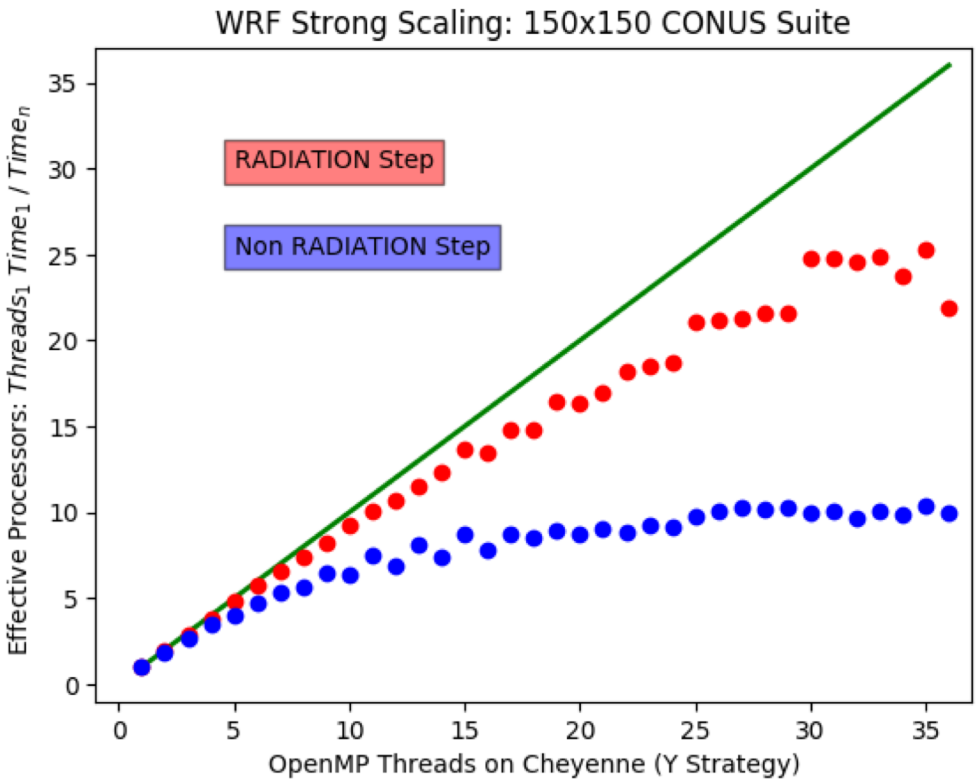


Using OpenMP Threading in WRF – Single Node

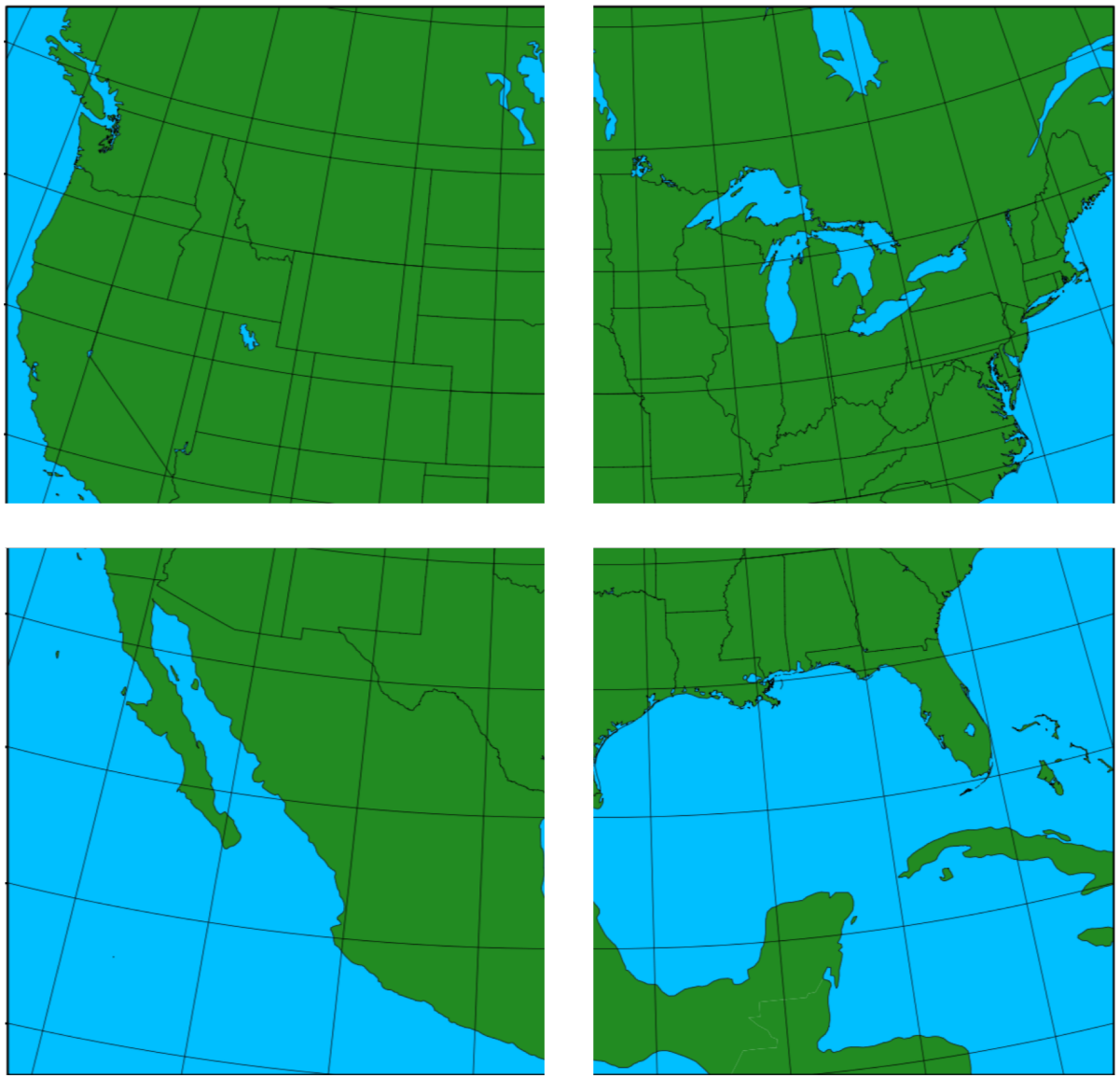




For MPI distributed memory jobs, we no longer can assume that neighboring processors can access the same memory

Each processor works independently, on its own patch.

Later the information is sent to other patches.

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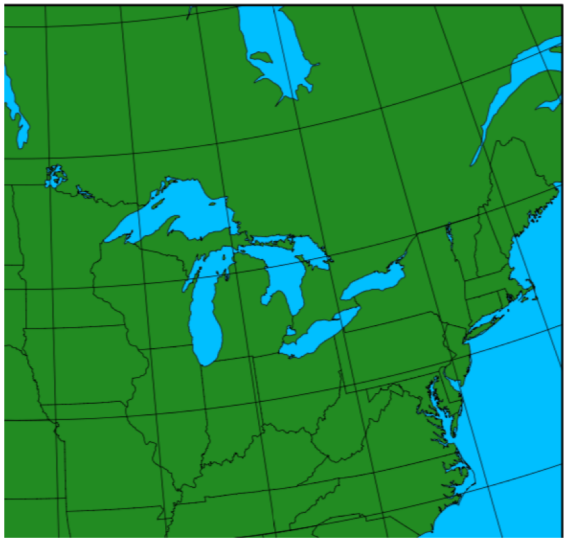


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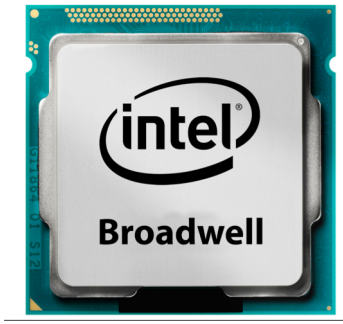
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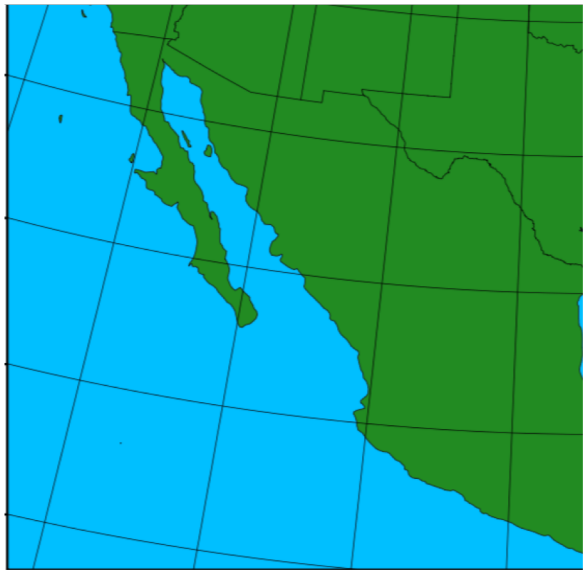

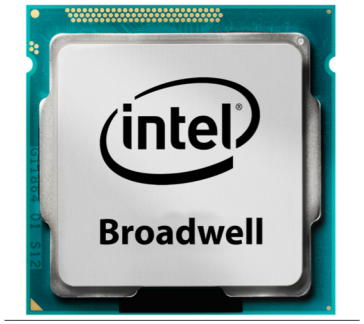
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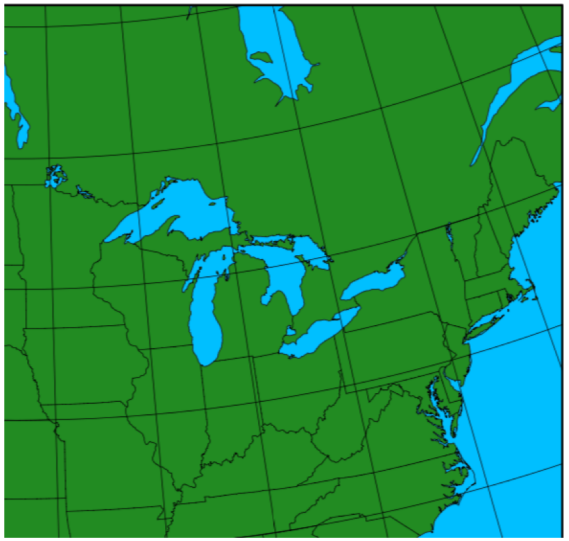
Processor 2

rsl.out.0002

rsl.error.0002



Processor 3

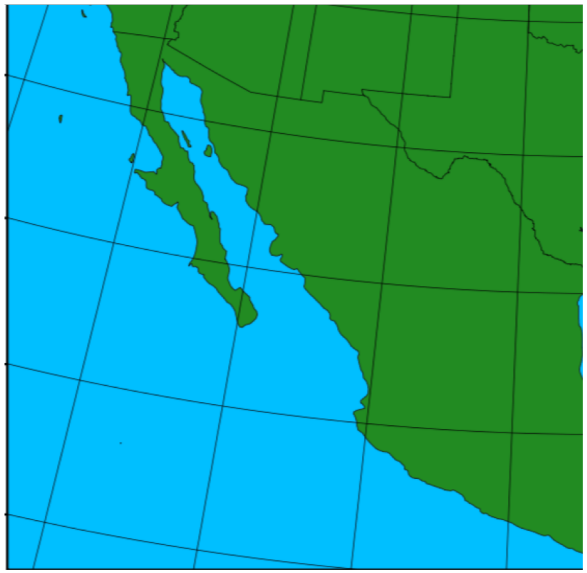
rsl.out.0003

rsl.error.0003

Processor 0

rsl.out.0000

rsl.error.0000

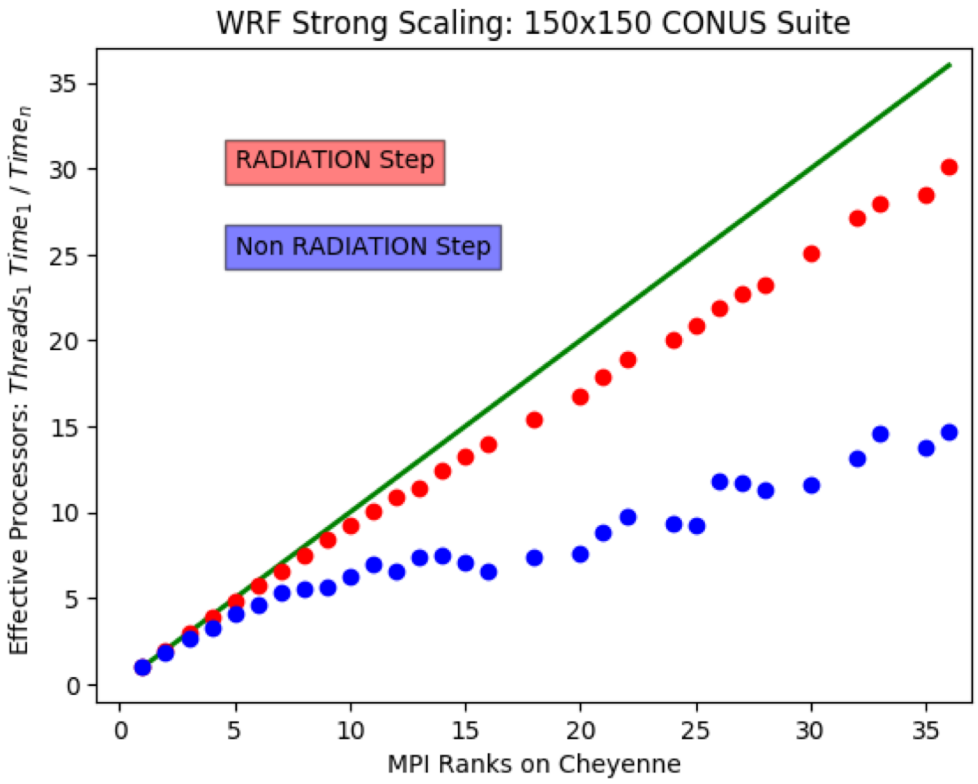


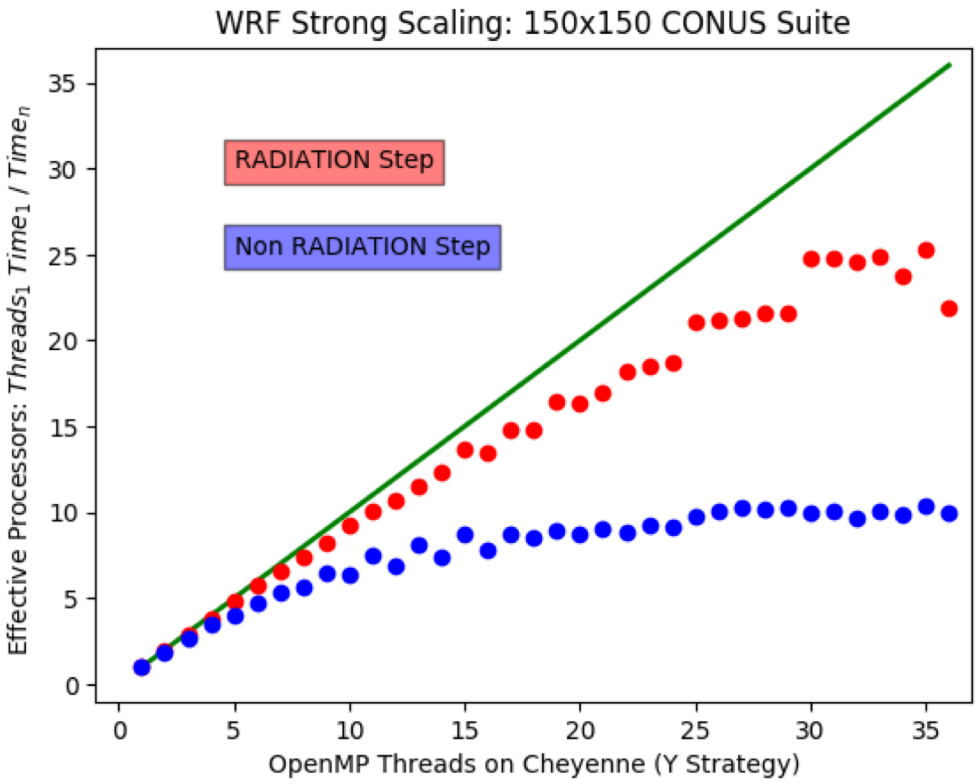
Processor 1

rsl.out.0001

rsl.error.0001

Using MPI vs OpenMP in WRF – Single Node





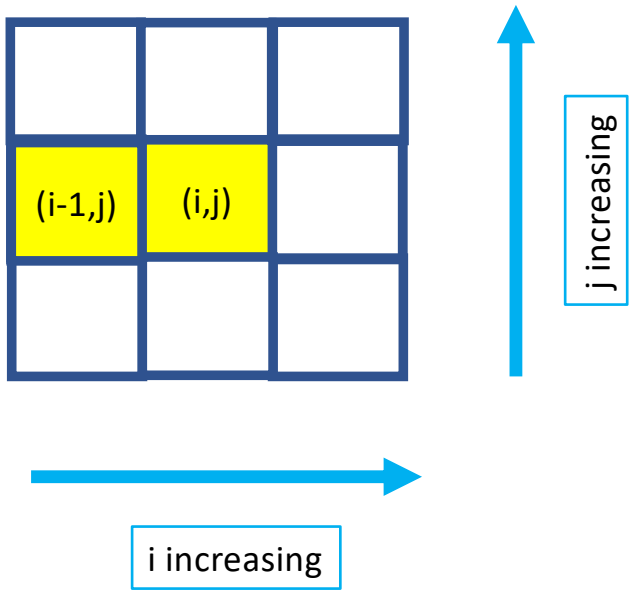
OpenMP and MPI in WRF

- For a sufficiently large WRF domain, MPI scales to about 70% efficiency over a processor range of about 150x nodes
  - Smallest node count is determined by memory requirements of WRF
  - Efficiency tends to drop before reaching a maximum allowable node count
- NOTE: within node scaling is not effective and is not typically used on a supercomputer
- OpenMP is ALWAYS within a single share-memory processing unit
- With MPI patches need to sometimes send and receive information from each other, referred to as messages and message passing
- WRF uses HALO regions to assist with message passing

HALO

```
porig(i,k,j) = ( po(i,k,j) + po(i-1,k,j) ) * 0.5
```

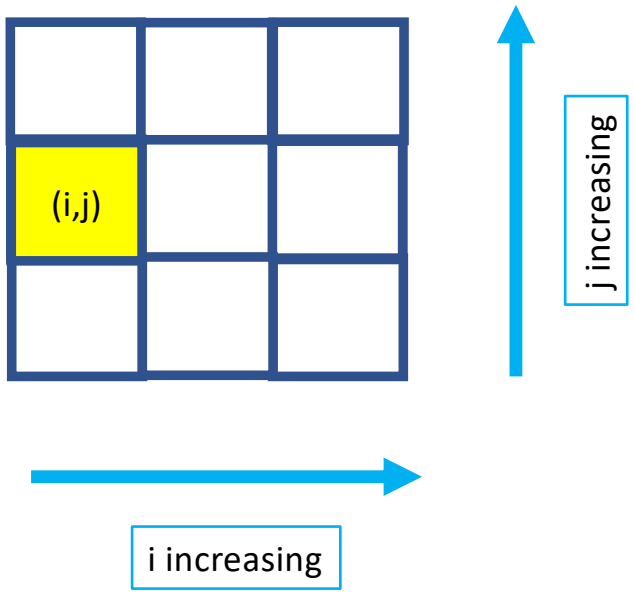
- Solve a simple 2-point stencil, used for averaging a mass-point pressure to a momentum cell face location
- The assumption is that for each (i,j), the (i-1,j) location is a neighboring point



HALO

```
porig(i,k,j) = ( po(i,k,j) + po(i-1,k,j) ) * 0.5
```

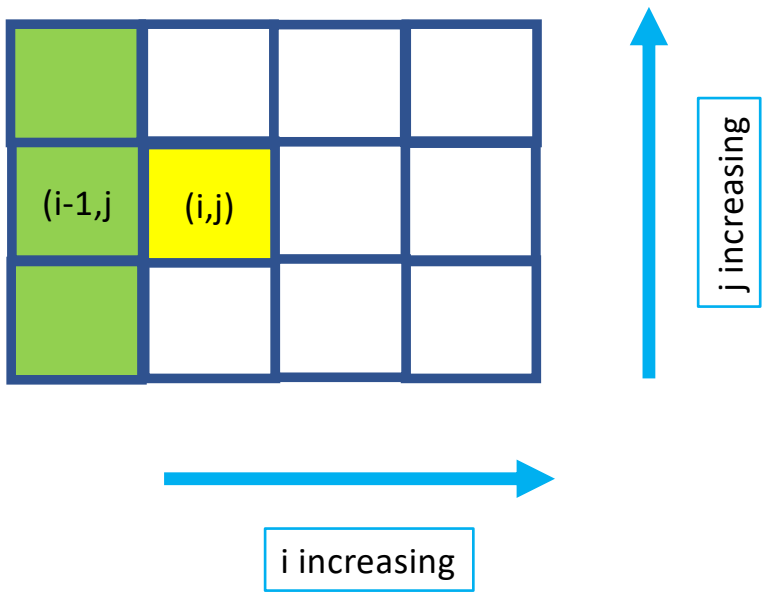
- For this stencil, if our grid cell lies on a western boundary, there is no neighboring point
- To get the information, we could communicate with the next patch and request the data
- However, communication is much slower than local memory access

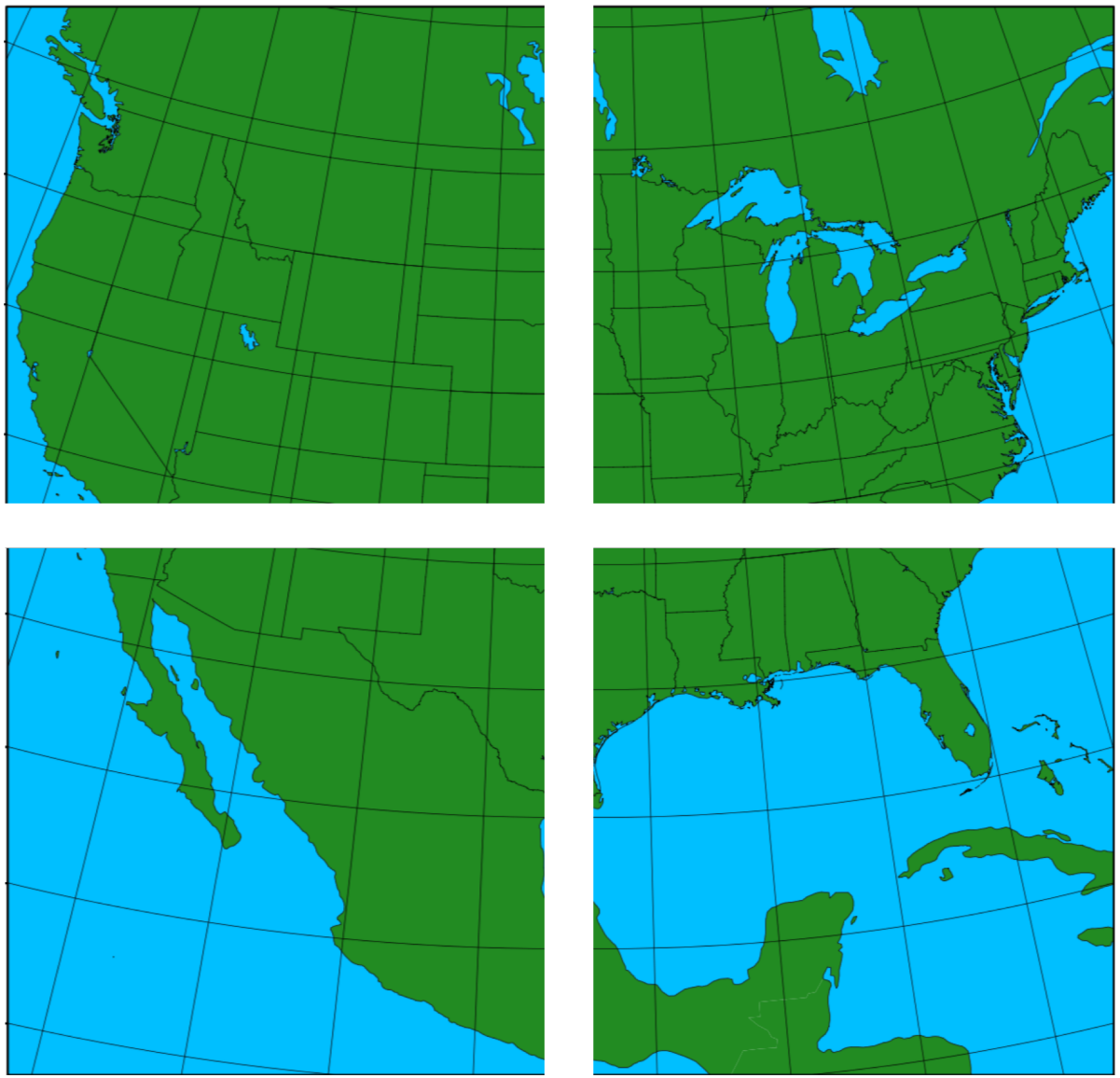


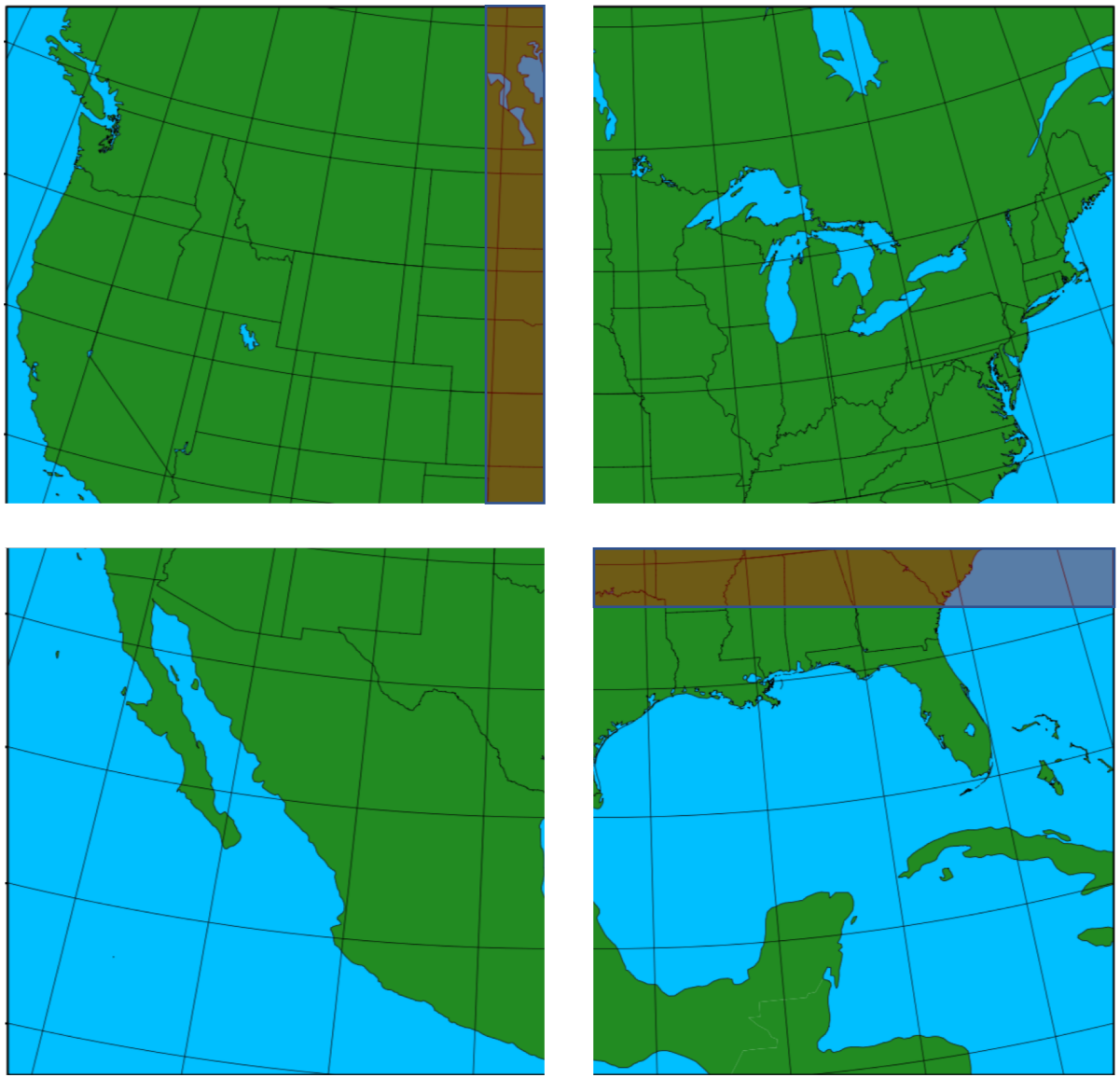
HALO

```
porig(i,k,j) = ( po(i,k,j) + po(i-1,k,j) ) * 0.5
```

- Instead of communicating with a distributed memory processor for each computation, a surrounding group of cells along the boundary holds read-only information
- This halo region is kept updated periodically from the neighboring distributed memory processor

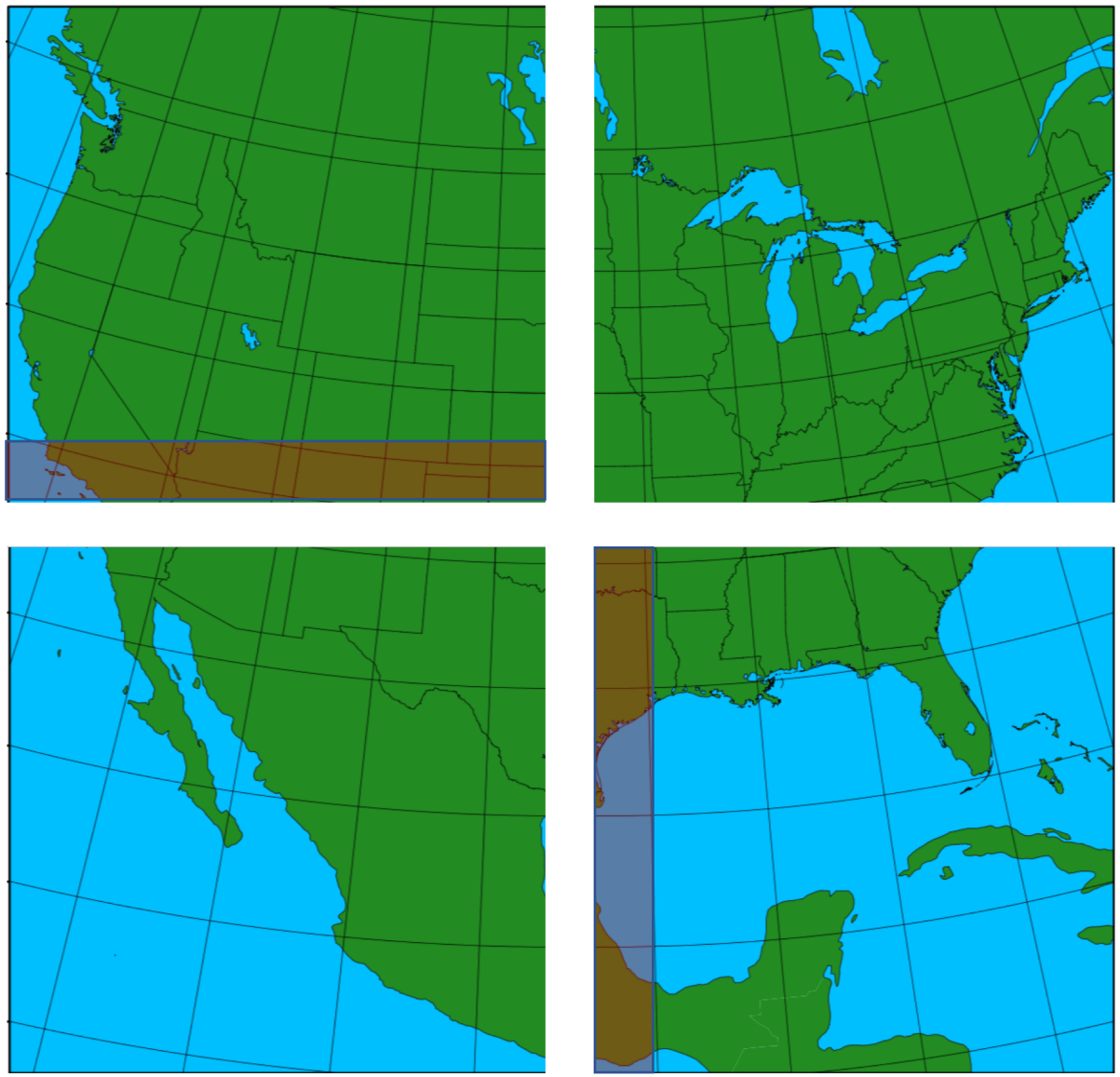


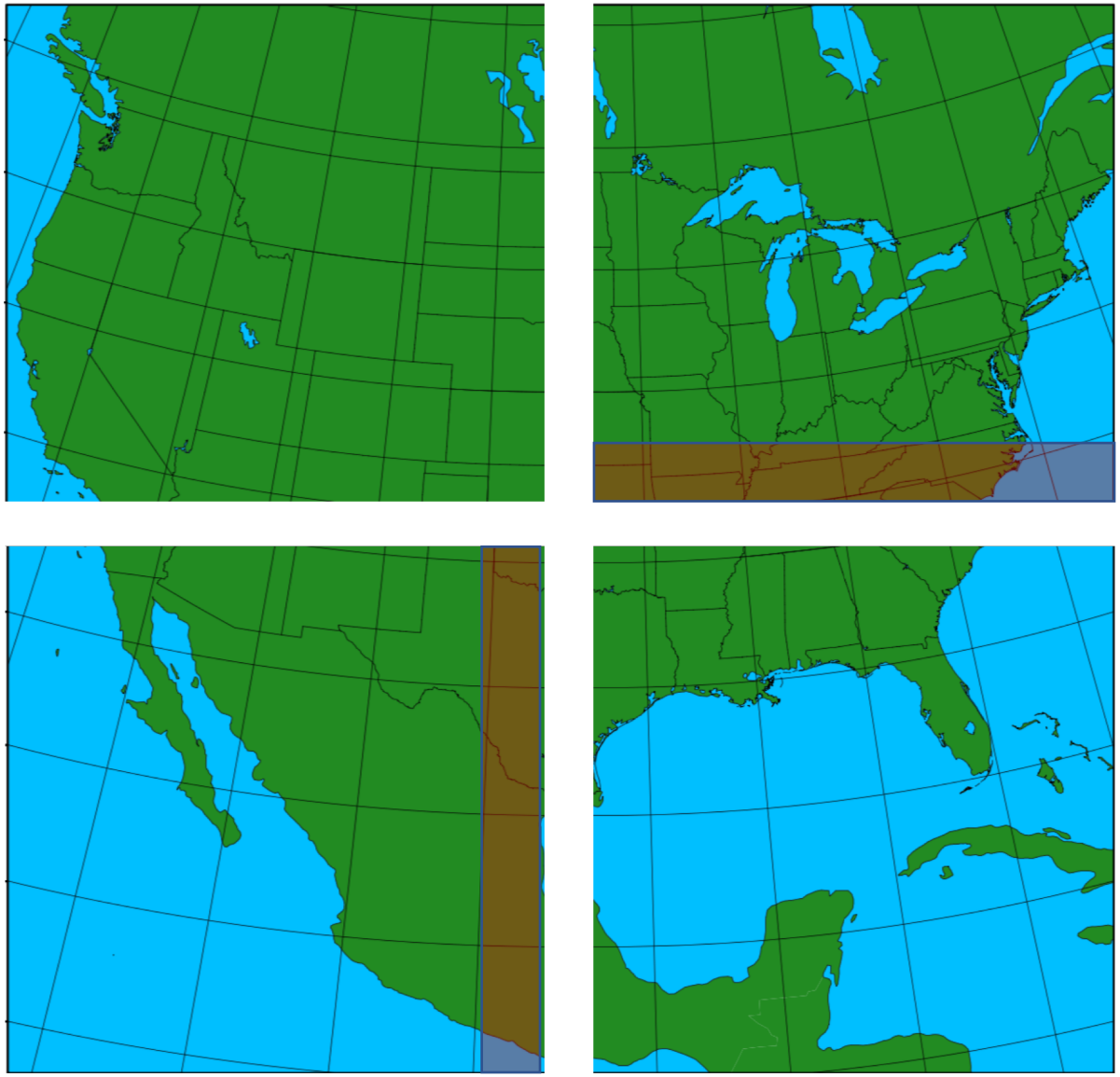




Halos to the left and below

Halos to the right and above





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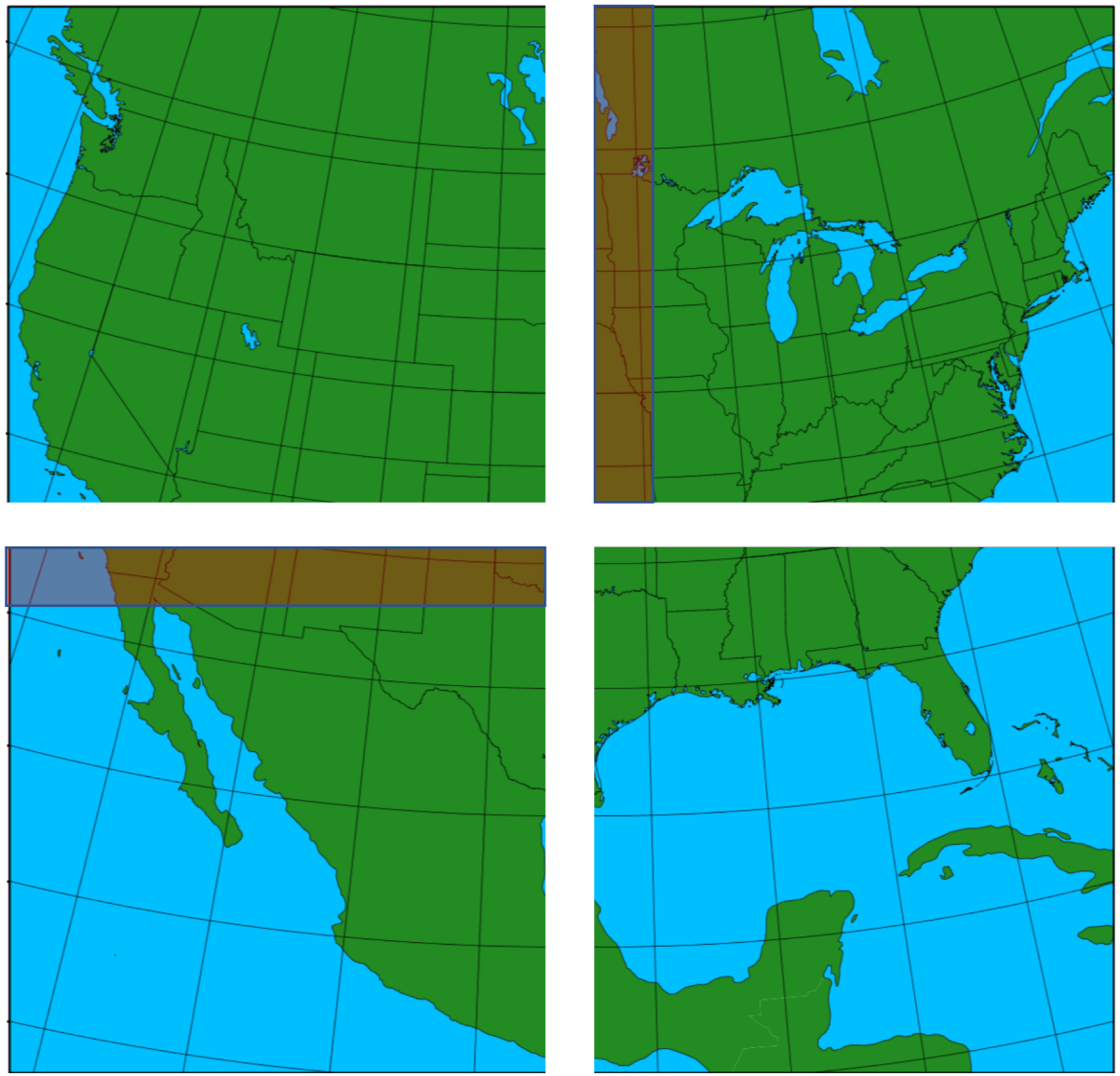
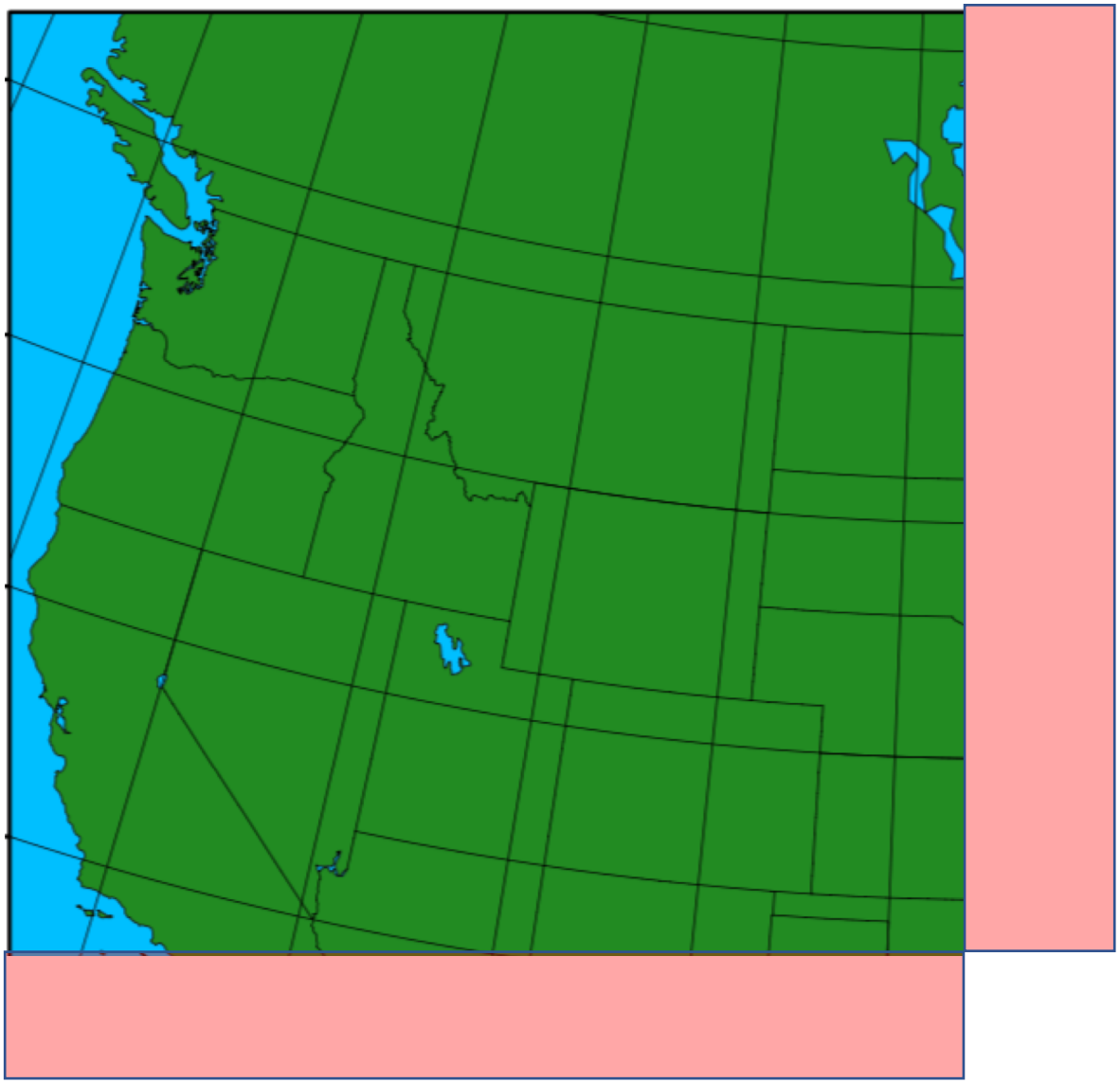
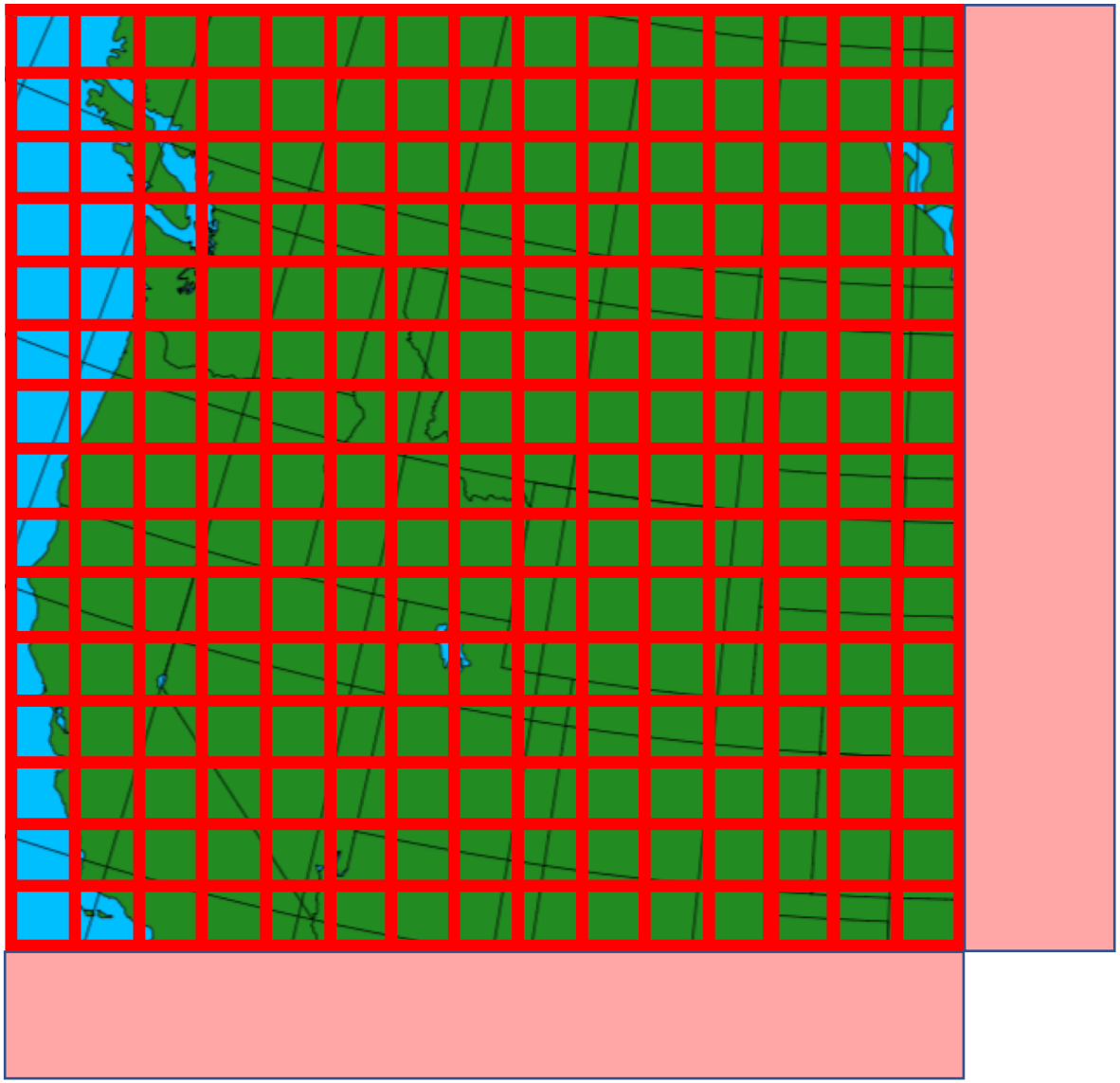
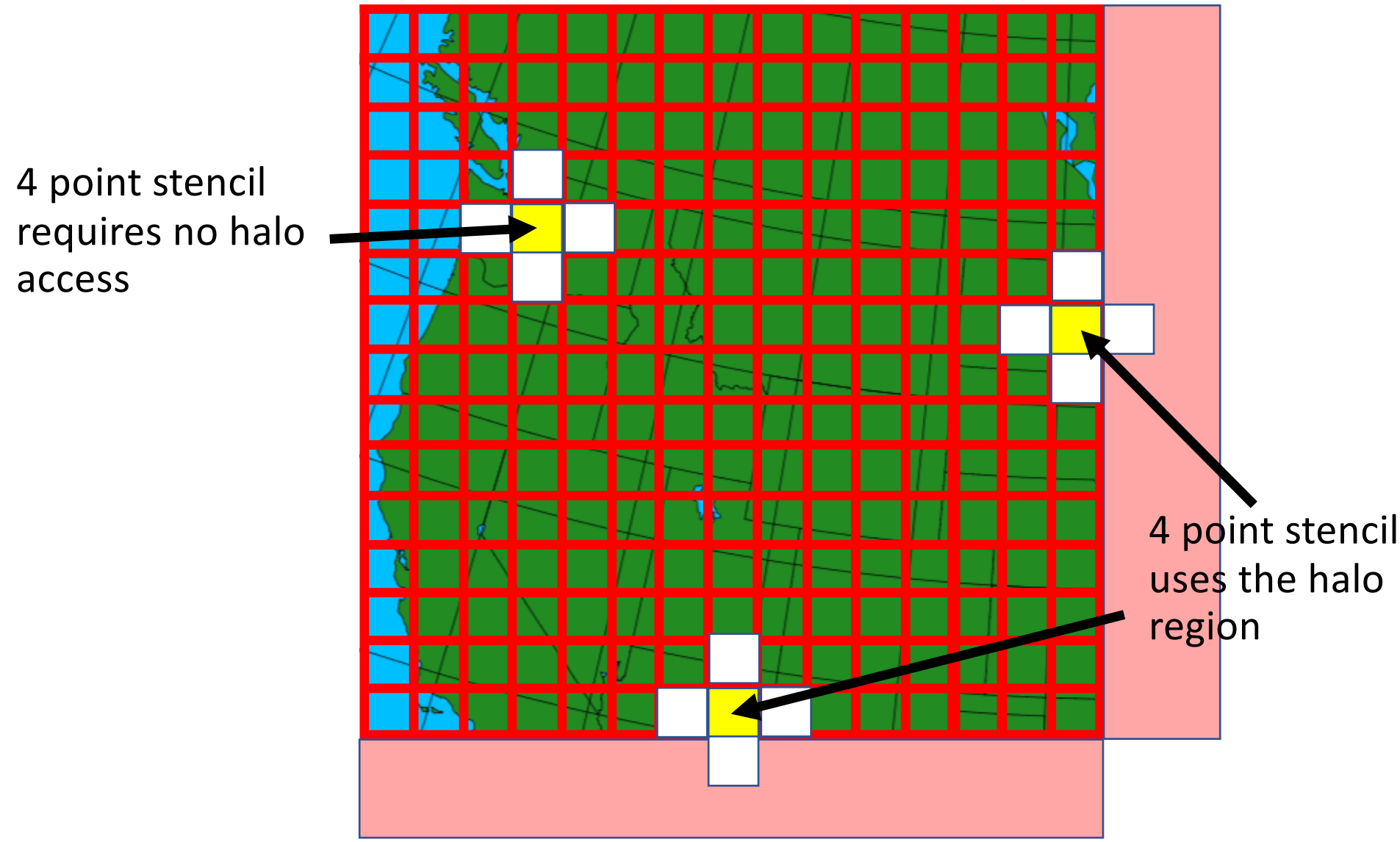







4 point stencil requires no halo access
4 point stencil uses the halo region

Domain Decomposition

- When we decompose the WRF domain into smaller pieces, we distribute work to additional processors

```
> mpirun -np ??? wrf.exe
```

- QUESTIONS:
- How do we determine how many processors to use for a job
- What is the shape of the resultant decomposed grids
- What are performance consequences of these decisions

Domain Decomposition

- How many processors to use - MINIMUM

- The minimum number of processors is based on the amount of memory that is available
- In the 1500x1500 benchmark case, a minimum of 4 nodes were required (4x36 processor cores) for the regular nodes, but only 2 nodes were required when using the large-memory nodes
- The WRF model would not run with a single node, it required too much memory

Domain Decomposition

- How many processors to use - MAXIMUM

- The maximum number of processors is based on the underlying stencil communications inside of the WRF model
- The model gracefully halts if you try to make a resultant distributed memory patch with < 10 grid cells on either side
- For the 1500x1500 benchmark case, we could have 150 units of patches that are 10 grid cells across (in the i- and j- directions)
- Therefore a maximum of 150x150 = 22,500 MPI processor cores

Domain Decomposition

- How many processors to use - RECOMMENDED

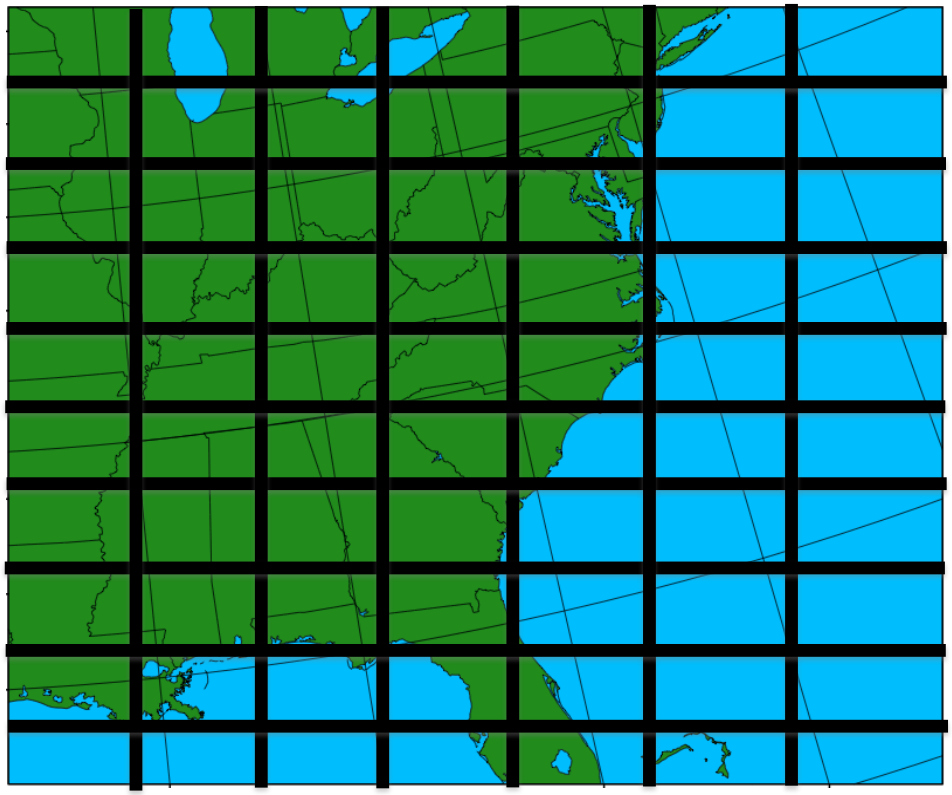
- The recommended number of processors is based on the timing performance that the WRF model is able to provide weighed against the timeliness of the required solution
- Usually, a fewer number of processors tends to more efficiently utilize the machine
- As long as there are enough processors (for memory) and not too many (for stencil sizes), the WRF model solution is correct

Domain Decomposition

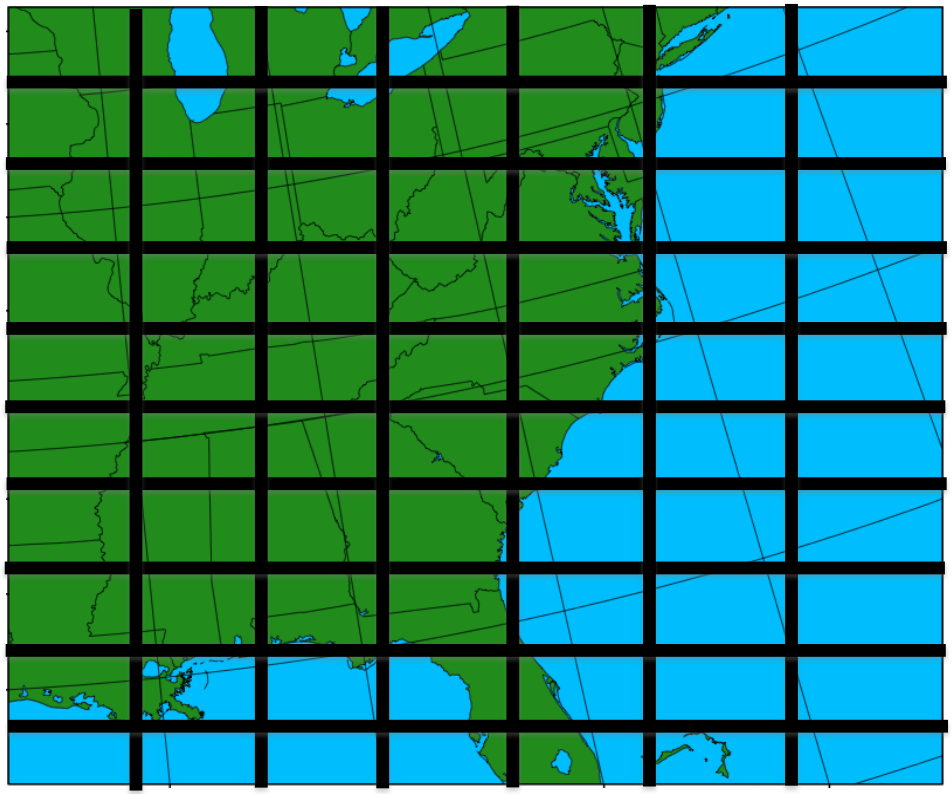
- How are the processor decompositions chosen

- By default, the decomposition of MPI tasks is computed as the two closest multiplicative factors
  - For example: 32 MPI tasks = 4x8 decomposition, NOT 2x16
  - For example: 144 MPI tasks = 12x12 decomposition, NOT 4x36
- The larger of the two factors decomposes the j-direction
- What to avoid: primes or large prime factors

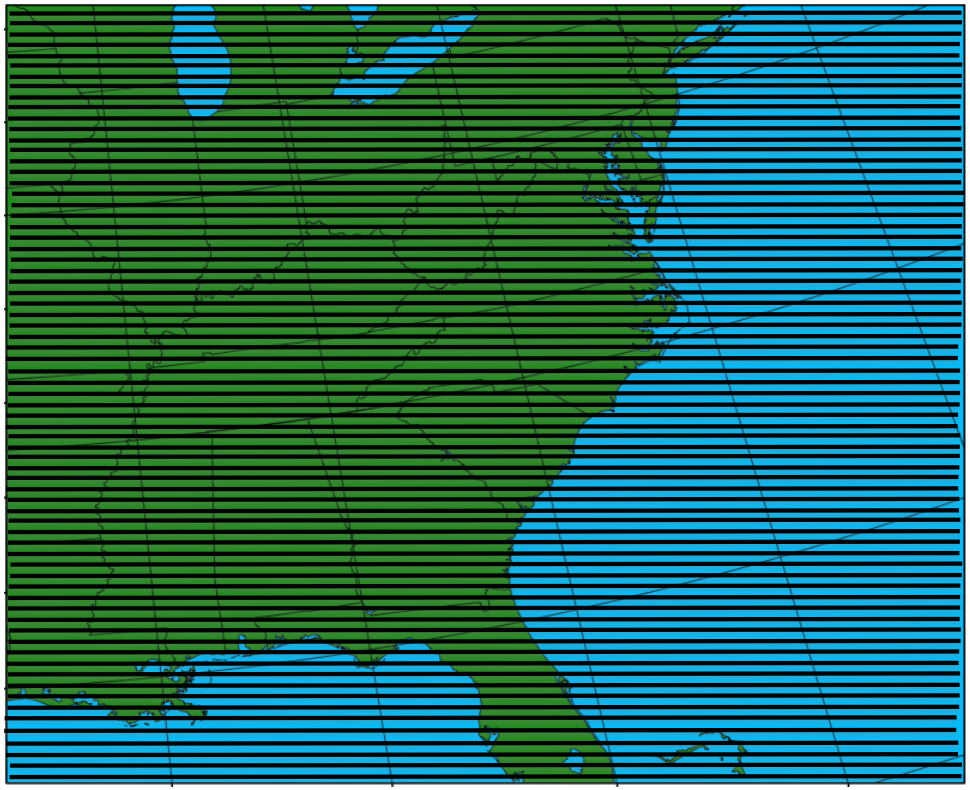
- 70 tasks
- 10 (j) x 7 (i)



- 70 tasks
- 10 (j) x 7 (i)



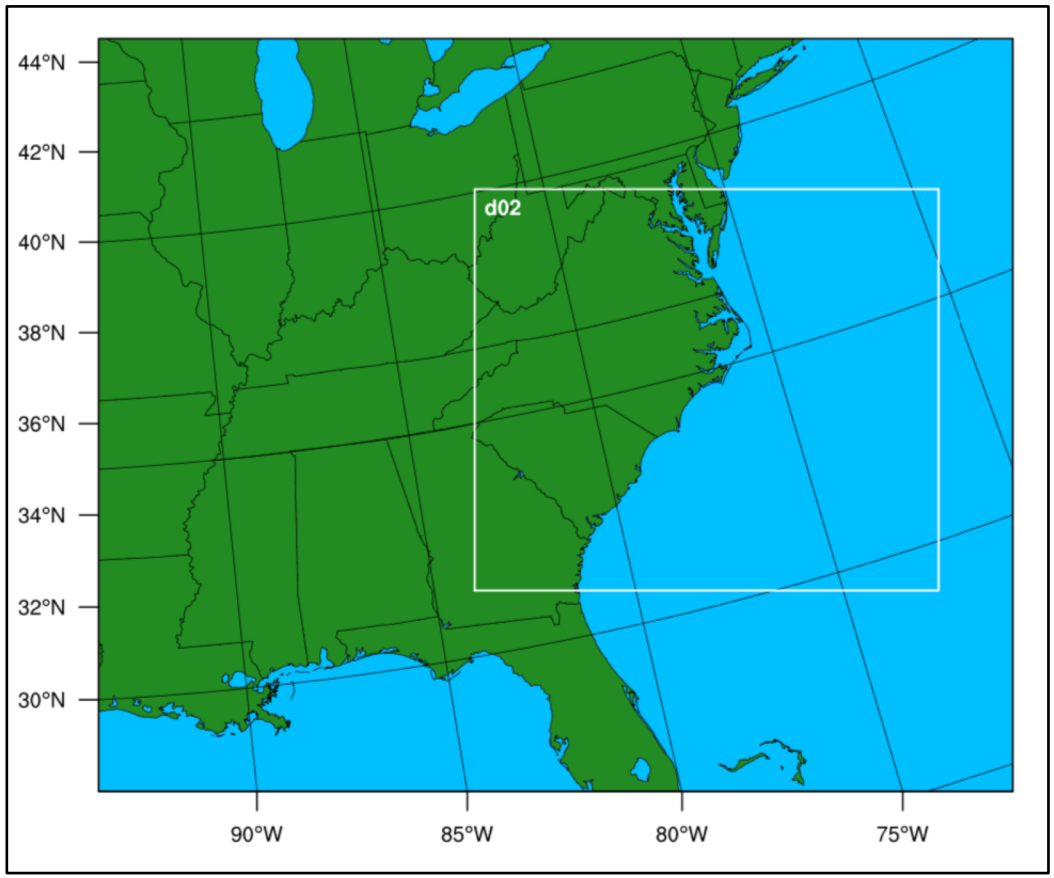
- 71 tasks
- 71 (j) x 1 (i)



Domain Decomposition

- Domain decomposition choices are important with nesting
- All domains within the WRF model use the exact same number of processors, with the same processor decomposition
- Choosing inconsuistent grid domains that have a large grid cell count difference negatively impacts timing performance
- A small coarse grid (compared to the nest) restricts the number of processors that are able to be utilized by the fine grid domain (the expensive domain)
- The fine grid is the expensive domain

Domain Decomposition




```
&geogrid
 parent_id         =   1,   1,
 parent_grid_ratio =   1,   3,
 i_parent_start    =   1,  31,
 j_parent_start    =   1,  17,
 e_we              =  74, 112,
 e_sn              =  61,  97,
/
```

- Default max cores on CG: 36
- Default max cores on FG: 81
- With namelist options: 42 vs 99
- Do not make CG smaller than FG

Where is all of this information

- When running the WRF model with MPI, two text files are generated by default for each MPI task
  - rsl.out.*nnnn*
  - rsl.error.*nnnn*
  - Where *nnnn* is the processor number of the WRF job, 0000 through n-1 for the ”mpirun –np n wrf.exe” job submission
- For a successfully completed job, important information is inside the rsl.out.0000 file

Where is all of this information

- How many MPI tasks are used

```
Ntasks in X            9 , ntasks in Y            12
```

- What is the decomposed domain size

```
Parent domain
ids,ide,jds,jde          1        1500          1        1500
ims,ime,jms,jme         -4         174         -4         132
ips,ipe,jps,jpe          1         167          1         125
```

- How much memory is allocated on the heap

```
alloc_space_field: domain     1 ,              792646428  bytes allocated
```

Where is all of this information

- How much time to write out data

```
Timing for Writing wrfout_d01_2019-05-05_22:00:00 for domain  1: 139.06874 elapsed seconds
```

- How much time to do a time step (first includes I/O time)

```
Timing for main: time 2019-05-05_22:00:18 on domain 1:  171.42862 elapsed seconds
Timing for main: time 2019-05-05_22:00:36 on domain 1:    6.98657 elapsed seconds
Timing for main: time 2019-05-05_22:00:54 on domain 1:    6.99922 elapsed seconds
Timing for main: time 2019-05-05_22:01:12 on domain 1:    6.99057 elapsed seconds
```

- Parallelism in WRF
  - Why is it required
  - What is “scaling”
- OpenMP and MPI
- Halos
- Domain Decomposition
  - Reasonable, max, min, bad
  - Dimensions and decomposition
  - Coarse grid vs nest grid
- Where is all of this information
  - Using rsl files