FV^3: model configurations for NGGPS

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- Horizontal & vertical resolutions, physics & dynamics time steps
- FV^3's island-preserving terrain filter (same filtering philosophy as the FV transport scheme)
- Consistent parameters for model evaluations
- A note on the divergence & vorticity damping
- Two configurations for NGGPS:
    1) Implicit diffusion (monotonic constraints)
    2) Explicit diffusion and energy conservation

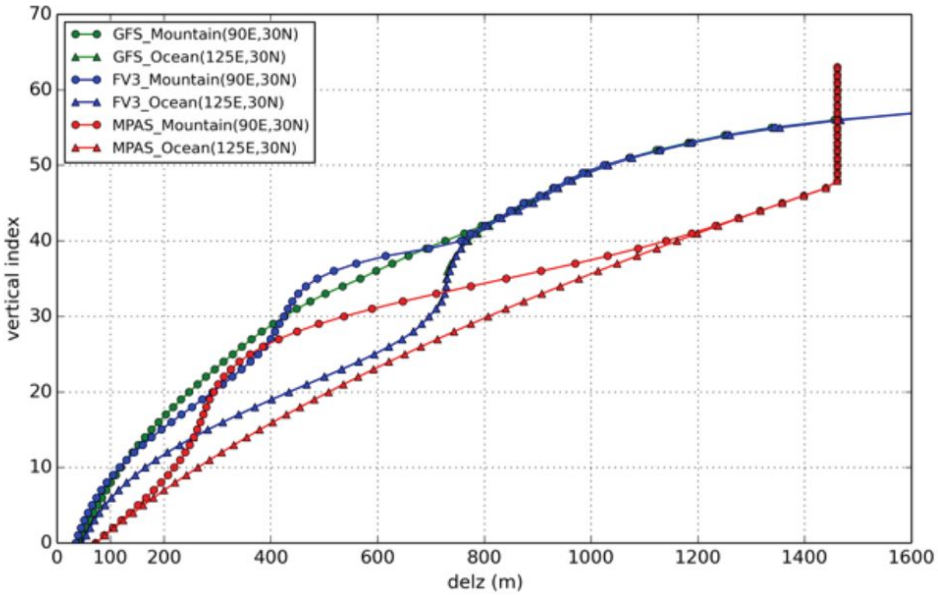
FV^3 & MPAS configurations for NWP with GFS physics:

	Phase-1 MPAS	Phase-2 MPAS	C768 FV3	C640 FV3 (alt)	C1024 var 3	GFS_TL1534
Grid Type	Voronoi mesh	Voronoi mesh	Cubed-sphere	Cubed-sphere	Stretched-Cubed-sphere	Gaussian/Reduced-Gaussian
Total number of grid points	4,096,002	2,621,442	3,538,944	2,457,600	6,291,456	4,718,592/3,126,128
Avg. Resolution (km)	12	15	12.05	14.46	[3, 30]	13
Bottom layer thickness (m)	n/a	**72.5**	**28-50**	**28-50**	**28-50**	**28-50**
Short-wave rad time step (s)	n/a	**1800**	**3600**	**3600**	**3600**	**3600**
Long-wave rad time step(s)	n/a	**1800**	**3600**	**3600**	**3600**	**3600**
Phys time step(s)	n/a	**90**	**225**	**225**	**60**	**225**
Dynamic split steps	1	3	2	1	1	n/a
True dynamic time step (s)	72	30	112.5	225	60	450
Acoustic steps	6	6	6	10	12	n/a
Effective acoustic time step (s)	12	5	18.75	22.5	5	n/a

- From phase-1 to phase-2, MPAS total grid points reduced by 36% (12 km to 15 km)
- FV^3 *standard configuration* C768 (12.05 km) remains the same
- The *alternative configuration* FV^3 C640 (14.46 km) has 30% less grid points than C768

- FV^3 uses the same physics time step (225 sec) as GFS (per EMC instruction)
- MPAS uses a smaller 90 sec physics time step

Vertical grids: GFS, FV3, and MPAS

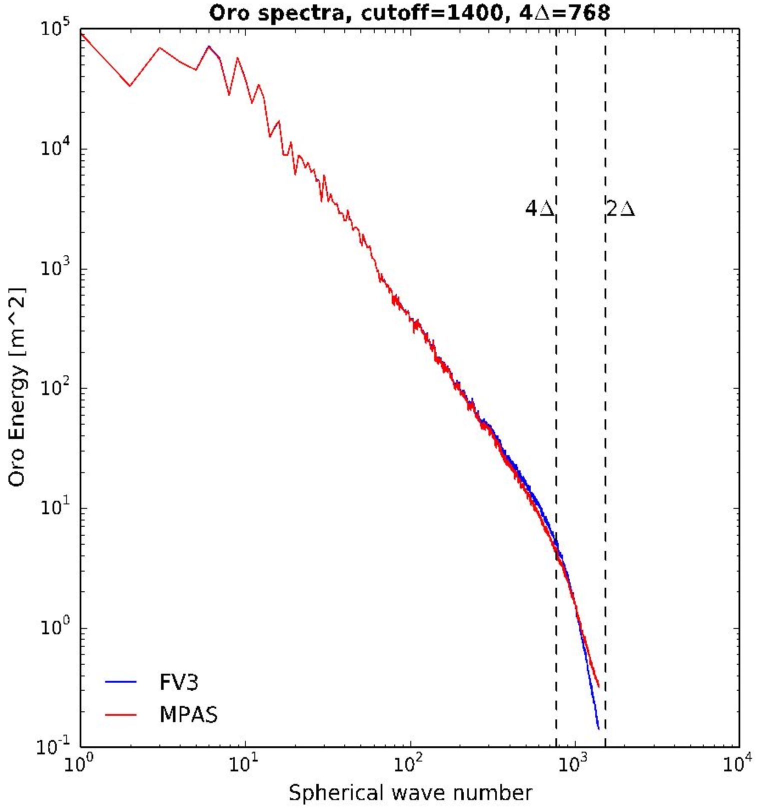


Note: FV3 time step size is not limited by vertical CFL condition

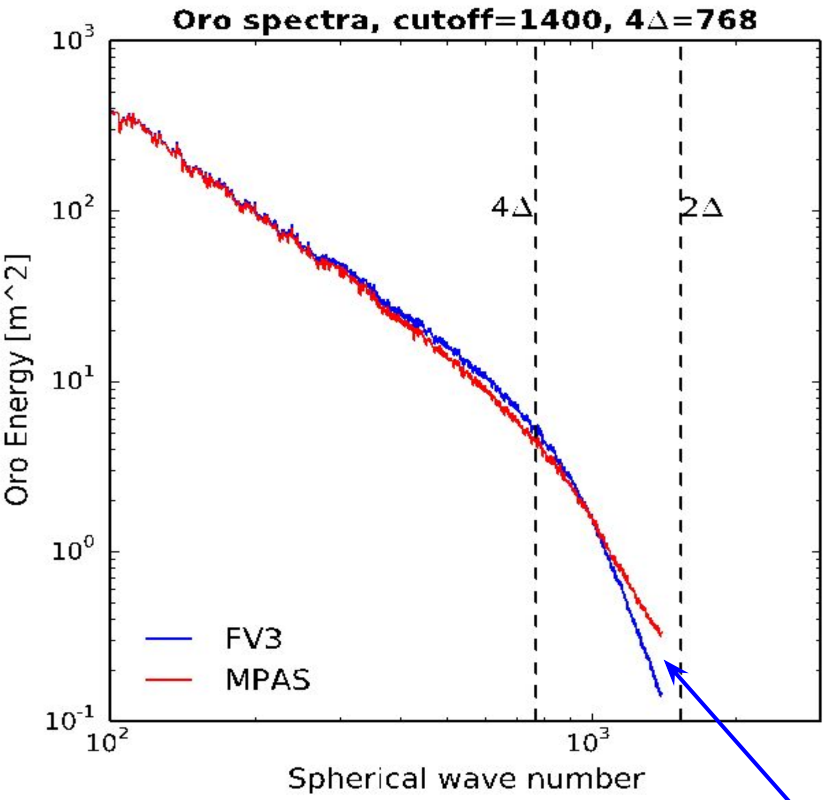
	PBL > 850 mb	Free Troposphere 850 - 150 mb	UTLS 150 - 50 mb	Upper stratosphere < 50 mb
GFS	13	24	8	19
FV3	13	24	9	18
MPAS	9	24	6	25

FV3's island-preserving terrain filter

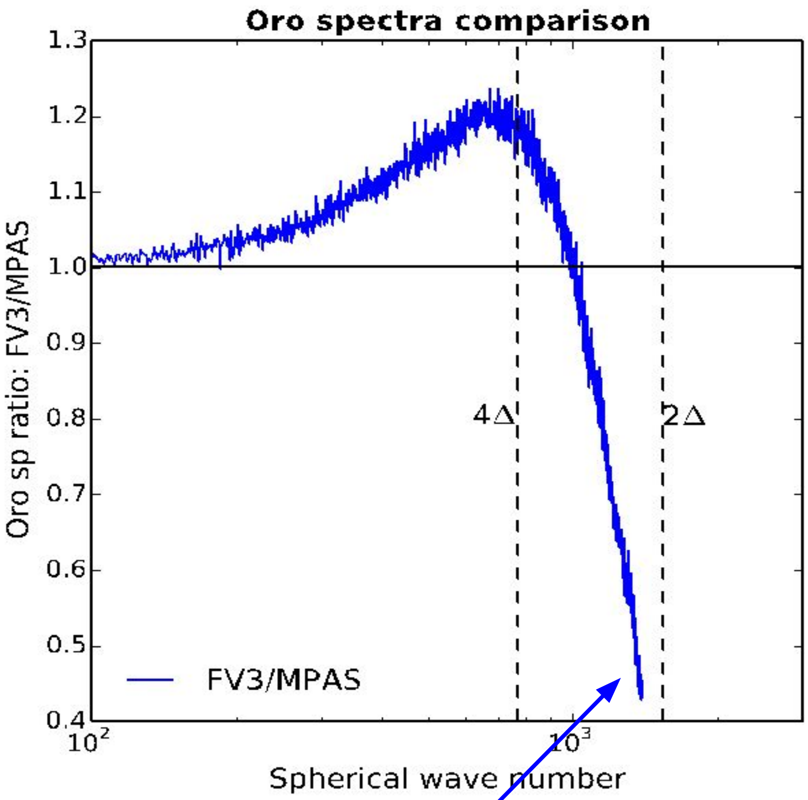
- Two passes of FCT filter for monotonicity, and preservation of land-sea mask.
    - 2-delta structures not supported by the dynamics are strongly suppressed.
- The FCT filter is the non-linear combination of del-4 and monotonic del-2 schemes



The Orography spectra

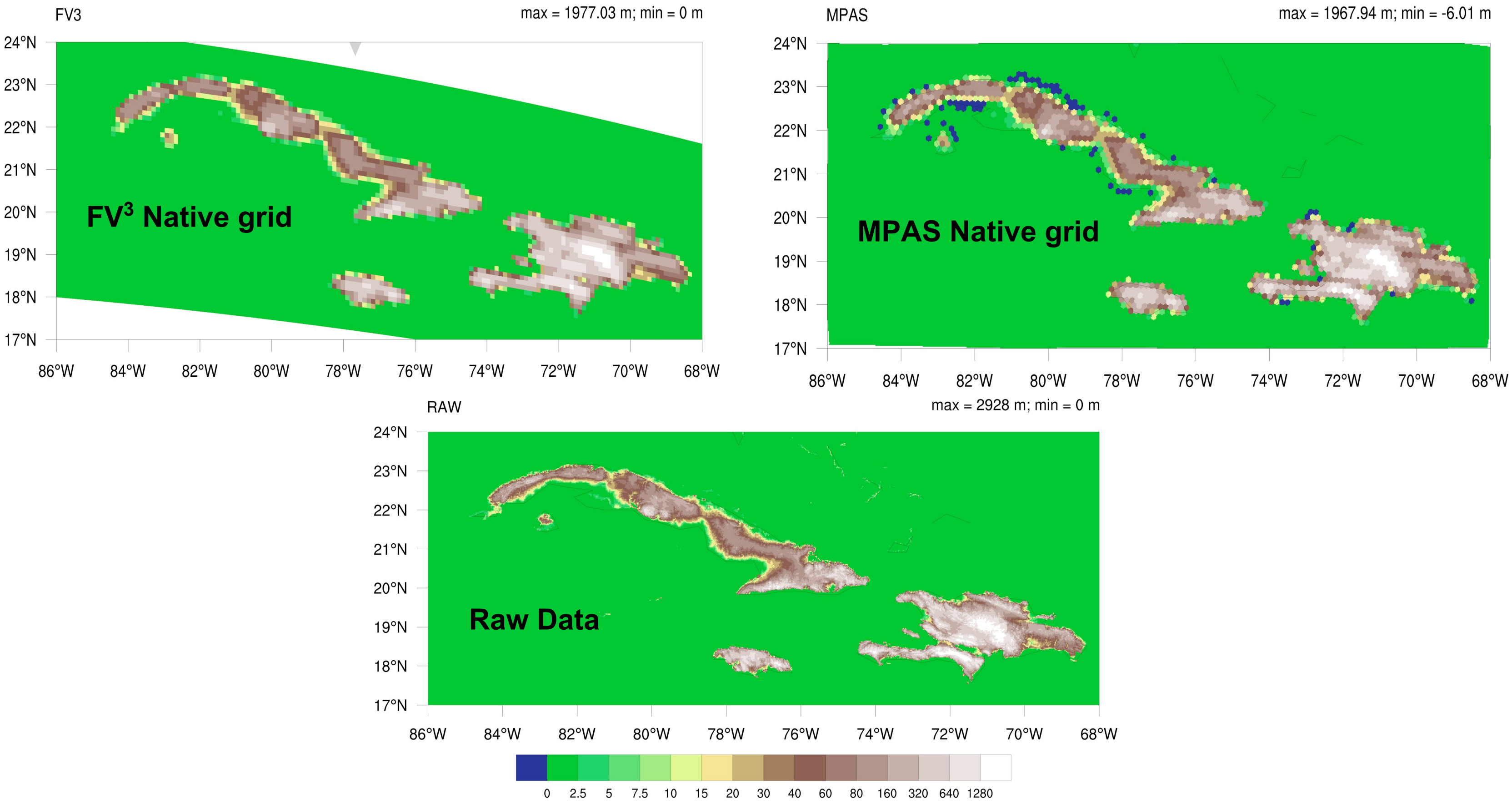


The ratio: FV3/MPAS



FV^3 applies more aggressive filter on 2-delta-waves

The island-preserving terrain filter of FV3 preserves well the peaks/valleys, and does not produce negative mountains over ocean



Consistent parameters for model evaluations:

- Physics and dynamics should be tuned together as a package.
  - For NGGPS, the GFS physics should not be tuned
  - Only dynamical parameters (e.g., diffusion) can be tuned

- ***Unless the physics or model configuration is changed, one should never change any parameter from run to run.***
  - Parameters must be the same during the whole hindcast period or an AMIP run.
  - ***If one forecast fails, requiring a parameter change, one must re-make all the hindcast runs with the new parameters***

- Sensitivity tests, if needed, must be an open process, requiring iterations between the developers and the testers.

Divergence & Vorticity damping:

- Vertical vorticity is transported by the FV algorithm. With monotonic advection there is no need to add explicit damping to the vorticity.

- Since the divergence is not damped implicitly, a scale-selective divergence damping (either del-4 or del-6) is used.

- The linear “5^{th} order” scheme is FV^3’s least diffusive scheme
  - Used at NASA/GMAO for 4D Var and at GFDL for ultra-high resolution (1-4 km) global cloud-resolving simulations.

- With the non-diffusive “linear” scheme, a scale-selective damping on vorticity and other fluxes is recommended. The lost KE can then be added locally as heat for better conservation of total energy

FV^3 Namelist Document

Complete list of FV^3 namelist options has been sent to the DTG

Email S-J Lin or Lucas Harris if you would like another copy

Focusing on solver and diffusion options in this presentation; see document for complete coverage

FV^3

Namelist options in the GFDL
Finite-Volume Cubed-Sphere Dynamical Core

Shian-Jiann Lin and Lucas Harris

Initial Version 12 Aug 2013
Version 2.0a Revised 7 Jan 2016

Entries in fv_core_nml

Required options:

layout Integer(2): Processor layout on each tile. The number of PEs assigned to a domain must equal layout(1)*layout(2)*ntiles. Must be set.

npx Integer: Number of grid *corners* in the x-direction on one tile of the domain; so one more than the number of grid cells across a tile. On the cubed sphere this is *one more than* the number of cells across a cube face. Must be set.

npy Integer: Number of grid *corners* in the y-direction on one tile of the domain. This value should be identical to npx on a cubed-sphere grid; doubly periodic or nested grids do not have this restriction. Must be set.

npz Integer: Number of vertical levels. Each choice of npz comes with a pre-defined set of hybrid sigma-pressure levels and model top (see atmos_cubed_sphere/tools/fv_eta.F90). Must be set.

ntiles Integer: Number of tiles on the domain. For the cubed sphere, this should be 6, one tile for each face of the cubed sphere; normally for most other domains (including nested grids) this should be set to 1. Must be set.

Initialization options:

add_noise Real: amplitude of random thermal noise (in K) to add upon startup. Useful for perturbing initial conditions. -1 by default; disabled if 0 or negative.

Domain specification

```
&fv_core_nml
    npx    = 769
    npy    = 769
    npz    = 64
    n_sponge = 8
    tau = 5.
    rf_cutoff = 8.e2
    d2_bg_k1 = 0.16
    d2_bg_k2 = 0.02
    hydrostatic = .F.
    k_split  = 2
    n_split  = 6
    fv_sg_adj = 1800
    nord =  1
    d4_bg = 0.15
    vtdm4 = 0.
    do_vort_damp = .false.
    d_con = 0.
    hord_mt =  8
    hord_vt = -8
    hord_tm = -8
    hord_dp = -8
    hord_tr = -8
```

`npx` and `npy` control the number of grid corners across a cube face; subtract one to get the number of grid cells

> c768 corresponds roughly to ⅛ degree, or 12 km global average grid-cell width

`npz` is the number of grid levels, with a hard-coded specification of level placement

> 64-level model top at 0.28 mb

Timestepping

```
&fv_core_nml
      npx    = 769
      npy    = 769
      npz    = 64
      n_sponge = 8
      tau = 5.
      rf_cutoff = 8.e2
      d2_bg_k1 = 0.16
      d2_bg_k2 = 0.02
      hydrostatic = .F.
      k_split  = 2
      n_split  = 6
      fv_sg_adj = 1800
      nord =  1
      d4_bg = 0.15
      vtdm4 = 0.
      do_vort_damp = .false.
      d_con = 0.
      hord_mt =  8
      hord_vt = -8
      hord_tm = -8
      hord_dp = -8
      hord_tr = -8
```

```
&coupler_nml
     dt_atmos = 225
```

`dt_atmos` is the physics timestep: **225 s**, matching GFS

Vertical remapping and advection is done `k_split` times per physics timestep

> **112.5 s**: Lagrangian vertical coordinate has *no* Courant number restriction!

Acoustic solver and horizontal dynamics called `n_split` times between vertical remappings:

> **18.75 s**: Forward-in-time solver

Monotonic scheme

```
&fv_core_nml
     npx    = 769
     npy    = 769
     npz    = 64
     n_sponge = 8
     tau = 5.
     rf_cutoff = 8.e2
     d2_bg_k1 = 0.16
     d2_bg_k2 = 0.02
     hydrostatic = .F.
     k_split  = 2
     n_split  = 6
     fv_sg_adj = 1800
     nord =  1
     d4_bg = 0.15
     vtdm4 = 0.
     do_vort_damp = .false.
     d_con = 0.
     hord_mt =  8
     hord_vt = -8
     hord_tm = -8
     hord_dp = -8
     hord_tr = -8
```

Non-monotonic ("linear") scheme

```
&fv_core_nml
     npx    = 769
     npy    = 769
     npz    = 63
     n_sponge = 8
     tau = 5.
     rf_cutoff = 8.e2
     d2_bg_k1 = 0.16
     d2_bg_k2 = 0.02
     hydrostatic = .F.
     k_split  = 2
     n_split  = 6
     fv_sg_adj = 1800
     nord =  1
     d4_bg = 0.15
     vtdm4 = 0.04
     do_vort_damp = .true.
     d_con = 1.
     hord_mt =  6
     hord_vt = -5
     hord_tm = -5
     hord_dp = -5
     hord_tr = -8
```

Optimized monotonic and non-monotonic ("linear") schemes for computing fluxes. Tracer advection is *always* monotonic (-8) and is *never* explicitly diffused

Monotonic scheme (+8, -8) is intrinsically diffusive to 2-delta-waves. Explicit horizontal damping from 4th-order (`nord = 1`) divergence damping

No explicit ("vorticity") damping on other fluxes

```
do_vort_damp = .false.
```

Monotonic scheme	Non-monotonic ("linear") scheme
&fv_core_nml	&fv_core_nml
npx = 769	npx = 769
npy = 769	npy = 769
npz = 64	npz = 64
n_sponge = 8	n_sponge = 8
tau = 5.	tau = 5.
rf_cutoff = 8.e2	rf_cutoff = 8.e2
d2_bg_k1 = 0.16	d2_bg_k1 = 0.16
d2_bg_k2 = 0.02	d2_bg_k2 = 0.02
hydrostatic = .F.	hydrostatic = .F.
k_split = 2	k_split = 2
n_split = 6	n_split = 6
fv_sg_adj = 1800	fv_sg_adj = 1800
nord = 1	nord = 1
d4_bg = 0.15	d4_bg = 0.15
vtdm4 = 0.	**vtdm4 = 0.04**
do_vort_damp = .false.	**do_vort_damp = .true.**
d_con = 0.	**d_con = 1.**
hord_mt = 8	**hord_mt = 6**
hord_vt = -8	**hord_vt = -5**
hord_tm = -8	**hord_tm = -5**
hord_dp = -8	**hord_dp = -5**
hord_tr = -8	hord_tr = -8

Non-monotonic scheme (6, -5) applies *no* monotonicity constraint ("linear"), only a 2dx filter to suppress oscillations.

Needs consistent damping to vorticity and momentum fluxes. This damping (`vtdm4`) should be weaker than the divergence damping.

The local dissipated kinetic energy is added back as heat (`d_con > 0`)

The 2-dz filter

```
&fv_core_nml
     npx    = 769
     npy    = 769
     npz    = 64
     n_sponge = 8
     tau = 5.
     rf_cutoff = 8.e2
     d2_bg_k1 = 0.16
     d2_bg_k2 = 0.02
     hydrostatic = .F.
     k_split  = 2
     n_split  = 6
     fv_sg_adj = 1800
     nord =  1
     d4_bg = 0.15
     vtdm4 = 0.
     do_vort_damp = .false.
     d_con = 0.
     hord_mt =  8
     hord_vt = -8
     hord_tm = -8
     hord_dp = -8
     hord_tr = -8
```

The 2-dz filter is a *local* vertical mixing to suppress K-H instabilities on the relaxation timescale `fv_sg_adj`, using ideas similar to those of Smagorinsky and Lilly.

Here, it is applied only on the top `n_sponge` levels to suppress instability due to the accumulation of vertically-propagating waves at the model top

The filter conserves energy, air and tracer mass, and momentum.

This is the *only* explicit vertical diffusion in FV^3, and is not strictly necessary; used as a safety valve to ensure model stability under adverse conditions

Rayleigh damping and sponge layer

```
&fv_core_nml
     npx    = 769
     npy    = 769
     npz    = 64
     n_sponge = 8
     tau = 5.
     rf_cutoff = 8.e2
     d2_bg_k1 = 0.16
     d2_bg_k2 = 0.02
     hydrostatic = .F.
     k_split  = 2
     n_split  = 6
     fv_sg_adj = 1800
     nord =   1
     d4_bg = 0.15
     vtdm4 = 0.
     do_vort_damp = .false.
     d_con = 0.
     hord_mt =  8
     hord_vt = -8
     hord_tm = -8
     hord_dp = -8
     hord_tr = -8
```

Rayleigh damping is applied *consistently* to (u, v, w), converting lost kinetic energy to heat, with the same timescale (5 days) as in GFS

Rayleigh damping is only applied above `rf_cutoff` (in Pa); the top 6 layers in this case

Sponge layer is active in the top two layers of the model, using second-order horizontal damping to suppress wave-reflection