The GFDL Finite-Volume Cubed-Sphere Dynamical Core

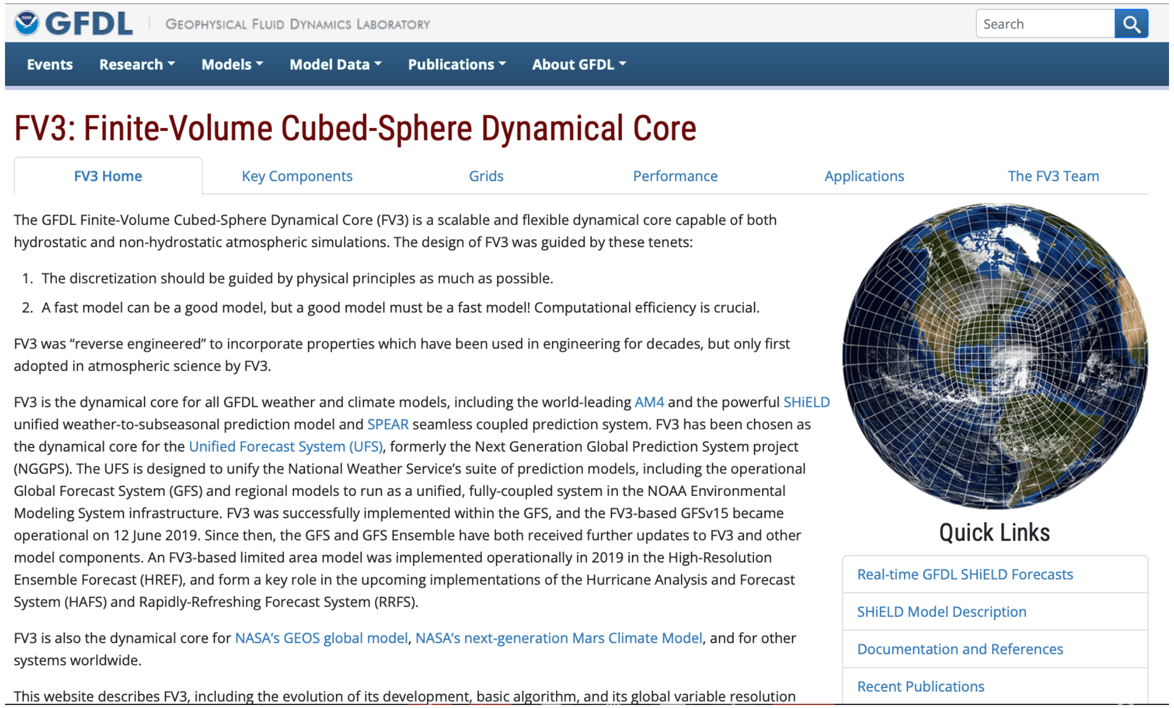
Structure and Usage

Lucas Harris
for the GFDL FV3 Team

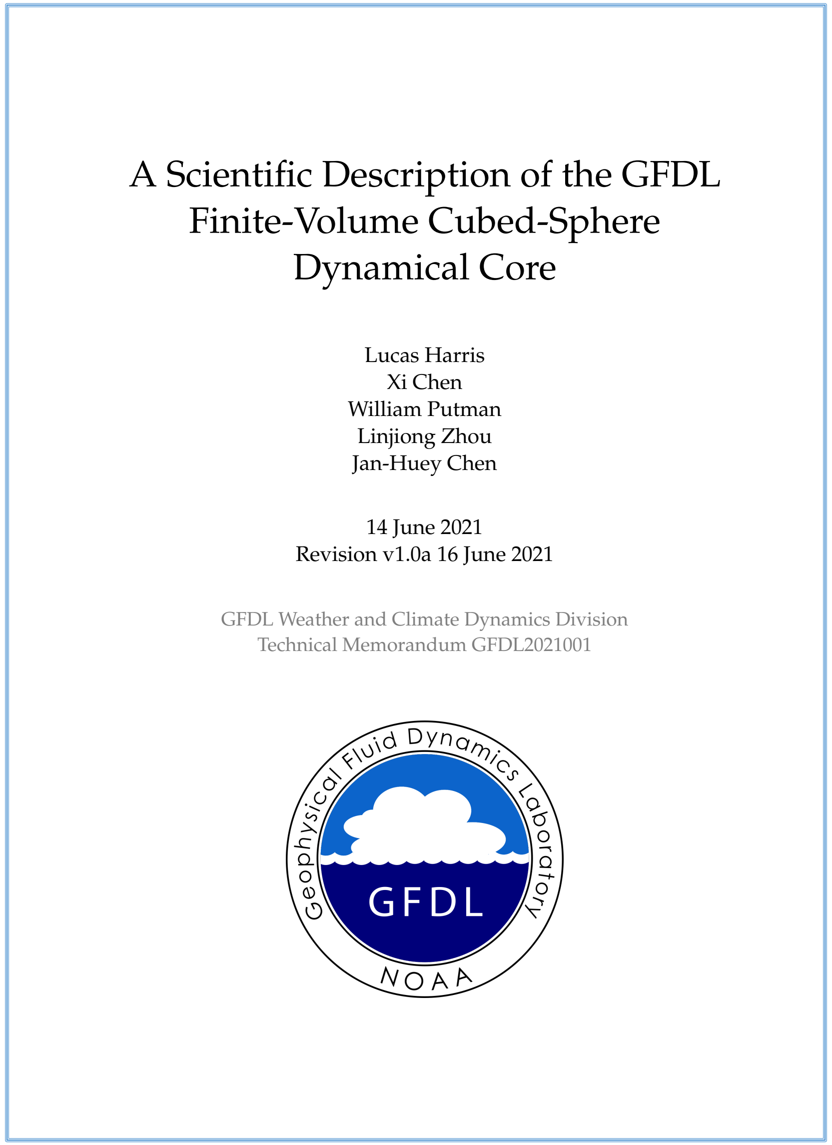
AOS 575

3 November 2022

FV3 Reference Info



FV3 Portal: www.gfdl.noaa.gov/fv3



A Scientific Description of the GFDL Finite-Volume Cubed-Sphere Dynamical Core

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Xi Chen
William Putman
Linjiong Zhou
Jan-Huey Chen

14 June 2021
Revision v1.0a 16 June 2021

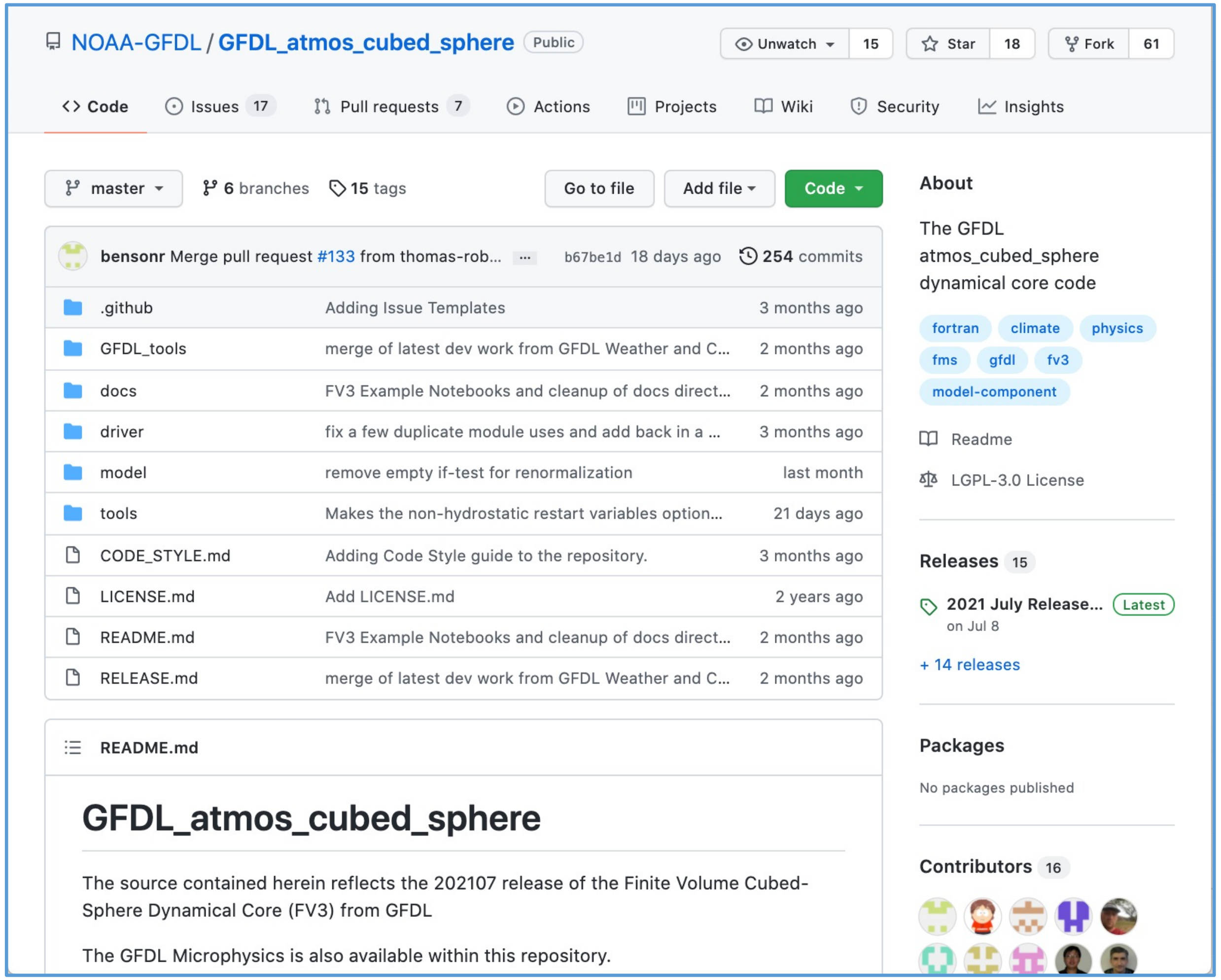
GFDL Weather and Climate Dynamics Division
Technical Memorandum GFDL2021001

Geophysical Fluid Dynamics Laboratory
GFDL
NOAA

Harris et al. (2021)
Comprehensive FV3 Scientific Documentation on GitHub and NOAA Institutional Repository

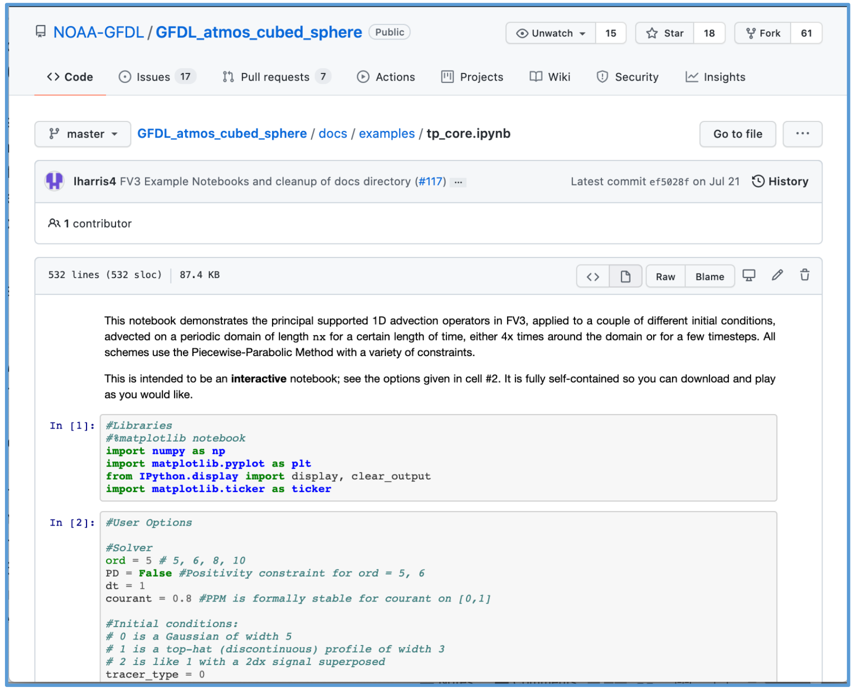
FV3 Community GitHub

Fork FV3 on GitHub



github.com/NOAA-GFDL/GFDL_atmos_cubed_sphere

Official site for FV3 releases, examples, issue tracking, documentation, and more



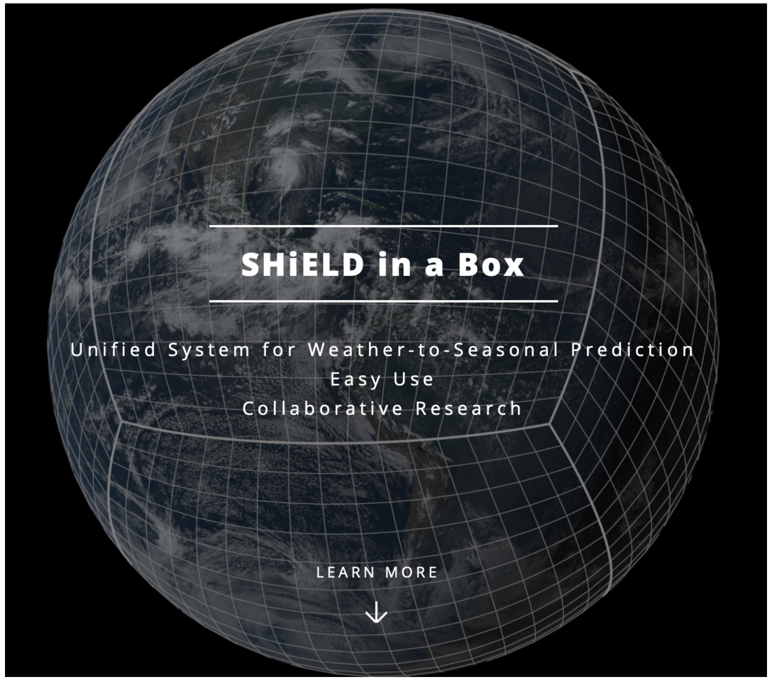
Examples directory: Jupyter notebooks demonstrating FV3 capabilities. Updates released regularly.

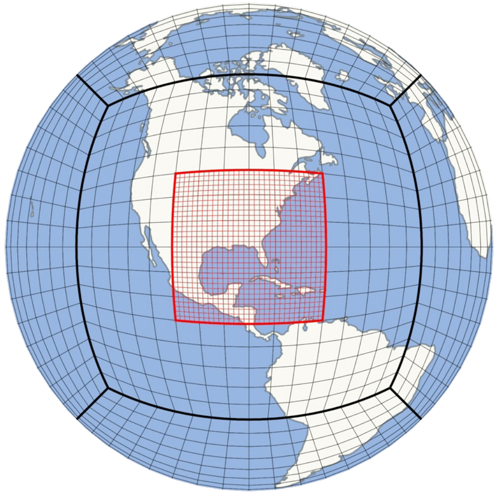
SHiELD and solo FV3 Container

- Convenient, portable, and reproducible SHiELD and FV3 demonstration
  - 35-km regional and nested domains
  - Includes idealized “solo_core” FV3 tests
- Docker and Singularity containers run on supercomputers, workstations, and laptops

Literature

Cheng et al. 2022a
Jeevanjee and Zhou (2022)





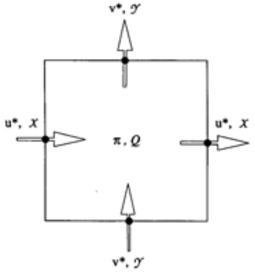
shield.gfdl.noaa.gov/shield-in-a-box/

FV3: The GFDL Finite-Volume Cubed-Sphere Dynamical Core

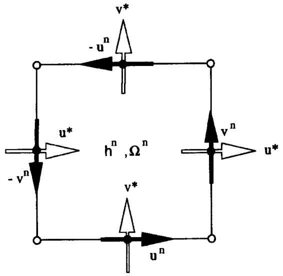
The FV3 Way

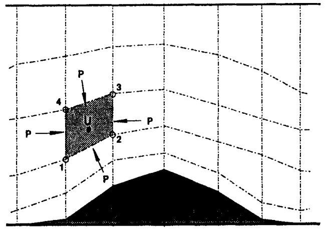
- Physical consistency
- Fully-FV numerics
- Component coupling
- Computational efficiency

Lin & Rood 1996
Efficient 2D high-order conservative FV transport



Lin & Rood 1997
FV horizontal solver focusing on nonlinear vorticity dynamics

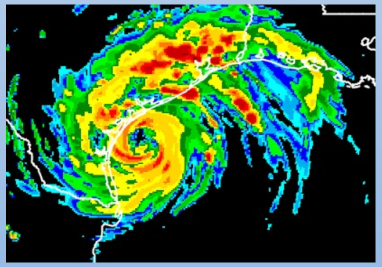


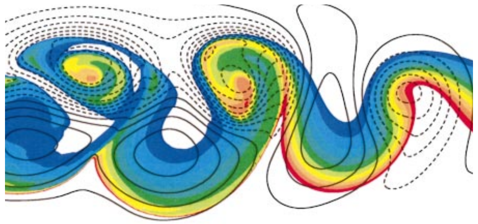


Lin 1997 Efficient, mimetic FV PGF

FV3 for the 2020s

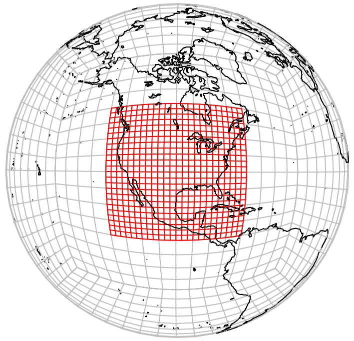
Rigorous Thermodynamics
Flexible dynamics
Adaptable physics interface
Variable-resolution techniques
Regional & periodic domains
Powerful initialization, DA, and nudging functions

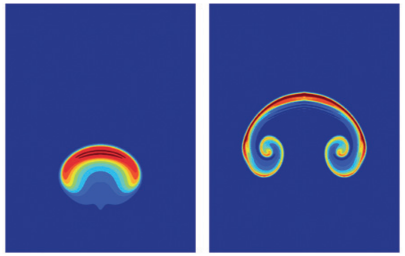




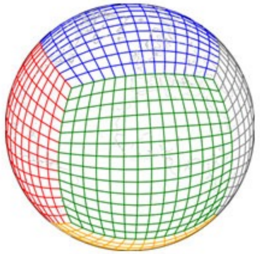
Lin 1998–2004 FV core with “floating” Lagrangian vertical coordinate

Harris & Lin 2013, 2016
Variable resolution with two-way nesting and Schmidt grid stretching





Lin 2006, X Chen & Lin et al 2013
Consistent Lagrangian nonhydrostatic dynamics



Putman & Lin 2007
Scalable cubed-sphere grid, doubly-periodic domain

The Global FV3 Community

Past, present, future earth and beyond

UFS
UNIFIED FORECAST SYSTEM

GFDL
AM4 CM4 ESM4
SHiELD SPEAR

NATIONAL WEATHER SERVICE
GFSv15 v16 GEFSv12
MRW SRW HAFS …

NOAA RESEARCH
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

GFDL FV3

NASA
GEOS, DAS, MERRA(2)
Ames Mars GCM

HARVARD
GEOS Chem
GEOS-Chem High-Performance

NCAR
CAM-FV
CAM-FV3

IAP
Chinese Academy of Sciences
LASG FAMIL, F-GOALS

Taiwan Central Weather Bureau
CWBGFS

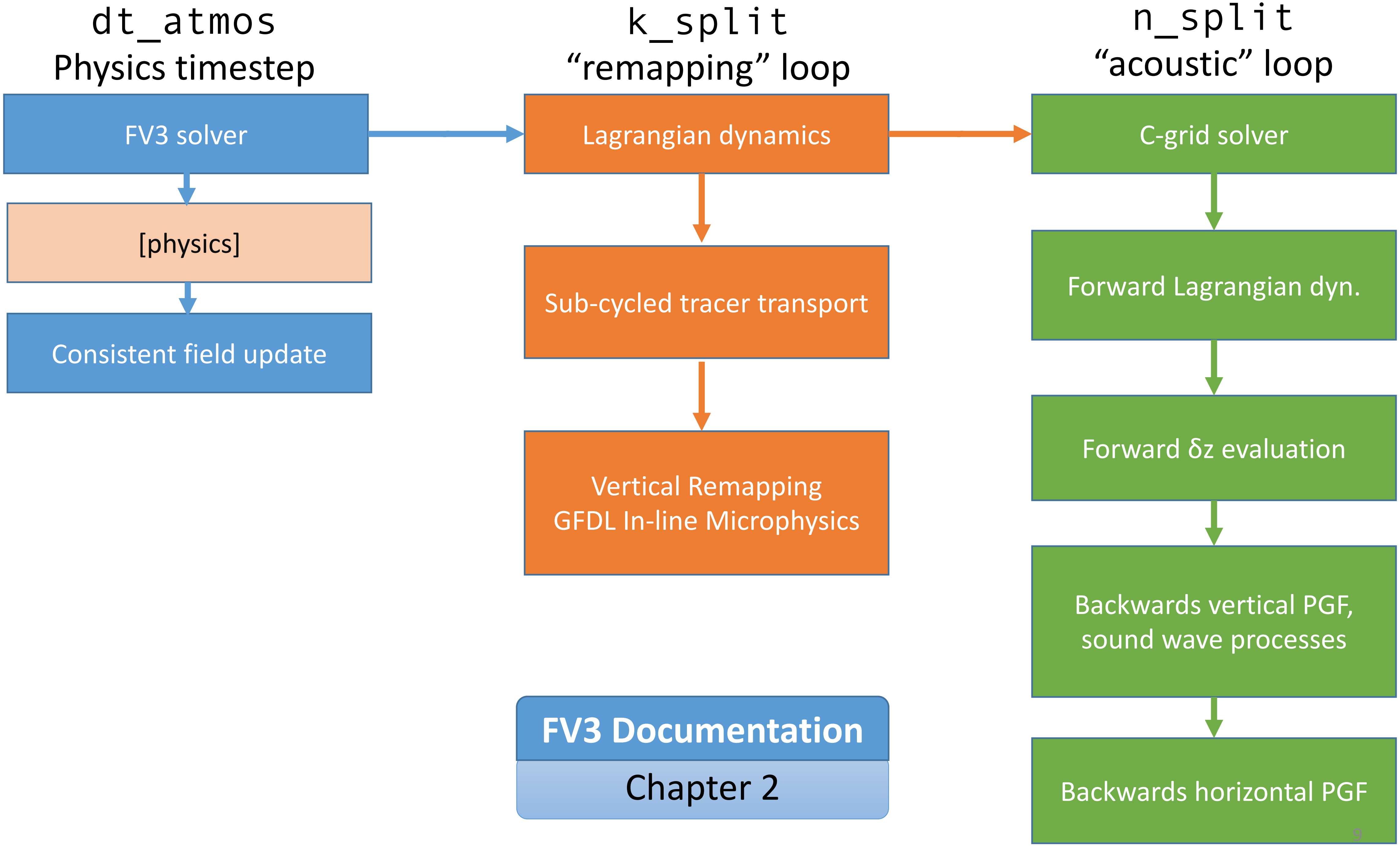
Finite-Volume Dynamical Cores

FV3 Documentation
Section 1.2

- All variables are 3D cell- or face-means…not gridpoint values
- We solve not the differential Euler equations but their cell-integrated forms using integral theorems
  - Everything is a flux, including the momentum equation. **Fully FV!**
  - Mass conservation ensured to rounding error
  - C-D grid: Vorticity computed *exactly*; accurate divergence computation
  - Mimetic: Physical properties recovered by discretization, particularly Newton's 3rd law
  - Fully compressible: calculation is horizontally local
  - Flow-following Lagrangian vertical coordinate
- FV3 is a fully forward-in-time solver with backwards PGF and acoustic terms

FV3 time integration sequence

- FV3 is a forward-in-time solver with multiple levels of time-integration
  - Flux-divergence terms and physics tendencies evaluated forward-in-time
  - Pressure-gradient and sound-wave terms evaluated backward-in-time for stability
  - HEVI: Everything is *explicit* in the horizontal but *implicit* in the vertical
- *Lagrangian vertical coordinate*: flow constrained along time-evolving Lagrangian surfaces. This greatly simplifies the inner “acoustic” or “Lagrangian dynamics” timestep.


dt_atmos
Physics timestep
FV3 solver
[physics]
Consistent field update
k_split
“remapping” loop
Lagrangian dynamics
Sub-cycled tracer transport
Vertical Remapping
GFDL In-line Microphysics
n_split
“acoustic” loop
C-grid solver
Forward Lagrangian dyn.
Forward δz evaluation
Backwards vertical PGF,
sound wave processes
Backwards horizontal PGF
FV3 Documentation
Chapter 2

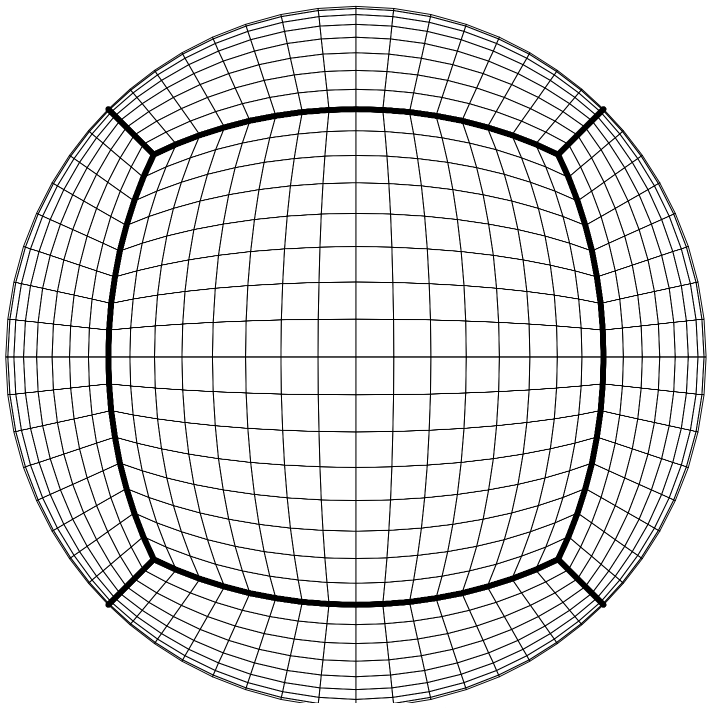
The Cubed-Sphere Grid

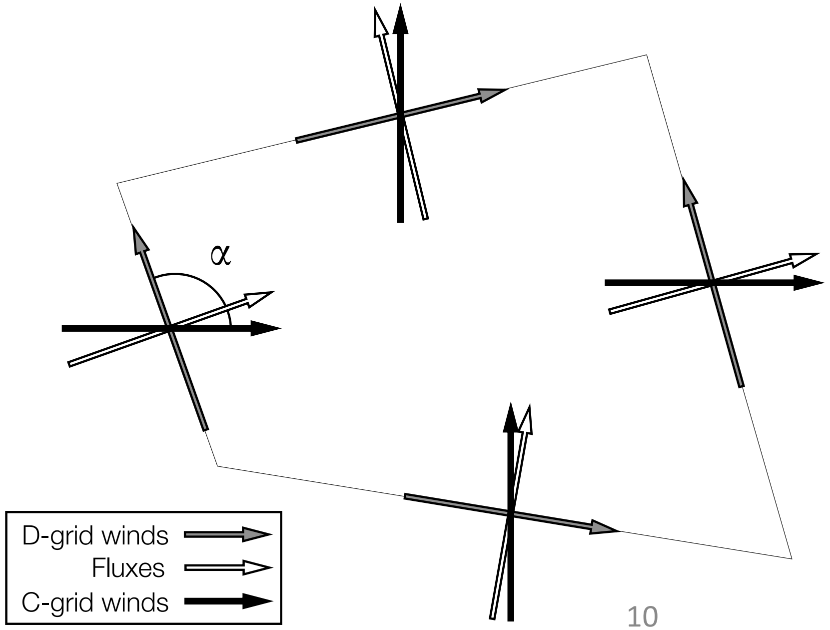
The 3 in FV3

- Gnomonic cubed-sphere grid: coordinates are great circles but non-orthogonal
  - Solution winds are covariant, advection is by contravariant winds
- Winds u and v are defined internally in the local coordinate; output is *always* rotated to earth-relative coords
- Special handling at edges and corners

FV3 Documentation
Chapter 3

Literature
Putman + Lin 2007

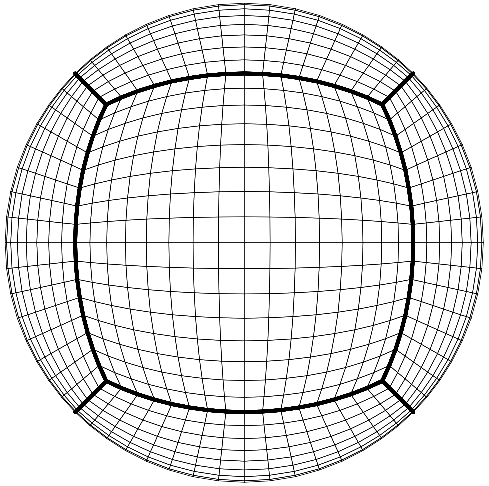


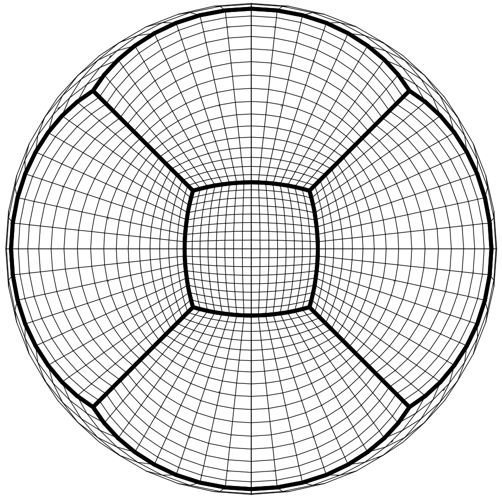


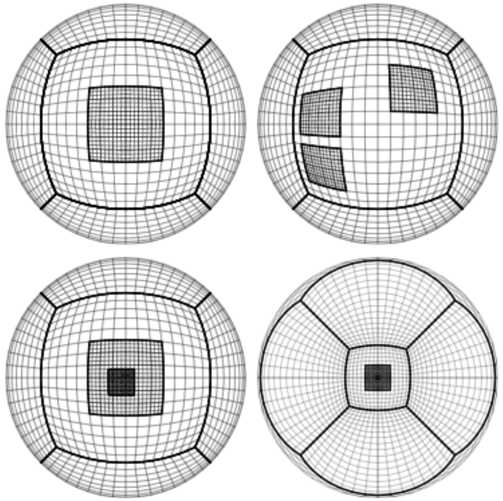
The Cubed-Sphere Grid and Arbitrary Grid Domains

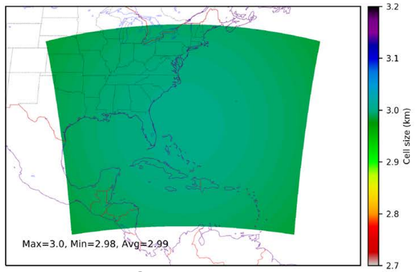
FV3 uses a global cubed-sphere grid **or** any arbitrary regular non-orthogonal quadrilateral grid

This permits Schmidt-stretched grids, two-way nested grids, and uniform regional domains

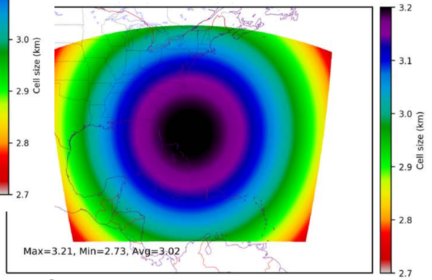








Extended Schmidt gnomonic grid



Ordinary gnomonic grid

Regional-Domain Grid-cell Width
Courtesy Jim Purser and
Chan-Hoo Jeon (NCEP/EMC)

FV Advection

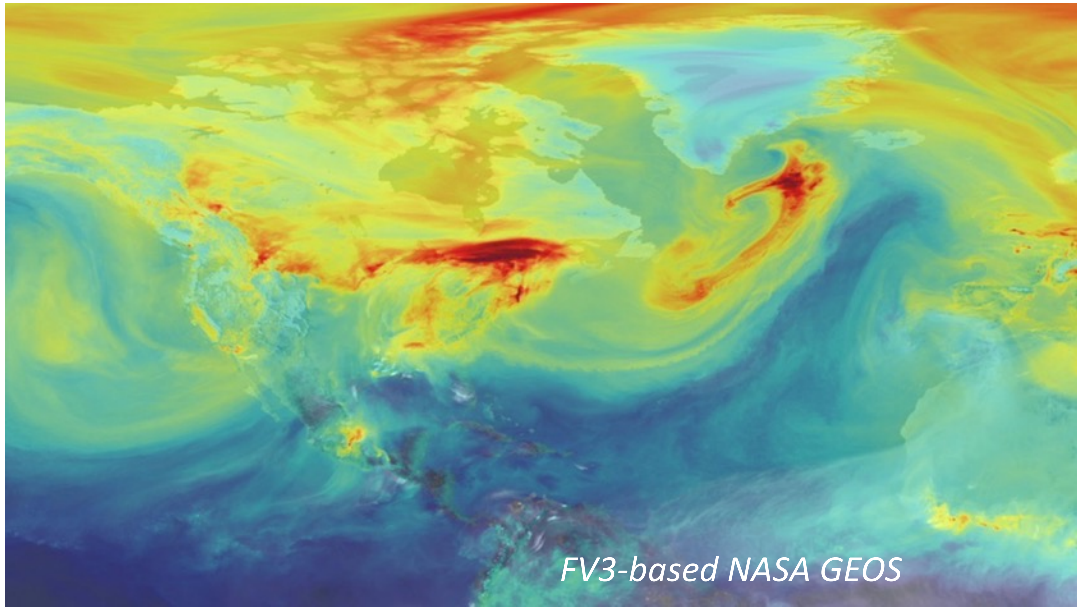
- "Reverse-engineered" forward-in-time 2D scheme constructed from 1D Piecewise-Parabolic Method (PPM) operators
  - Mass-conservative
  - Correlation-preserving for monotonic limiter
  - Cancels splitting error
  - Separate Courant number limit in x and y
  - Upwinding preserves hyperbolicity and causality
- Tracers are advected with a longer, adaptive timestep using the accumulated mass fluxes
- *All* quasi-horizontal processes, except PGF, can be represented as advection
- Highly adaptable: Positive-definite tracer advection greatly improves hurricane structure

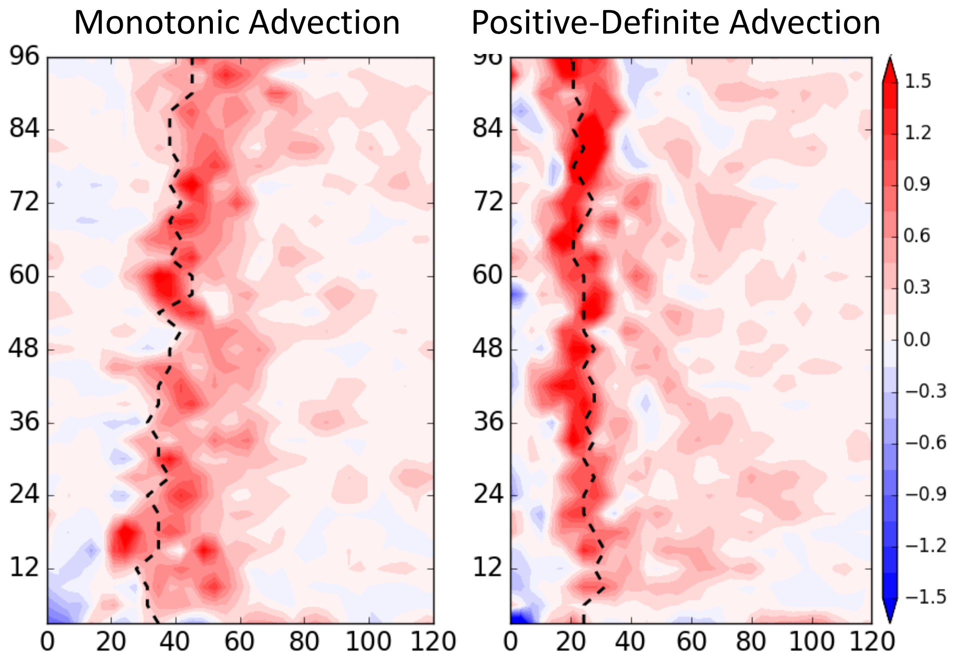
FV3 Documentation

Chapter 4

Literature

Lin and Rood 1996
Putman and Lin 2007

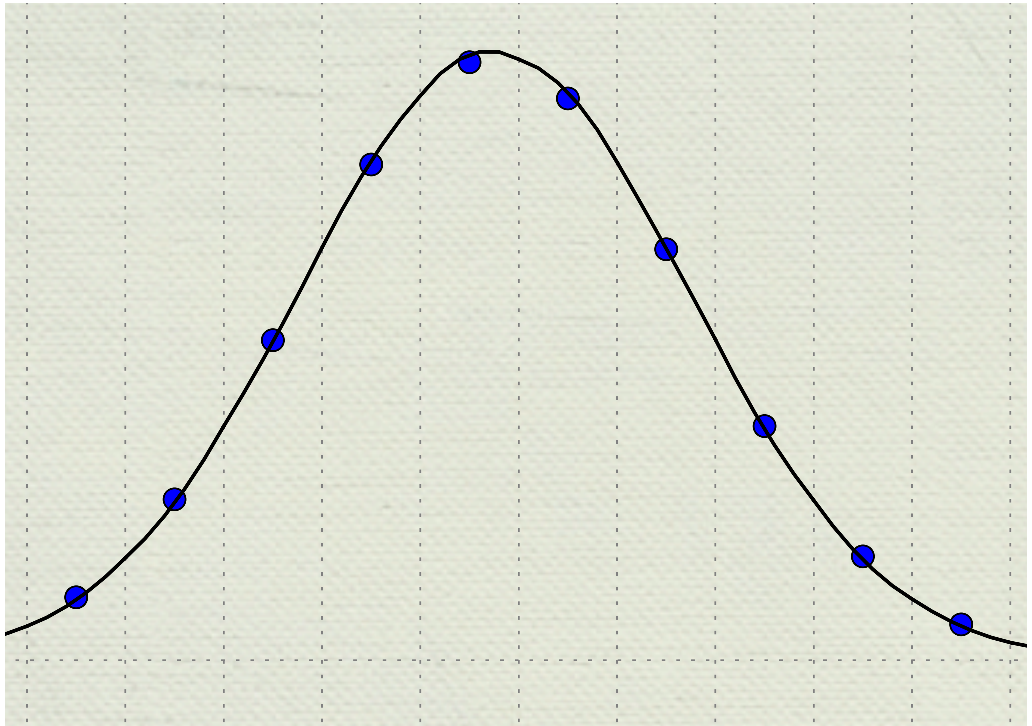




Axisymmetric 5-km W in Hurricane Irma
Gao et al. 2021, JAS

The Piecewise-Parabolic Method: The cornerstone of FV numerics

- Extension to higher order of the Van Leer piecewise-linear method, itself an extension of Godunov's first-order finite-volume scheme
- The internal variation of each grid cell is approximated by a parabola, from which the fluxes through each cell interface can be integrated



Literature

Collela & Woodward 1984
Van Leer 1971–1979

FV3 Documentation

Section 4.1

The Piecewise-Parabolic Method: The cornerstone of FV numerics

- "Vanilla" PPM reconstruction is formally 4th order if Δx is constant.
- But you are free to do much more with your degrees of freedom. You can flatten or steepen or …?
- This is useful for shape-preservation (monotonicity, positive-definite) or for simply eliminating undesirable $2\Delta x$ noise

"Imagine PPM as something akin to the Toll House chocolate chip cookie recipe. The cookies you get by following the package exactly are really, really good. At the same time, you can modify the recipe to produce something even better while staying true to the basic framework. The basic cookies will get you far, but with some modification you might just win contests or simply impress your friends. PPM is just like that."

wjrider.wordpress.com/2017/11/17/the-piecewise-parabolic-method-ppm/

Which solution is the best?

"Accuracy" analyses assume continuous sinusoid modes. They cannot incorporate discontinuities.

Centered-differencing schemes produce a lot of noise at discontinuities!! And staggered grids *preserve* the junk!

Monotonic schemes are more diffusive—but PPM gives you the freedom to balance shape-preservation with accuracy

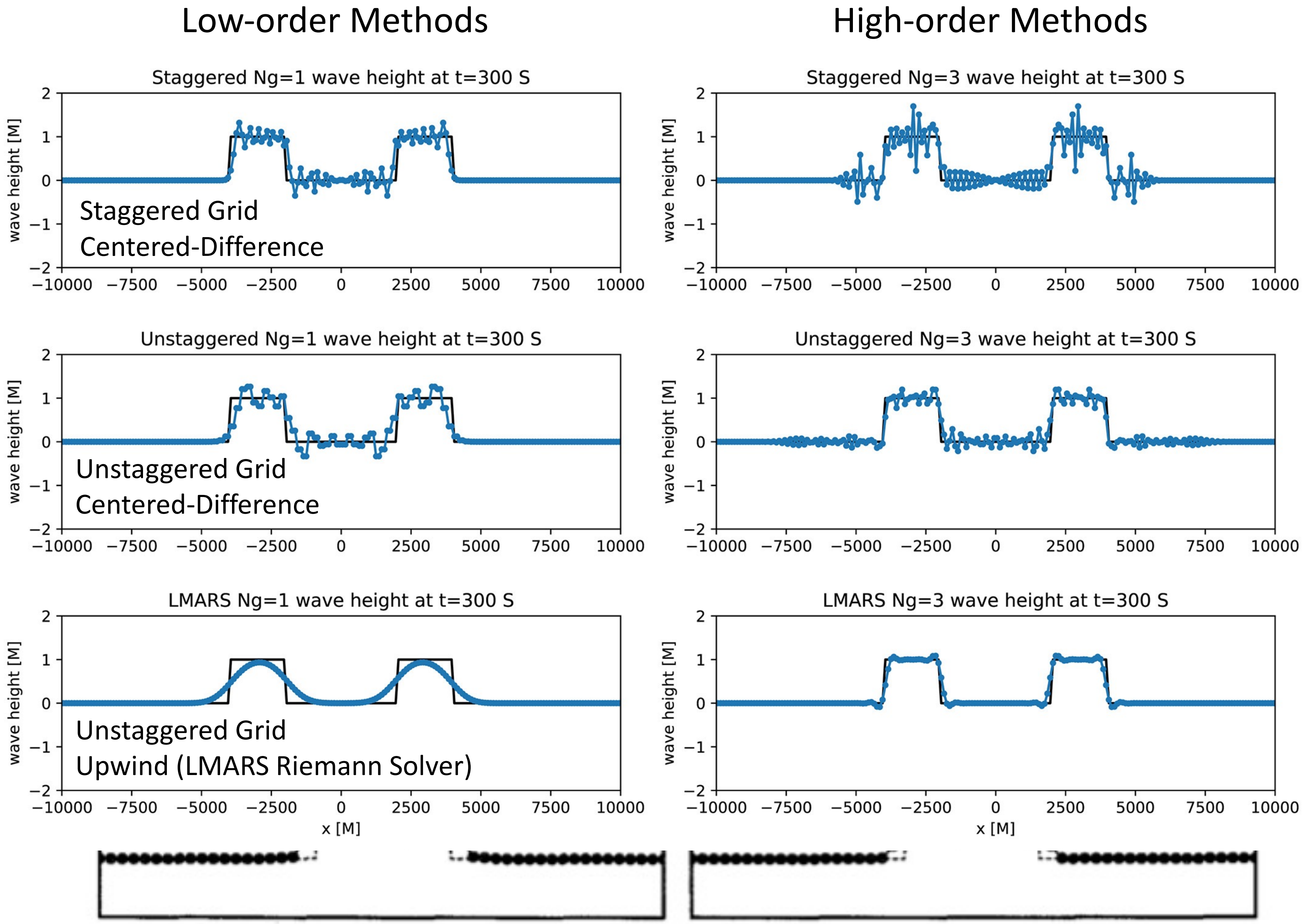
Literature

Lin and Rood 1996

X Chen et al. 2018

Notebooks

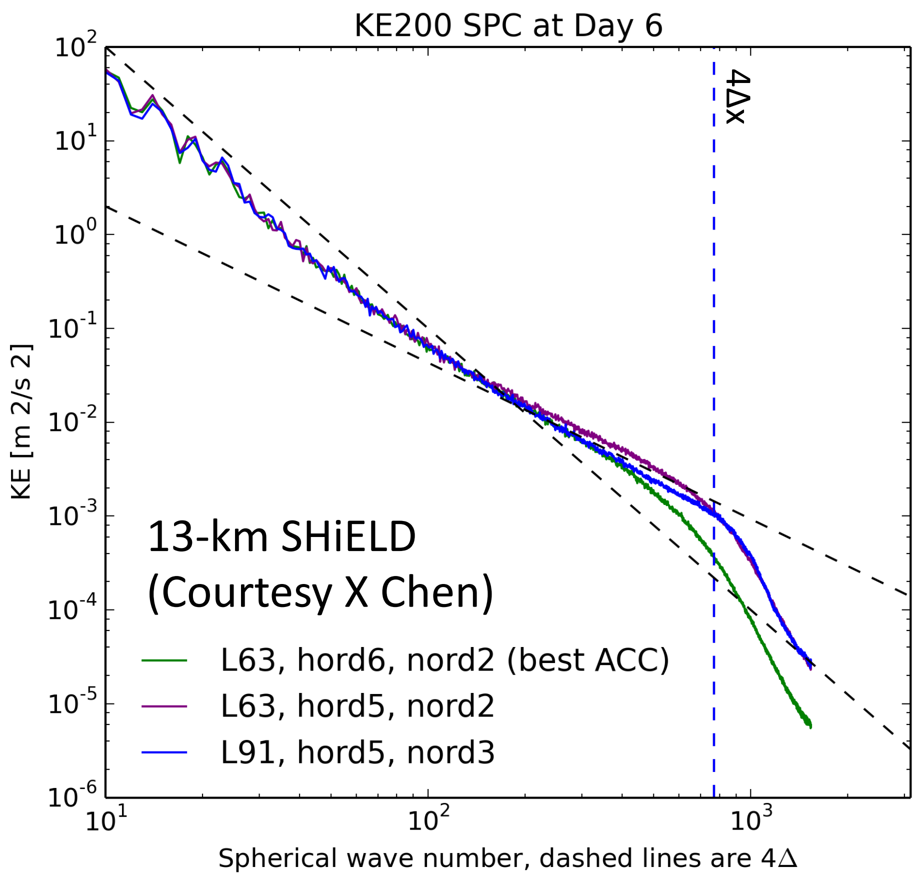
RHwave, tp_core

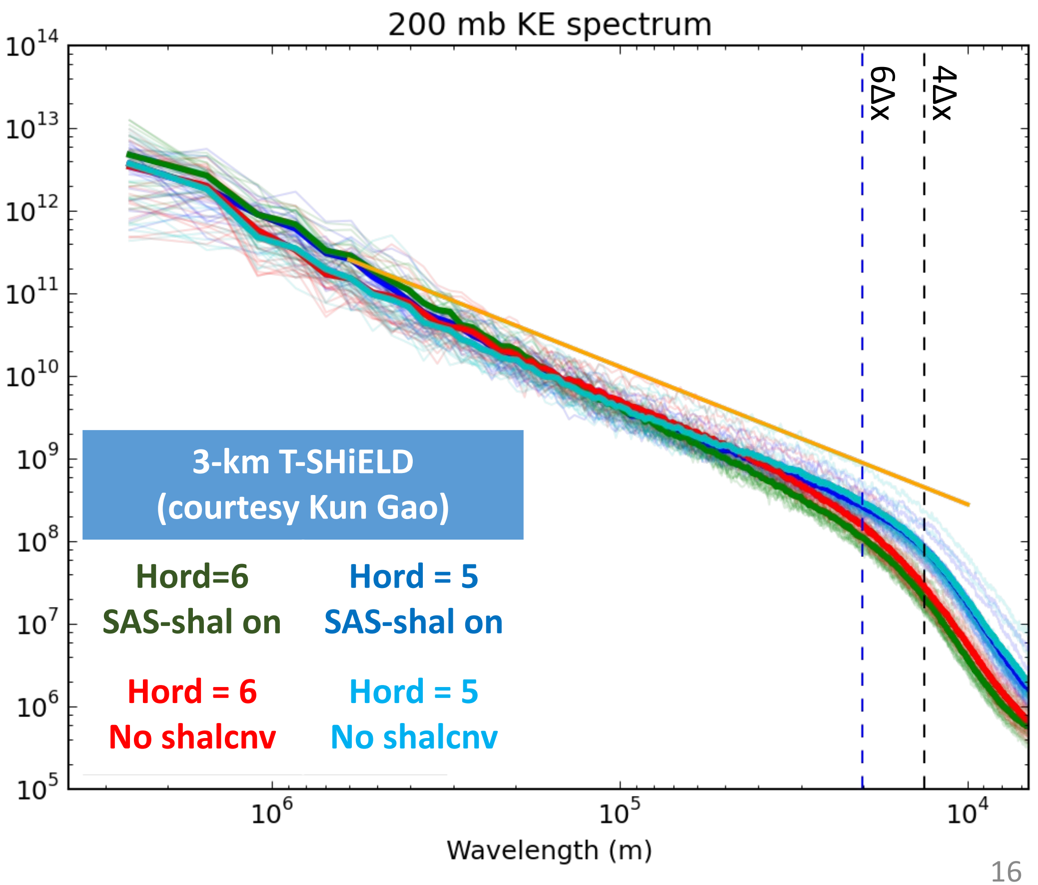


Effect of advection options: 200-mb KE spectra

WARNING

Variance spectra depend on many factors, show case-to-case variability, and may not depict scientifically-credible features. Parental discretion is advised.

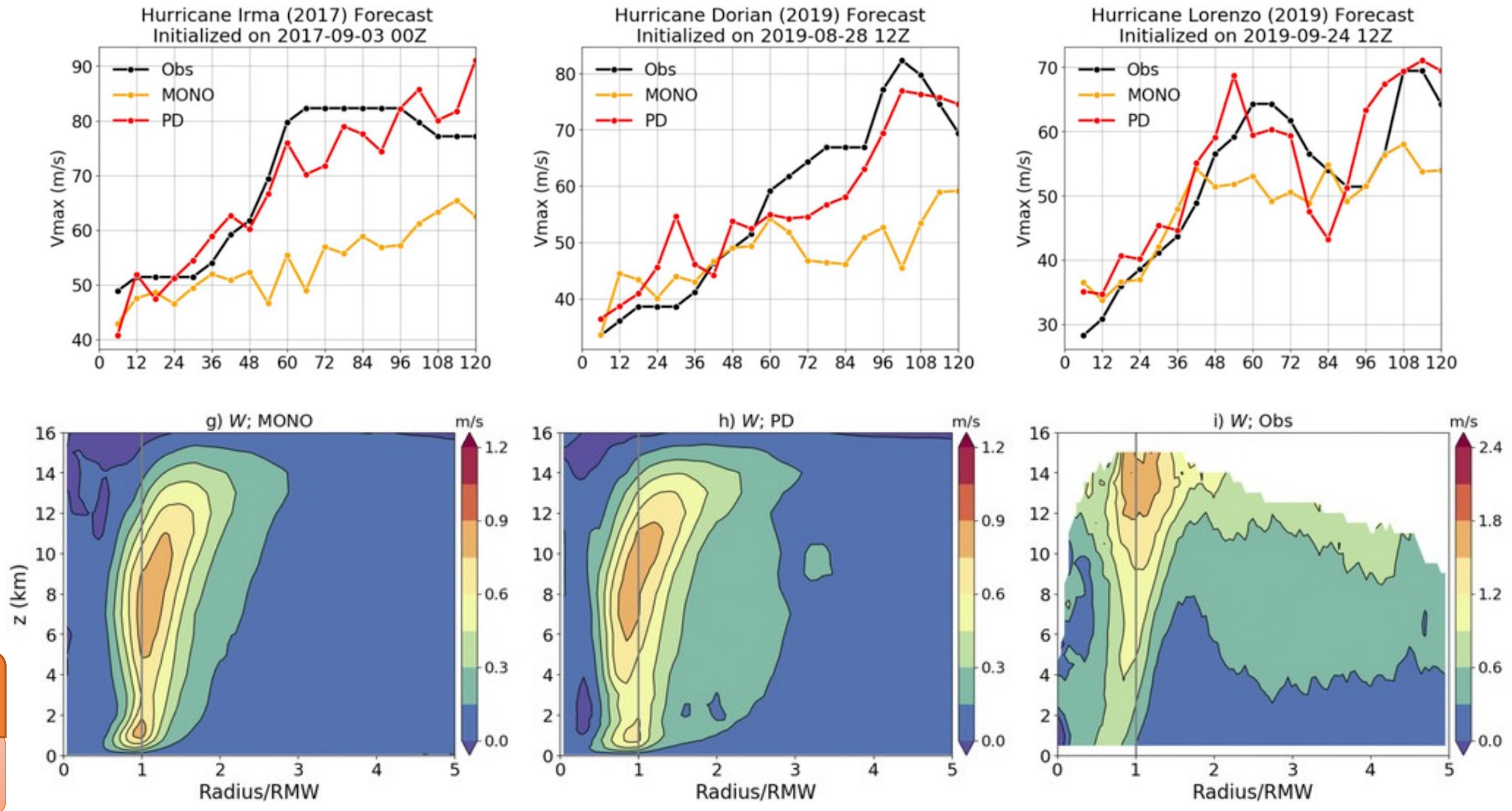




T-SHiELD Positive-Definite Advection: Rapid Intensification and Storm Structure

Positive-definite (PD) tracer advection
➔ successful rapid intensification (RI) predictions compared to monotonic (MONO)

PD advection enables more WV into eyewall, permitting better updraft and TC structure: may contribute to RI processes



Literature

Gao et al. 2021

Lin-Rood FV Advection

$$q^{n+1} = \frac{1}{\pi^{n+1}}\left\{\pi^n q^n + F\left[q^n + \frac{1}{2}g(q^n)\right] + G\left[q^n + \frac{1}{2}f(q^n)\right]\right\}.$$

- F, G are **flux-form** PPM operators, ensuring mass conservation.
- f, g are **advective** form PPM operators.
- This “reverse-engineered” form cancels the leading-order deformation error. The Courant number restriction is then independent in both directions—**a truly two-dimensional scheme**
  - $\max(C_x, C_y) \le 1$ instead of $C_x + C_y \le 1$

FV3 Documentation

Chapter 4

Literature

Lin and Rood 1996

Putman and Lin 2007

Tracer advection and sub-cycling

FV3 Documentation
Section 4.2

- Tracers are advected with a longer timestep than the dynamics
  - $U_{max} \approx 200$ m/s but $U_{max}+c_s \approx 540$ m/s
  - Split-explicit methods that assume $U \ll c_s$ struggle in the stratosphere
- Free-stream preservation: FV3 accumulates mass fluxes during the acoustic timesteps. These fluxes are then used to advect the tracers.
  - One or two sub-cycled timesteps is usually enough for stability.
  - Adaptively determined timestep from domain-maximum wind speed
- Tracer advection is *always* monotone or positive definite to avoid new extrema. Explicit diffusion is not used.

Lagrangian Dynamics in FV3

- FV3 transforms the Euler equations of motion into a *Lagrangian vertical coordinate*, constraining the flow along quasi-horizontal surfaces
- Lagrangian surfaces deform during the integration. Vertical motion and advection is “free”
- Requires layer thickness δp (and δz for nonhydro) to be a prognostic variable

$$\frac{\partial \delta p^*}{\partial t} + \nabla \cdot (\mathbf{V}\delta p^*) = 0$$

$$\frac{\partial \Theta_v \delta p^*}{\partial t} + \nabla \cdot (\mathbf{V}\delta p^* \Theta_v) = 0$$

$$\frac{\partial w \delta p^*}{\partial t} + \nabla \cdot (\mathbf{V}\delta p^* w) = -\delta p'$$

$$\frac{\partial u}{\partial t} = \Omega v - \frac{\partial}{\partial x}\mathcal{K} - \frac{1}{\rho}\frac{\partial p}{\partial x}\bigg|_z$$

$$\frac{\partial v}{\partial t} = -\Omega u - \frac{\partial}{\partial y}\mathcal{K} - \frac{1}{\rho}\frac{\partial p}{\partial y}\bigg|_z$$

$$\frac{Dz}{Dt} = w = \frac{\partial z}{\partial t} + \mathbf{V} \cdot \nabla z,$$

FV3 Documentation

Chapter 5

Literature

Lin 2004

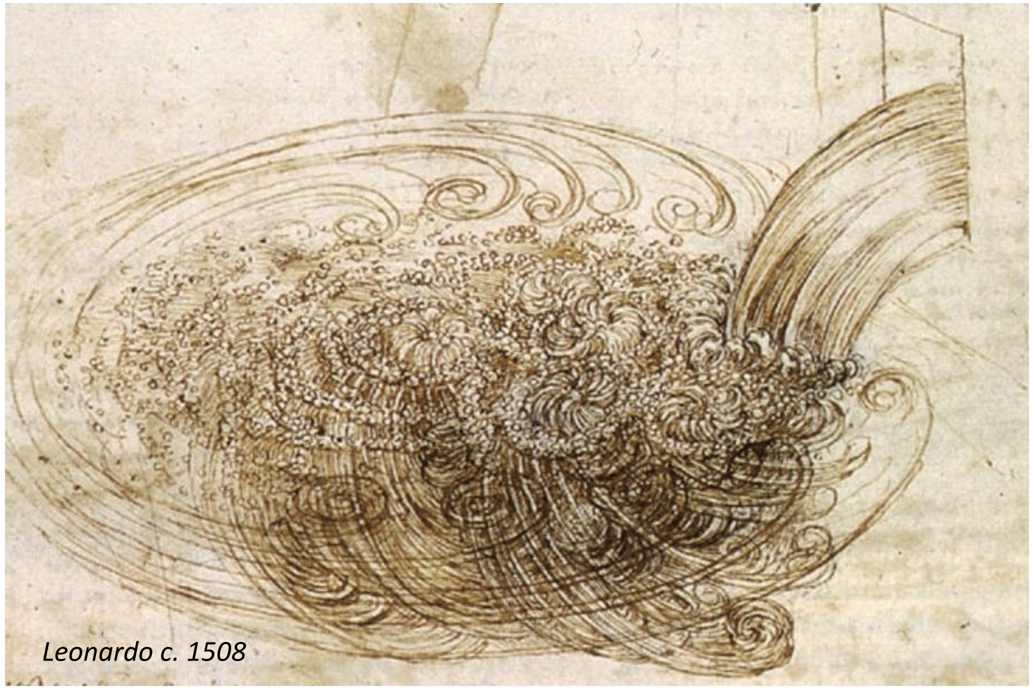
Prognostic Variables

δp	Total air mass (including vapor and condensates) Equal to *hydrostatic* pressure depth of layer
θ_v	Virtual potential temperature
u, v	Horizontal D-grid winds in local coordinate (defined on cell faces)
w	Vertical winds (nonhydrostatic)
δz	Geometric layer depth (nonhydrostatic)
q_i	Passive tracers

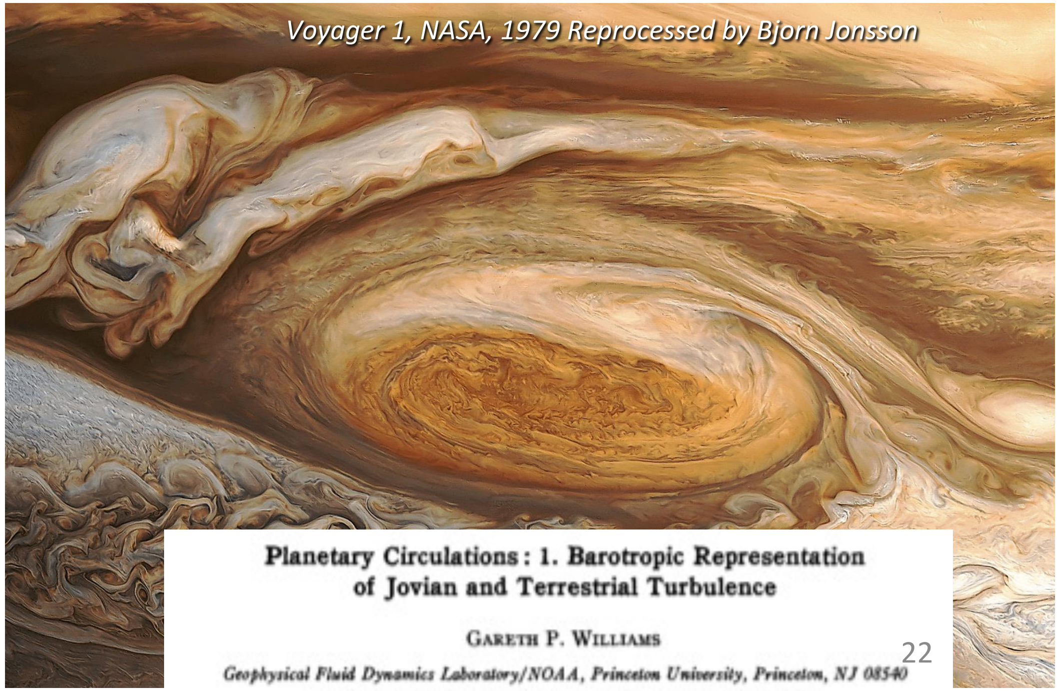
Cell-mean pressure, density, divergence, and specific heat are all *diagnostic* quantities
All variables are layer-means in the vertical: **No vertical staggering**

Vorticity Dynamics

- *Fluids are strongly vortical at all scales.* Vortical motions are especially critical in geophysical flows
- FV3's discretization emphasizes vorticity dynamics:
  - Vector-invariant equations: vorticity computed *exactly*
  - C-D Grid Discretization
  - Consistent advection of derived vorticial quantities



Leonardo c. 1508



Voyager 1, NASA, 1979 Reprocessed by Bjorn Jonsson

Planetary Circulations: 1. Barotropic Representation of Jovian and Terrestrial Turbulence

GARETH P. WILLIAMS

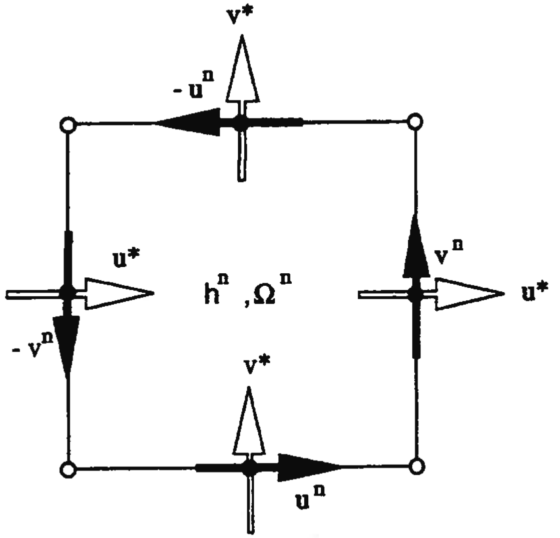
Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, NJ 08540

(Manuscript received 2 December 1975, in final form 13 April 1978)

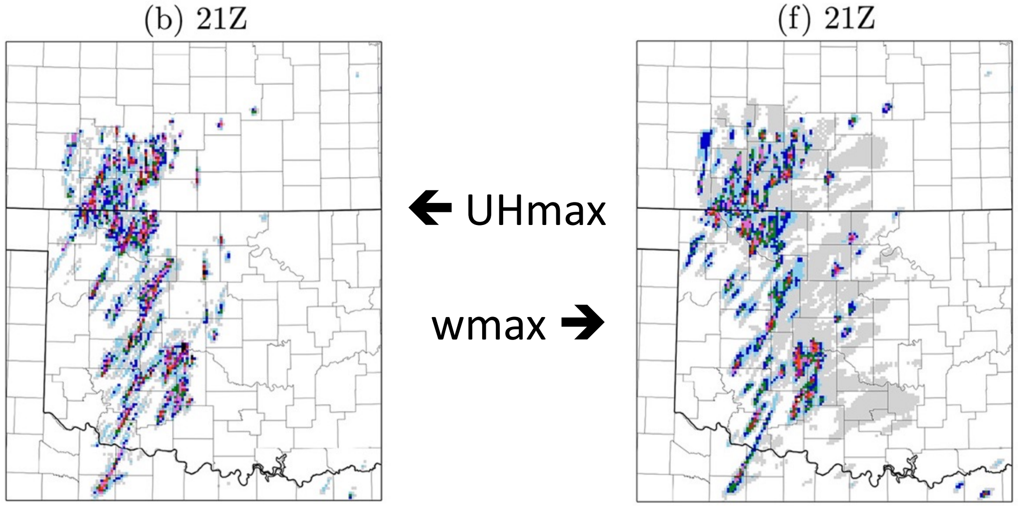
FV3 Documentation	Literature	Notebooks
Chapter 6	Lin et al. 2017	BTwave, BCwave, TornadicSupercell

Momentum equation

$$\frac{\partial \mathbf{V}}{\partial t} = -\Omega \hat{k} \times \mathbf{V} - \nabla\left(\kappa + \nu \nabla^2 D\right) - \frac{1}{\rho}\nabla p\bigg|_z$$



- FV3 solves nonlinear flux-form vector invariant equations using the absolute vorticity *fluxes* Ωv, -Ωu
- D-grid gives *exact* absolute vorticity Ω using Stokes' theorem—no averaging!
- Cell-mean vorticity is advected as a scalar, using the same fluxes as other variables. Products are also advected as scalars!
    - ex: Updraft helicity wΩ



Literature

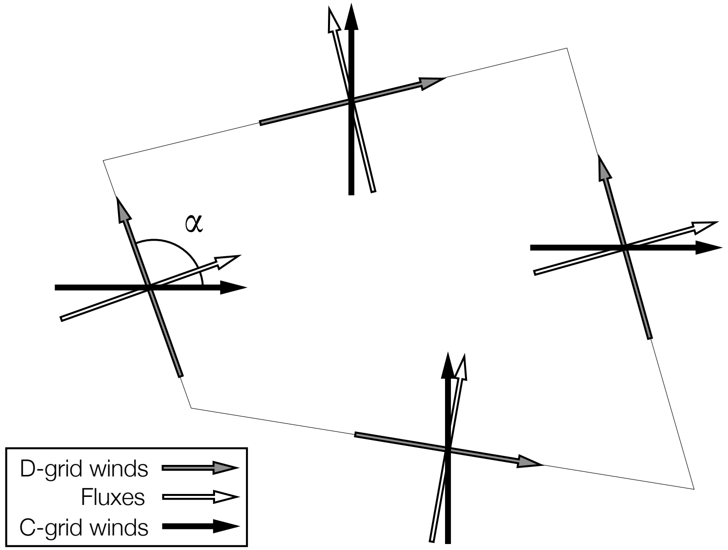
Lin & Rood 1996
Harris et al. 2019

Notebooks

RHwave,
HSzuritasuperrotation

The C-D grid solver

$$\frac{\partial \mathbf{V}}{\partial t} = -\Omega\hat{k} \times \mathbf{V} - \nabla\left(\kappa + \nu\nabla^2 D\right) - \frac{1}{\rho}\nabla p\Big|_z$$



- Flux evaluation requires face-normal and time-mean fluxes.
- The C-grid winds are interpolated and then advanced a half-timestep. These are used to compute the fluxes.
- Upstream flux also allows consistent computation of the KE gradient term, avoiding the Hollingsworth-Kallberg instability
- Two-grid discretization and time-centered upwind fluxes avoid computational modes, giving FV3 high accuracy and low noise

FV3 Documentation

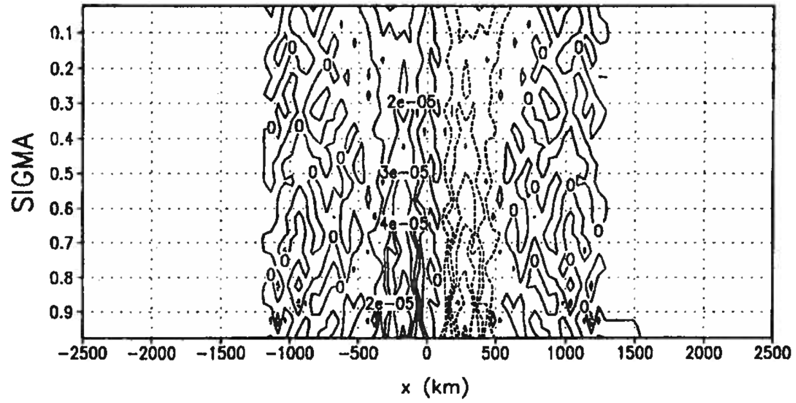
Section 6.2

Literature

Lin & Rood 1997

Backward horizontal pressure gradient force

- Computed from Newton's second and third laws, and Green's Theorem
- Errors lower, with much less noise, compared to traditional evaluations
  - Purely horizontal: **no** along-coordinate projection
  - PGF equal and opposite—3rd law! Momentum is conserved
  - Curl-free in the absence of density gradients



The pressure gradient (m s^{-2}) computed by the Arakawa–Suarez method. Contour interval is 1×10^{-5}.

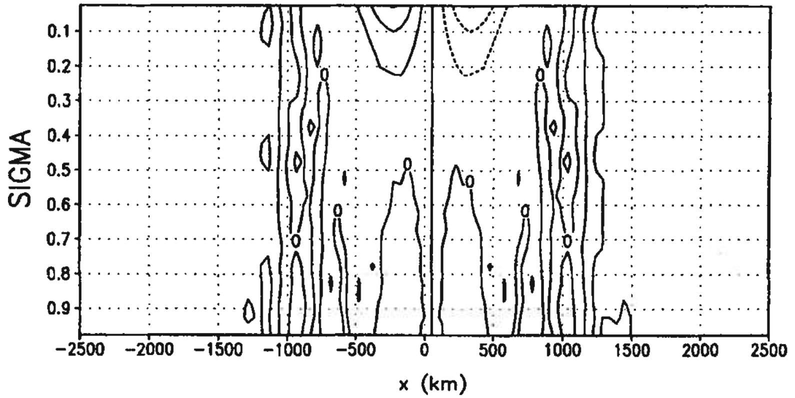


Figure 6. As in Fig. 5, but for the finite-volume method.

FV3 Documentation
Section 6.6

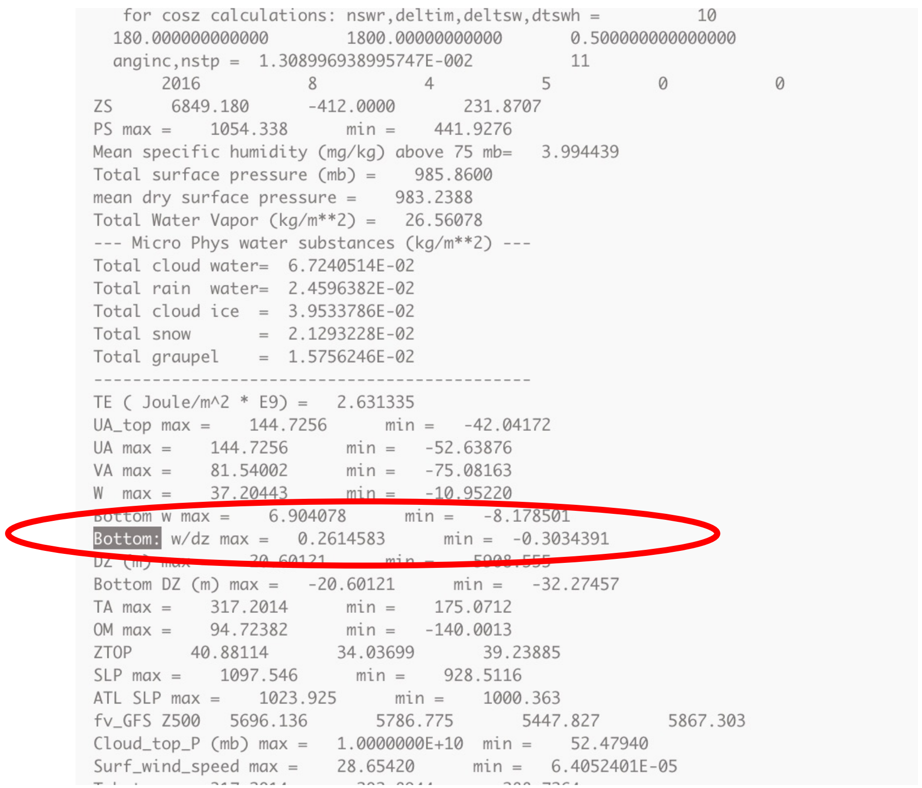
Literature
Lin 1997

Notebooks
mtn_rest_100km
mtn_wave_tests

The Lagrangian Vertical Coordinate

Literature	FV3 Documentation
Lin 2004	Sec. 5.1, 5.3; Chap 7

- Vertical motion and advection is *implicit* through the deformation of quasi-horizontal layers.
  - **No** Courant number restriction or time-splitting
  - Computing δp and δz is sufficient for vertical advection.
- Periodically, a high-order conservative remapping back to the reference “Eulerian” coordinate is done to avoid $\delta p \rightarrow 0$



```
  for cosz calculations: nswr,deltim,deltsw,dtswh =          10
 180.000000000000       1800.00000000000       0.500000000000000
 anginc,nstp =  1.308996938995747E-002          11
      2016           8           4           5           0           0
ZS      6849.180      -412.0000       231.8707
PS max =    1054.338      min =    441.9276
Mean specific humidity (mg/kg) above 75 mb=   3.994439
Total surface pressure (mb) =    985.8600
mean dry surface pressure =    983.2388
Total Water Vapor (kg/m**2) =   26.56078
--- Micro Phys water substances (kg/m**2) ---
Total cloud water=  6.7240514E-02
Total rain  water=  2.4596382E-02
Total cloud ice  =  3.9533786E-02
Total snow       =  2.1293228E-02
Total graupel    =  1.5756246E-02
---------------------------------------------
TE ( Joule/m^2 * E9) =   2.631335
UA_top max =    144.7256      min =   -42.04172
UA max =    144.7256      min =   -52.63876
VA max =    81.54002      min =   -75.08163
W  max =    37.20443      min =   -10.95220
Bottom w max =    6.904078      min =   -8.178501
Bottom: w/dz max =   0.2614583      min =  -0.3034391
Bottom DZ (m) max =   -20.60121      min =   -32.27457
TA max =    317.2014      min =    175.0712
OM max =    94.72382      min =   -140.0013
ZTOP      40.88114      34.03699      39.23885
SLP max =    1097.546      min =    928.5116
ATL SLP max =    1023.925      min =    1000.363
fv_GFS Z500   5696.136      5786.775      5447.827      5867.303
Cloud_top_P (mb) max =   1.0000000E+10  min =    52.47940
Surf_wind_speed max =    28.65420      min =   6.4052401E-05
```

3.25-km X-SHiELD: remap dt = 36 s

→ vertical courant number = [-10.9,9.36]

Semi-implicit nonhydrostatic solver

- Semi-implicit solver cleanly extends FV Lagrangian dynamics into nonhydrostatic regime
- Start with advected w*, z*
  - *Consistent* with other variables
- Vertical pressure gradient and non-advective changes to layer depth δz are solved by semi-implicit solver
  - Simultaneous solution for w and δz through diagnosed p'
  - p' accurately interpolated to interfaces using cubic spline
- Vertically-propagating sound waves weakly damped. That's OK.

$$\frac{\partial}{\partial t}\delta z^* = \delta w^*.$$

$$\frac{\partial}{\partial t}\left(w^*\delta m\right) = \delta p',$$

$$\frac{\partial p'}{\partial t} = \gamma p \frac{\delta w^*}{\delta z^*}.$$

$$p = \left(\frac{\delta m}{\delta z} R_d \Theta_v\right)^\gamma$$

$$p = p^* + p'$$

FV3 Documentation

Section 7.1

Lagrangian nonhydrostatic dynamics, how do they work?

- Recall that FV3 uses a hybrid-pressure coordinate. Cell mass δp is constant during sound wave processes.
- Nonhydrostaticity creates pressure perturbation
  - p computed by ideal gas law, incorporating heating
  - p* computed through δp above
- Vertical gradients in p' create vertical accelerations, deforming the Lagrangian interfaces
- Elastic straining (expansion/compression) of the Lagrangian layers alters δz
- Adiabatic changes to δz changes p'…

$$\frac{\partial}{\partial t}\delta z^* = \delta w^*.$$

$$\frac{\partial}{\partial t}(w^*\delta m) = \delta p',$$

$$\frac{\partial p'}{\partial t} = \gamma p \frac{\delta w^*}{\delta z^*}.$$

$$p = \left(\frac{\delta m}{\delta z} R_d \Theta_v\right)^\gamma$$

$$p = p^* + p'$$

FV3 Documentation

Section 7.2

Notebook

DPsupercell

- **MYTH**: Numerical diffusion is evil, only used to cover for discretization deficiencies, and should be avoided at all costs.

- **TRUTH**: Numerical diffusion is a necessary part of any model used for environmental simulation.

Numerical Diffusion and Physical Dissipation

- *All useful atmospheric models have grid-scale motions removed by numerical diffusion (whether they know it or not).*
- Energy cascades to grid scales and **must** be removed since dissipative scales (O(1 cm)) are not explicitly resolved
- Models aren't perfect, noise and errors must be removed
  - C-grids produce particularly prodigious noise at discontinuities
- Diffusion is also a powerful tool to **improve** simulations
  - Tompkins and Semie 2017; Pressel et al. 2017; see also *Implicit LES*

FV3 Documentation

Sections 8.1, 8.2

Literature

Zhao et al. 2012

X Chen et al. 2018

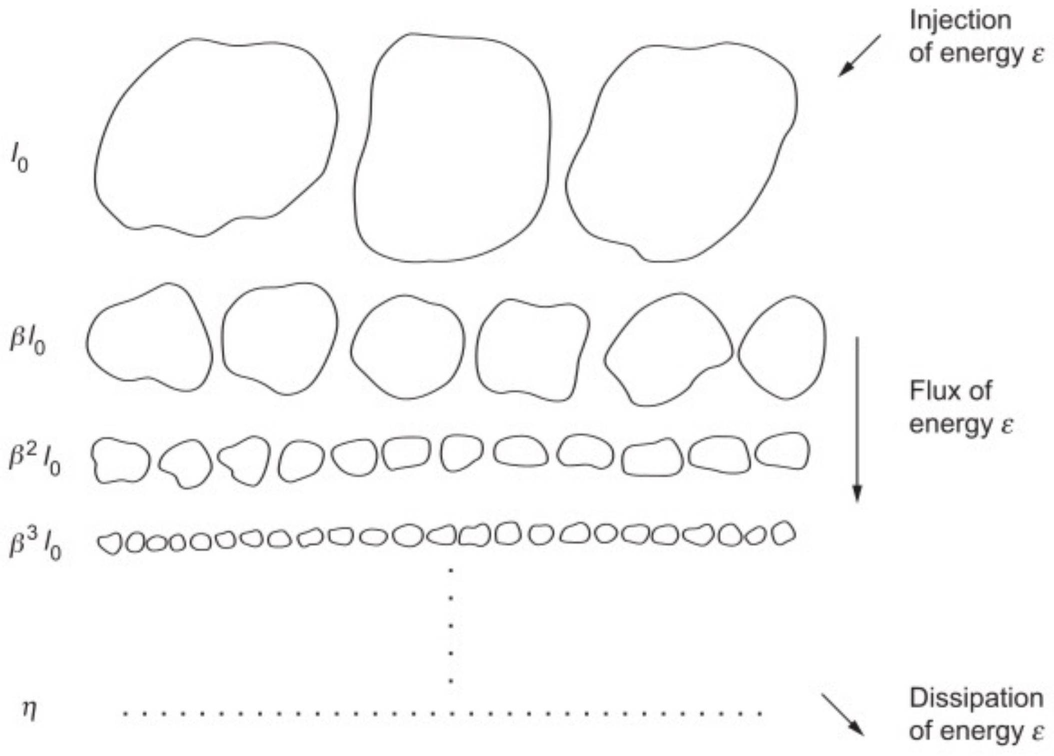
The Turbulent Energy Cascade

"Big whirls have little whirls
that feed on their velocity,
And little whirls have lesser whirls
and so on to viscosity"
—*Lewis F. Richardson, 1922*

Kinetic energy cascades from the large energy-containing scale to increasingly small-wavelength modes.

In a continuous fluid, the cascade continues until molecular diffusion can dissipate kinetic energy to heat.

In large-scale flows this is complicated by a second *upscale* turbulent cascade.



Ecke: "The Turbulence Problem" (2005)

Damping in FV3

FV3 Documentation

Sections 8.3, 8.4, 8.5

- FV3's physical consistency produces very few computational modes and thus can be minimally-diffusive.
  But well-configured diffusion can give *improved* results
- FV3 applies **no** direct implicit diffusion to divergent modes which cascade to grid scale *unimpeded*.
  Scale-selective divergence damping represents their physical dissipation.
- Rotational modes can be damped implicitly by monotonic advection or explicitly by vorticity damping.
  - For consistency also damps δp, δz, θ_v, w.
    No explicit damping for tracers.
- Note that **all** implicit (except vertical remapping) and explicit diffusion is **along** Lagrangian surfaces.

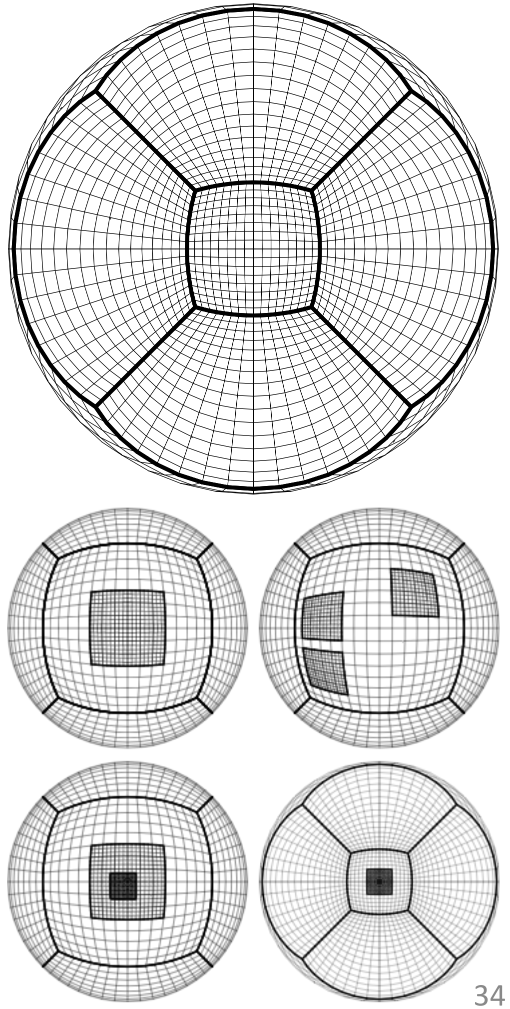
The Upper Boundary

- FV3 has a *flexible* constant-pressure upper boundary, greatly reducing reflection of vertically-propagating gravity waves. So the sponge layer can be much shallower.
  - Much less problematic than constant-height rigid lid upper boundaries
- In FV3 the top two layers are reserved as sponge layers.
  - These layers are very deep (Δz), already implicitly dissipating vertically-propagating wave.
  - In these layers a much stronger, less scale-selective second-order damping is applied on the acoustic timestep.
- Tunable Rayleigh damping and a $2\Delta z$ filter are also available.
  Both convert damped KE to heat—energy conserving

Variable-resolution techniques

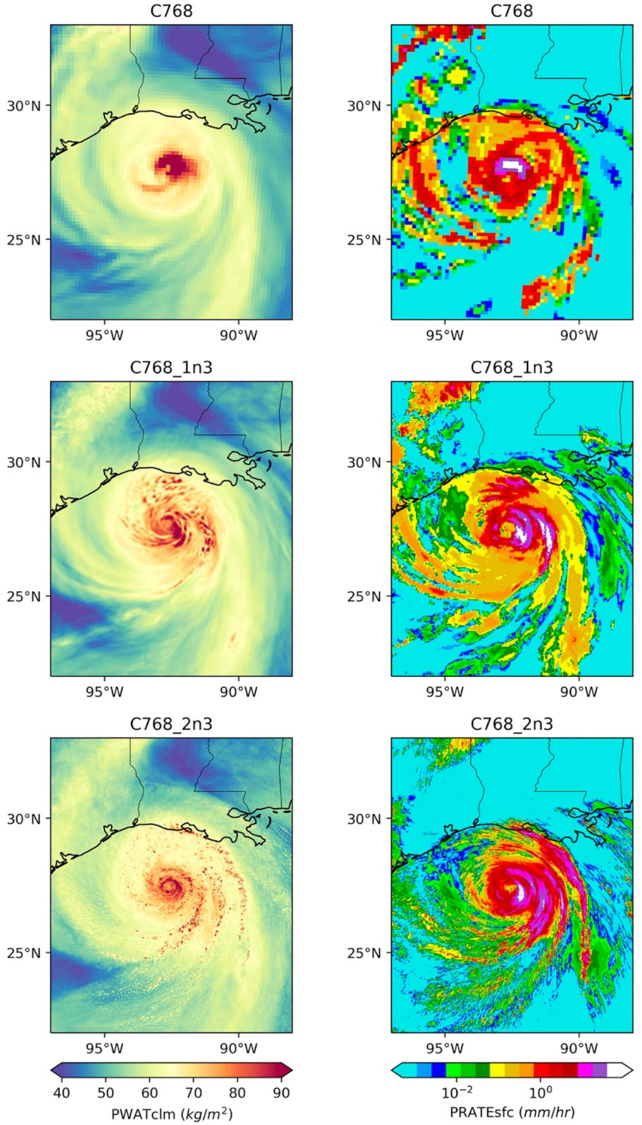
FV3 Documentation
Chapter 10

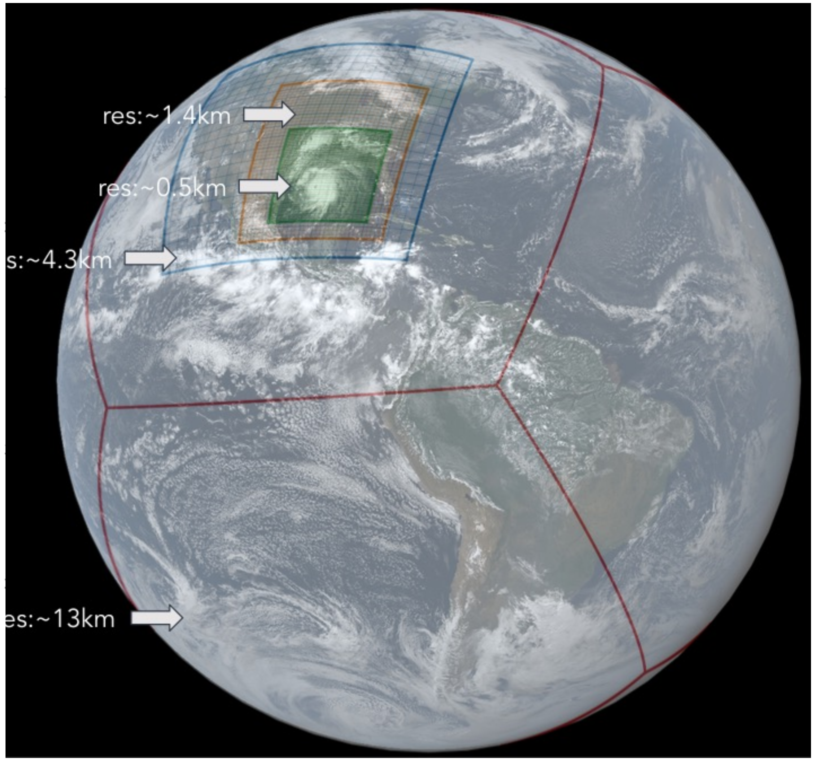
- Variable-resolution is the future of convective-scale modeling (C-SHiELD, HAFS-B)
- Stretched global grid is the easy, simple way to grid refinement.
- Two-way nesting is flexible and highly configurable.
  - Inflow BCs “baked-in” to numerics
  - Nesting methodology designed to be consistent with numerics
  - Concurrent nesting is extremely efficient:
    Run as many grids as you want at the same time!



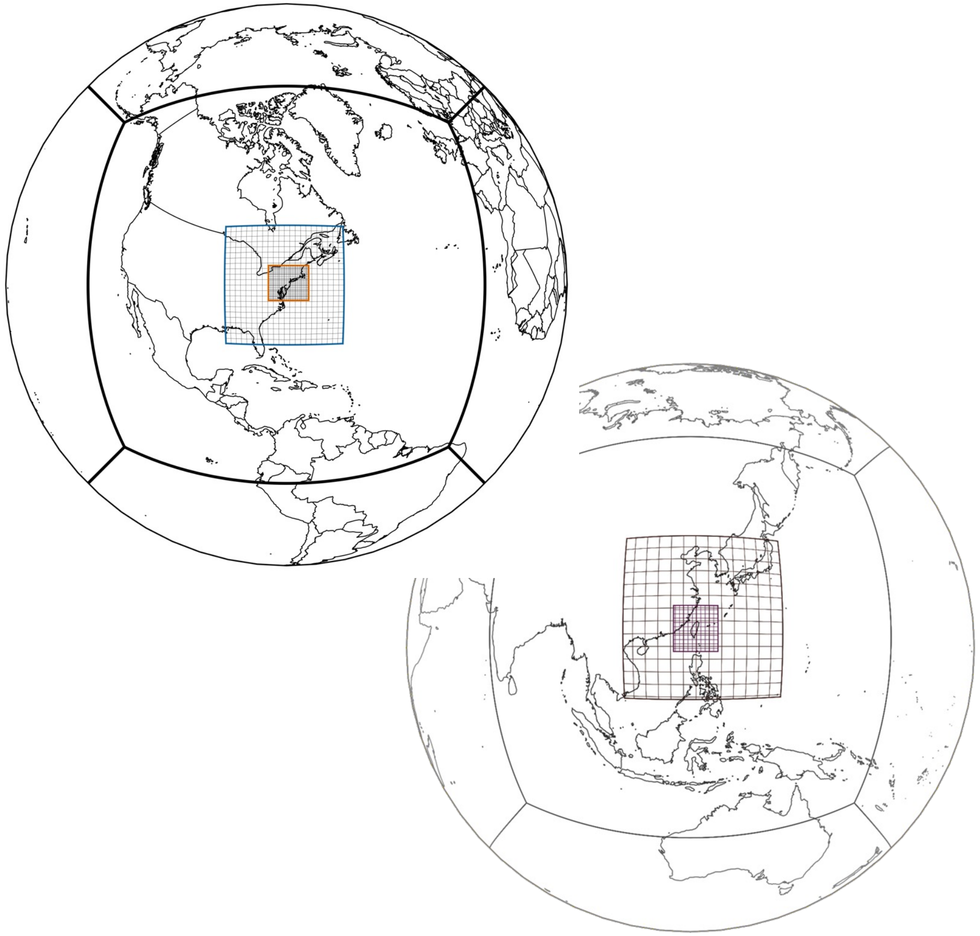
Telescoping Nesting

As many levels as you want





Triple-nests onto Hurricane Laura



Tele-SHiELD: 1.4 km onto Northeast Corridor and Taiwan

Literature

Mouallem et al. 2022

Rigorous Thermodynamics and Physics-Dynamics Coupling

Literature
Zhou et al. 2022abc

FV3 Documentation
Sec. 7.2, Chapter 9

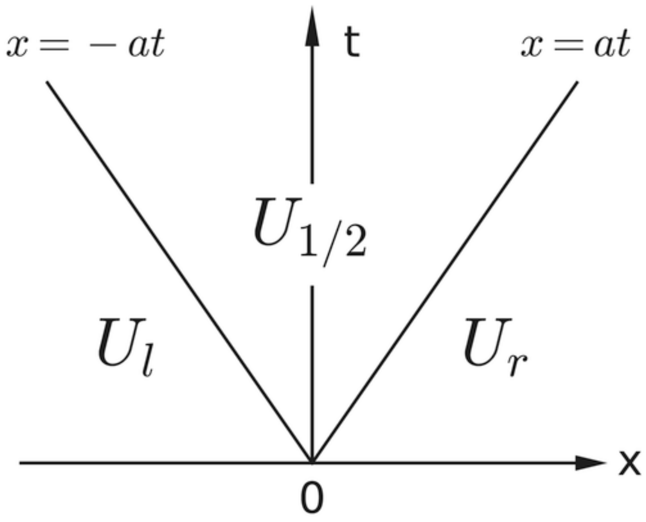
- Mass δp in FV3 includes water vapor and all condensates. Condensate loading and moist-mass effects are baked-in.
- FV3 incorporates the heat content of water vapor and condensates in adiabatic processes and diabatic heating
- Diabatic heating is applied consistently with the dynamics
  - c_p in hydrostatic: δp constant, δz dependent on T (hypsometric equation)
  - c_{vm} in nonhydrostatic: δz constant, p dependent on T (ideal gas law)

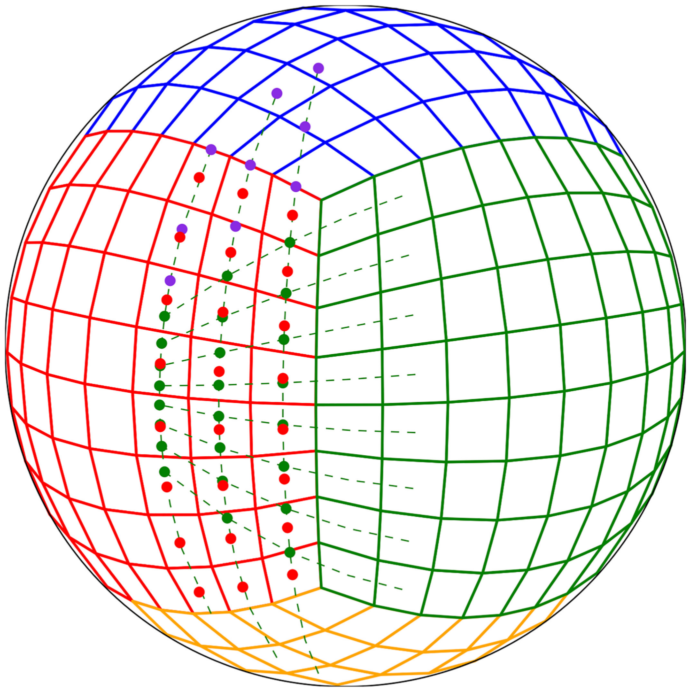
LMARS horizontal solver and Duo-Grid

- Efficient Riemann solver allows accurate unstaggered solution to improve physics coupling
- Shows way to *true* total energy conservation
- Duo-grid eliminates grid imprinting and provides unified approach to cubed-sphere grid design

Literature

X Chen et al 2018, 2020
Li & Chen 2019



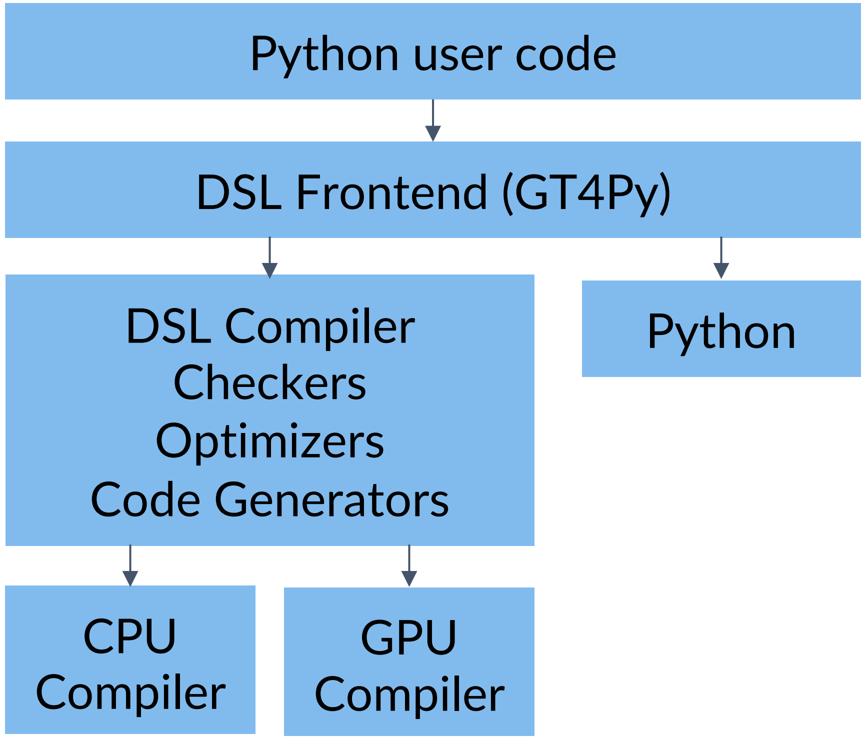


AI2 Pace

Accelerating to km-scale

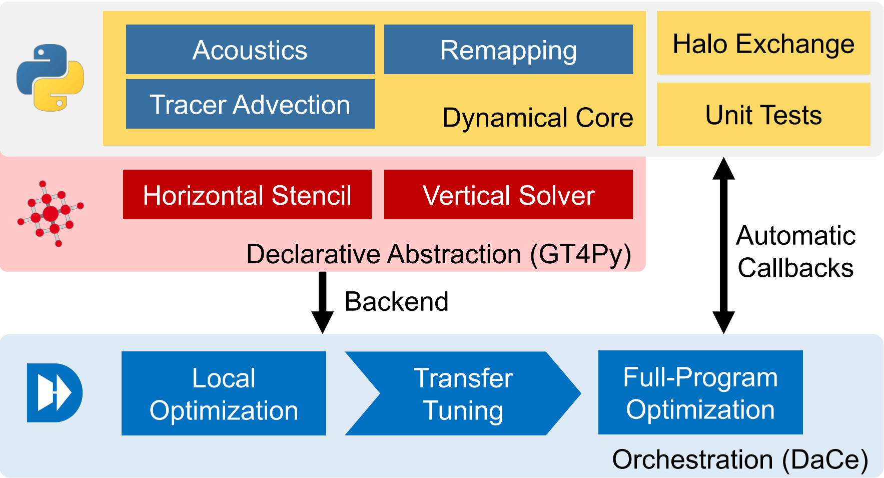
- The CPU-MPI era is (?) ending
- **GT4py Domain Specific Language (DSL)**
  Model re-written in Python and compiled to optimized code for any processor
  - GridTools in operations at MeteoSwiss
  - Evaluation underway by ECMWF and MPI
- Pace: GT4py implementation of FV3GFS
  Performance + Python Flexibility

Literature
Ben-Nun et al. 2022 Gibbon et al. 2022



Flowchart courtesy Oliver Elbert, AI2

GT4py FV3

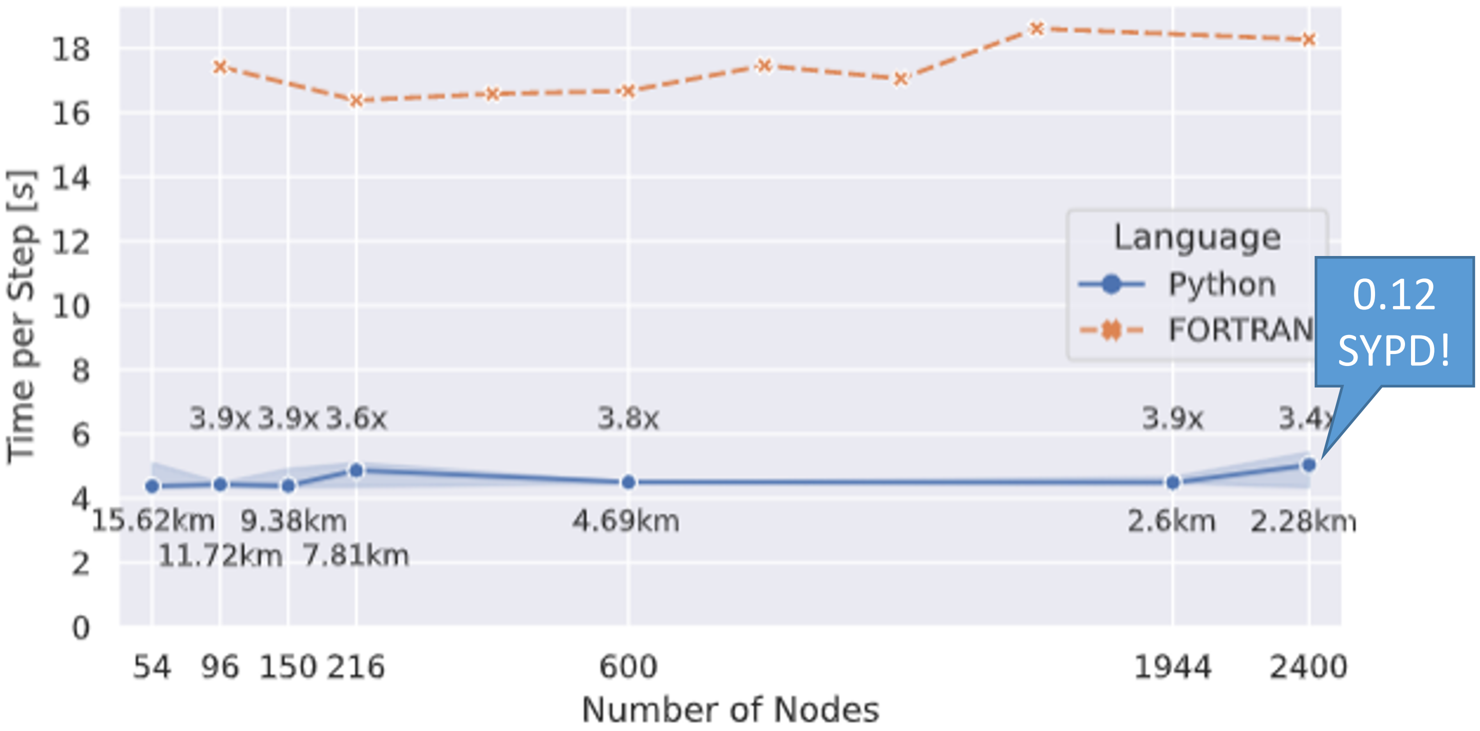


Lines of Code vs. FORTRAN: **0.42x**
Speedup: **3.92x** (P100), **8.48x** (A100)

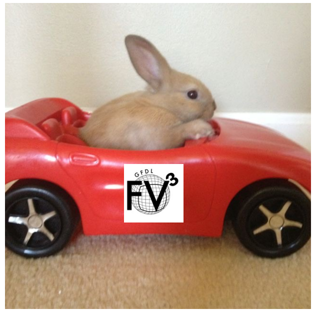
Literature

Ben-Nun et al. 2022
Gibbon et al. 2022

2.6 km FV3 Dycore



Socket-for-socket comparison on Piz Daint
(CSCS Switzerland, Intel Haswell + NVIDIA P100)



Pinterest user Elizabeth Chambers