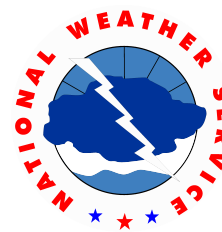
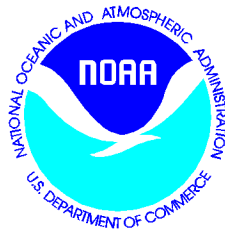
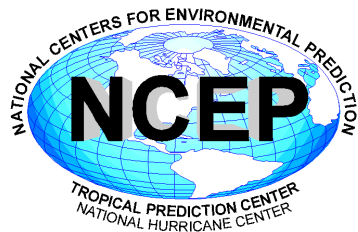
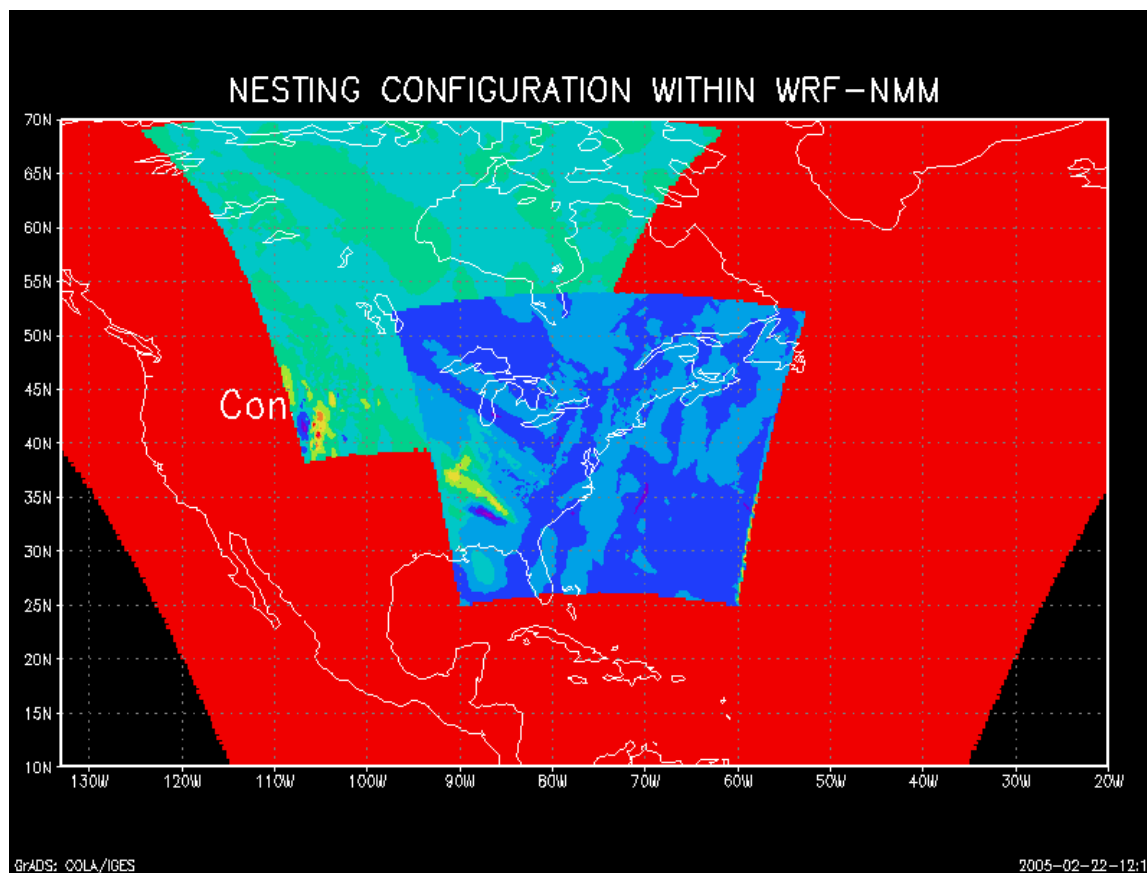


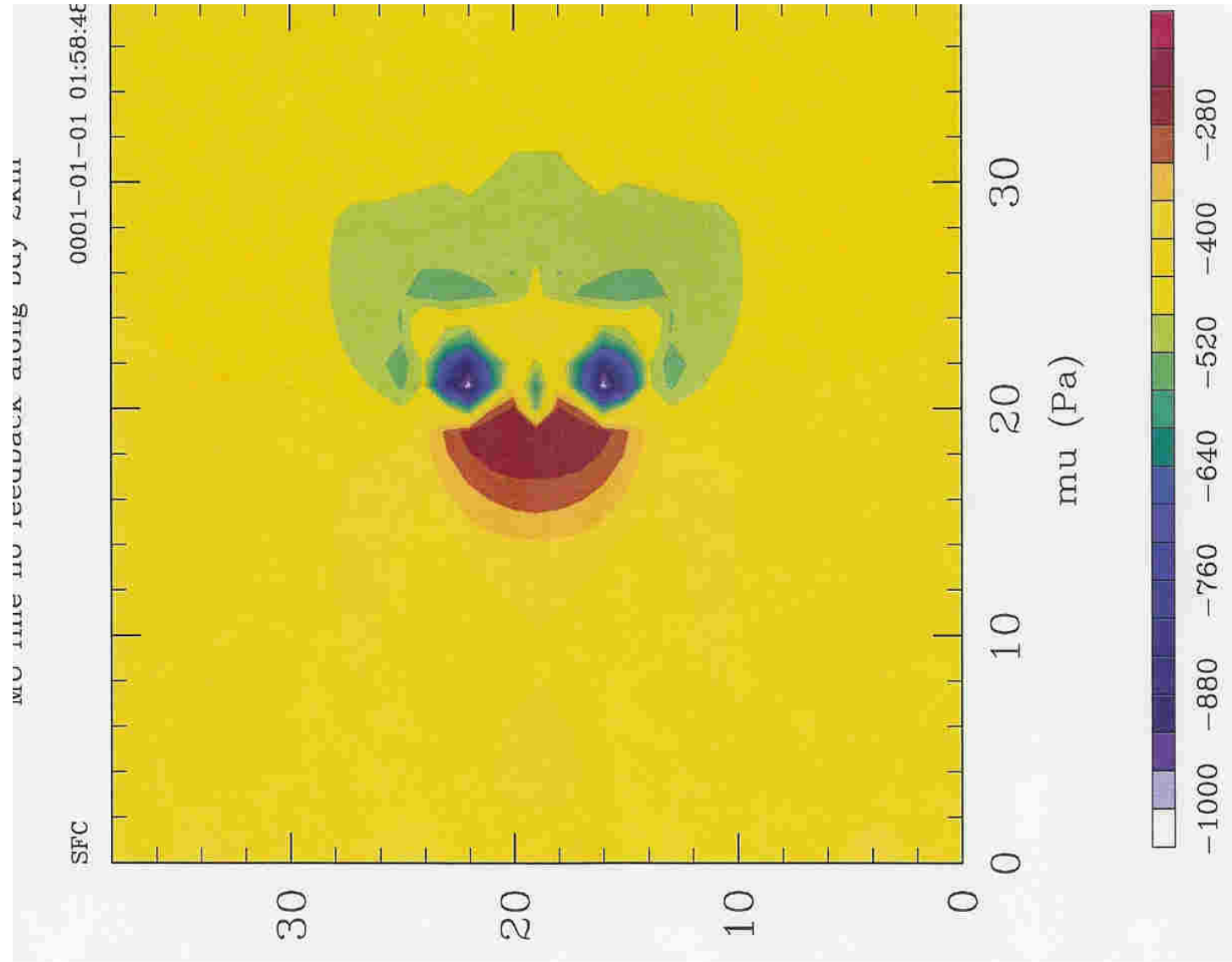
Nesting in WRF

Dave Gill
Matthew Pyle



ARW Nesting

Dave Gill



- Nesting definitions
- NMM and ARW nesting capabilities
- Domains, staggering, feedback
- Nesting performance
- Data routing for nesting forecasts
- Intermediate domains
- Masked interpolation and feedback
- IO from the Registry
- Some suggestions

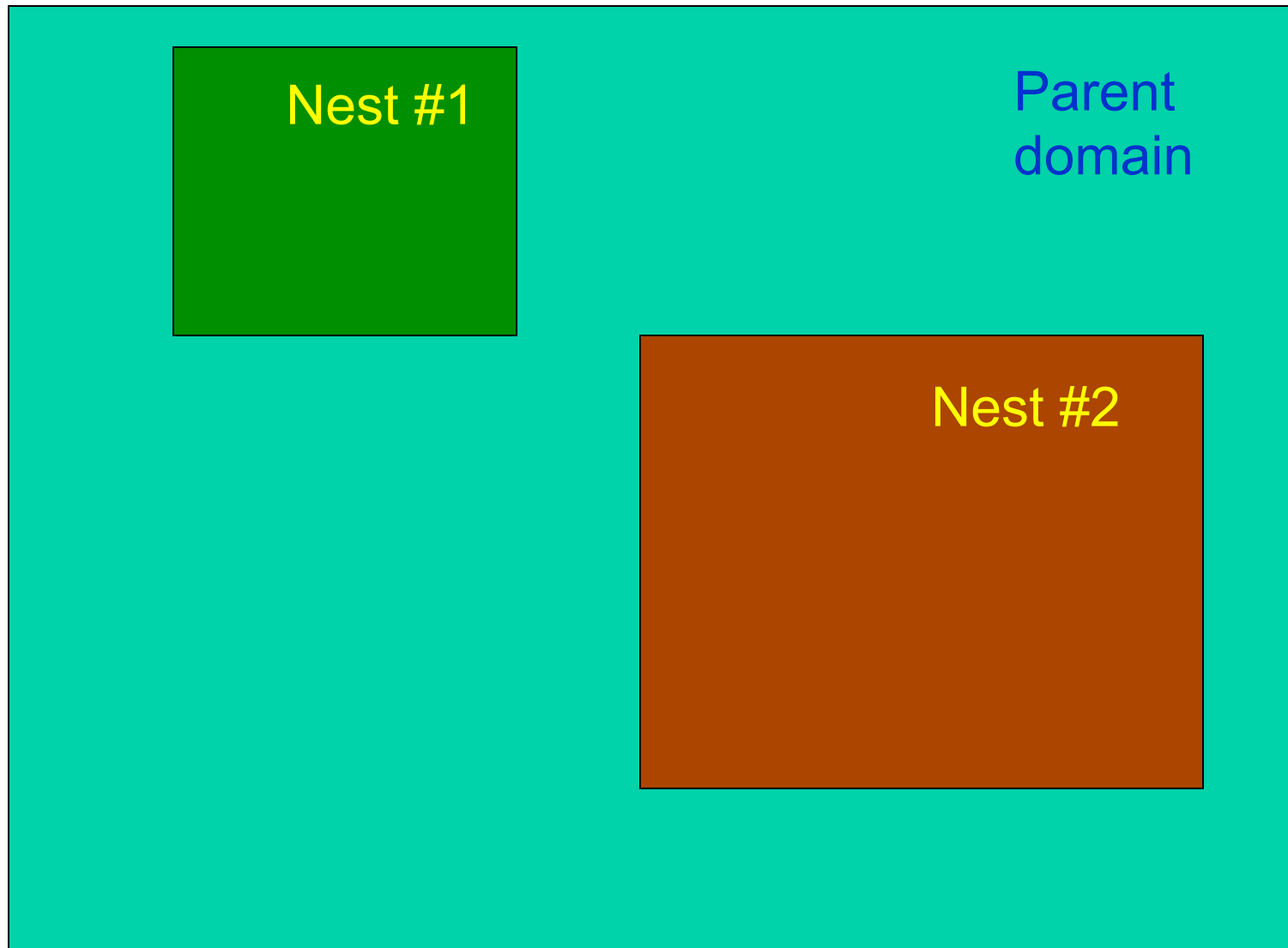
Nesting Basics - What is a nest

- A nest is a *finer-resolution* model run. It may be *embedded* simultaneously within a coarser-resolution (parent) model run, or *run independently* as a separate model forecast.
- The nest *covers a portion* of the parent domain, and is driven along its *lateral boundaries* by the parent domain.
- Nesting enables running at finer resolution without the following problems:
 - Uniformly high resolution over a large domain - prohibitively expensive
 - High resolution for a very small domain with mismatched time and spatial lateral boundary conditions

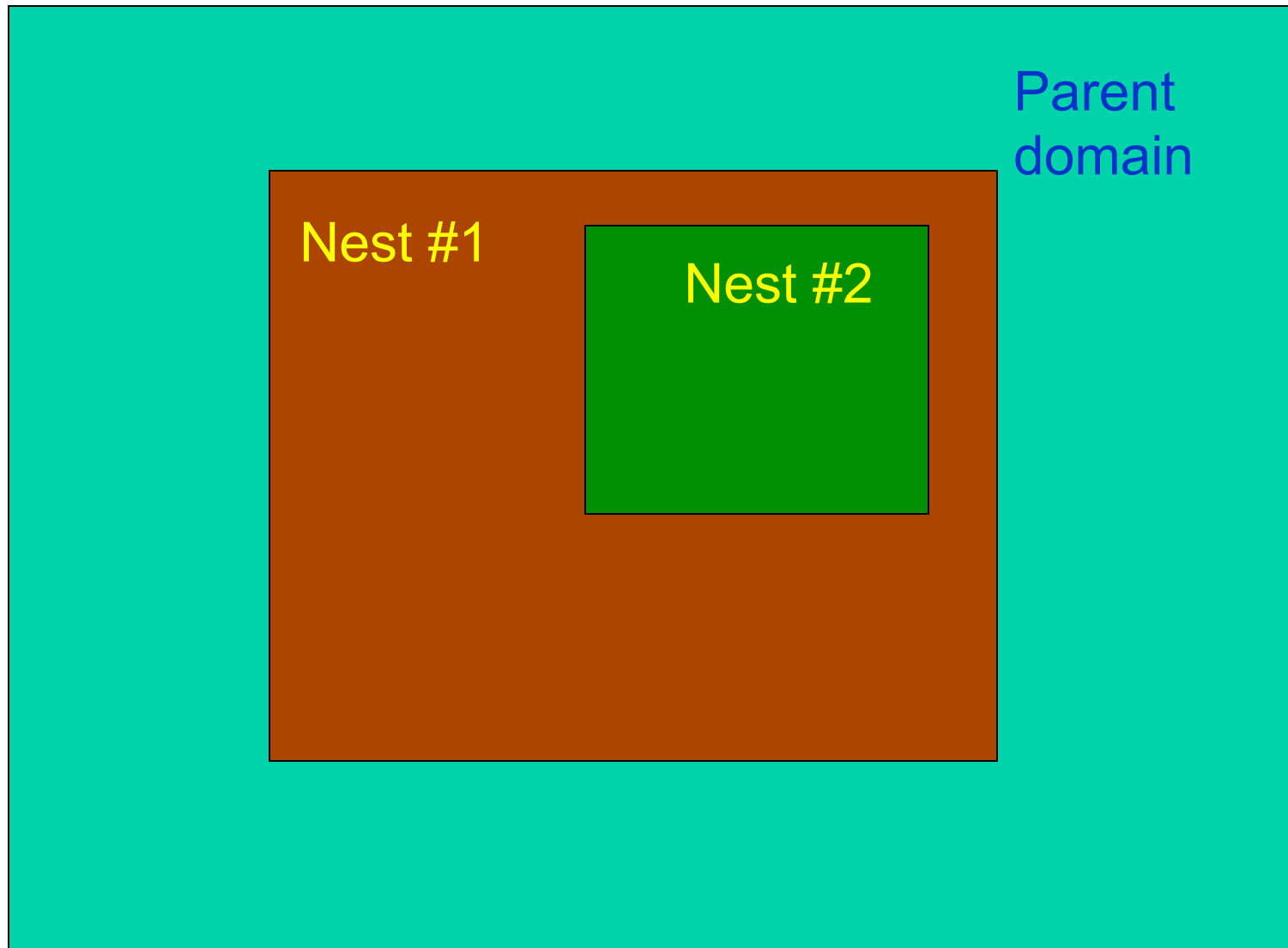
Nesting Basics - ARW

- One-way nesting via **multiple model forecasts**
- One-way nesting with a **single model forecast**, without feedback
- One-way/two-way nesting with a **single input file**, all fields interpolated from the coarse grid
- One-way/two-way nesting with multiple input files, each domain with a **full input data file**
- One-way/two-way nesting with the coarse grid data including all meteorological fields, and the fine-grid domains including only the **static files**
- One-way/two-way nesting with a **specified move** for each nest
- One-way/two-way nesting with an **automatic move** on the nest determined through 500 mb low tracking

Two nests on the same “level”, with a common parent domain

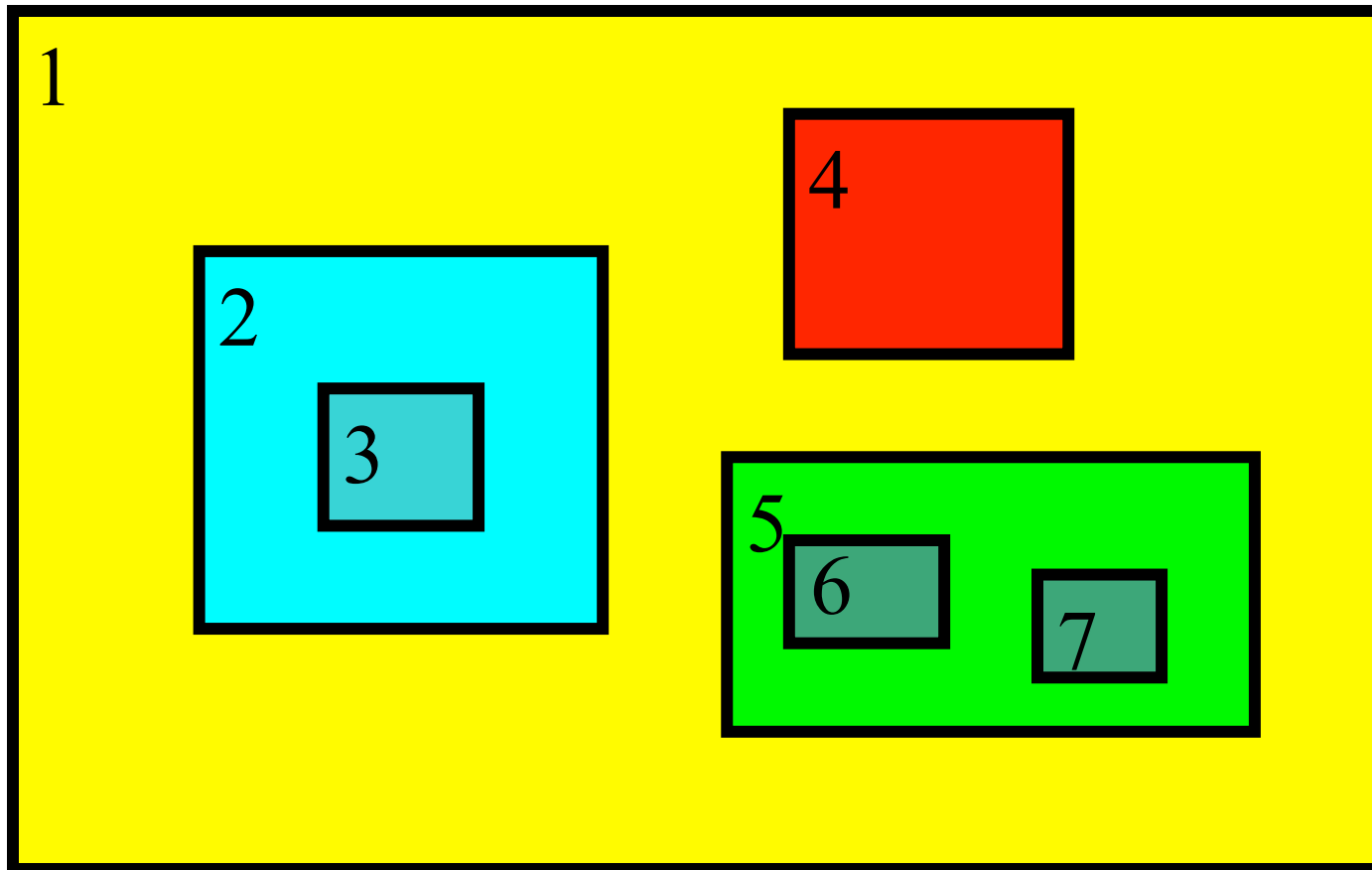


Two levels of nests, with nest #1 acting as the parent
for nest #2



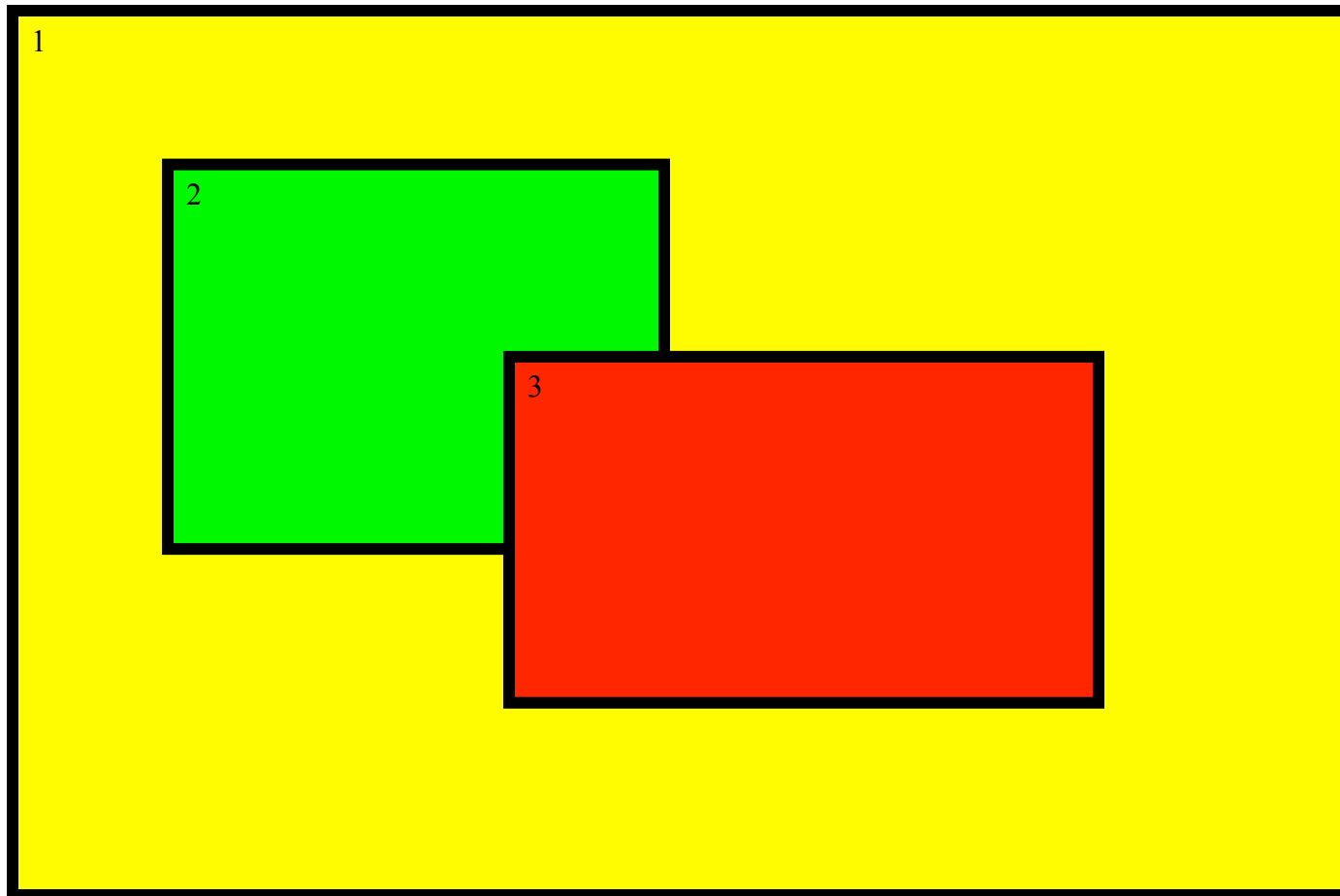
These are all OK

Telescoped to any depth
Any number of siblings



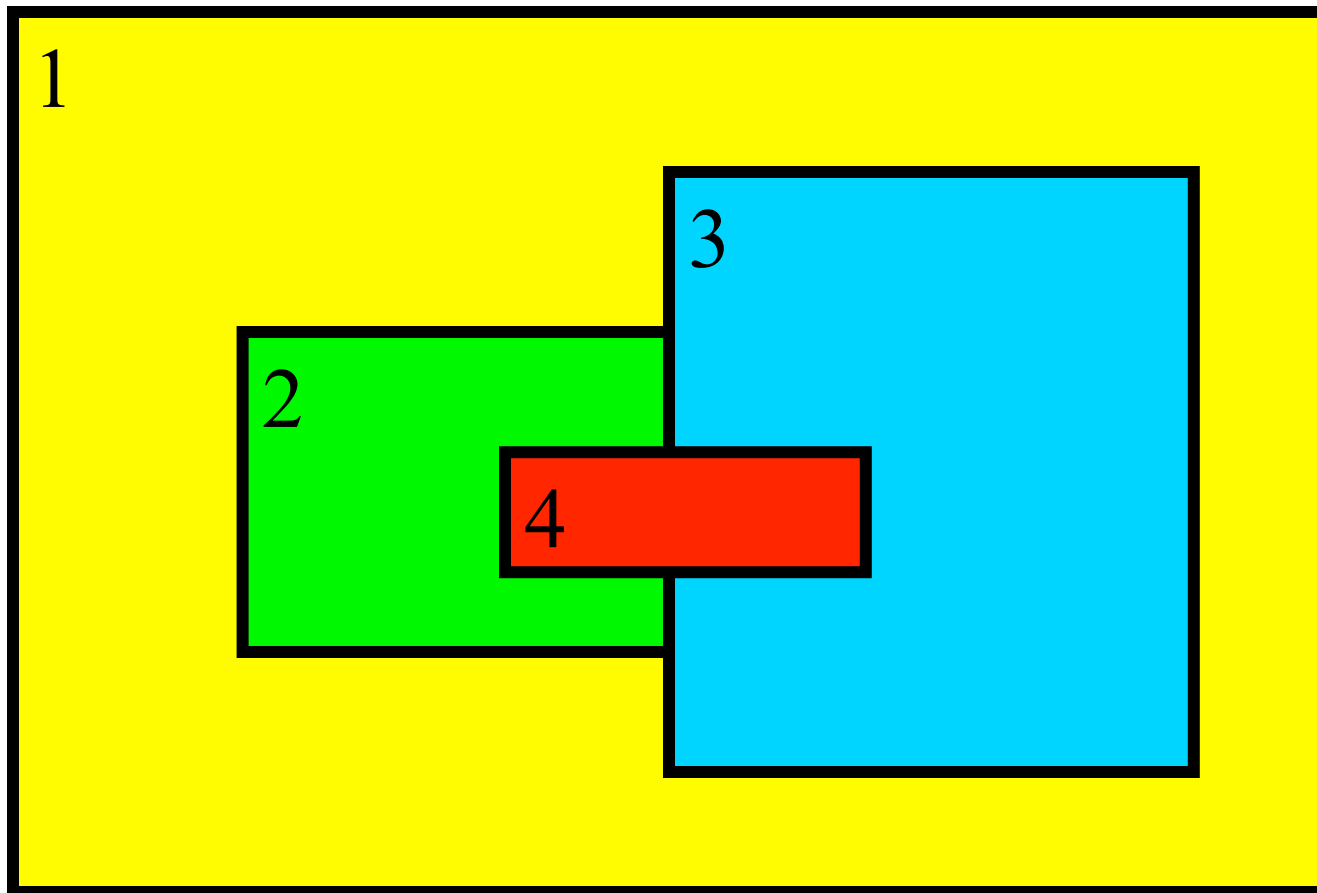
Not OK for 2-way

Child domains *may not* have overlapping points in the parent domain (1-way nesting excluded).



Not OK either

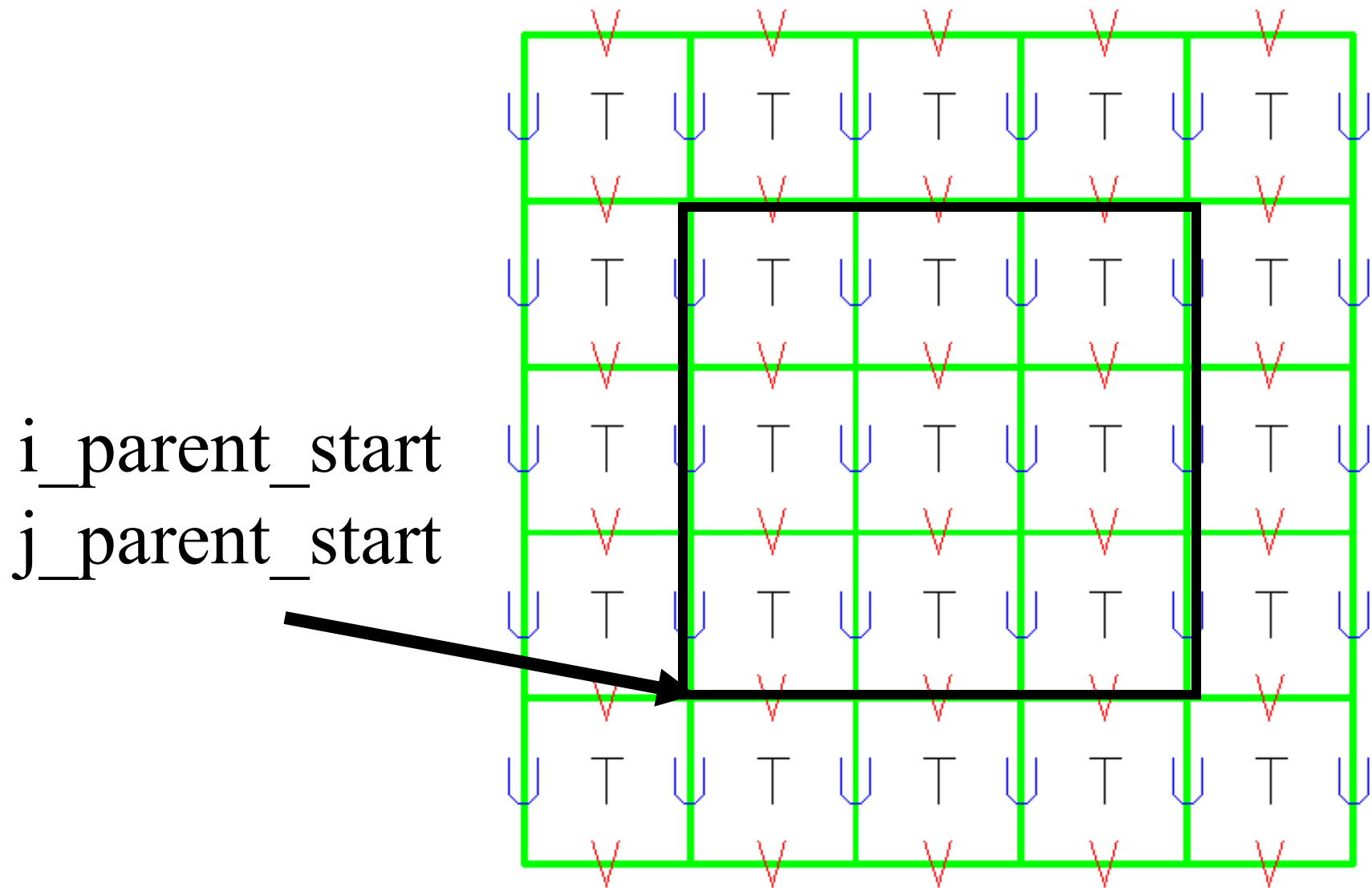
Domains have one, and only one, parent -
(domain 4 is NOT acceptable even with 1-way nesting)



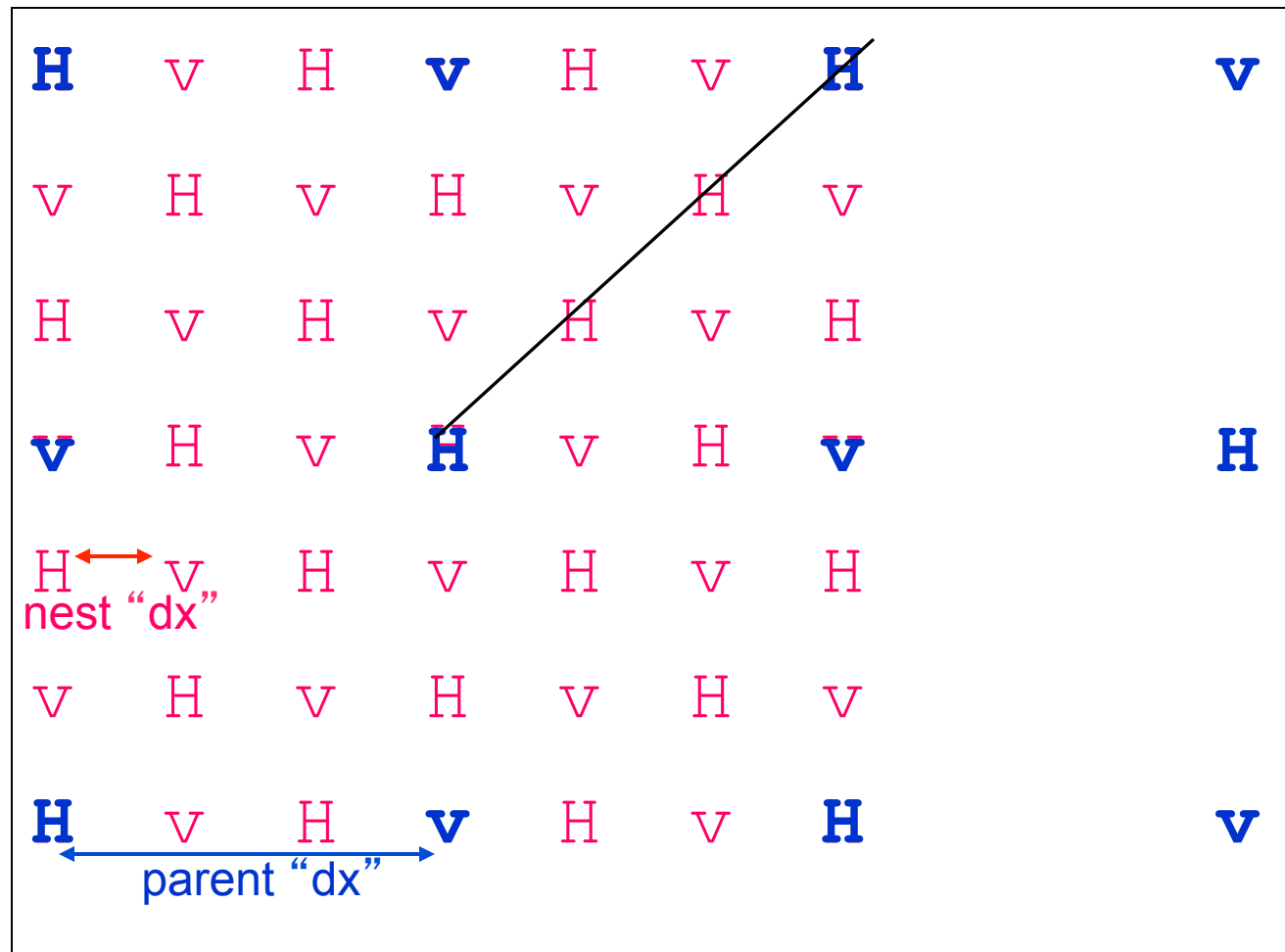
WRF Coarse-Fine Overlap

- The **rectangular fine grid** is coincident with a portion of the high-resolution grid that **covers the entire coarse grid cell**
- The nested domain can be **placed anywhere** within the parent domain and the nested grid cells will exactly overlap the parent cells at the coincident cell boundaries.
- Coincident parent/nest grid points eliminate the need for complex, generalized remapping calculations, and enhances model performance and portability.
- The grid design was created with moving nests in mind.

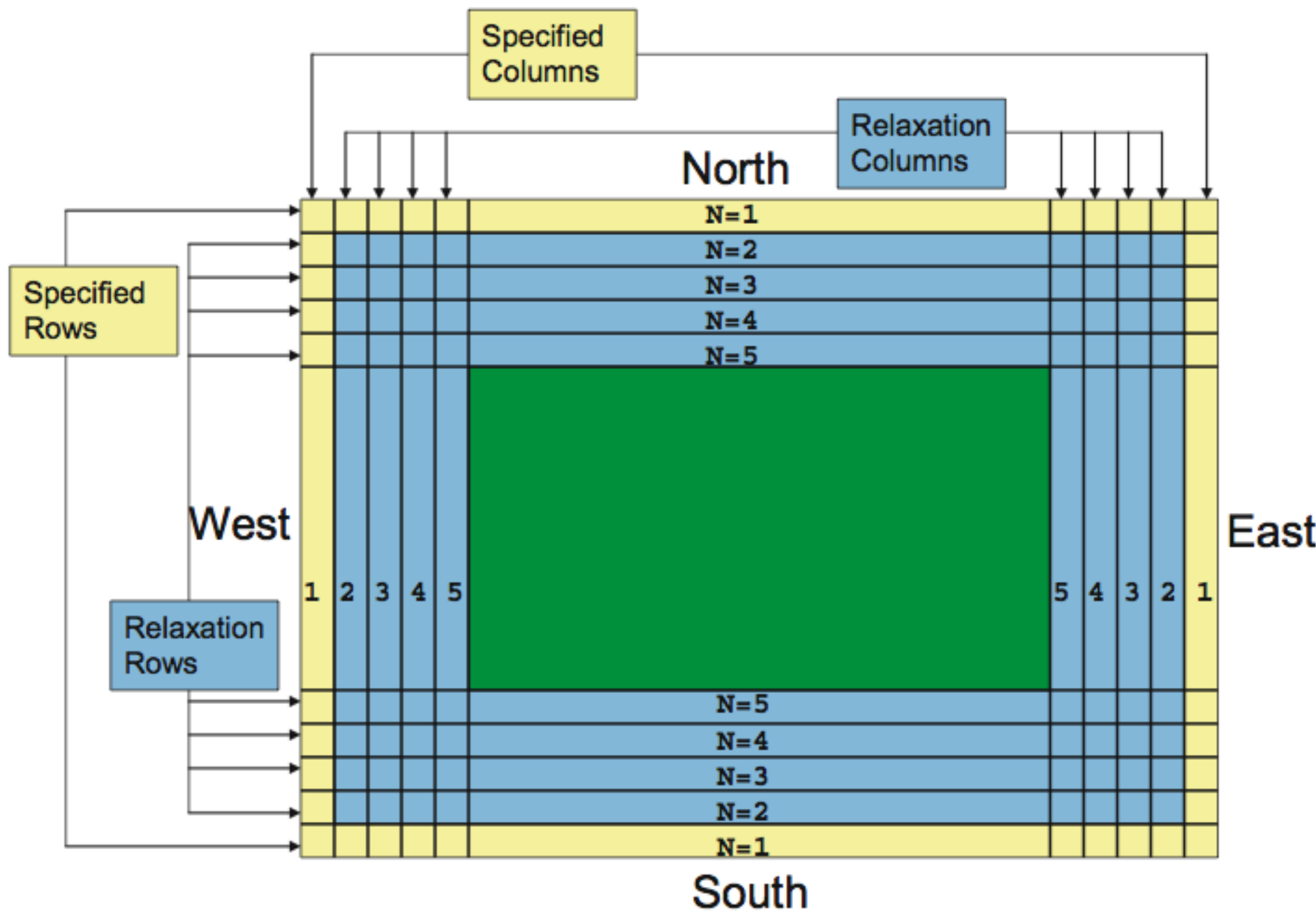
ARW Coarse Grid Staggering



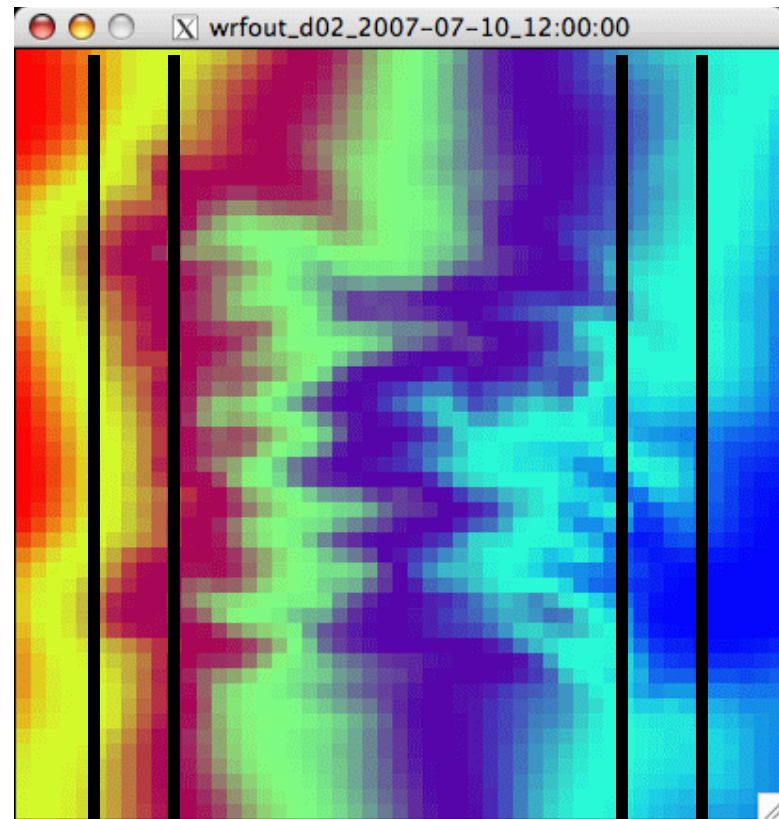
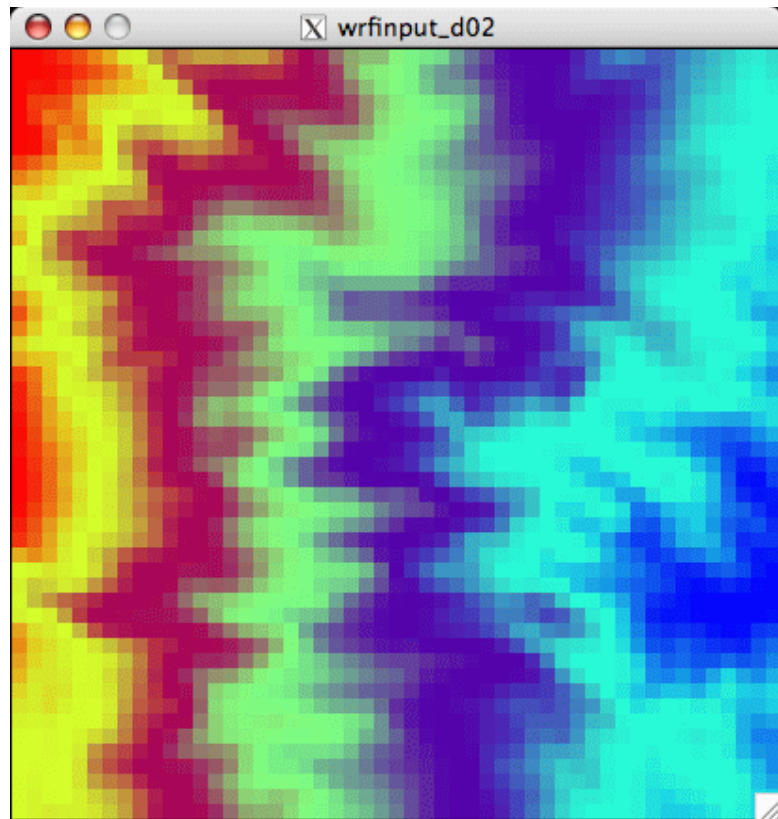
An odd grid ratio introduces parent/nest points being coincident, and a 3:1 ratio is preferred as it has been extensively tested.



Real-Data Lateral Boundary Condition: Location of Specified and Relaxation Zones

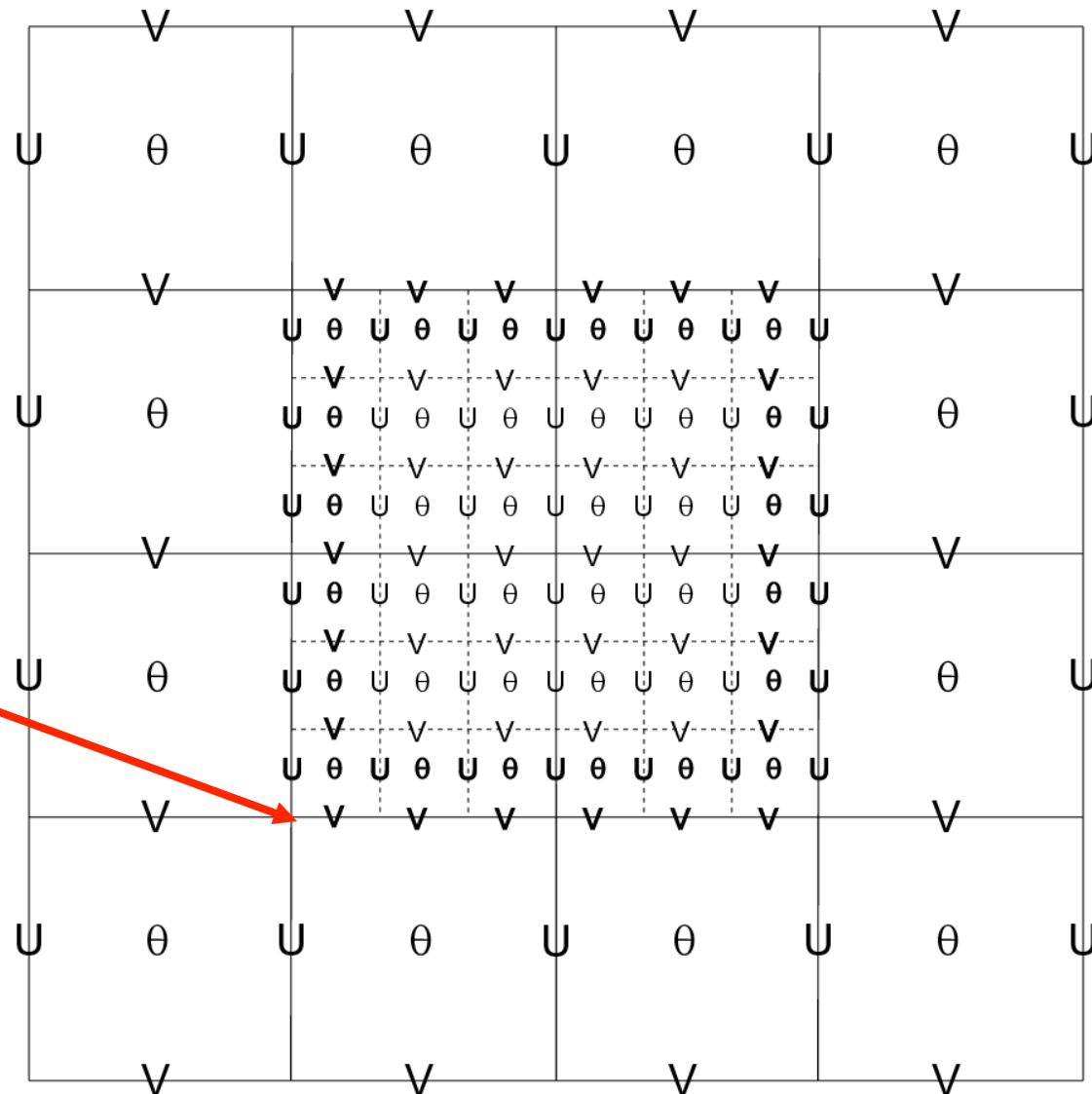


ARW Lateral Smoothing



ARW Coarse Grid Staggering 3:1 Ratio

**Starting
Location
 $I = 31$**



CG ... 30

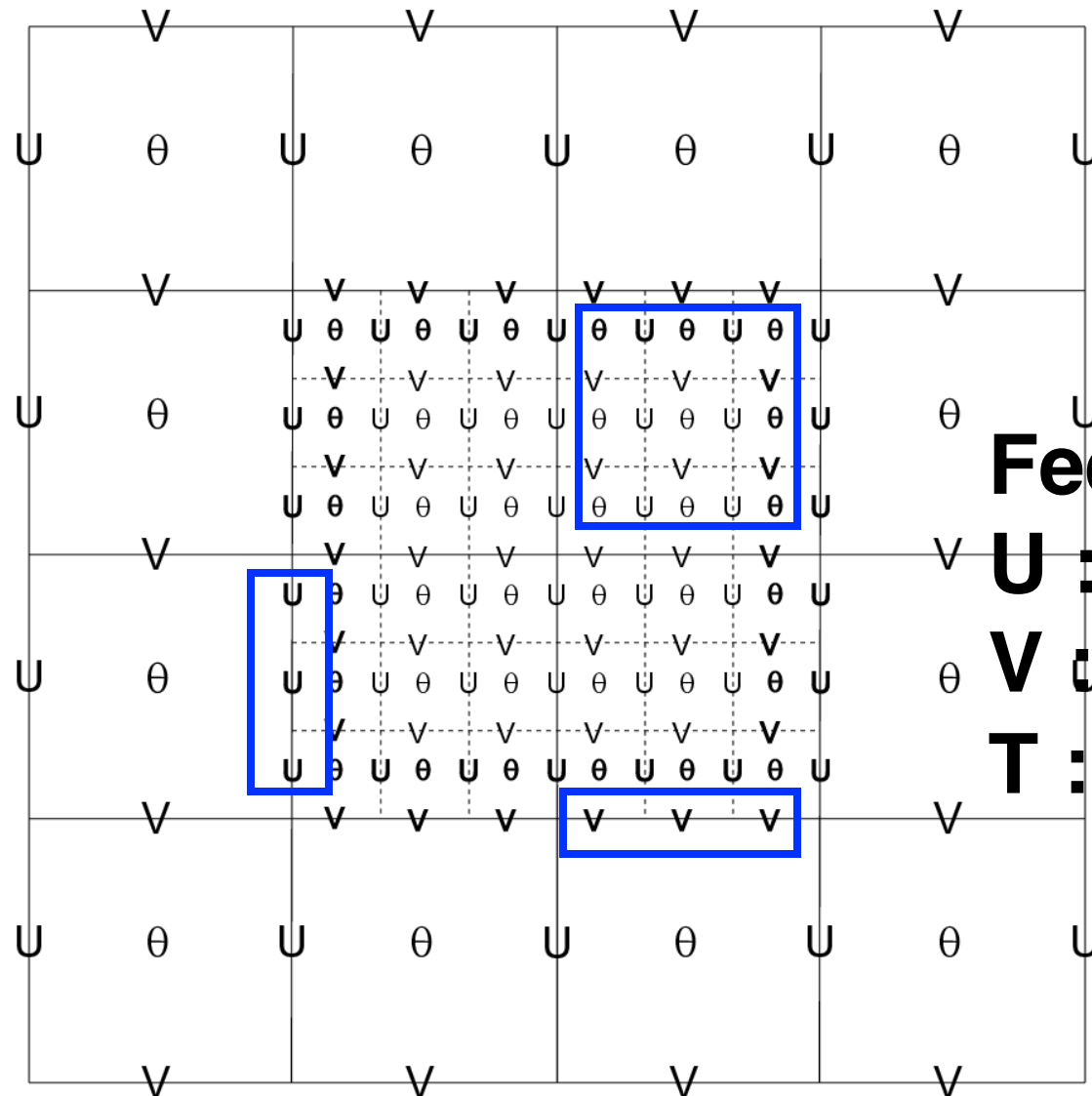
31

32

33

34

ARW Coarse Grid Staggering 3:1 Ratio



Feedback:
U : column
V : row
T : cell

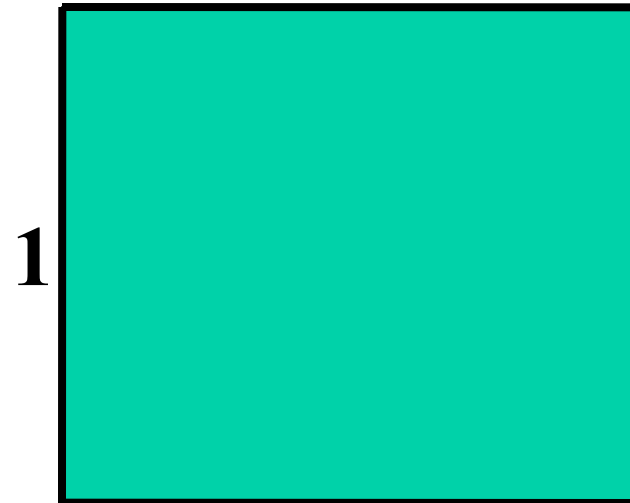
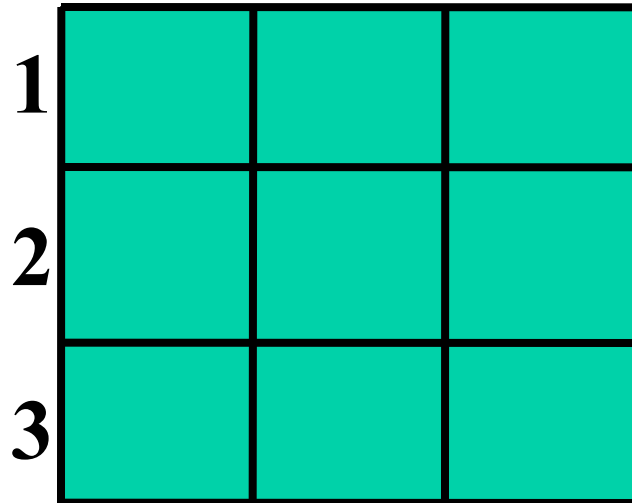
ARW Coarse Grid Staggering 3:1 Ratio

Feedback:

U : column

V : row

T : cell



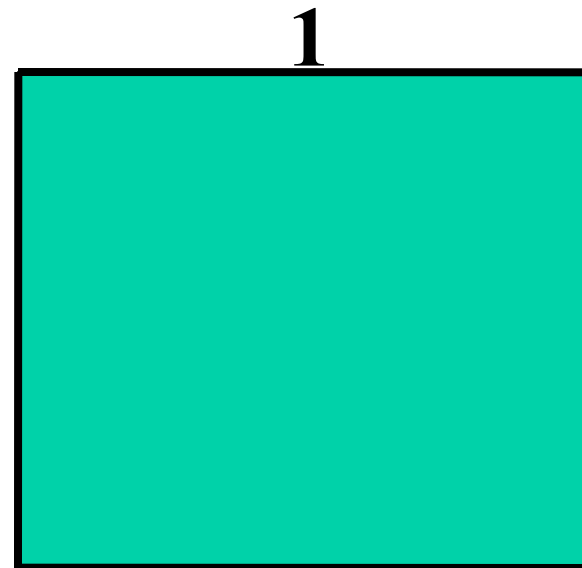
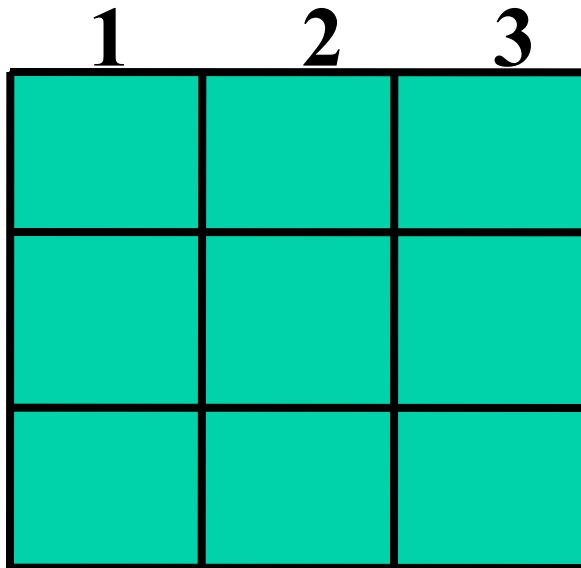
ARW Coarse Grid Staggering 3:1 Ratio

Feedback:

U : column

V : row

T : cell



ARW Coarse Grid Staggering 3:1 Ratio

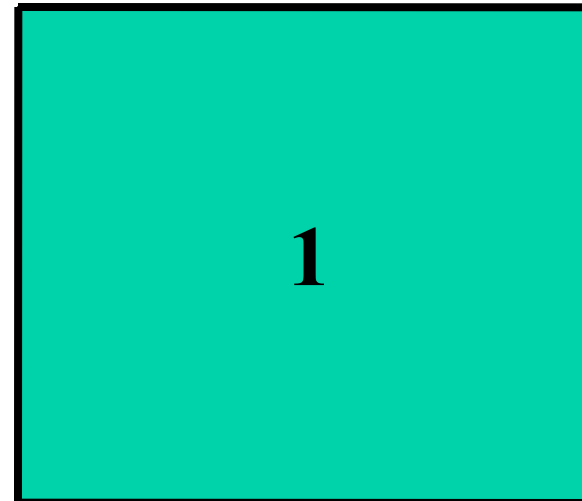
Feedback:

U : column

V : row

T : cell

1	2	3
4	5	6
7	8	9



Nesting Performance

- The **size** of the nested domain may need to be chosen with computing **performance** in mind.
- Assuming a 3:1 ratio and the same number of grid cells in the parent and nest domains, the fine grid will **require 3x as many time steps** to keep pace with the coarse domain.
- A simple nested domain forecast is approximately **4x the cost** of just the coarse domain.
- Don't be *cheap* on the coarse grid, **doubling** the CG points results in only a **25%** nested forecast time increase.

Nesting Performance

- Example: assume 3:1 nest ratio

If the nest has the same number of grid cells, then the **amount of CPU** to do a single time step for a coarse grid (CG) and a fine grid step (FG) is **approximately the same**.

Since the fine grid (3:1 ratio) has $1/3$ the grid distance, it requires $1/3$ the model time step. Therefore, the **FG requires 3x the CPU** to catch up with the CG domain.

Nesting Performance

- Example: assume 3:1 nest ratio

If you try to cover the SAME area with a FG domain as a CG domain, you need **(ratio)² grid points**.

With the associated FG time step ratio, you require a **(ratio)³**.

With a 3:1 ratio, a FG domain covering the same area as a CG domain **requires 27x CPU**.

Nesting Performance

- Example: assume **10:1 nest ratio**

To change your test case from 50-km resolution to a finer 5-km resolution would be **1000x more** expensive.

NMM: Initial Conditions

- Simple horizontal **bilinear interpolation** of the parent initial conditions is used to initialize all meteorological fields on the nest.
- **Nearest neighbor** interpolation is used for land/sea masked fields.
- Topography and land-sea mask are redefined over the nested domain using the appropriate “**nest level**” of WPS info from **geogrid**.
- **Re-balancing** is carried out after introducing the high-resolution topography to the interpolated meteorological fields.

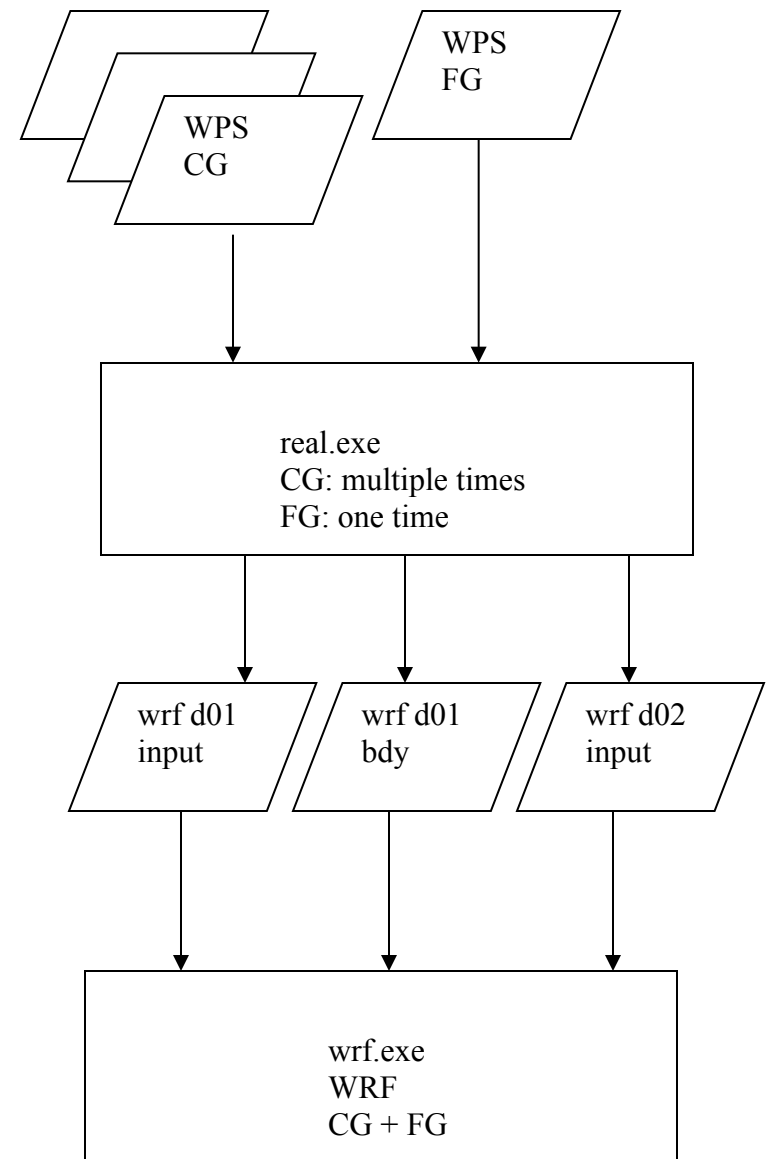
ARW: 2-Way Nest with 2 Inputs

Coarse and fine grid domains must start at the same time, fine domain may end at any time

Feedback may be shut off to produce a 1-way nest (cell face and cell average)

Any integer ratio for coarse to fine is permitted, odd is usually chosen for real-data cases

Options are available to ingest only the static fields from the fine grid, with the coarse grid data horizontally interpolated to the nest



ARW: 2-Way Nest with 2 Inputs

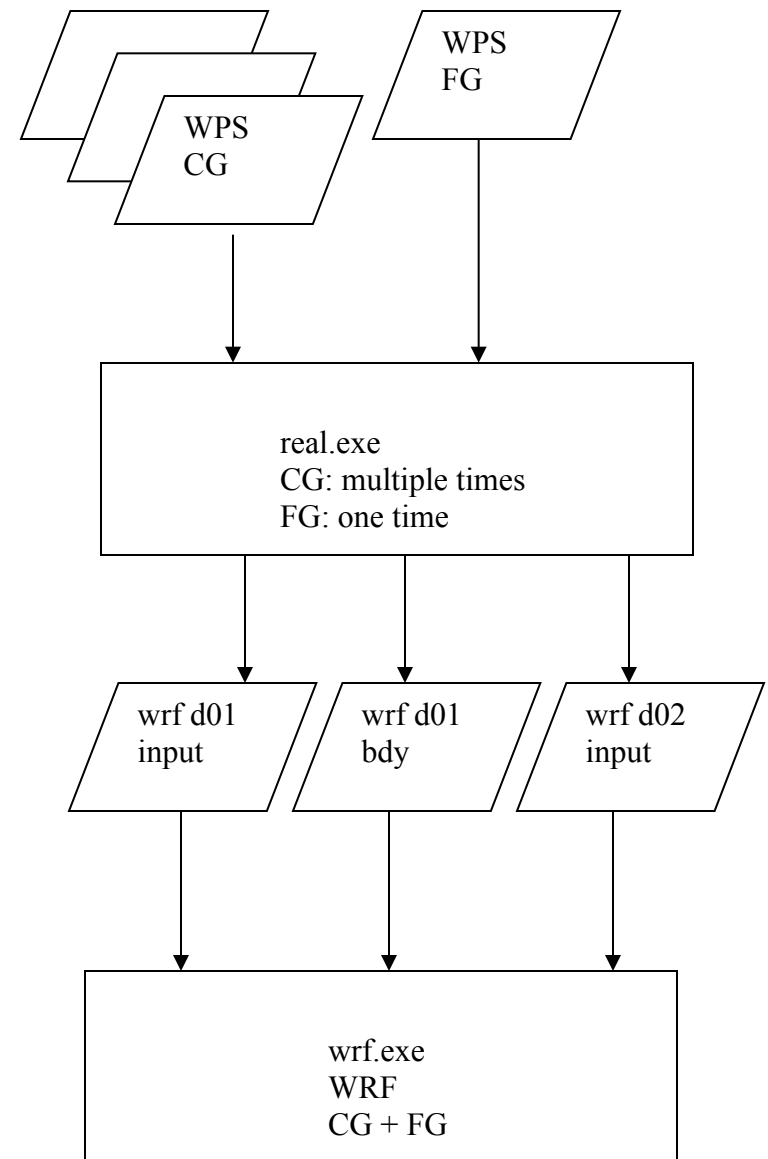
No vertical nesting

Usually the same physics are run on all of the domains (excepting cumulus)

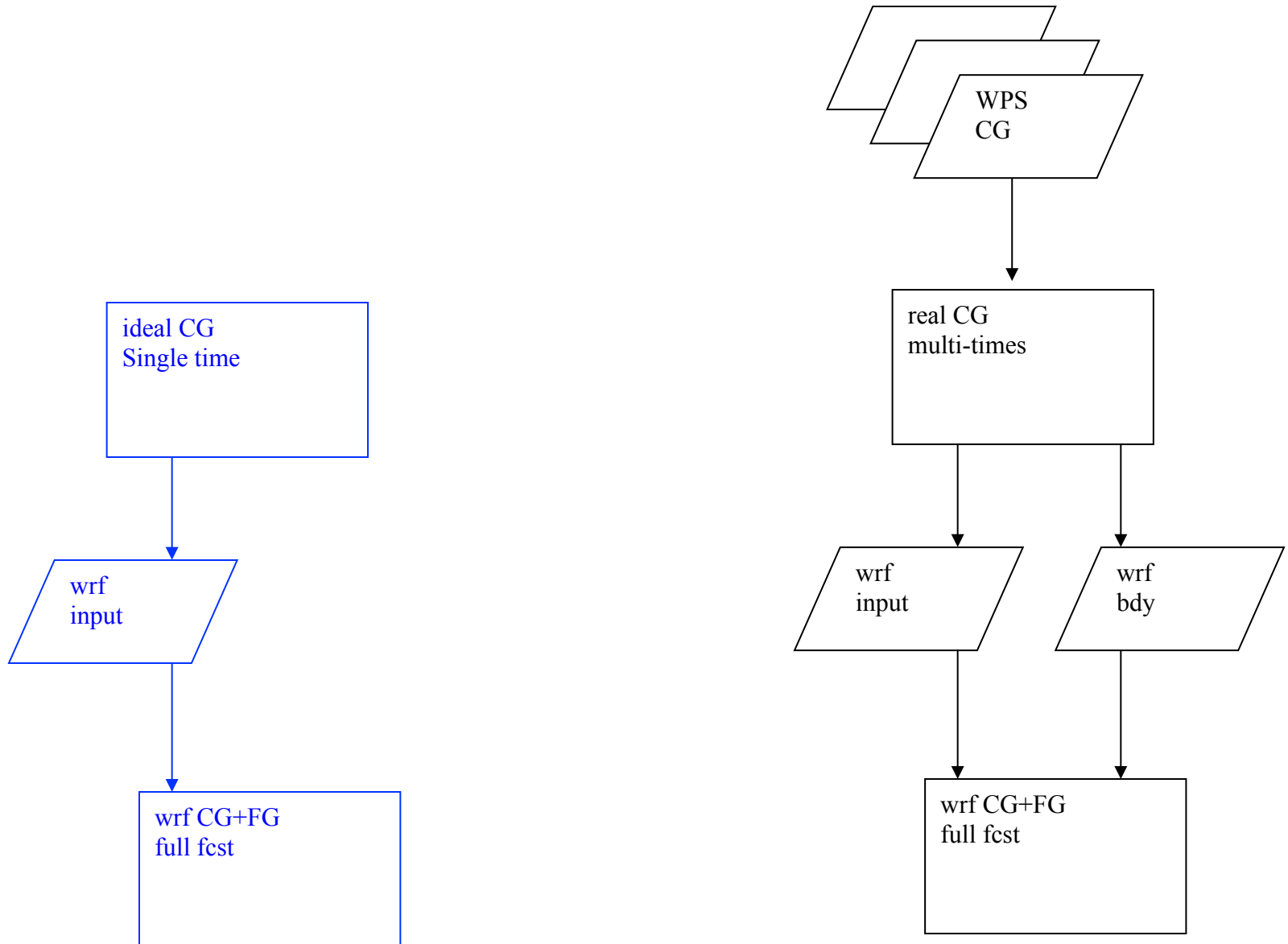
The grid distance ratio is not strictly tied to the time step ratio

Topography smoothly ramps from coarse grid to the fine grid along the interface along the nest boundary

All fine grids must use the nested lateral boundary condition



ARW: 2-Way Nest with 1 Input



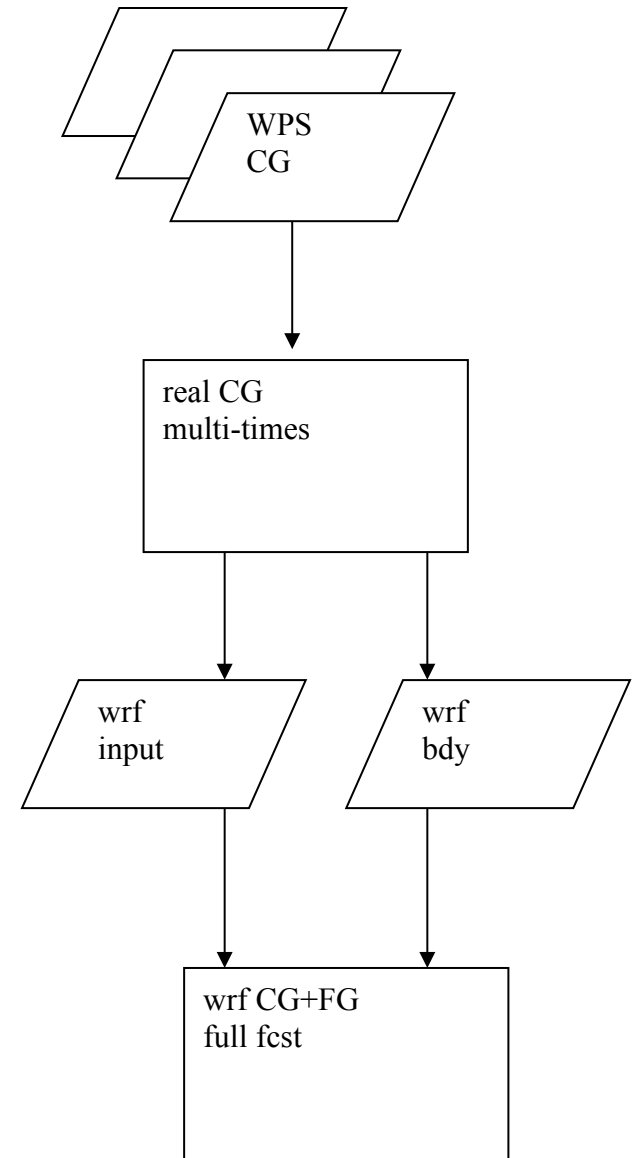
ARW: 2-Way Nest with 1 Input

A single namelist column entry is tied to each domain

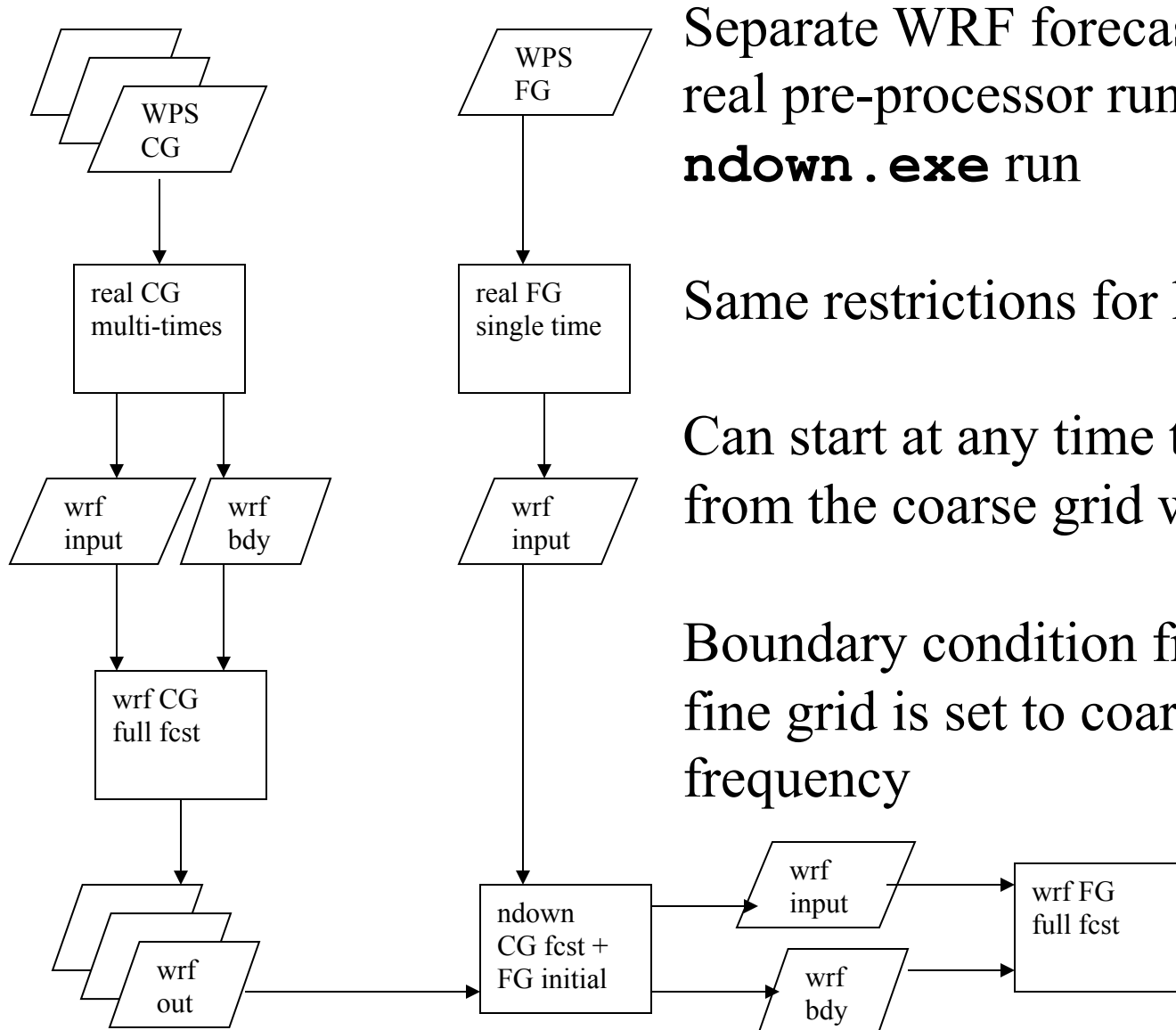
The horizontal interpolation method, feedback, and smoothing are largely controlled through the Registry file

For a 3:1 time step ratio, after the coarse grid is advanced, the lateral boundaries for the fine grid are computed, the fine grid is advanced three time steps, then the fine grid is fed back to the coarse grid (recursively, depth first)

Helpful run*.tar files are located in the
`./WRFV3/test/em_real` directory



ndown: 1-Way Nest with 2 Inputs



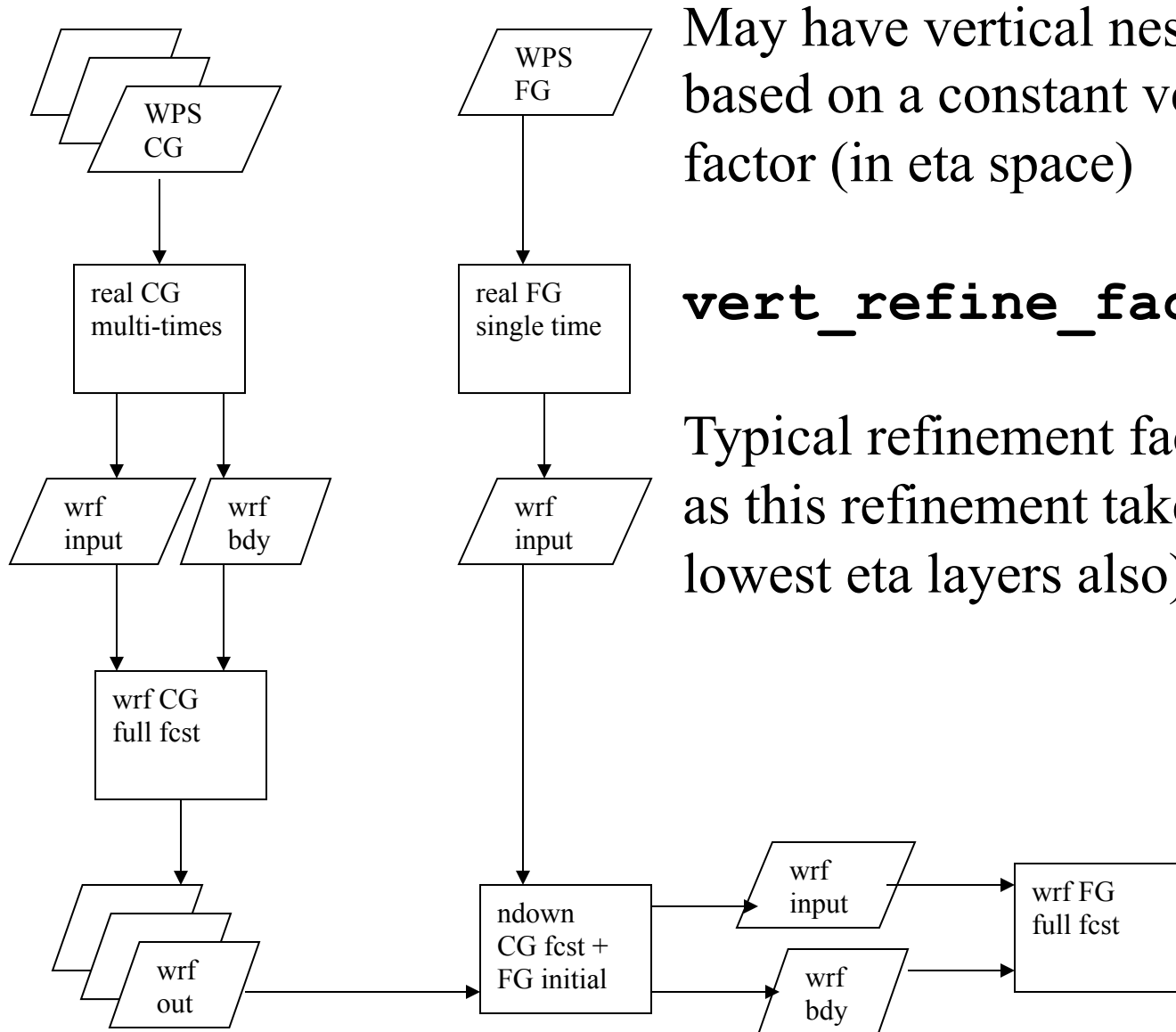
Separate WRF forecast runs, separate real pre-processor runs, intervening **ndown.exe** run

Same restrictions for horizontal nest ratios

Can start at any time that an output time from the coarse grid was created

Boundary condition frequency for the fine grid is set to coarse grid output frequency

ndown: 1-Way Nest with 2 Inputs



May have vertical nesting on the fine grid based on a constant vertical refinement factor (in eta space)

vert_refine_fact

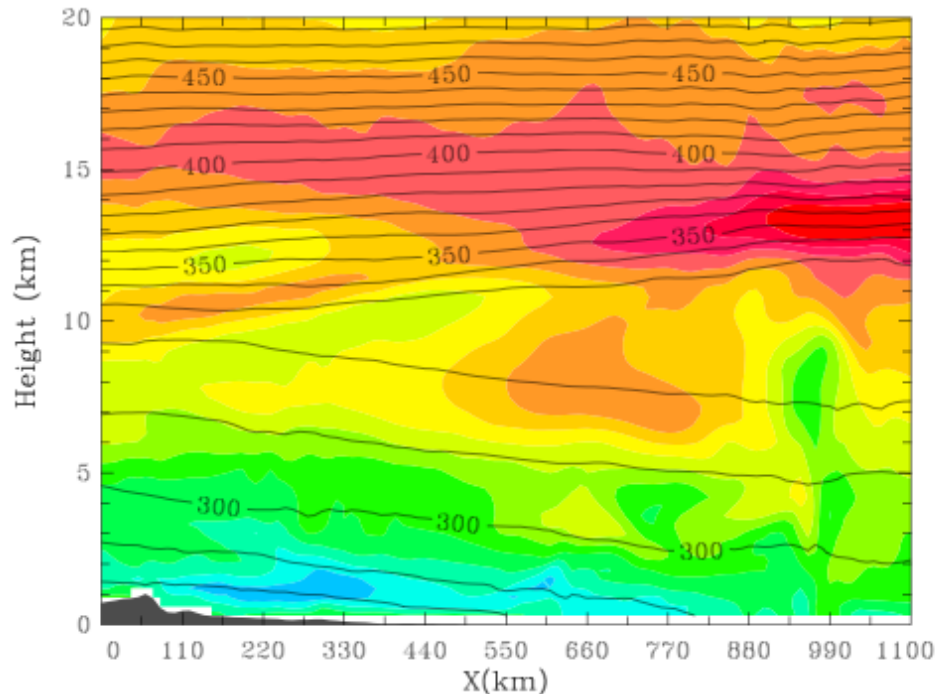
Typical refinement factors 2-5 (be careful, as this refinement takes place in the lowest eta layers also)

West East Cross section

Shaded: v ; Contour: θ

6-h Forecast, from Mohamed Moustououi

Standard Levels



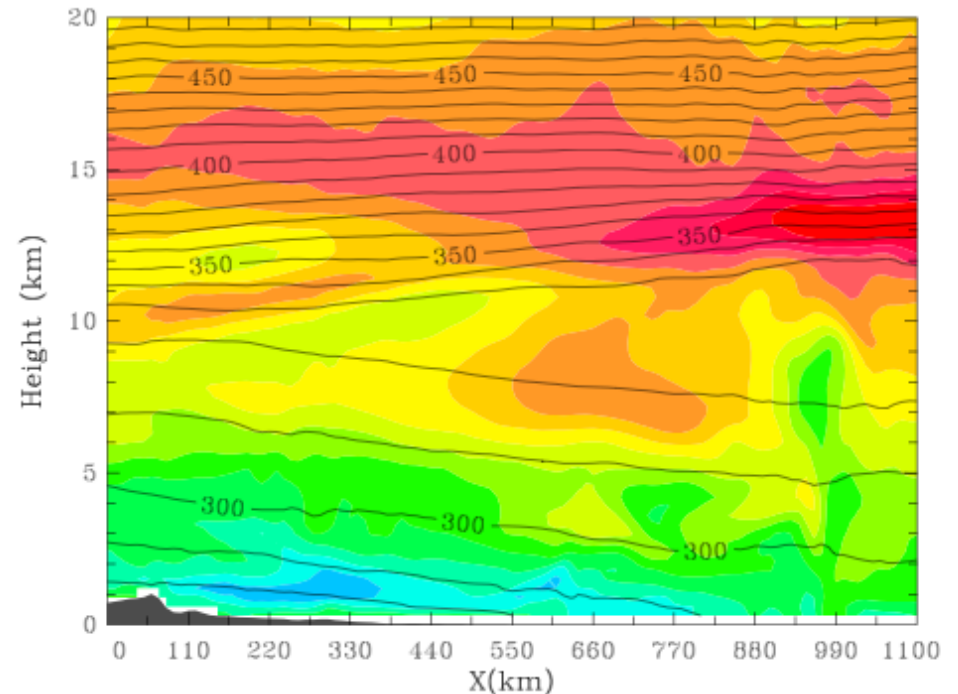
Eastward wind (m/s)



WRF domain2 (dx=3km, 03/25, 20UTC) with Klemm

UPPER ABSORBING LAYER

3x Refinement



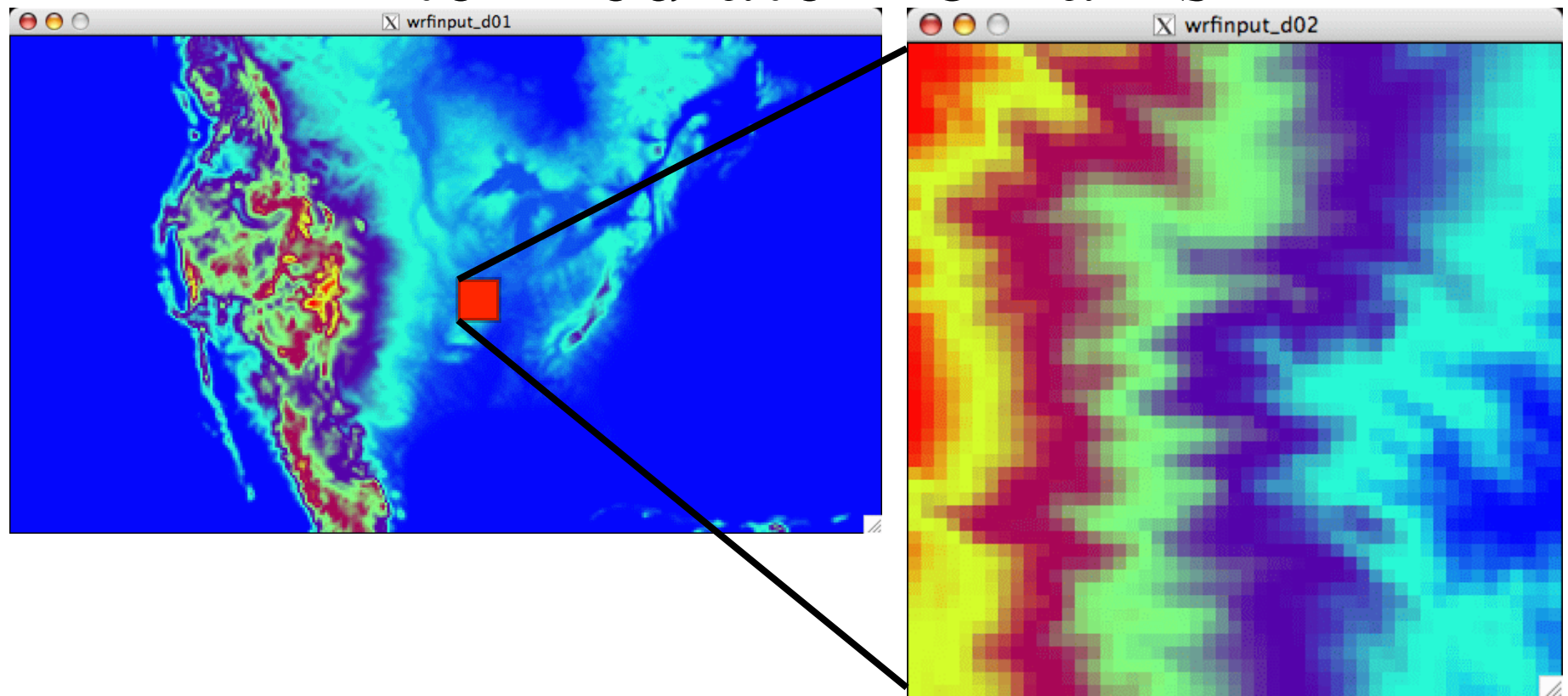
Eastward wind (m/s)



WRF domain2 (dx=3km, 03/25, 20UTC) with Klemm

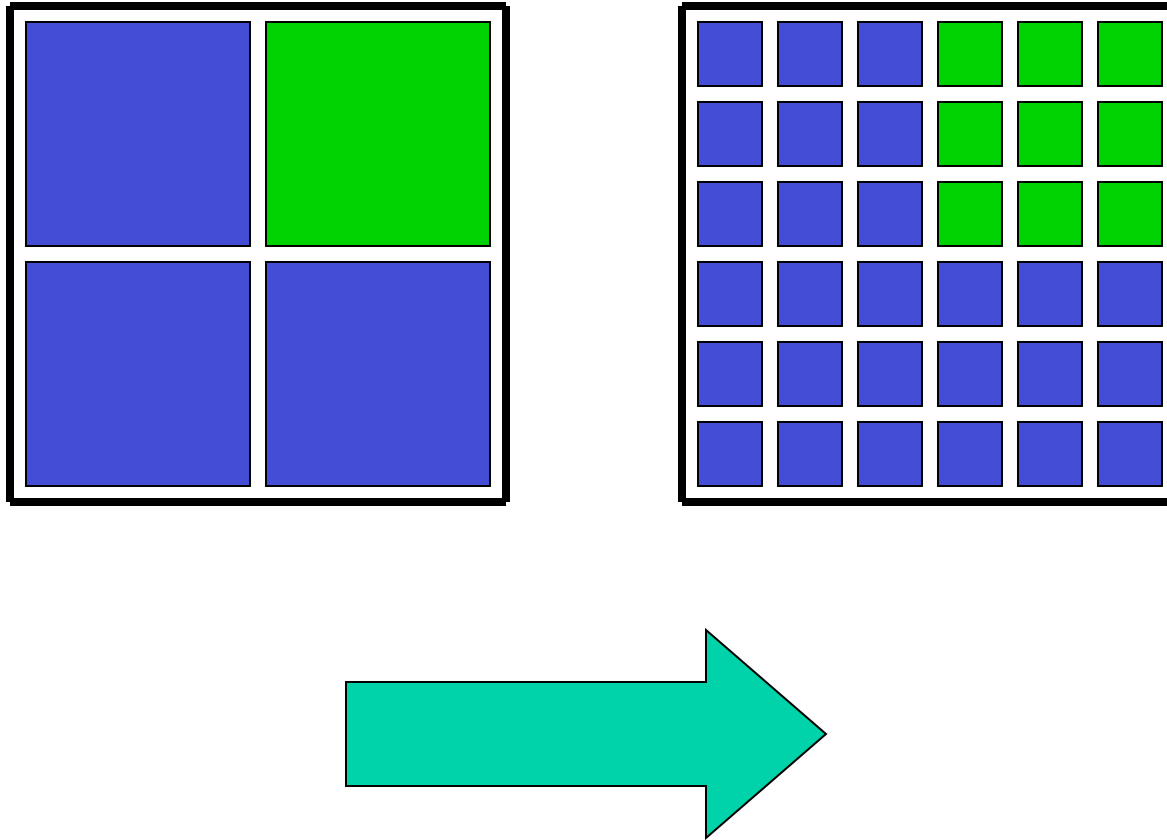
UPPER ABSORBING LAYER

Intermediate Domains

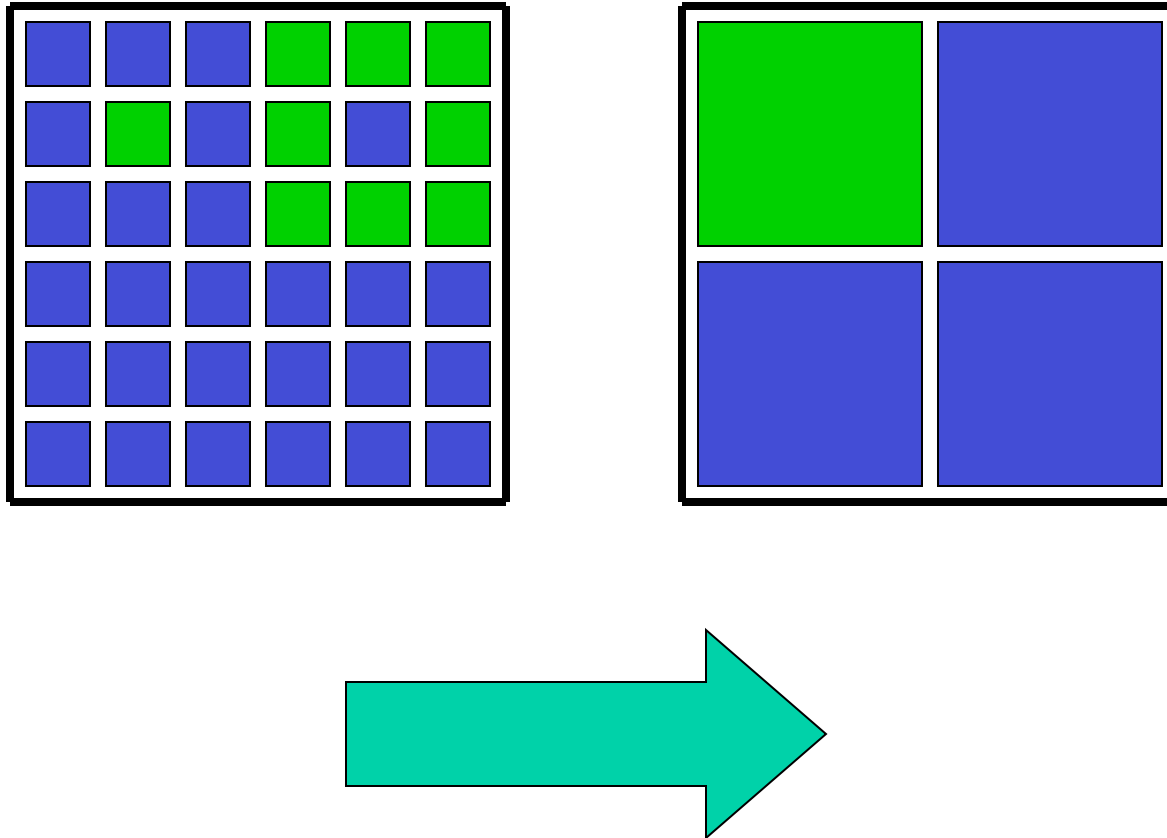


The intermediate domain between a parent and a child is the resolution of the coarse grid over the size of the fine grid. It allows the model to re-decompose the domain among all of the processors.

ARW Masked Interpolation



ARW Masked Feedback



What are those “usdf” Options

```
state real u ikjb dyn_em 2 x \  
  i01rhusdf=(bdy_interp:dt) \  
  "U" "x-wind component" "m s-1"
```

“f” defines what lateral boundary forcing routine (found in **share/interp_fcn.F**) is utilized, colon separates the additional fields that are required (fields must be previously defined in the Registry)

What are those “usdf” Options

```
state real landmask ij misc 1 - \
  i012rhd=(interp_fcnm)u=(copy_fcnm) \
  "LANDMASK" "LAND MASK (1=LAND, 0=WATER) "
```

“u” and “d” define which feedback (up-scale) and horizontal interpolation (down-scale) routines (found in share/interp_fcn.F) are utilized

Default values (i.e. not a subroutine name listed in the parentheses) assume non-masked fields

At compile-time, users select options

What are those “usdf” Options

```
state real ht ij misc 1 - i012rhdus "HGT" \  
  "Terrain Height" "m"
```

“^s” if the run-time option for smoothing is activated, this field is to be smoothed - only used for the parent of a nest domain, smoothing is in the area of the nest, excluding the outer row and column of the nest coverage

Whether or not smoothing is enabled is a run-time option from the namelist

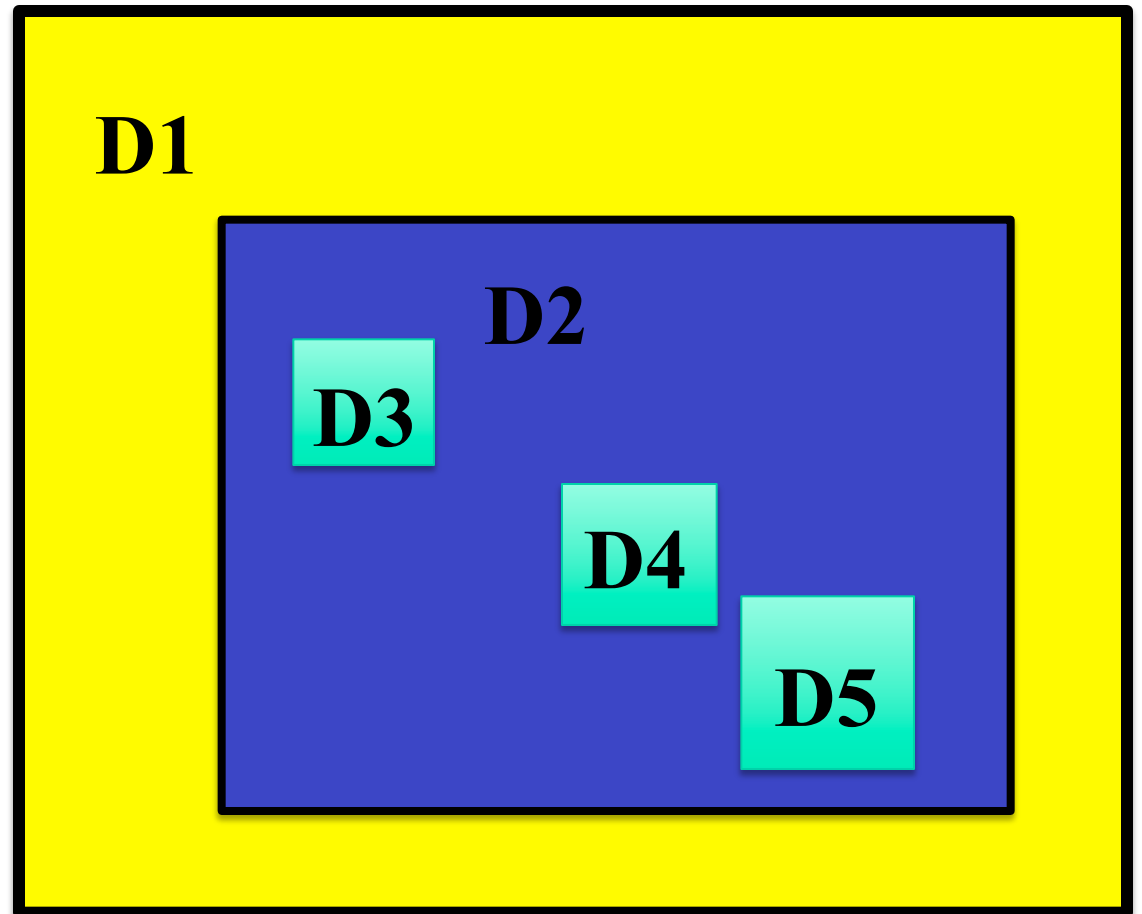
Special IO Stream #2 Fields

```
state real msft ij  misc 1 - \
  i012rhdu=(copy_fcnm)  "MAPFAC_M"  \
  "Map scale factor on mass grid" ""
```

```
state real msfu ij  misc 1 X \
  i012rhdu=(copy_fcnm)  "MAPFAC_U"  \
  "Map scale factor on u-grid" ""
```

```
state real msfv ij  misc 1 Y \
  i012rhdu=(copy_fcnm)  "MAPFAC_V"  \
  "Map scale factor on v-grid" ""
```

WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.



WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is

D1

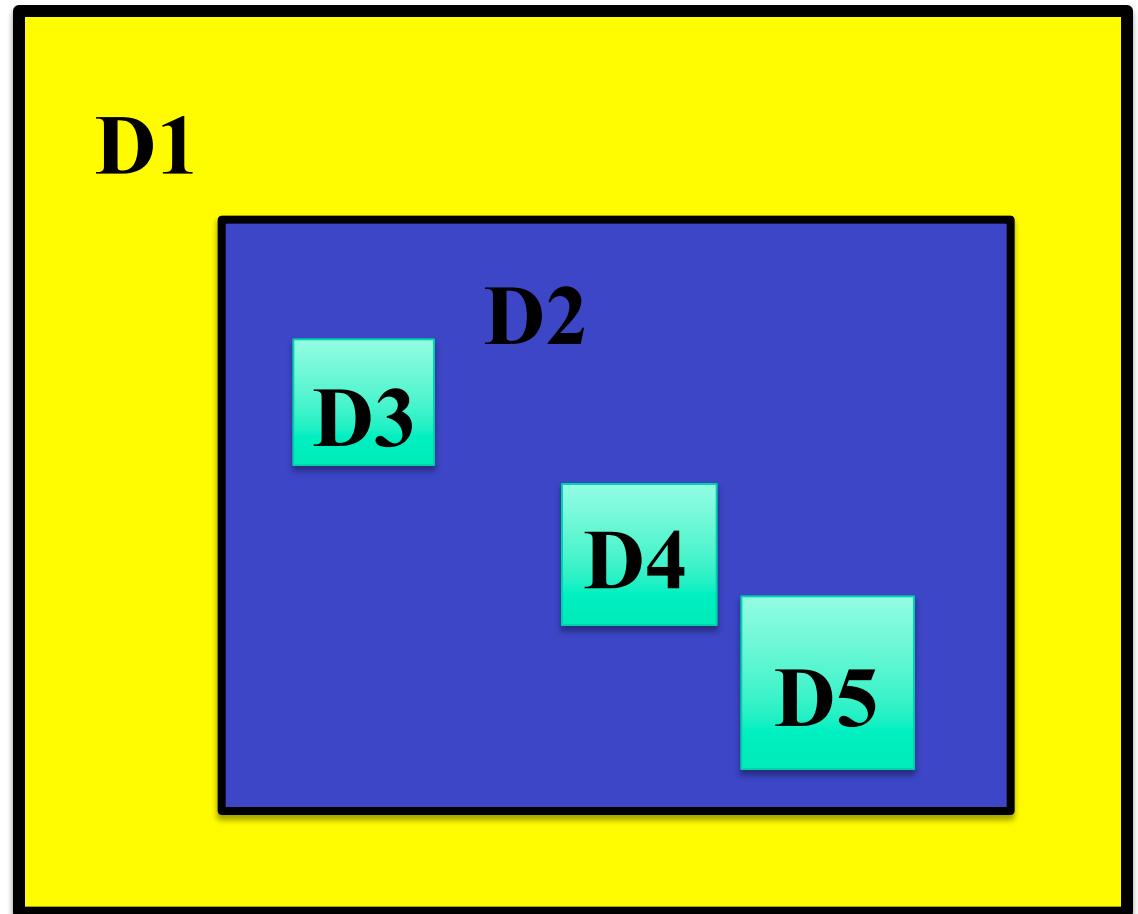
D2

D2

D3 D3 D3

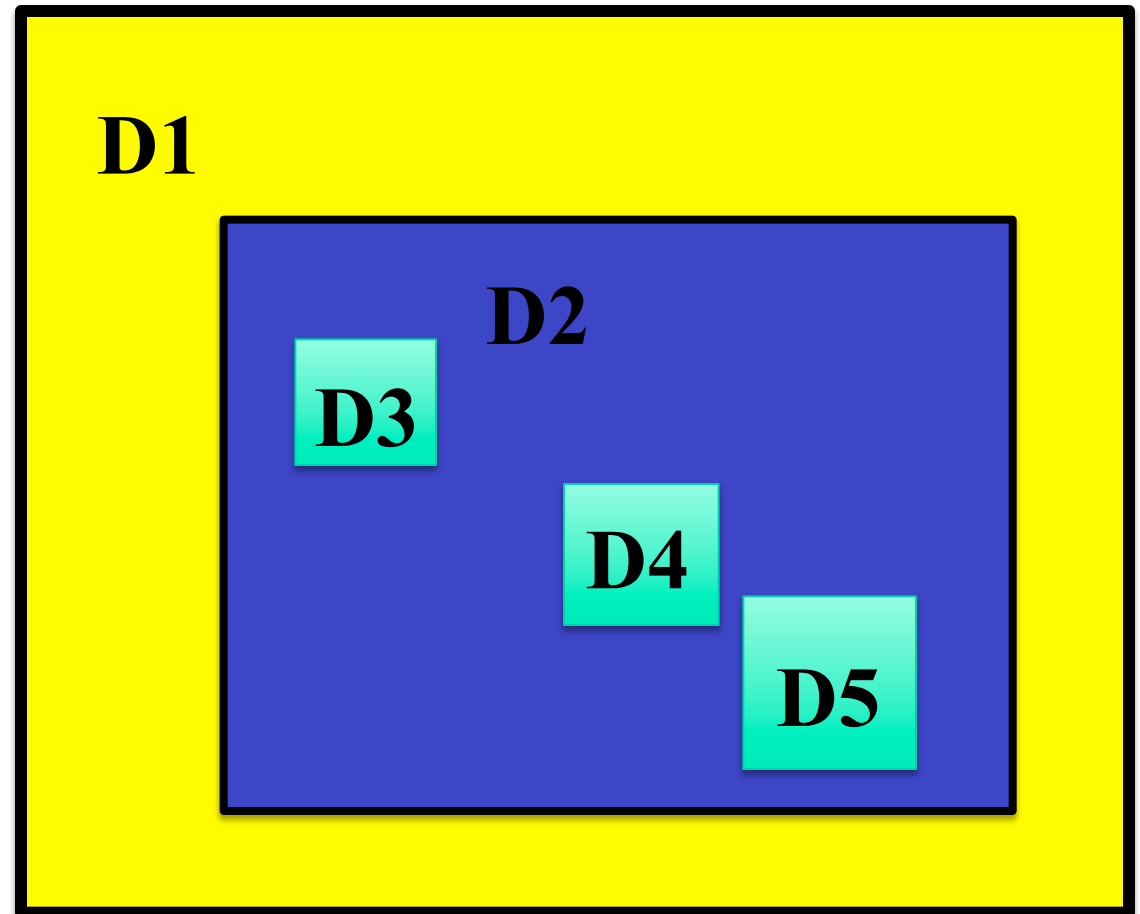
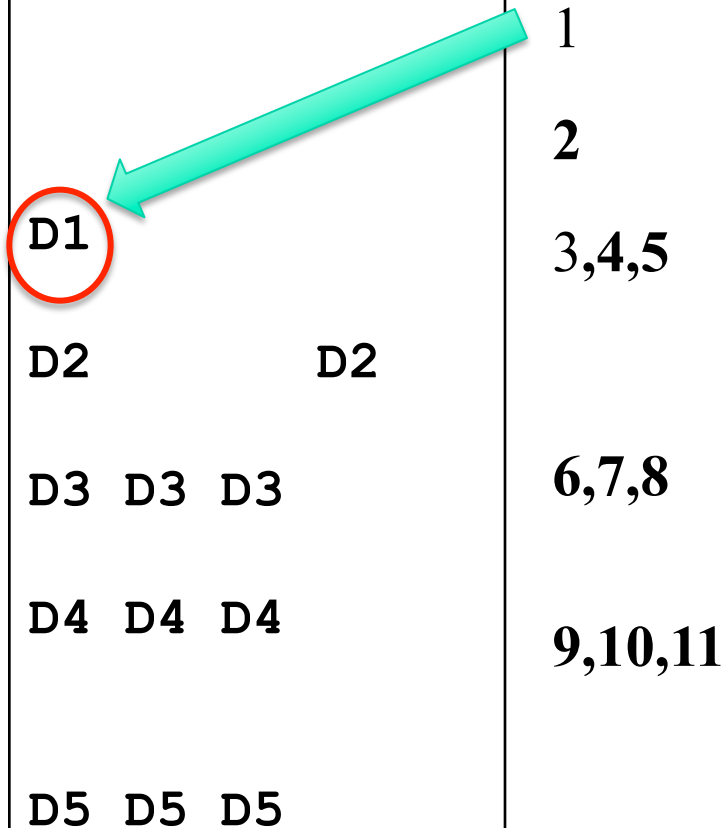
D4 D4 D4

D5 D5 D5



WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is



WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is

D1

D2

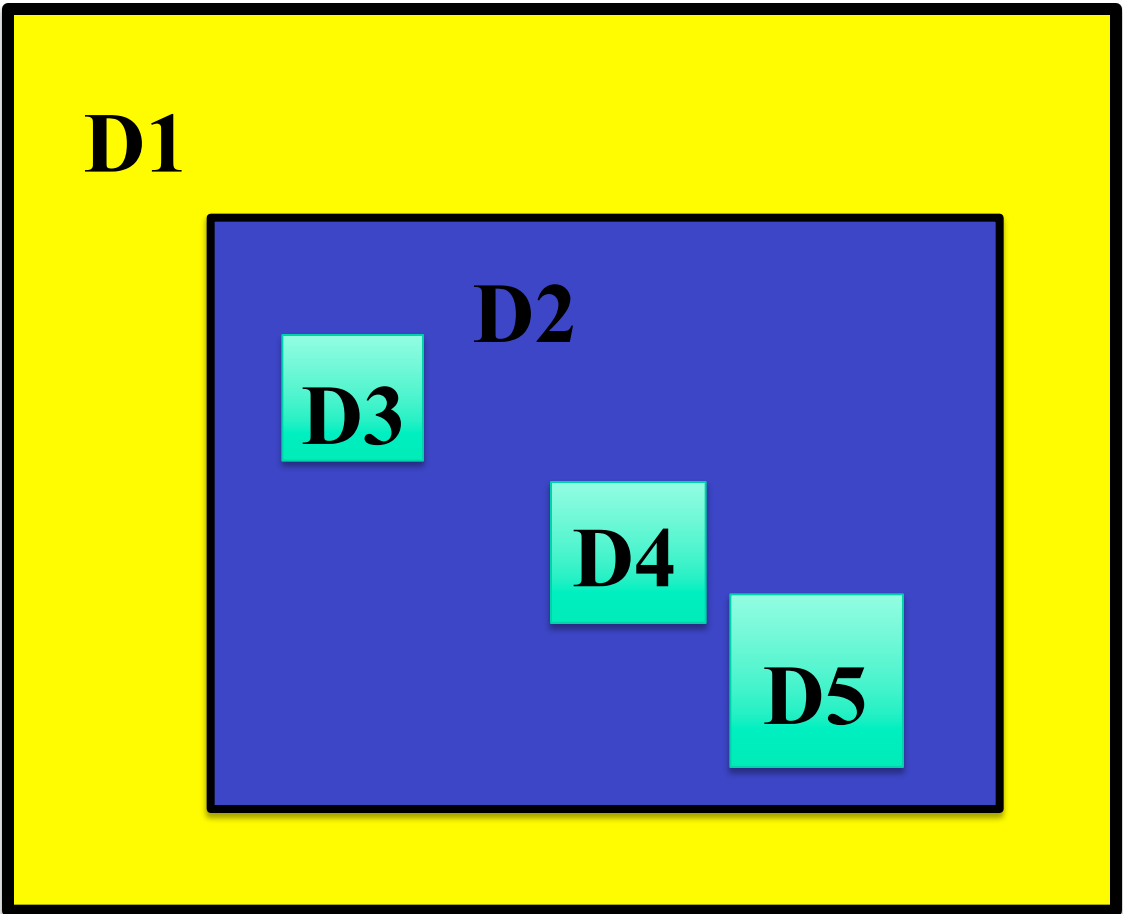
D2

D3 D3 D3

D4 D4 D4

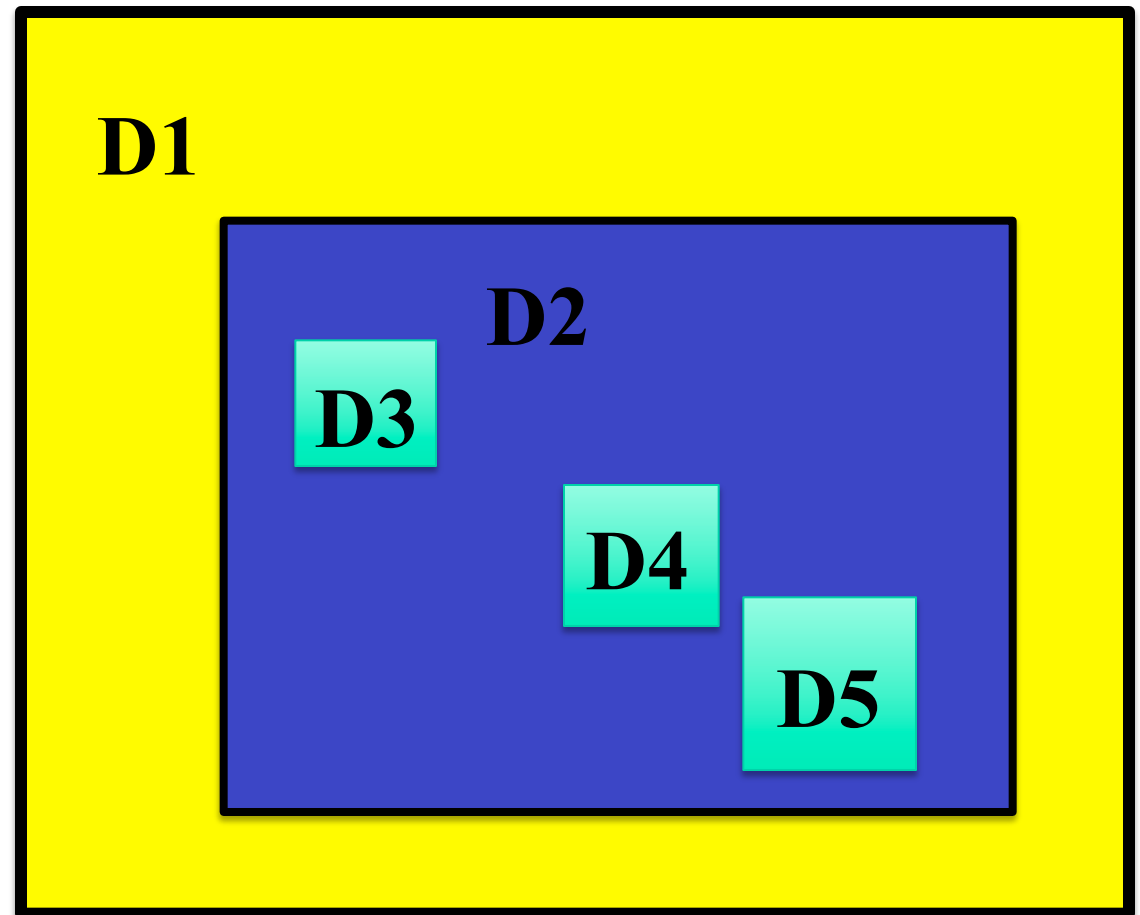
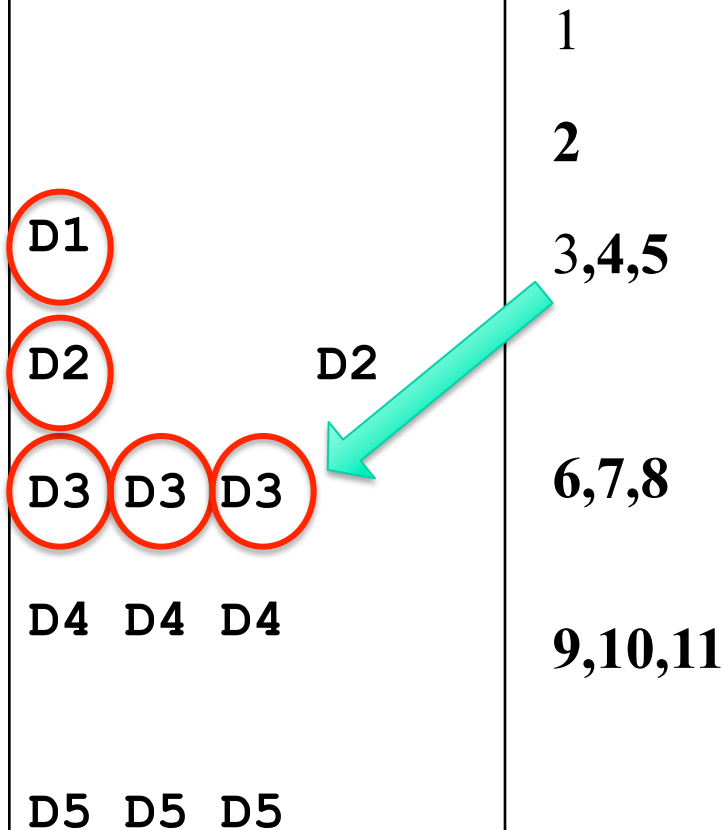
D5 D5 D5

1
2
3,4,5
6,7,8
9,10,11



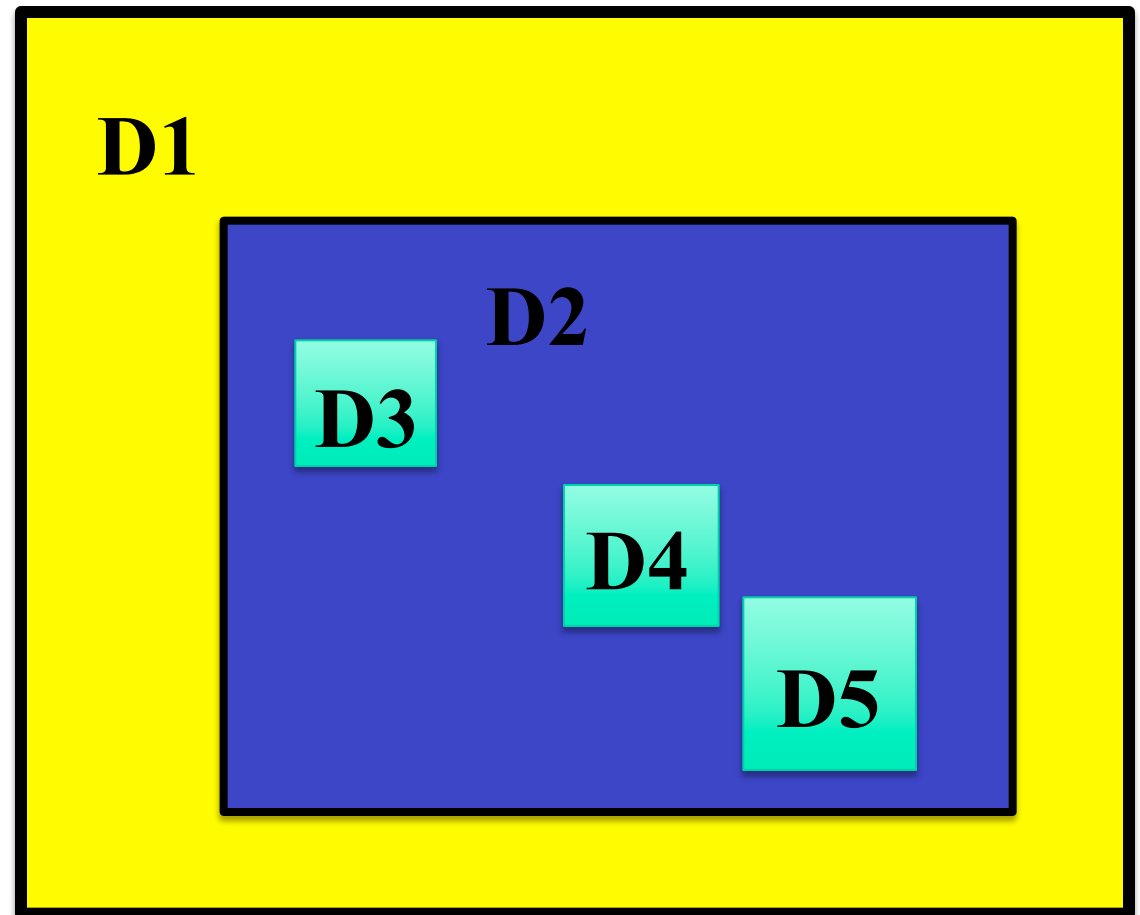
WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is



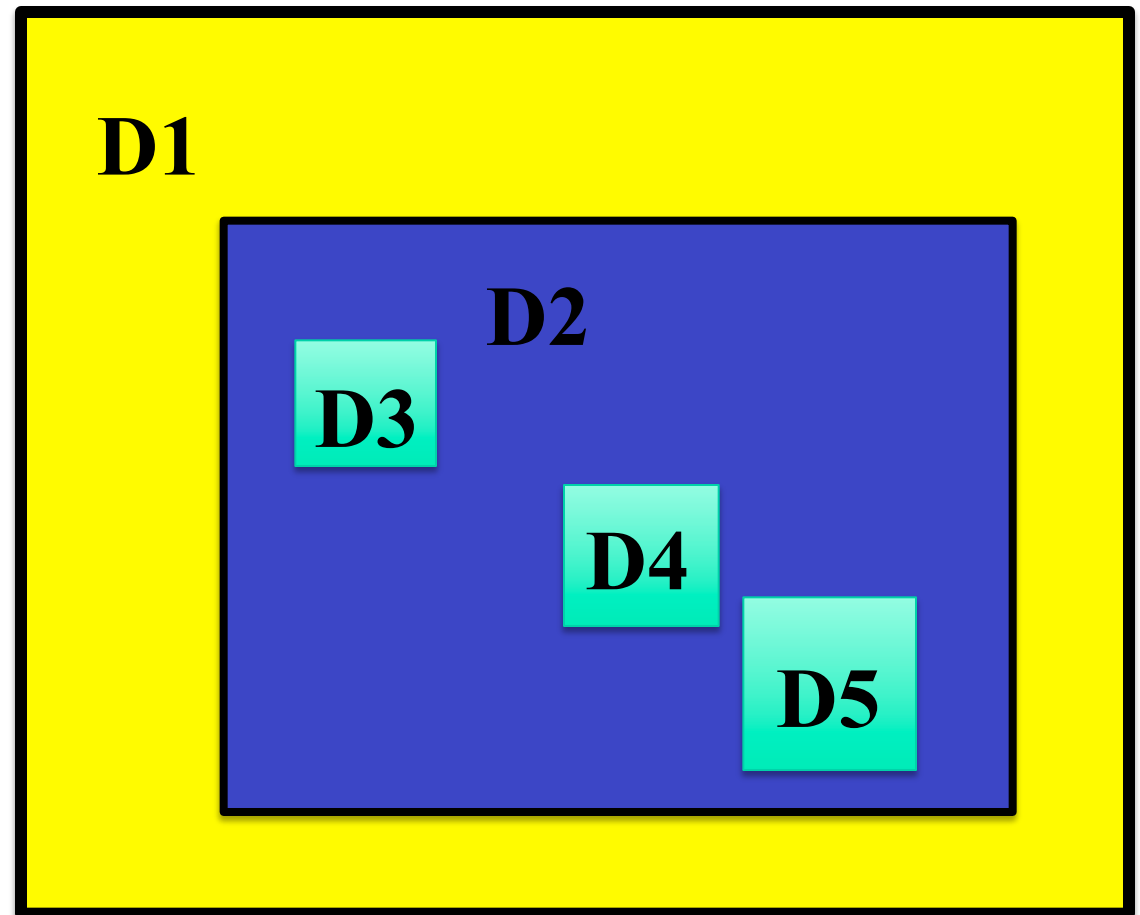
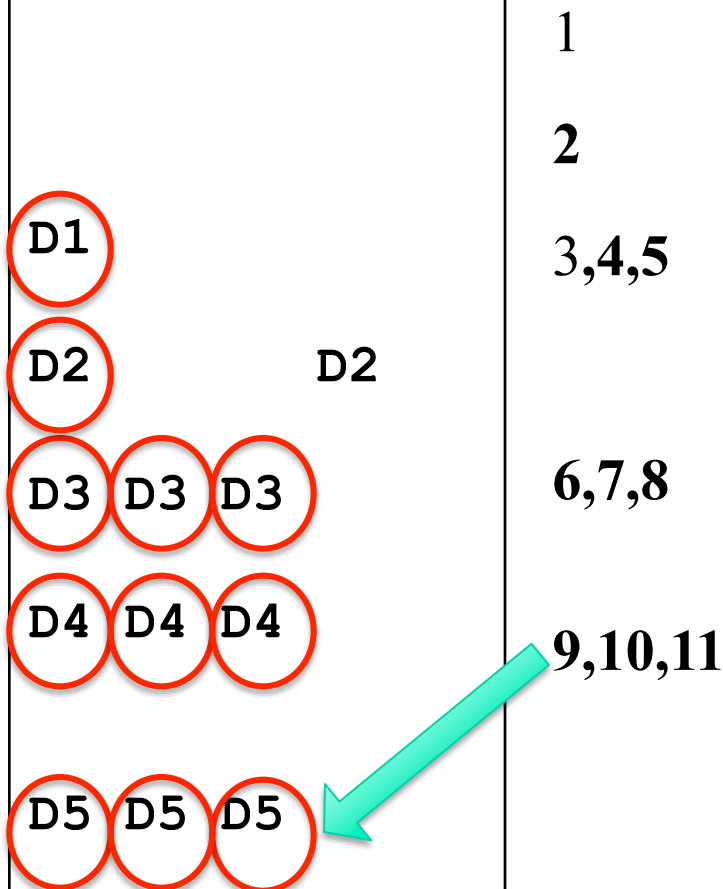
WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

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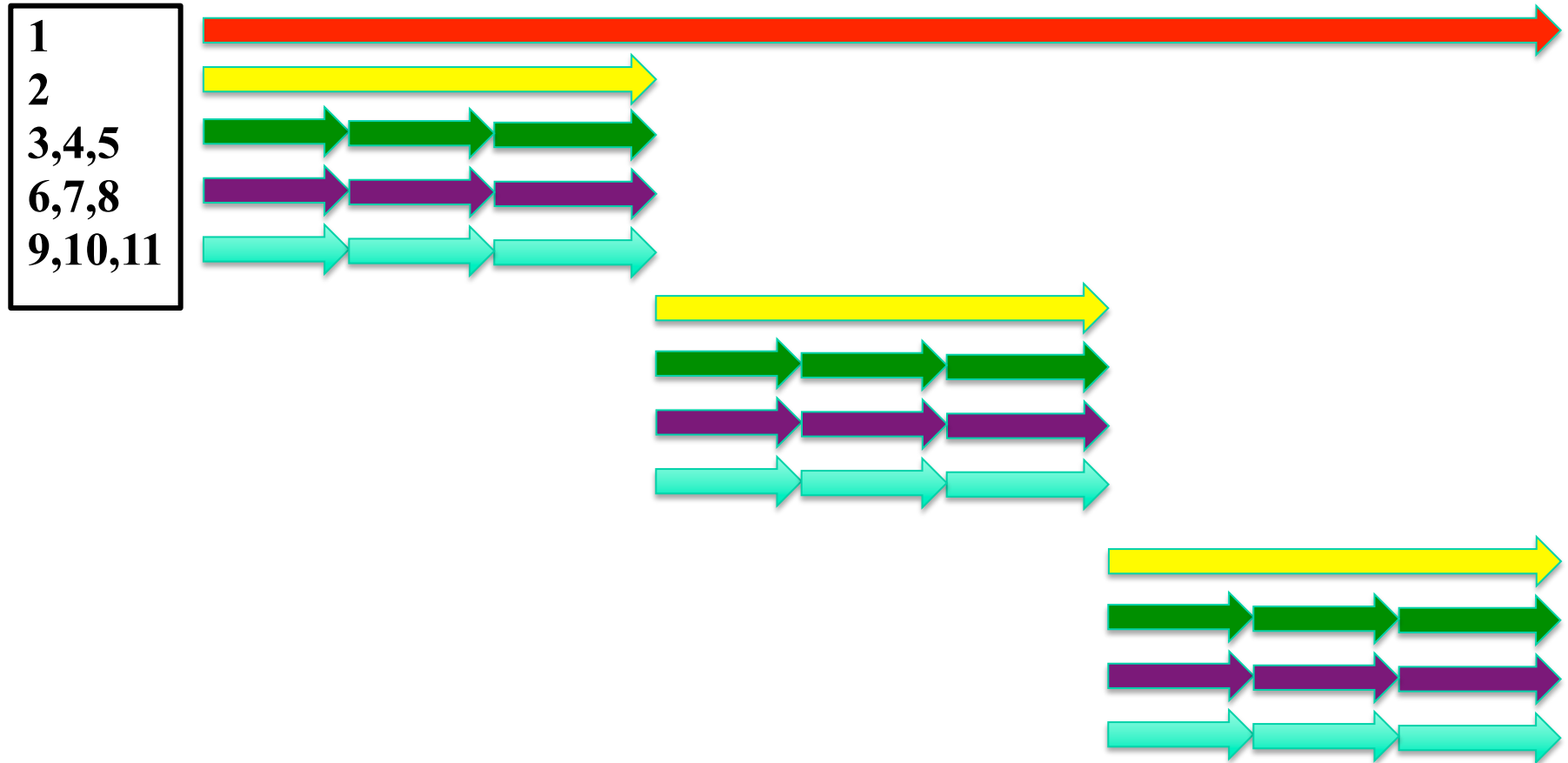


WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.

The order of integration is

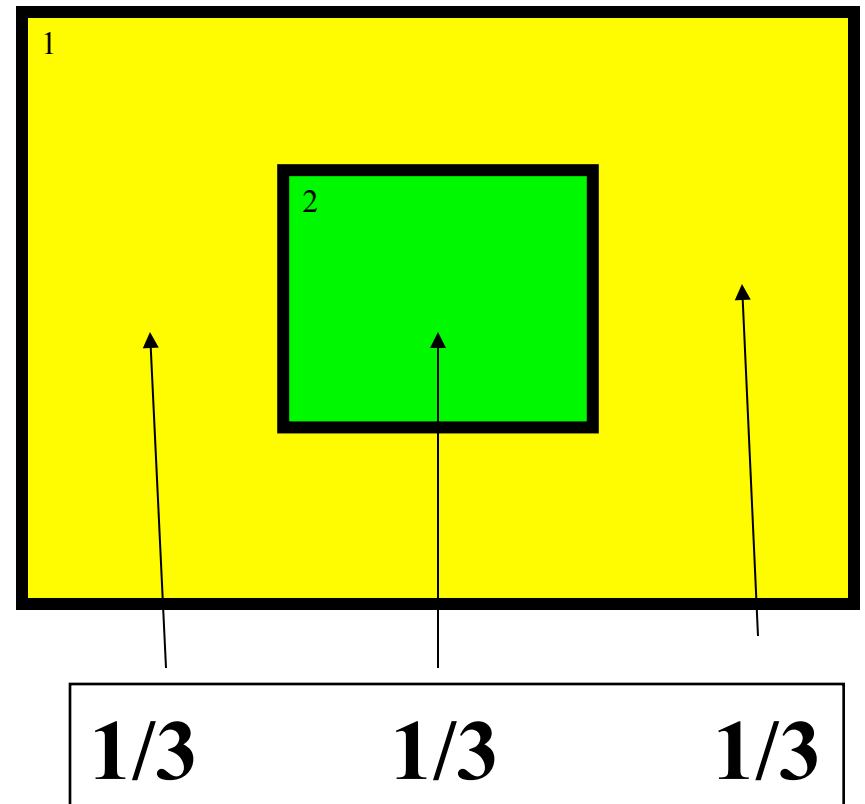


WRF 5-domain run: Domain 1 (a single 3 min dt), then Domain 2 (a single 1 min dt). Then Domain 3, in 20 s pieces up to 1 min. Then Domain 4, in 20 s pieces up to 1 min, and same with Domain 5.



Nesting Suggestions

- The **minimum distance** between the nest boundary and the parent boundary is FOUR grid cells
- You should have a **MUCH larger buffer zone**
- It is not unreasonable to have approximately **1/3** of your coarse-grid domain surrounding each side of your nest domain



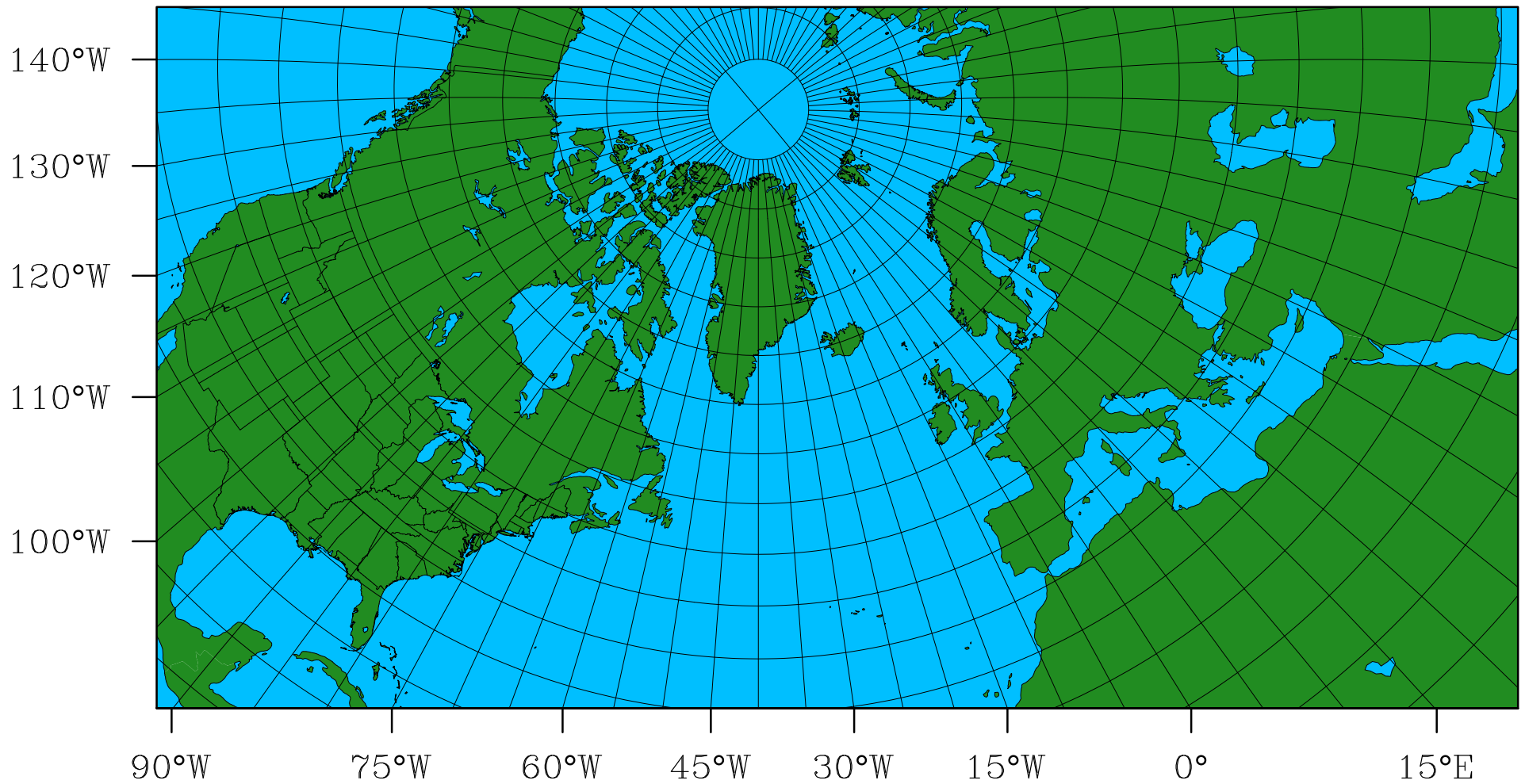
Nesting Suggestions

- **Start** with designing your **inner-most domain**. For a traditional forecast, you want everything important for that forecast to be **entirely contained** inside the domain.
- Then start adding parent domains at a 3:1 or 5:1 ratio. A **parent should not have a smaller size** (in grid points). Keep adding domains until the most coarse WRF grid has a no more than a 3:1 to 5:1 ratio to the external model (first guess) data.

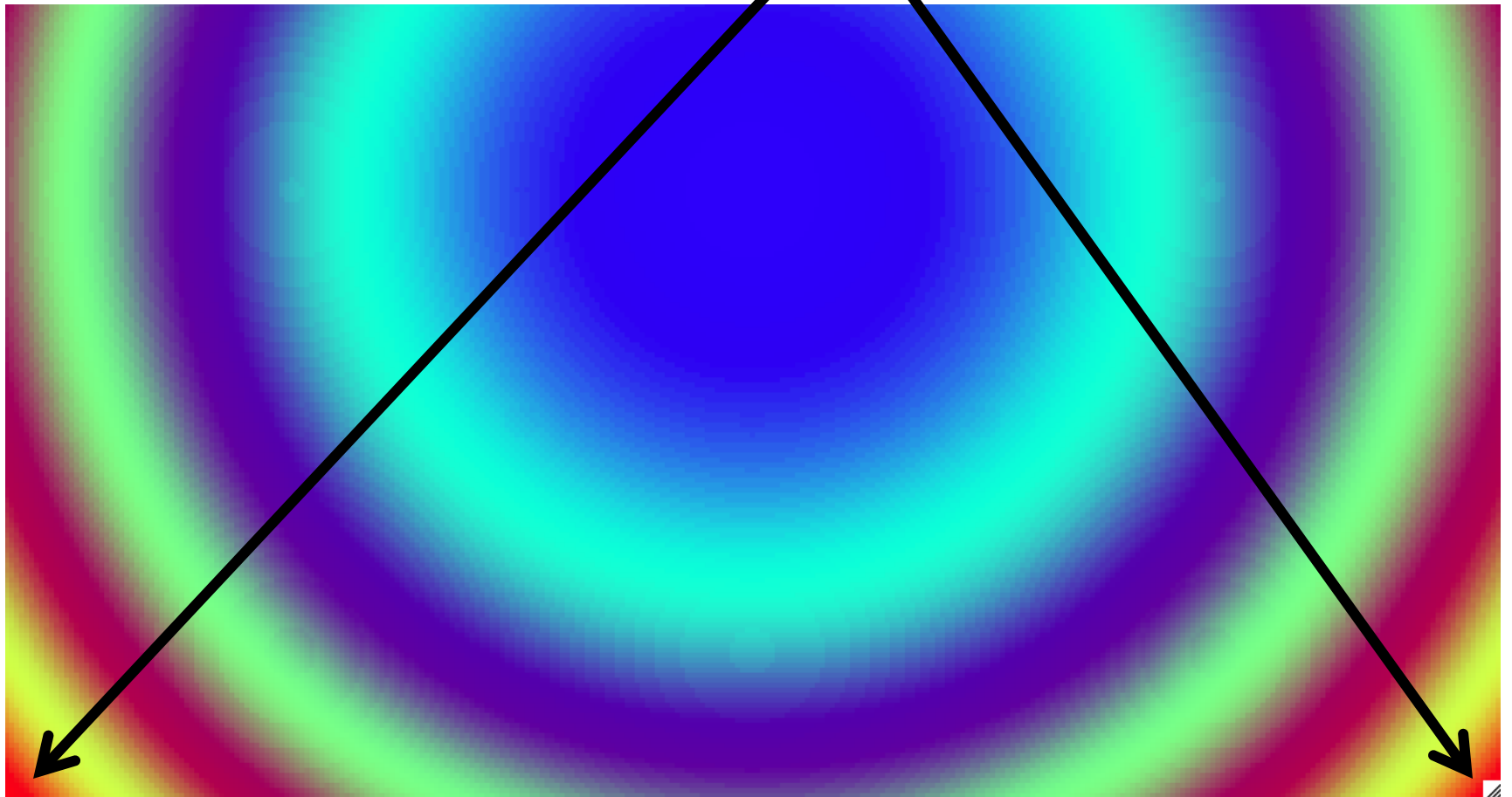
Nesting Suggestions

- Larger domains tend to be better than smaller domains.
- A 60 m/s parcel moves at > 200 km/h. A 2-km resolution grid with 100×100 grid points could have most of the upper-level initial data swept out of the domain within a couple of hours.

Nesting Suggestions



Map factors > 1.6



Nesting Suggestions

- The most-coarse domain may have a geographic extent that causes large map factors.

<code>time_step</code>	<code>= 300 (BLOWS UP)</code>
<code>dx</code>	<code>= 45000, 15000, 5000</code>
<code>grid_id</code>	<code>= 1, , 2, , 3</code>
<code>parent_id</code>	<code>= 0, , 1, , 2</code>
<code>parent_grid_ratio</code>	<code>= 1, , 3, , 3</code>
<code>parent_time_step_ratio</code>	<code>= 1, , 3, , 3</code>

Nesting Suggestions

- Reducing the time step so that the coarse grid is stable makes the model too expensive. 1.6x

time_step	= 180 (STABLE, PRICEY)
dx	= 45000, 15000, 5000
grid_id	= 1, , 2, , 3
parent_id	= 0, , 1, , 2
parent_grid_ratio	= 1, , 3, , 3
parent_time_step_ratio	= 1, , 3, , 3

Nesting Suggestions

- Only reduce the time step on the coarse grid, and keep the fine grid time steps at their approx original values.

<code>time_step</code>	<code>= 180 (STABLE, CHEAP)</code>
<code>dx</code>	<code>= 45000, 15000, 5000</code>
<code>grid_id</code>	<code>= 1, , 2, , 3</code>
<code>parent_id</code>	<code>= 0, , 1, , 2</code>
<code>parent_grid_ratio</code>	<code>= 1, , 3, , 3</code>
<code>parent_time_step_ratio</code>	<code>= 1, , 2, , 3</code>

Nesting Suggestions

- Model time step is always **proportional** to the time step of the **most coarse grid**.
- The coarse grid is the only grid impacted with large map factors: $dt(s) = 6 * dx(km)$ but the nominal grid distance needs to be scaled: **$dt(s) = dx(km) / MAX$ (map factor)**
- Reducing the coarse grid time step does not significantly reduce model performance if you can **tweak the time step ratio**.

Nesting Suggestions

- The time step ratio and grid distance ratio are not necessarily identical, and may be used effectively when large map factors in the coarse grid domain force a time step reduction for stability.
- If map factors are causing stability troubles, it is usually only the most coarse grid that is impacted since the fine grid is usually in the middle of the domain.

Nesting Suggestions

- Set up domain first to provide good valid forecast, then deal with efficiency
- Selecting a set of domains with the reason “it is all I can afford” gets you into trouble
- Numerically stable and computationally expedient do not imply scientifically or physically valid