HWRF Nesting

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AOML/HRD & UM/CIMAS

Acknowledgements

Collaborators: EMC Hurricane Project (Lead: M. Avichal); DTC (Lead: K. Newman); HRD Modeling Group (Lead: Gopalakrishnan)

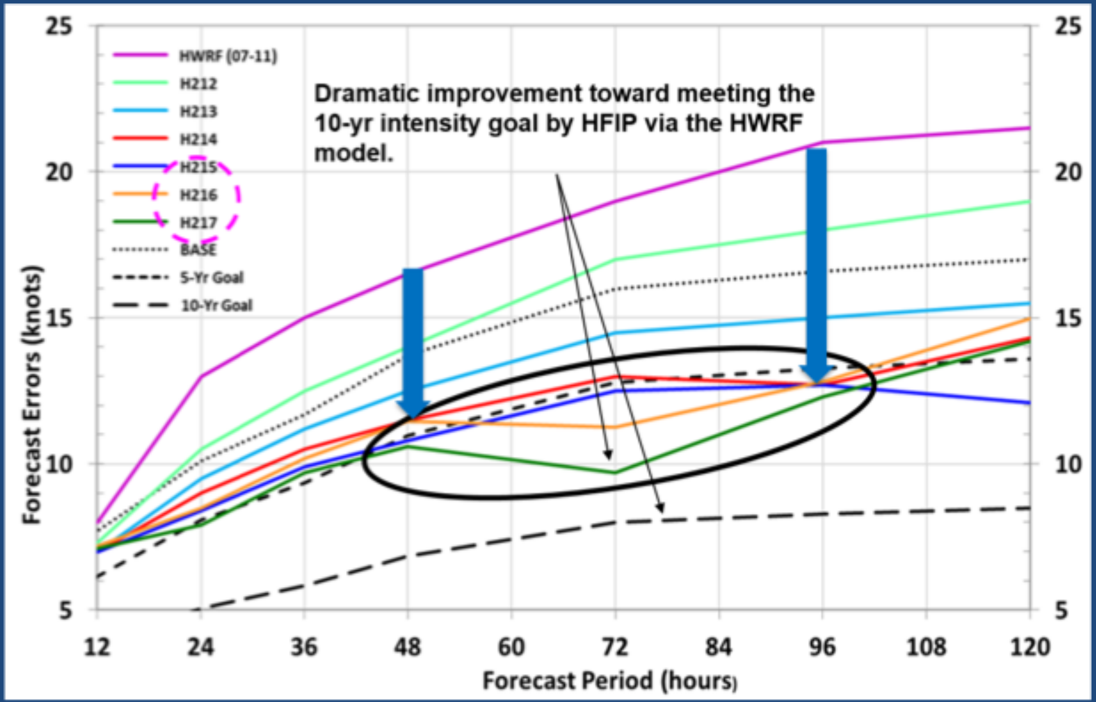
Computer resource: Jet supercomputer

HFIP support

HFIP Vision and Goals (2009-2018)

VISION

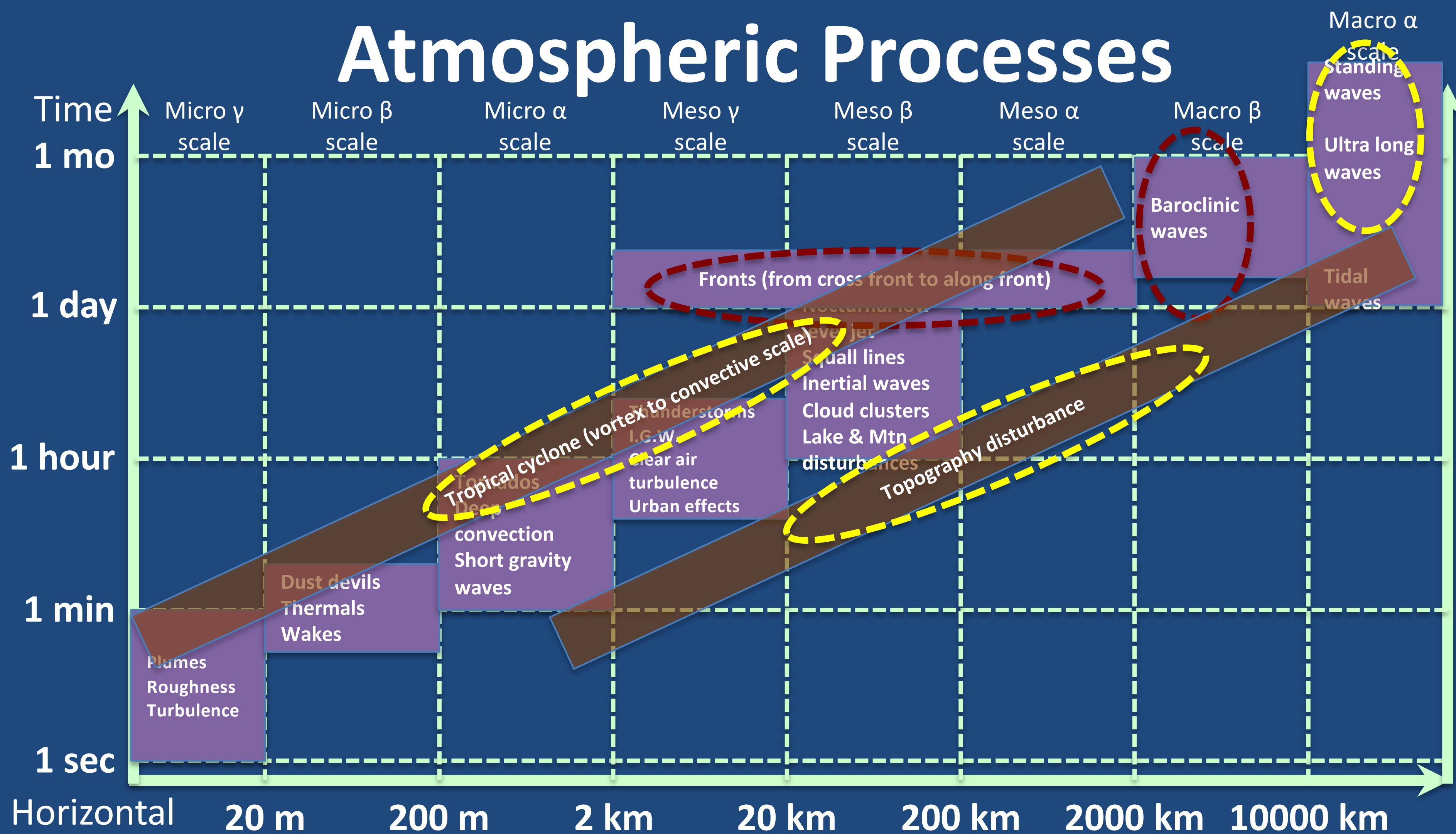
Organize the hurricane community to dramatically improve numerical forecast guidance to NHC in 5-10 years.



GOALS

- Reduce numerical forecast errors in track and intensity by 20% in 5 years, 50% in 10 years
- Extend forecast guidance to 7 days with skill comparable to 5 days at project inception
- Increase probability of predicting rapid intensification (RI) at day 1 to 90% and 60% at day 5
- Improve products on storm surge prediction

Horizontal-Temporal Scales of Atmospheric Processes



Adopted from Orlanski (1975)

Scientific Objectives

- Preserve across-scale processes on TC genesis, intensifying, decaying, and landfall processes within an integrated modeling system to represent the full-scale spectrum of atmospheric waves and study on multi-scale interactions e.g. TC-terrain interaction, and landfall processes and QPF etc.
- Enhance resolved resolution that can represent TC inner core physics and can predict TC dynamics (3 km or less)
  - Non-hydrostatic model becomes required
  - Physics schemes should be suitable to the high-resolution model

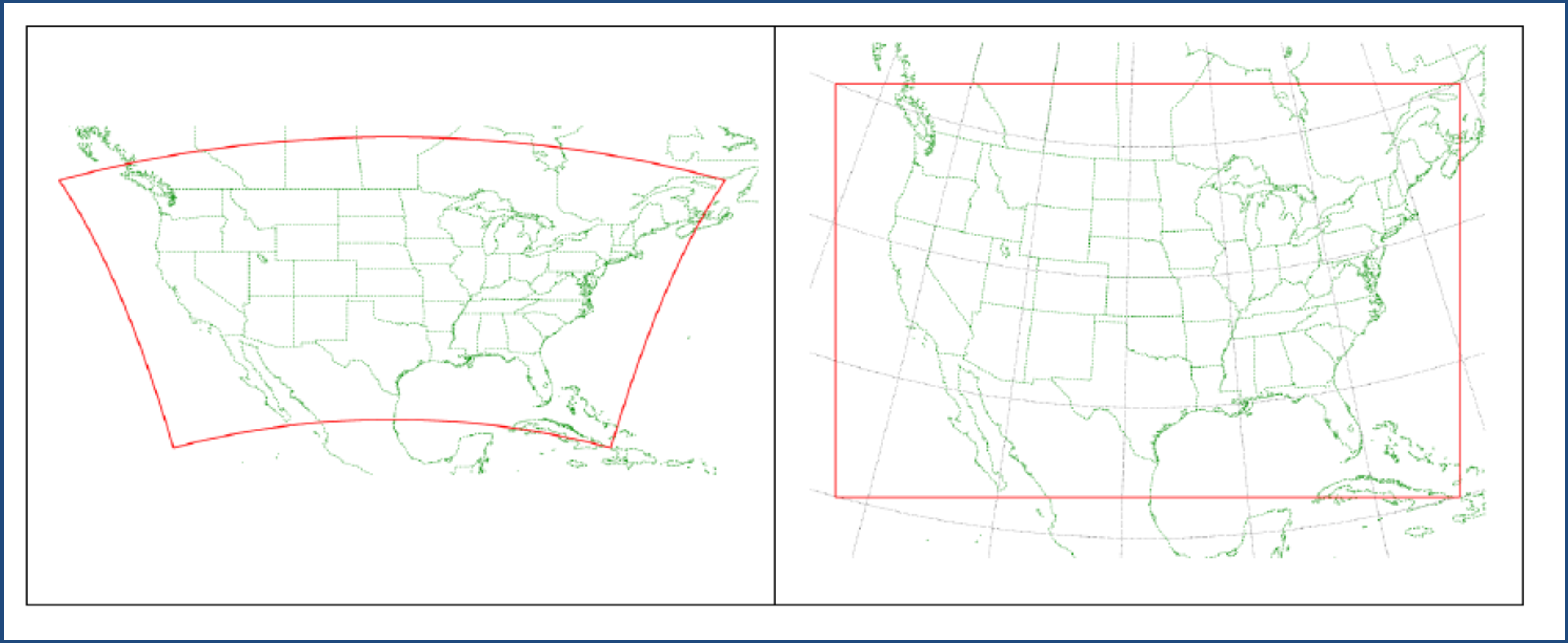
Model Development Objectives

- Tailor a tool that is operationally feasible and transferable within the operational resource capability
- Address the vision and goals of HFIP
- Meet the NHC operational requirements
- Develop model capabilities required by the advancements on observing and data assimilation technology

HWRF Grid System

- Horizontal: Rotated Latitude-Longitude E-Grid
- Vertical: σ-p hybrid
- Nesting
  - Coincident grid points at start and end points
  - Fixed nest ratio: 1:3
  - Moving one grid each time

Rotated Latitude-Longitude Domain

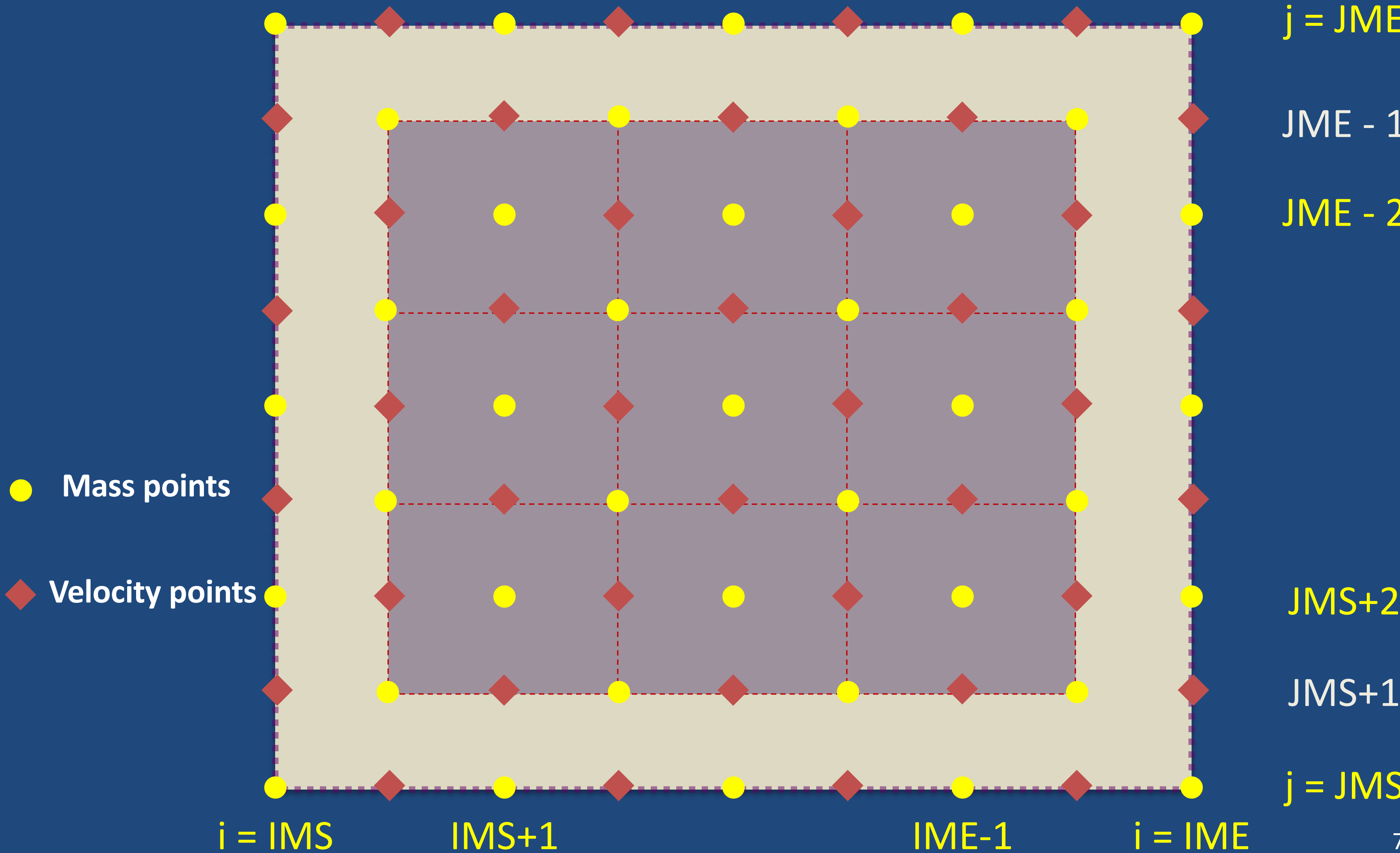


Regular Latitude-Longitude map background

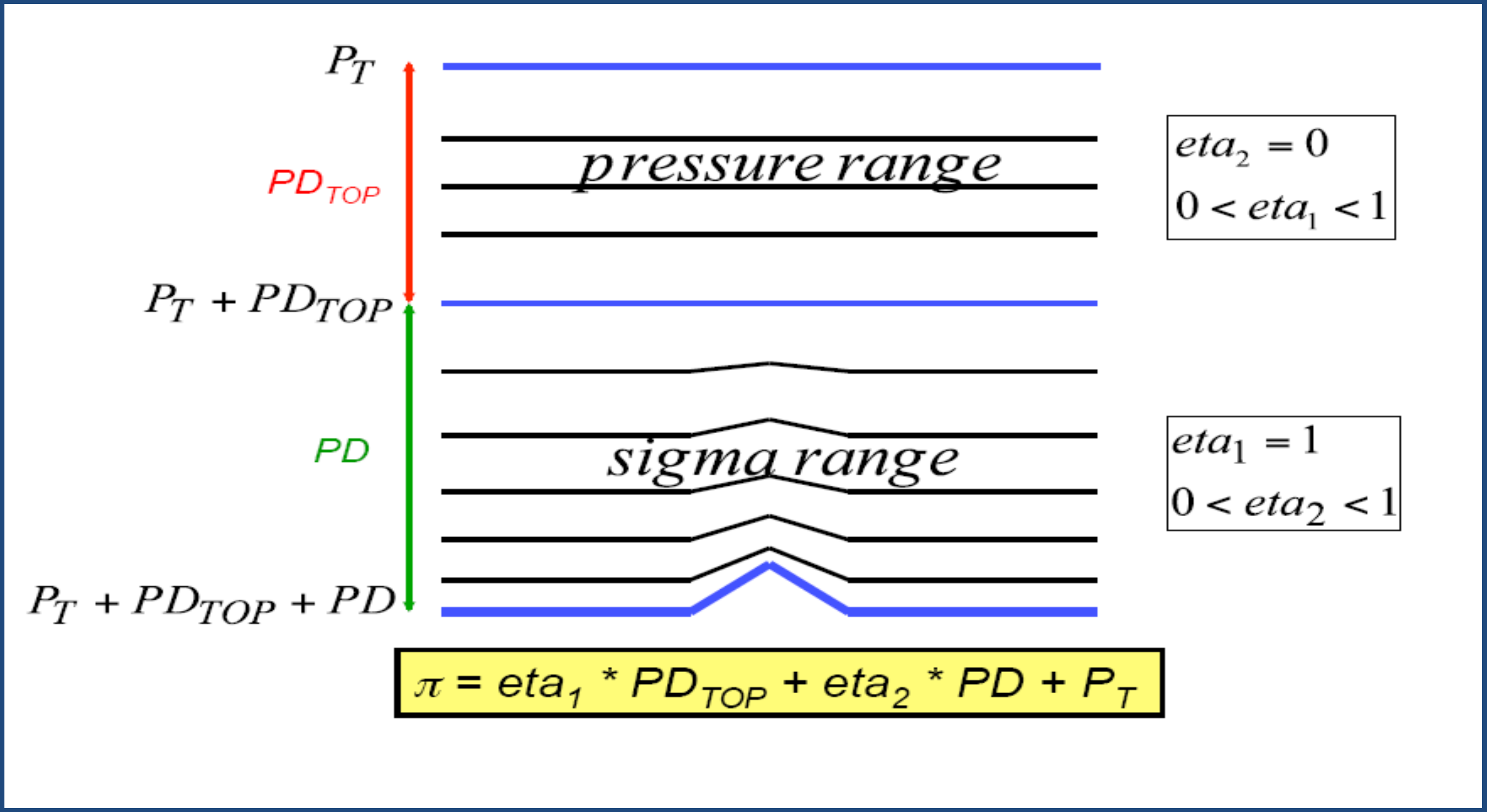
Rotated Latitude-Longitude map background

Credit: Zavisa Janjic

E-GRID Structure

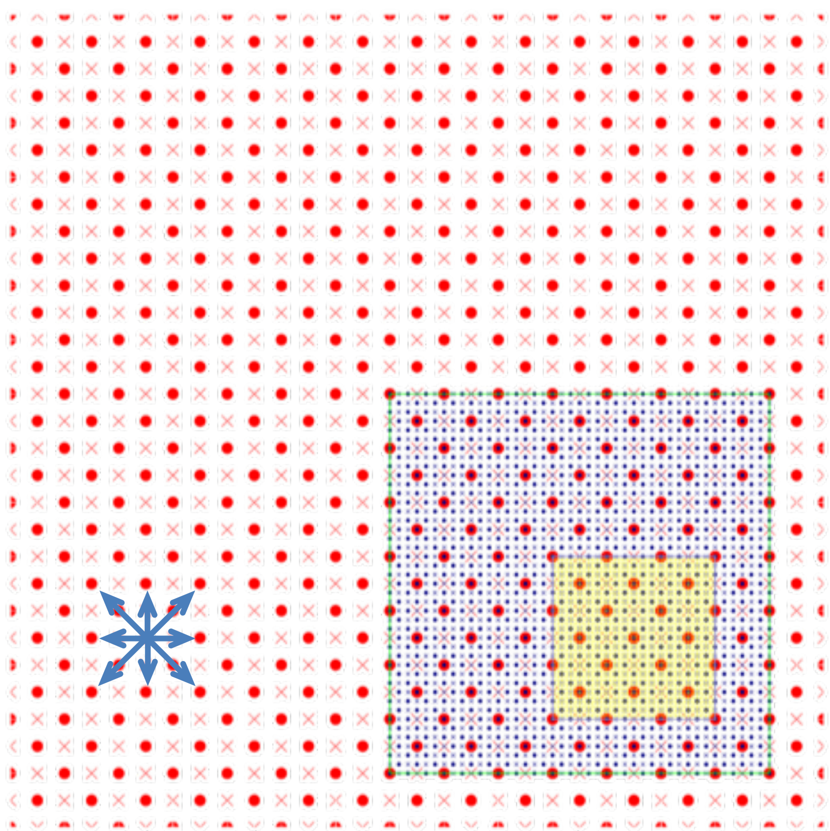


Sigma-Pressure Hybrid Coordinate



Credit: Zavisa Janjic

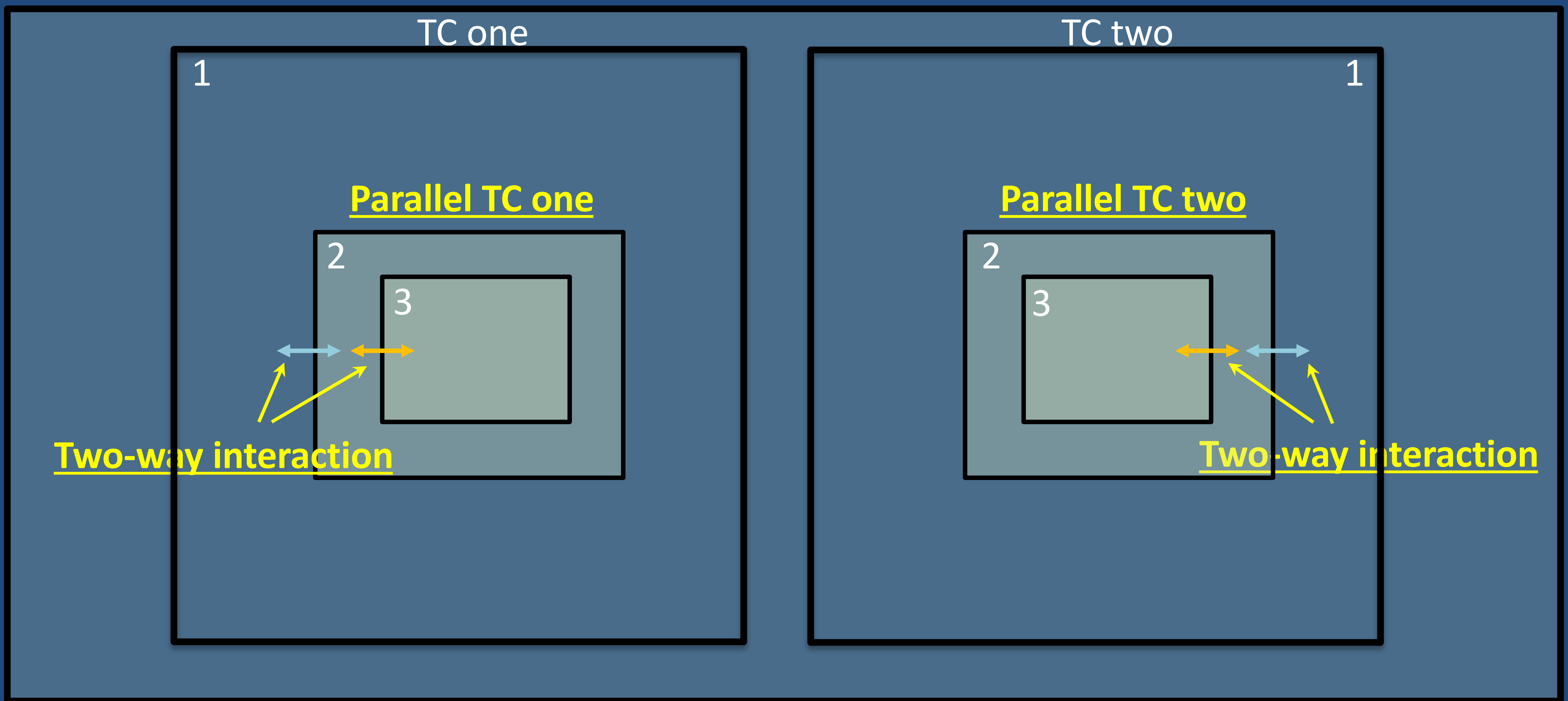
Idea of Moving Nest



Moving Nest Setup

- Domain starting point at mass point
- Grids aligning at mass points
- Fine grids adjusting mass
- Leading edge initialization
- Feedback to coarse grids
- Domain movement
- Innermost domain following the intermediate domain in the current operational HWRF

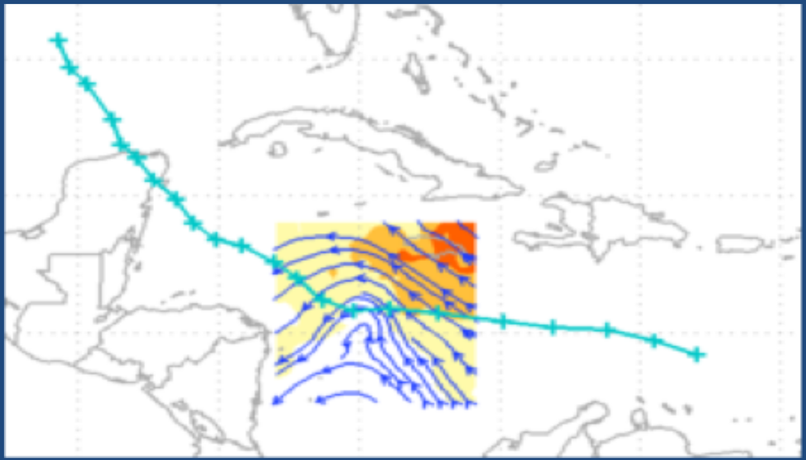
Nesting Scheme and Feedback



The operational HWRF

Nest Motion Solution

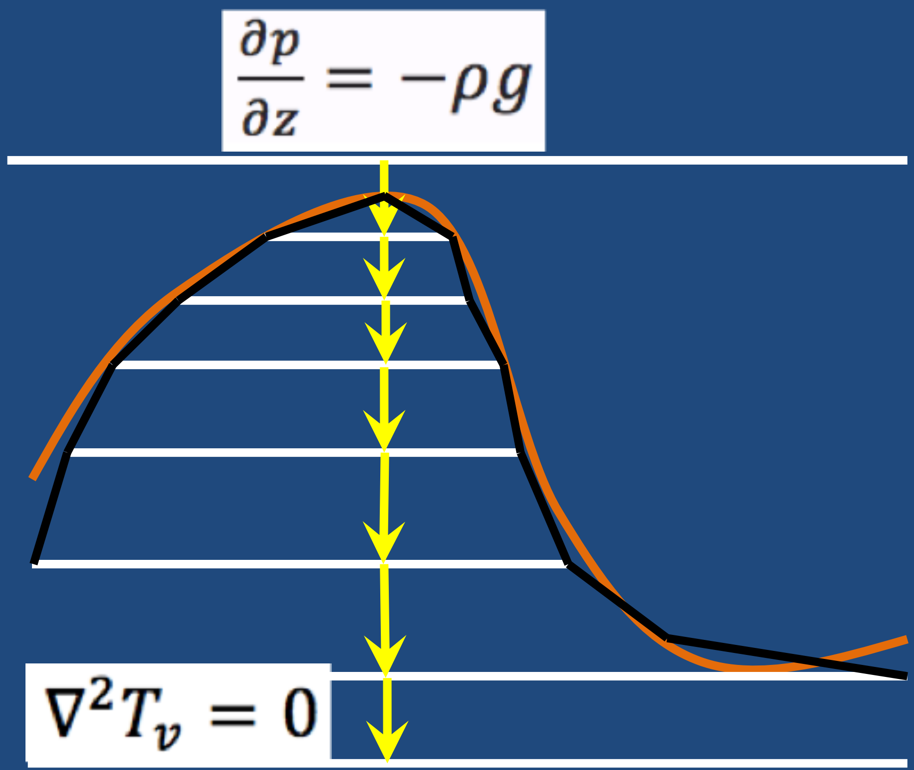
- MSLP or vorticity alone is not enough
- New method is nearly 100% successful
  - Only problems are when nest movement interval is too small for storm speed.
  - Rare: decaying extra-tropical systems



Vortex Tracking Nests

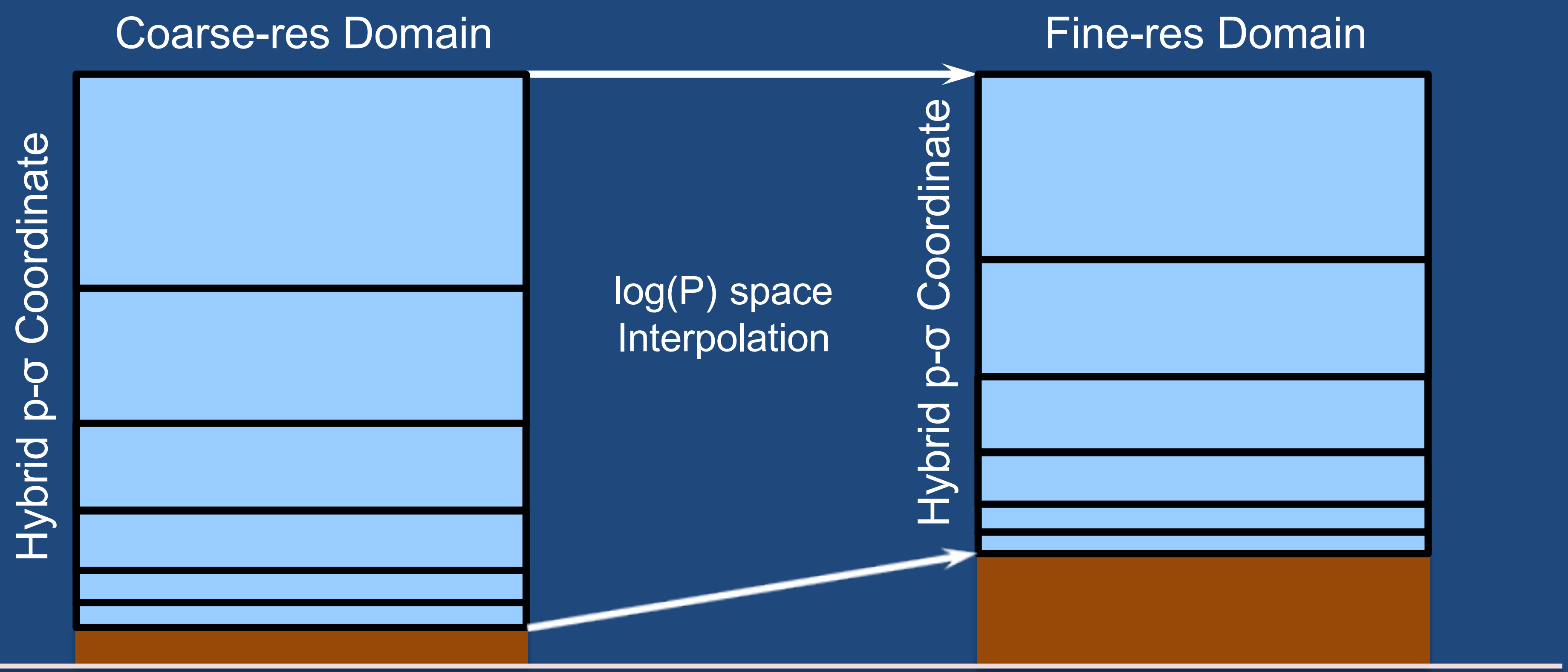
- Track nine smoothed fields:
  - Vorticity – 10 m, 850 mb, 700 mb
  - Wind minimum – 10 m, 850 mb, 700 mb
  - Height – 850 mb, 700 mb
  - Membrane MSLP (developed by Hui-Ya Chuang at EMC)
- Discard fields that are far from the average
- Final average is a new location

Membrane MSLP



- Project atmosphere on pressure levels
- Extrapolate virtual temperature on pressure surfaces
- Smooth atmosphere
- Integrate to get P(z=0)

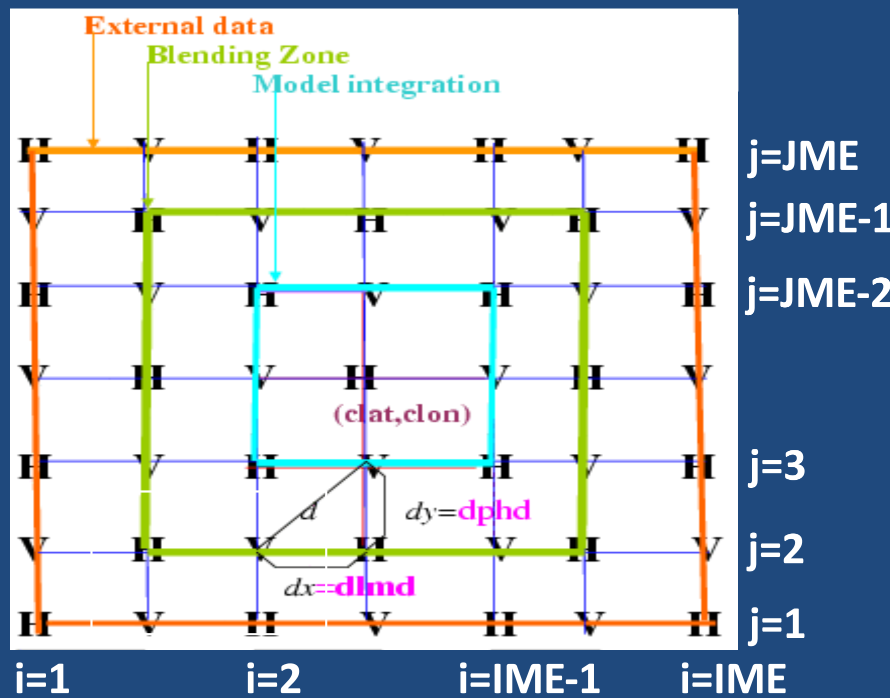
Mass Adjustment



Directly interpolated from parent hybrid to nested hybrid (sigma levels don't match!)

- The height, temperature and moisture fields from the parent domain levels are interpolated horizontally onto nested grids on the same hybrid levels in the parent domain.
- The refined meteorological fields from the parent domain are vertically interpolated onto hybrid levels in the nested domain by using the high-resolution topography pseudo hydrostatic mass balancing.

HWRF NESTED BOUNDARY CONDITIONS



- External Data: Prescribed from the parent after mass adjustment of hydrostatic variables/direct interpolation of other variables
- Blending Zone: Simple 4 point averaging
- Dynamic Interface: Model integration starts from 3rd row/column
- Leading edge: following same procedure of initial condition

Feedback

- 9 point average
- Weighted equally between the parent and nest average
- Same vertical mass adjustment procedure

HWRF namelist.input: nest specific!

```
&domains
 max_dom             = 3,
 grid_id             = 1,       2,       3,
 parent_id           = 0,       1,       2,

&time_control
 start_year          = 2008,    2008,    2008,
 start_month         = 09,      09,      09,
 start_day           = 09,      09,      09,
 start_hour          = 00,      00,      00,
 start_minute        = 00,      00,      00,
 start_second        = 00,      00,      00,
 end_year            = 2008,    2008,    2008,
 end_month           = 09,      09,      09,
 end_day             = 09,      09,      09,
 end_hour            = 06,      06,      06,
 end_minute          = 00,      00,      00,
 end_second          = 00,      00,      00,
```

```
./frame/LOGICAL FUNCTION nests_to_open


CALL nl_get_max_dom ( 1, max_dom )

DO nestid = 2, max_dom

 IF ( .NOT. active_domain( nestid ) ) THEN
   CALL nl_get_parent_id ( nestid, parent_id )
    IF ( parent_id .EQ. parent%id ) THEN
       CALL nl_get_start_year (nestid,s_yr)
       CALL nl_get_end_year (nestid,e_yr)
       CALL nl_get_start_month (nestid,s_mm)
       CALL nl_get_end_month (nestid,e_mm)
       CALL nl_get_start_day (nestid,s_dd)
       CALL nl_get_end_day (nestid,e_dd)
       CALL nl_get_start_hour (nestid,s_h)
       CALL nl_get_end_hour (nestid,e_h)
       CALL nl_get_start_minute (nestid,s_m)
       CALL nl_get_end_minute (nestid,e_m)
       CALL nl_get_start_second (nestid,s_s)
       CALL nl_get_end_second (nestid,e_s)

…………
ENDDO
```

Domain configuration for the nest

```
&domains
 time_step                  = 54,
 time_step_fract_num        = 0,
 time_step_fract_den        = 1,
 max_dom                    = 3,
 s_we                       = 1,      1,    1,
 e_we                       = 216,   60,   60,
 s_sn                       = 1,      1,    1,
 e_sn                       = 432,  100,  100,
 s_vert                     = 1,      1,    1
 e_vert                     = 43,    43,   43,
 parent_grid_ratio          = 1,      3,    3,
 parent_time_step_ratio     =  1,     3,    3,
 dx                         = .18,  0.06, 0.02,
 dy                         = .18,  0.06, 0.02,
```

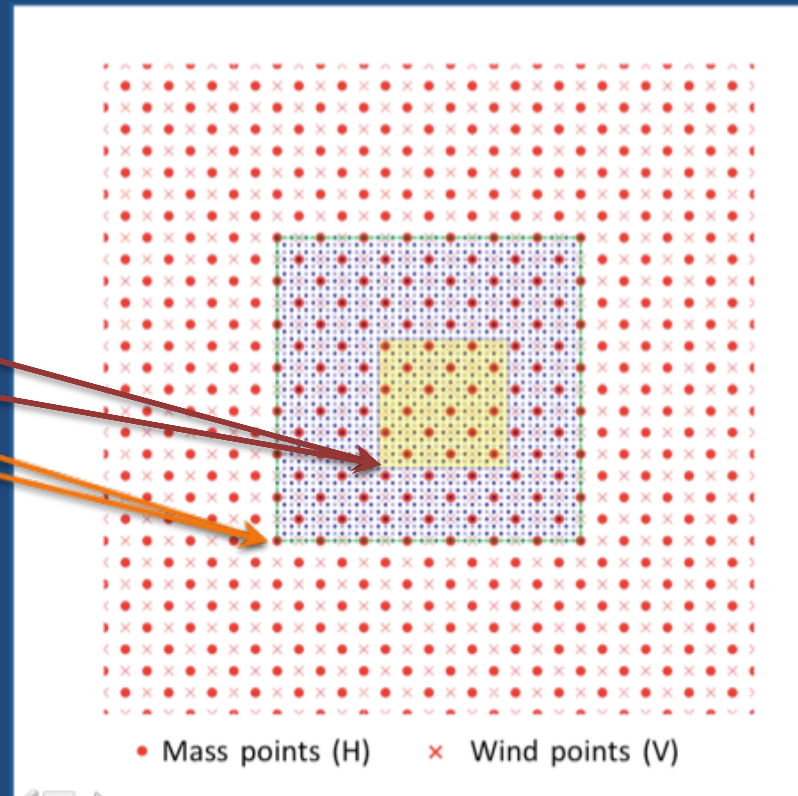
```
./frame/MODULE module_integrate

RECURSIVE SUBROUTINE integrate

 DO WHILE ( nests_to_open( grid , nestid , kid ) )
         ! nestid is index into model_config_rec (module_configure) of the grid
         ! to be opened; kid is index into an open slot in grid's list of children
         a_nest_was_opened = .true.
         CALL med_pre_nest_initial ( grid , nestid , config_flags )
         CALL alloc_and_configure_domain ( domain_id  = nestid ,   &
#ifdef DM_PARALLEL
                        active_this_task = domain_active_this_task( nestid ), &
#endif
                            grid       = new_nest , &
                            parent     = grid ,     &
                            kid        = kid        )
         CALL Setup_Timekeeping (new_nest)
         CALL med_nest_initial ( grid , new_nest , config_flags )
IF ( grid%active_this_task ) THEN
         IF ( grid%dfi_stage == DFI_STARTFWD ) THEN
           CALL wrf_dfi_startfwd_init(new_nest)
         ENDIF
         IF (coupler_on) CALL cpl_defdomain( new_nest )
ENDIF ! active_this_task
       END DO
```

HWRF: ISTART, JSTART AND GRID MOTION

```
&domains
 grid_id                 = 1,      2,      3,
 i_parent_start          = 0,  ISTART1,       ISTART2,
 j_parent_start          = 0,  JSTART1,       JSTART2,
 num_moves                = -99,
```



swcorner_dynamic.F can automatically determine the southwest corner index: istart?, jstart?, within the parent domain (coarse-resolution) for the child domain (fine-resolution).

Option: num_moves = -99 for automatic grid motion, specifically for Hurricanes; For locating the initial grid based on storm center, we are providing a utility ../hwrf-utilities/vortex_init/hwrf_set_ijstart/swcorner_dynamic.F. This code is compiled as part of the hwrf-utilities component of HWRF.

Registry/Registry.NMM
Interpolation Routines share/interp_fcn.F

- Three cases: upscale(Up/u), downscale(Down/d), boundary forcing(Bdy/f)
- Four methods: nearest neighbor (Near), binary copy (Copy), mass adjustment (Mass), velocity (Vel)

```
state real  u ijkb   dyn_nmm 1 v i01rh02u=(UpVel)d=(DownVel)f=(BdyVel)
state real  v ijkb   dyn_nmm 1 v i01rh02u=(UpVel)d=(DownVel)f=(BdyVel)
State real f_ice ikj dyn_nmm 1 -
rhd=(DownMassIKJ:@EExtrap,0.0)u=(UpMassIKJ:@EExtrap,0.0)
state real qv ijkfbt moist   1 m rhu=(UpMass:@ECopy,0.0),
d=(DownMass:@ECopy,0.0)f=(BdyMass:@ECopy,0.0)
```

```
@ECopy,0.0 = extrapolation method (below ground): copy lowest model
level
@EConst,5.5 = extrapolate using constant 5.5 below ground
@EExtrap,5.5 = linearly extrapolate to constant at 1030 mb
```

Summary

The HWRF nesting was developed for hurricane forecast application. The salient features are:

- Model configuration is easily controlled through namelist.input
- Telescopic nests follow the moving system
- Multiple nest moving options are available
- Mass balance between coarse grids to fine grids (downscale and feedback) are directly adjusted on σ levels
- Multiple up- and down-scale and forcing algorithms are available

Reference

Zhang, X., S.G. Gopalakrishnan, S. Trahan, T.S. Quirino, Q. Liu, Z. Zhang, G. Alaka, and and V. Tallapragada. Representing multiple scales in the Hurricane Weather Research and Forecasting modeling system: Design of multiple sets of movable multilevel nesting and the basin-scale HWRF forecast verification. Weather and Forecasting, 31(6):2019-2034, doi:10.1175/WAF-D-16-0087.1 2016