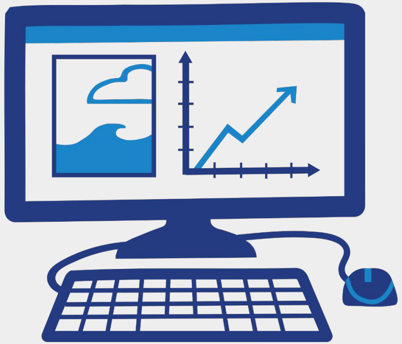


FV3, SHiELD, and all that: Innovations in Numerics and Subgrid physics

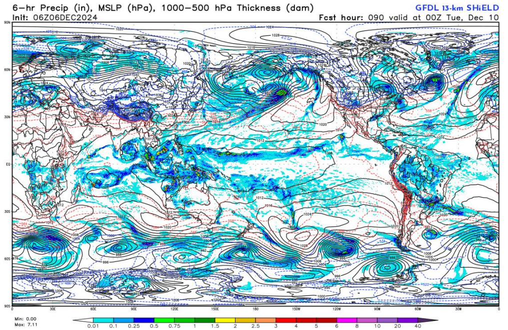
– Lucas Harris

Q1: Concerning GFDL's core strength of building and improving models of the weather, oceans, and climate for societal benefits, how can GFDL leverage advances in science and computational capabilities to improve its key models? What are the strengths, gaps, and new frontiers?

NOAA
GEOPHYSICAL FLUID
DYNAMICS LABORATORY

5-YEAR REVIEW
JANUARY 28-30, 2025

The GFDL Finite-Volume Cubed-Sphere Dynamical Core



FV3 is the fluid solver for a community of atmosphere models.

- ★ Accurate Numerics
- ★ Advanced Thermodynamics
- ★ Computationally Efficient

  "A good model must be a fast model" — S-J Lin
- ★ Flexible Solver and Interface
- ★ Advanced Grid Capabilities
- ★ Open community development

- ✓ Timely Forecasts
- ✓ Accelerated Development
- ✓ Ultra-high Resolution Models
- ✓ Many Applications

  Weather, data assimilation, chemistry, climate, ML, RCE/LES, reanalysis, extraterrestrial atmospheres

All NOAA and NASA global models use FV3, including the entire GFDL Seamless Modeling Suite.

- AM4/AM5: Hydrostatic FV3 for climate: 25 km – 200 km
- SHiELD: Nonhydrostatic and variable-resolution FV3 for weather to seasonal prediction: 125 m – 25 km

See more about the Worldwide FV3 Community in Jan-Huey's presentation and Mingjing's slides (Q3)

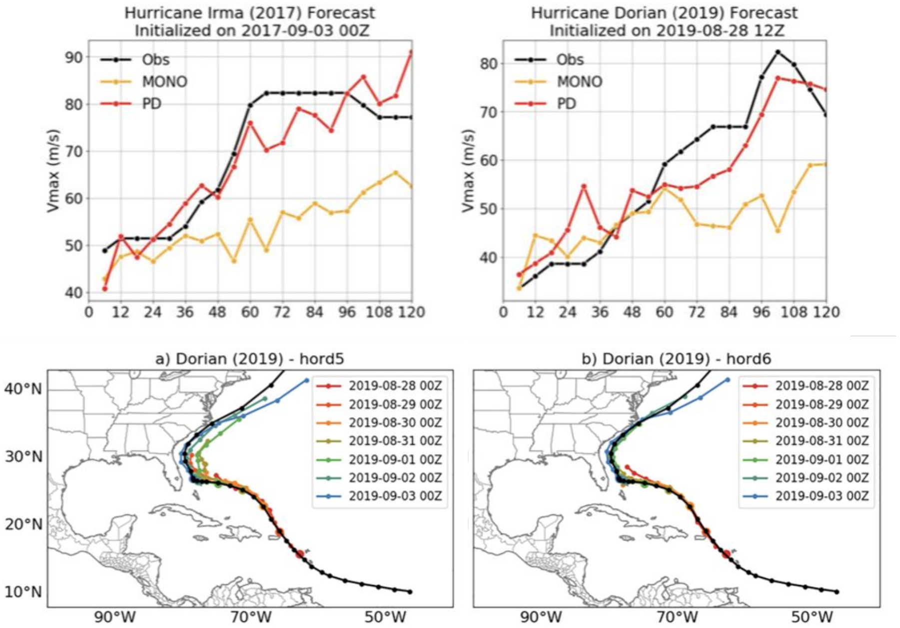
www.gfdl.noaa.gov/fv3

FV3: Advection Schemes, TC Intensification, and Explicit Convection

3-km nested T-SHiELD represents convection explicitly without a deep convective parameterization. Numerics drives much of the behavior of convection.

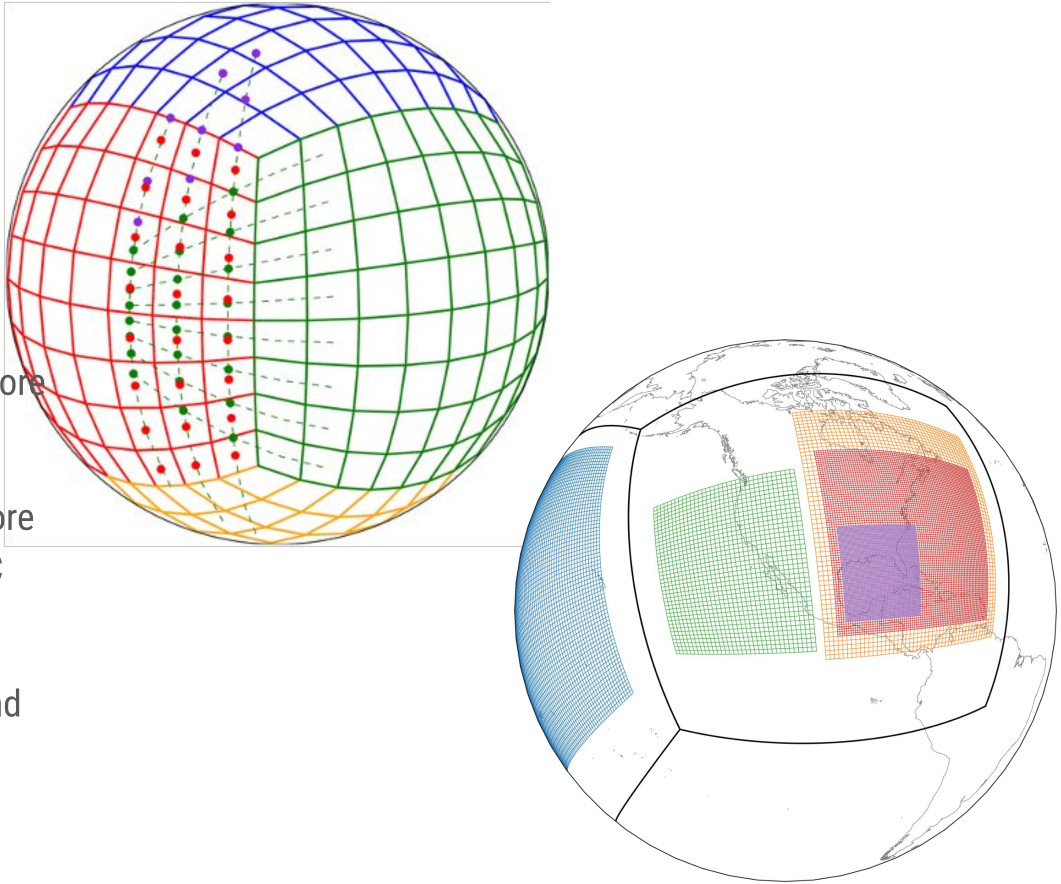
A *positive-definite* tracer advection scheme better allows moisture into the eyewall permitting **smaller storms that intensify more quickly**

A *virtually-inviscid* (hord5) vorticity and thermal advection scheme permits more small-scale convection but affects the **upscale** subtropical high, leading to steering flow changes and **larger TC track error**



Gao et al. (2021, 2023)
More about TCs in Kun's slides (Q2)

FV3: New Grid Systems



Duo-Grid: Natural revision to edge handling greatly reduces edge inaccuracies

LMARS: *Experimental* Riemann solver for simpler, more accurate horizontal discretization

Multiple and telescoping nests: zoom in on even more high-impact weather events. Supports AOML & EMC HAFS moving nest development

Vertical nesting: Efficiently enhance both vertical and horizontal resolution

Learn more about the Global-Nest Initiative in Jan-Huey's presentation (Q3)

FV3 Subgrid Turbulent Mixing

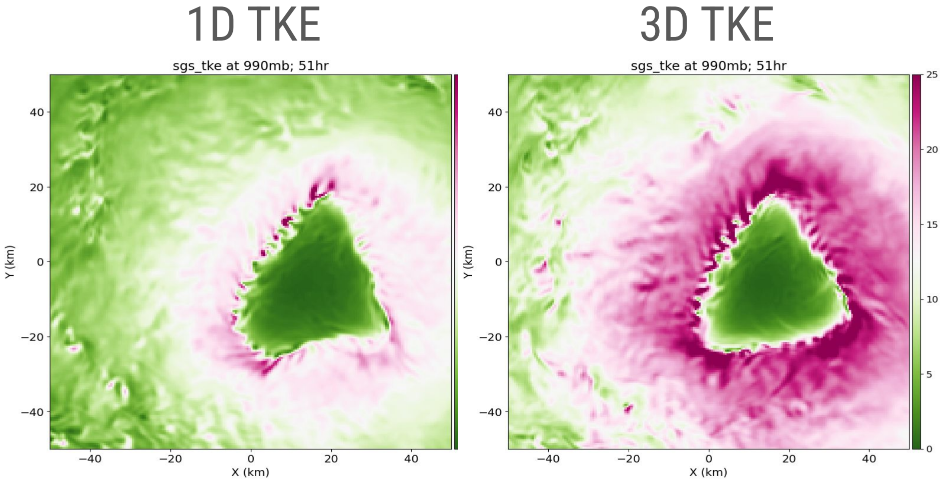
Collaboration with AOML and FIU

Goal: a *physical turbulent mixing scheme* consistent with FV3 numerics for best accuracy and efficiency

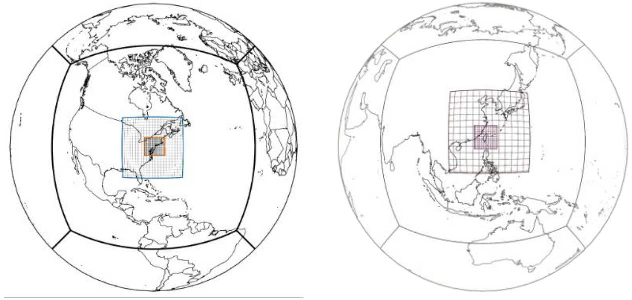
Leverage FV3 differential operators to construct best deformation estimate and apply mixing

Opens path to hectometer-scale process simulation and hyper-local multi-nest predictions

There's lots of room at the bottom.



500-m TC eyewall simulation



X-SHiELD: Global Storm Resolving Model

3.25-km global model with explicit deep convection – **Simple!**

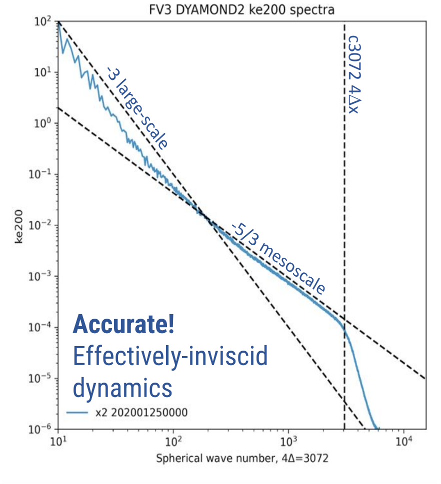
33 min/day on 27.8K Gaea C6 cores – **Efficient!**

Unprecedented years-long GSRM climate simulations:
Km-scale climate modeling has arrived.

Major contributor to DYAMOND Phases I, II, and III
New X-SHiELD v2024 simulations now done

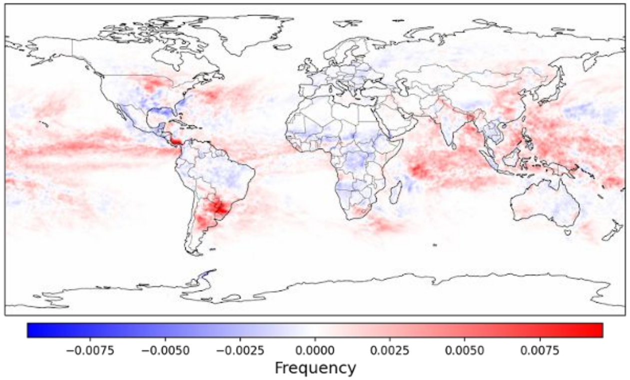
GSRMs/km-scale models give us a **unique** view of convection as a **global** phenomenon

X-SHiELD explicit *intense* convection generally greater in a warmed climate—but not everywhere



Accurate!
Effectively-inviscid dynamics

Change in intense convection with +4K SST: Cheng et al. (2022)



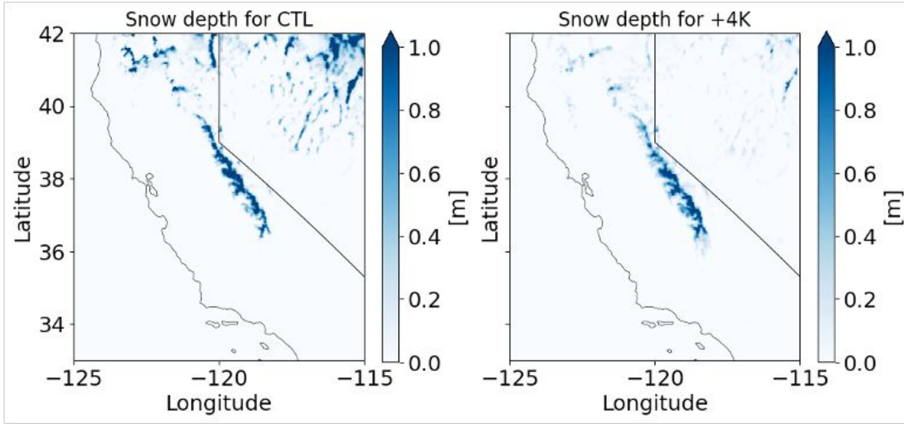
Learn more about SHiELD
in Linjiong's presentation (Q2)

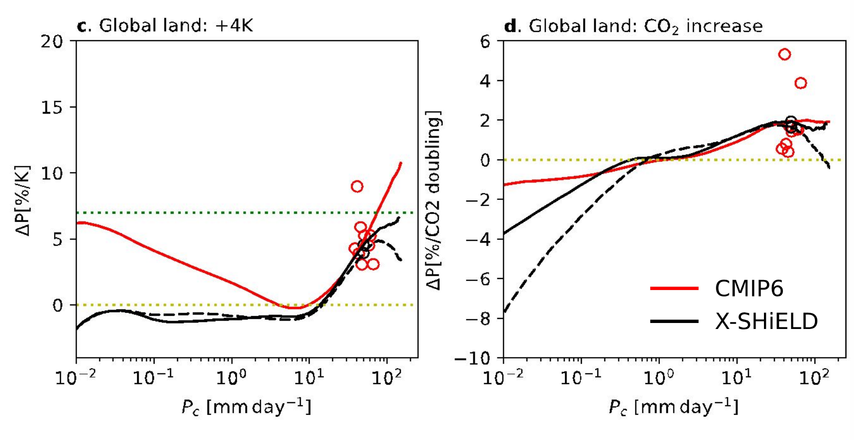
X-SHiELD: Precipitation and warming

What <u>new</u> things can you do with a global km-scale model? Global km-scale is great for global extreme and orographic precipitation

Western US Hydroclimate: high mountain snowpack may remain under warming. Resolution is paramount.

Less increase in extreme precipitation in X-SHiELD vs. CMIP6





Hsieh et al., in revision; Guendelman et al. 2024

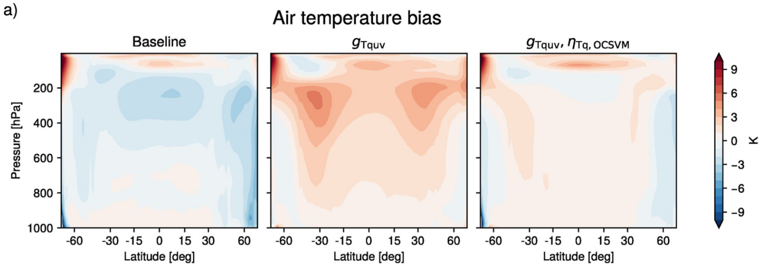
SHiELD-trained ML

FV3net corrective ML, trained on coarsened X-SHiELD output, yields significant improvement in coarse-resolution climate simulation. Now running on NOAA HPC.

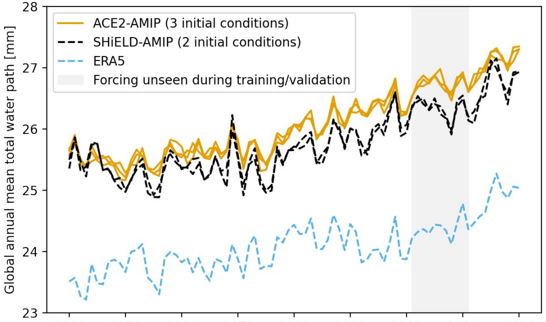
ACE: Ai2 Climate Emulator is a fully data-driven emulator of SHiELD stable, conservative, and accurate for 100+ year rollouts

Ai2

https://allenai.org/climate-modeling



C48 zonal temperature bias: Baseline, Corrective ML (T, q, and winds), and Corrective ML with Novelty Detection (Sanford et al., 2023)



81-year AMIP simulations with ACE2 (Watt-Meyer et al., submitted)

Introducing Pace & PyFV3

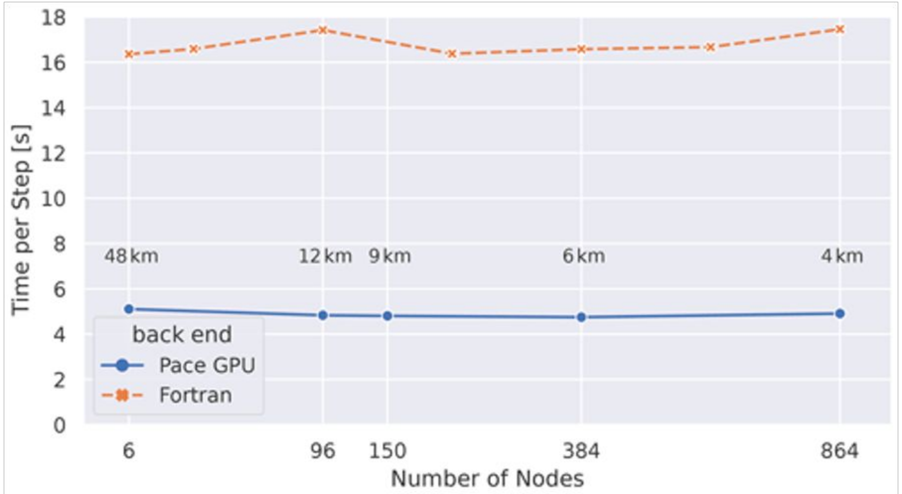
A NOAA-NASA Collaboration:
Learn more about Pace in
Oliver and Rusty's slides (Q1)

Pace: Re-write of FV3 and SHiELD in Python for **Performance Portable computing** especially GPUs

Full Python ecosystem available for science and development: convenient container too

PyFV3 transitioned from Ai2 into NOAA: **3x–8x** speedups on GPU vs. Fortran on CPUs

Now working to port physics and interface to radiation and FMS: **complete PySHiELD coming soon**.



Be a part of it

Install at github.com/NOAA-GFDL/Pace