Moving Nest Implementation for the Hurricane Analysis and Forecast System in the Unified Forecast System Framework

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HAFS Scientific Objectives

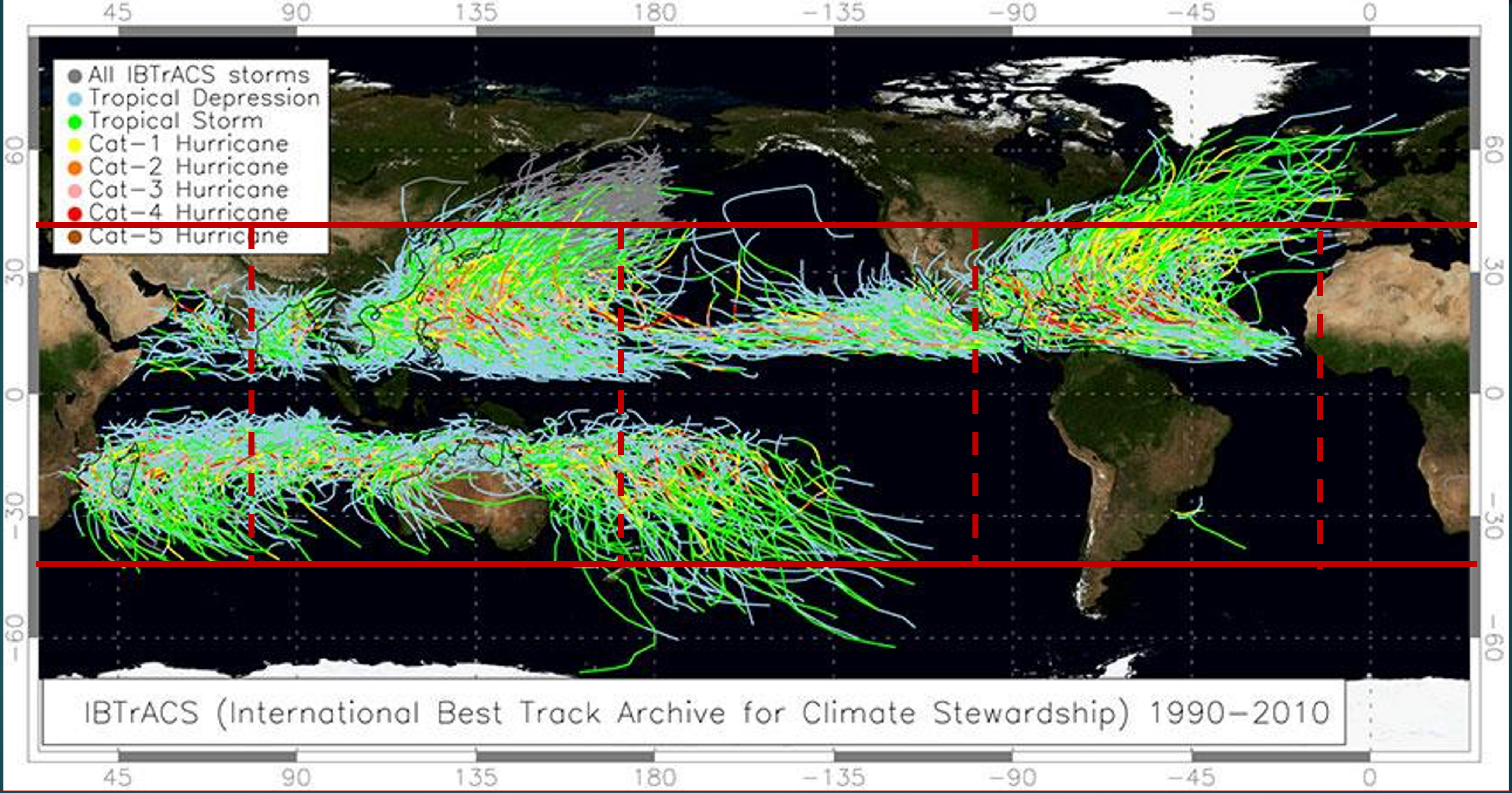
HAFS, a Unified Forecast System (UFS) application, is to:

- Provide inner-core analyses and global and regional forecast guidance of the Tropical Cyclone (TC) track, intensity, structure, and ambient flows to operational communities.
- Extend forecast guidance up to seven days to address Weather-Ready Nation priorities.
- Target on the scientific and forecast priorities under the guidance of the Hurricane Forecast Improvement Program (HFIP) and the UFS' Strategic Implementation Plan (SIP), i.e.,
  - improving guidance on track and intensity, rapid intensity changes, storm size and structure, genesis, rainfall, and tornado potential guidance associated with TCs.
  - facilitating the reliable downstream applications and forecasts, e.g., storm surge, inland flooding, damage prevention and mitigation.
  - fostering innovations and applications of the observing and assimilation technologies.

HAFS Current Available Capabilities

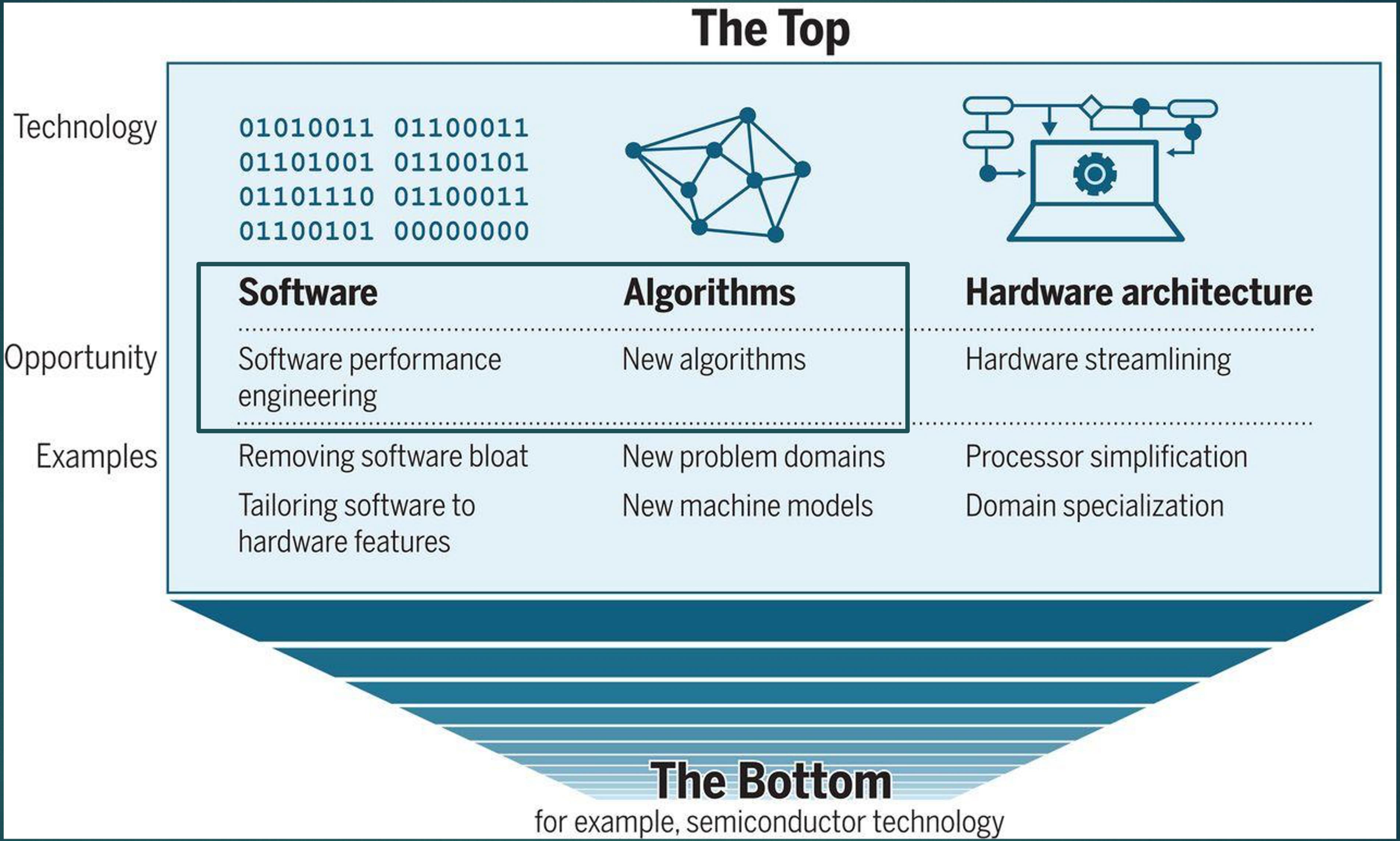
- Dynamics and numerics:
  - Fully-compressible vector-invariant Euler equations
  - Fully non-hydrostatic with semi-implicit solver
  - Lagrangian Dynamics
  - Quasi-orthogonal and quasi-uniform cubed-sphere grids
  - Finite-volume dynamic core for massive parallelization
  - Simultaneous integration for nesting
- CCPP framework for novel physics implementation and expansion
- ESMF based coupling design
- JEDI adaptable DA approach
- Operational and research interchangeable workflow
- Common products for research and forecasts

Distribution of Global TC Tracks



Ramsay, Hamish. 2017 "The Global Climatology of Tropical Cyclones." Oxford Research Encyclopedia of Natural Hazard Science. 15 Aug. 2018. http://naturalhazardscience.oxfordre.com/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-79.

Performance Gains After Moore's Law Ends



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Version	Implementation	Running time (s)	GFLOPS	Absolute speedup	Relative speedup	Fraction of peak (%)
1	Python	25,552.48	0.005	1	—	0.00
2	Java	2,372.68	0.058	11	10.8	0.01
3	C	542.67	0.253	47	4.4	0.03
4	Parallel loops	69.80	1.969	366	7.8	0.24
5	Parallel divide and conquer	3.80	36.180	6,727	18.4	4.33
6	plus vectorization	1.10	124.914	23,224	3.5	14.96
7	plus AVX intrinsics	0.41	337.812	62,806	2.7	40.45

Table 1 Speedups from performance engineering a program that multiplies two 4096-by-4096 matrices.
Each version represents a successive refinement of the original Python code. “Running time” is the running time of the version. “GFLOPS” is the billions of 64-bit floating-point operations per second that the version executes. “Absolute speedup” is time relative to Python, and “relative speedup,” which we show with an additional digit of precision, is time relative to the preceding line. “Fraction of peak” is GFLOPS relative to the computer’s peak 835 GFLOPS. See Methods for more details.

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Science AAAS

HAFS Development Approaches

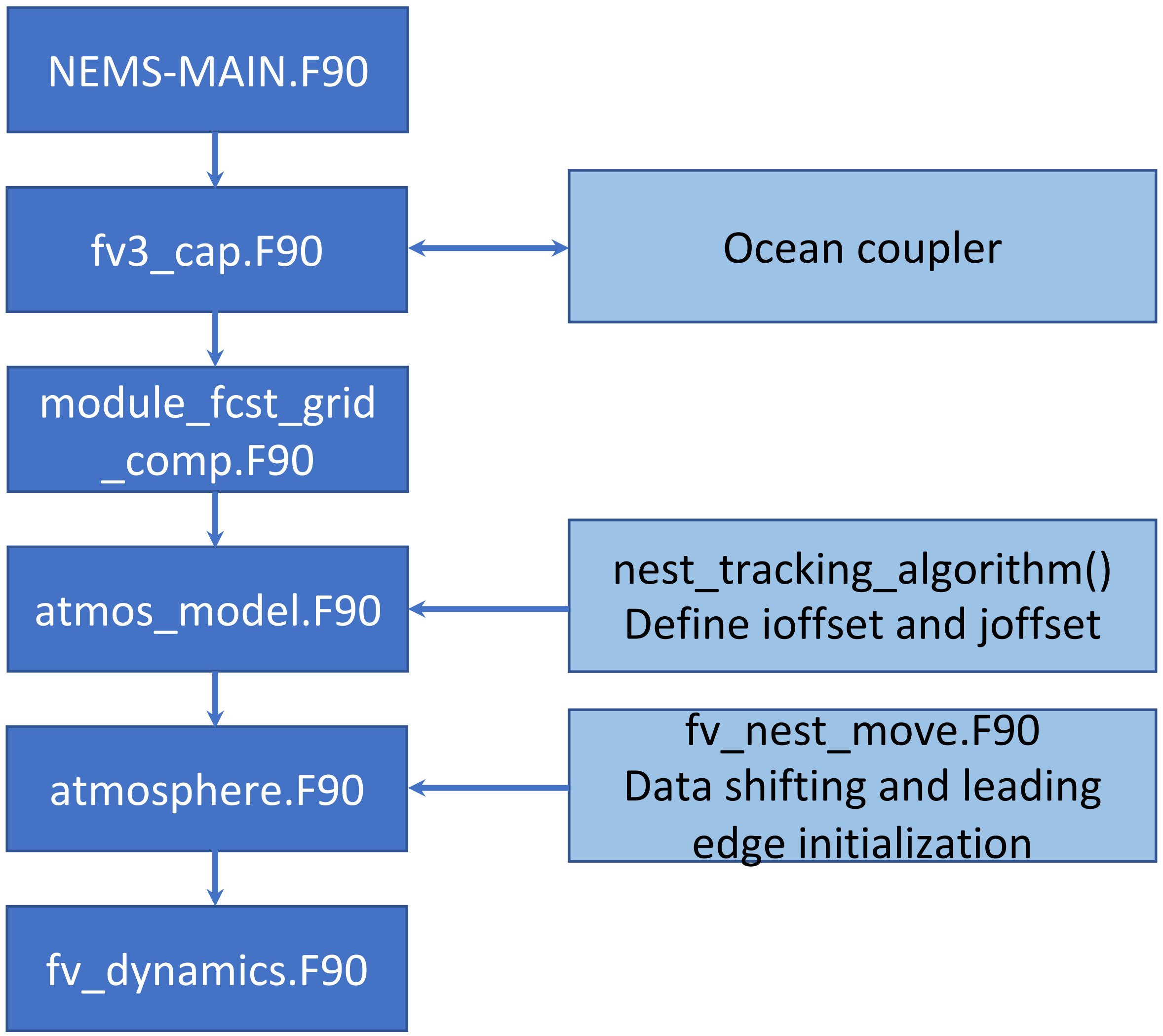
HAFS development is driven by the operational needs, scientific advancements, and innovative technologies, i.e.:

- Moving nest approach to achieve the required resolution for TC prediction
- Design an algorithm in the dynamic core to fully adaptive to modern technology
- UFS R2O and O2R constant iterations, i.e.:
  - Develop HAFS from operational UFS repository
  - Research-Operation-Research seamless transition
  - Development and implementation constantly

Moving Nest Development & Implementation

Development roadmap

- FMS modification
- Multiple static nests development & implementation
- Moving nest utilities (grid transformation and interpolation, memory shifting, and halo exchange, I/O)
- Dynamic efficient storm tracking system
- Dynamic core and physics test and evaluation
- Idealized TC capability
- Preprocessing & Initialization
- Inner core DA
- Moving nest coupling

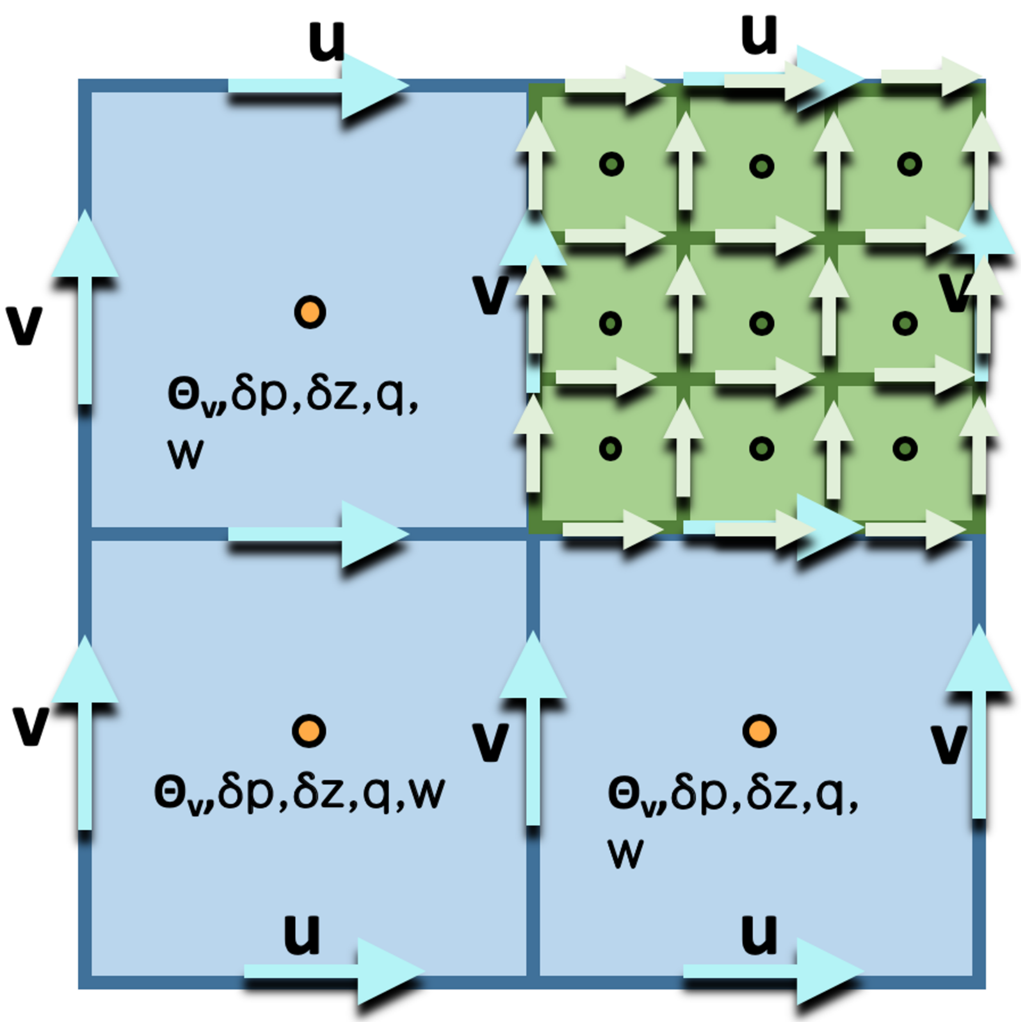


Completed Ongoing Not started yet

Moving Nest Development & Implementation

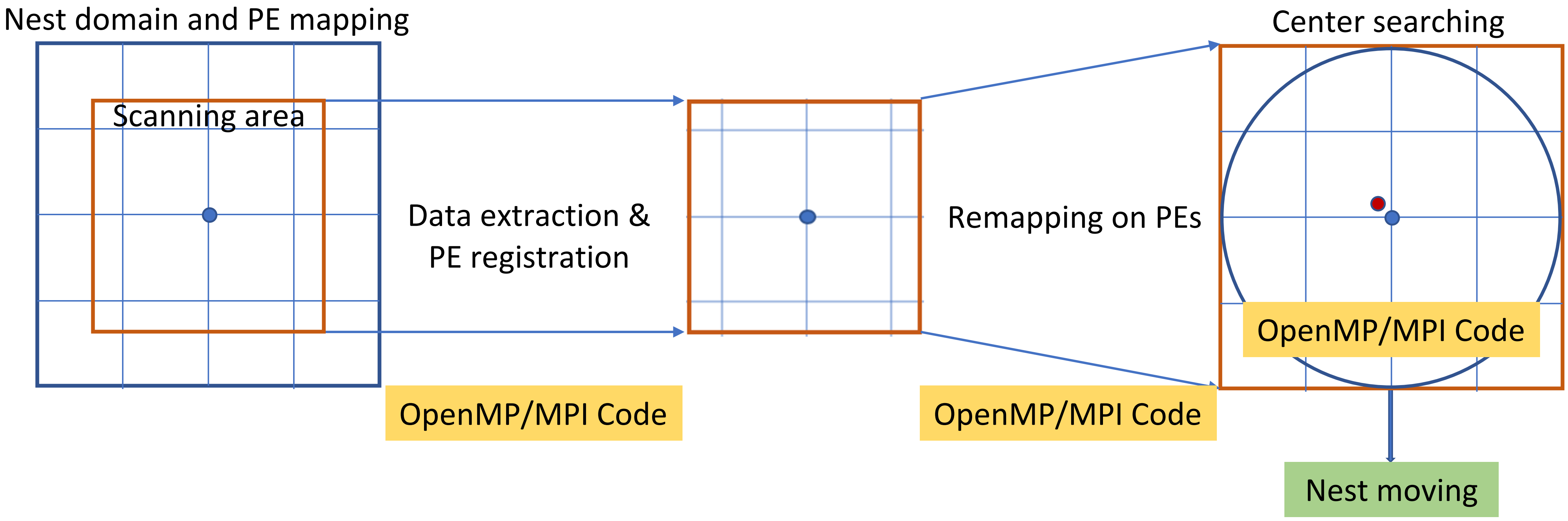
Moving nest algorithm and code inventory

- Moving nest infrastructure code (fv_moving_nest.F90)
    - Memory shifting routines
    - Interpolation routines
    - Offline testing driver
- Functions
    - Data shifting after nest moving
    - Halo refilling
    - Interpolation of prognostic diagnostic variables
    - C-D grid staggering
    - I/O data for diagnostic and coupling
- Inserting moving nest code into dycore (still testing)
- Code inventory: **mn_metadata_move_nest(), mn_var_fill_intern_nest_halos(), mn_metadata_recalc(), mn_var_shift_data(), mn_var_dump_to_netcdf()**



FV3 Prognostic Variable D-Staggering (Non-hydrostatic)

MPI Storm Tracking Algorithm



<u>Offline code test plan</u>

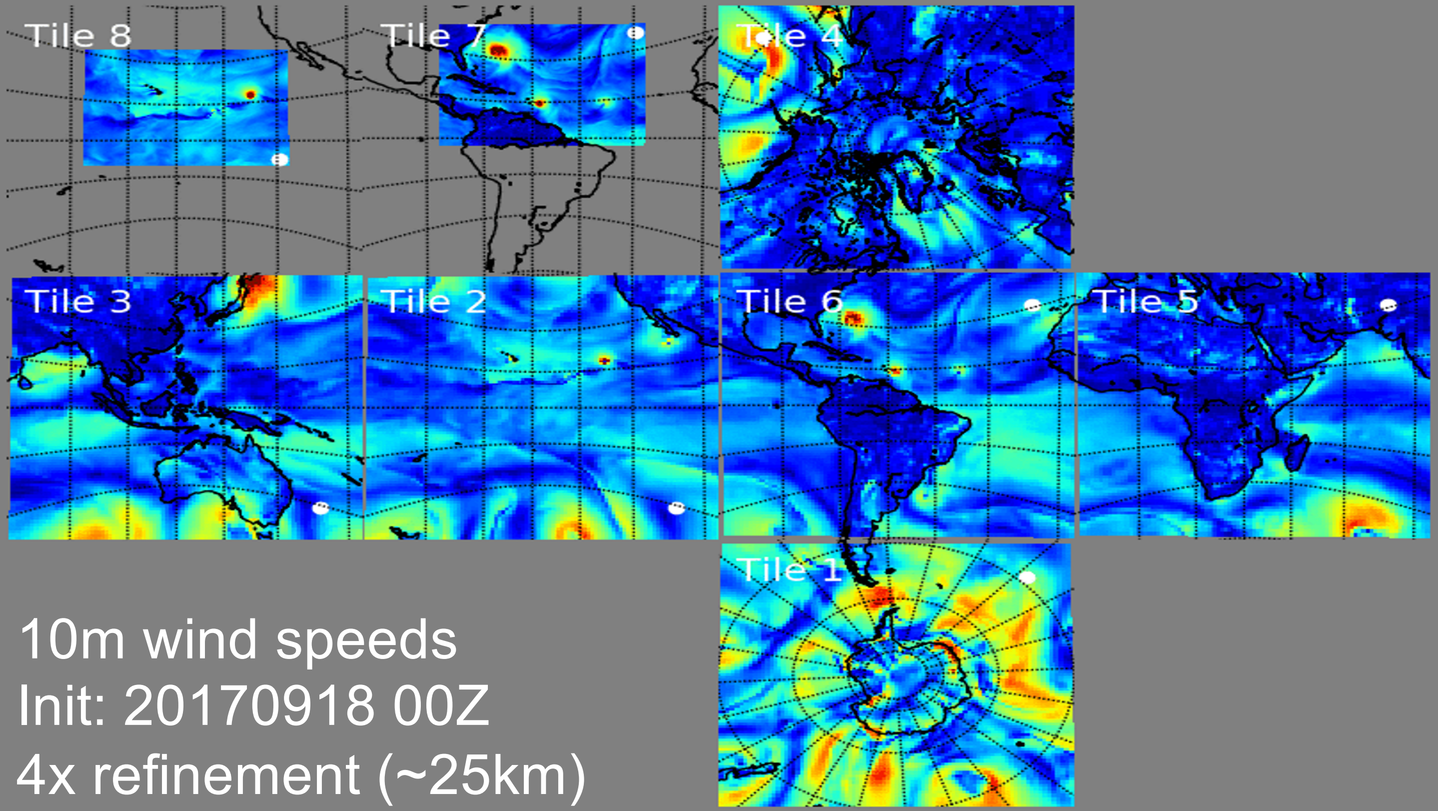
- Stability, uniqueness, and completeness (serial code)
- MPI code reproducibility
- Hybrid code reproducibility
- Scalability test

Multiple Static Nests Development & Implementation

Development roadmap

- Implementation of two static nests in HAFS completed
- Bitwise identical results with baseline HAFS code
- Successful 168-hour forecast run
- Second nest results also validated
- Workflow added in repository
- Preprocessing & Initialization
- HFIP near real-time demo

Maria, Jose (NATL) and Otis (EPAC)

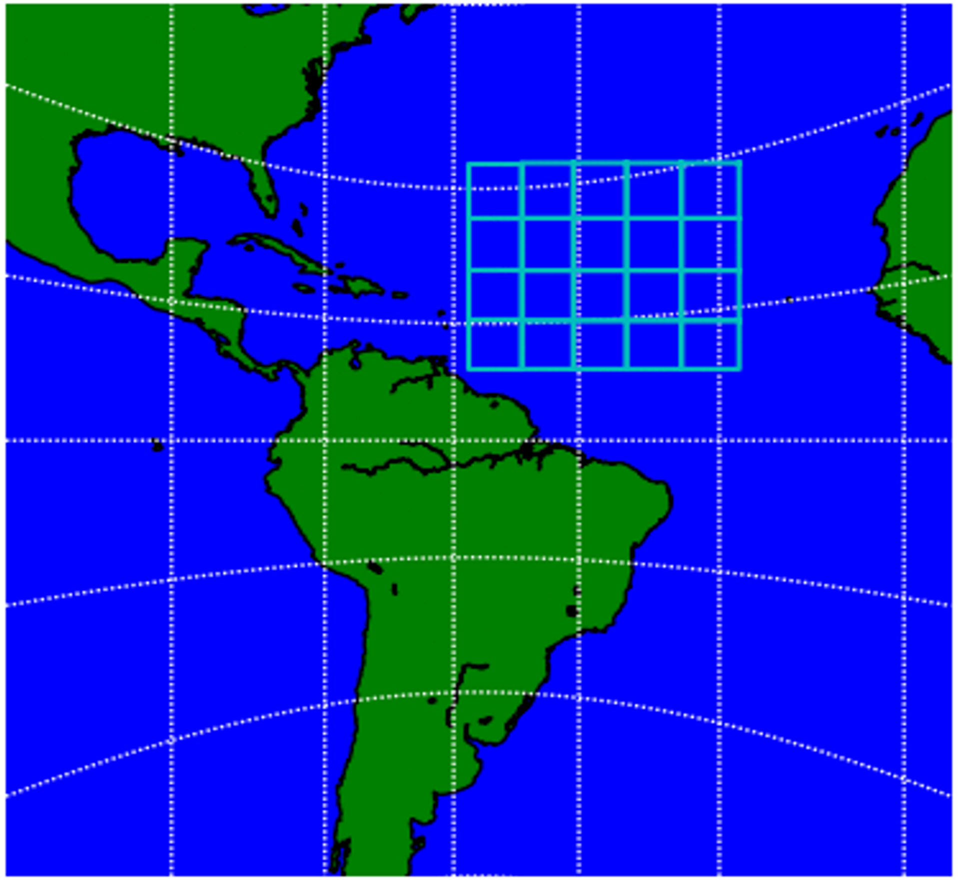


- 10m wind speeds
- Init: 20170918 00Z
- 4x refinement (~25km)

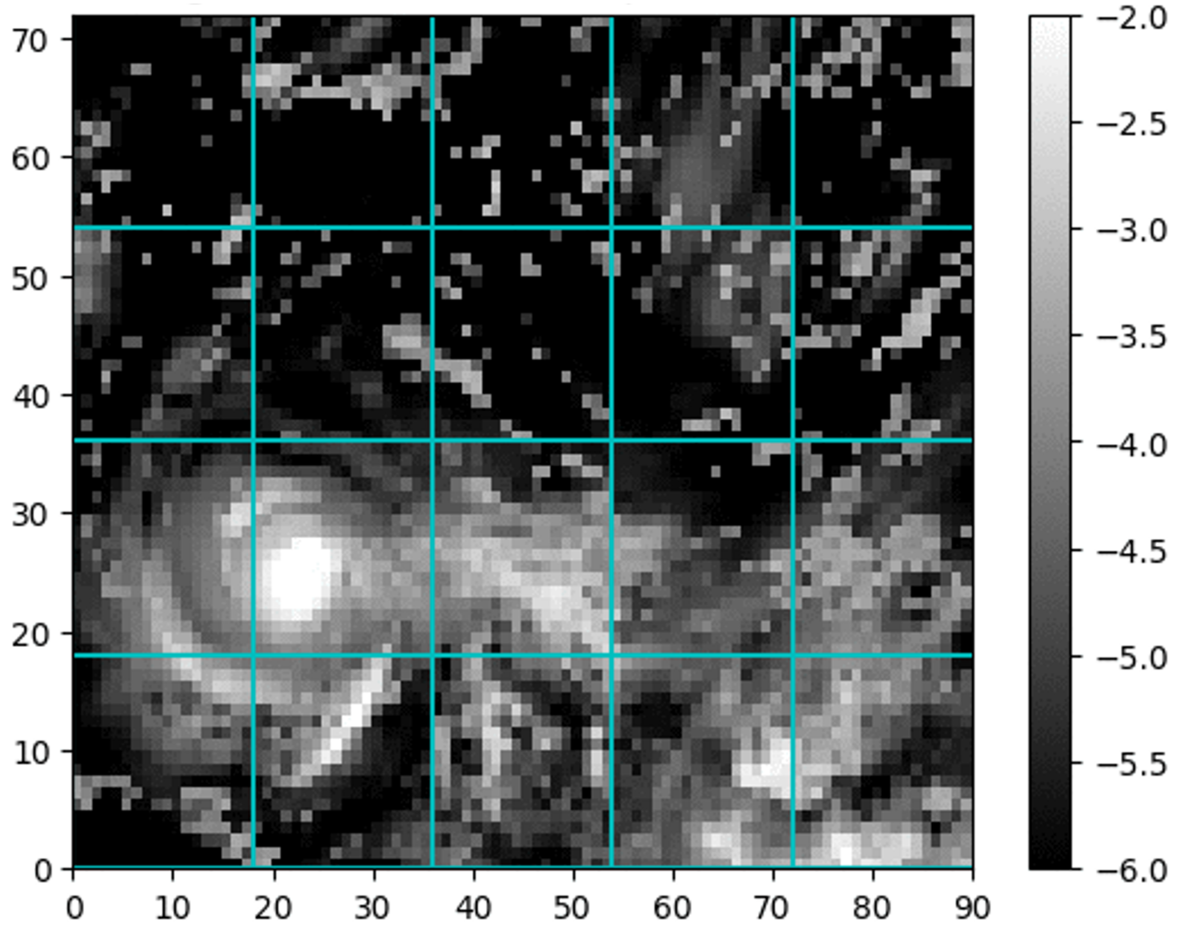
Completed Ongoing Not started yet

Highlight: Moving Nest Code Implementation

- Moving nest code running in dycore
- Moving metadata, A-grid variables

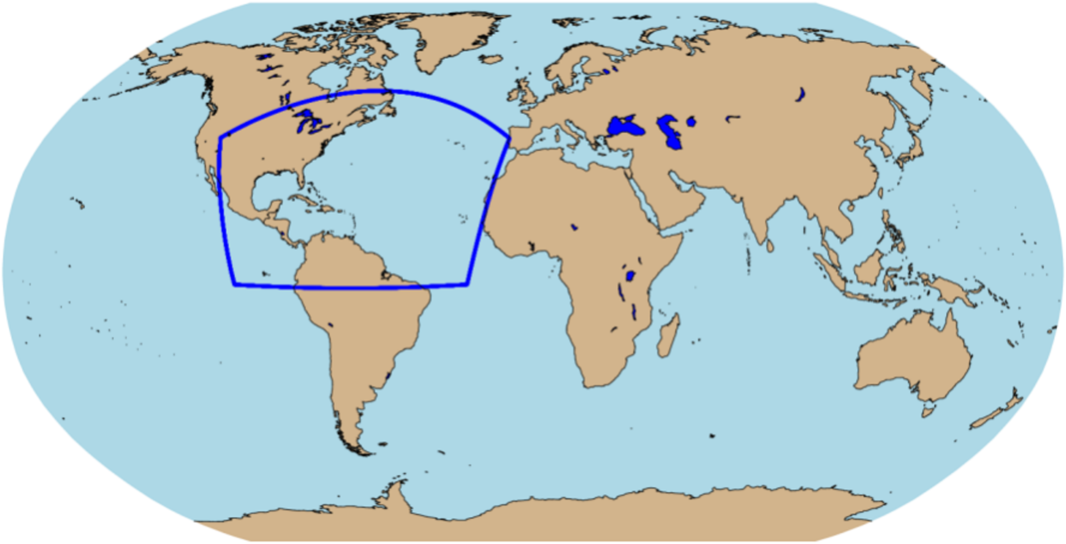


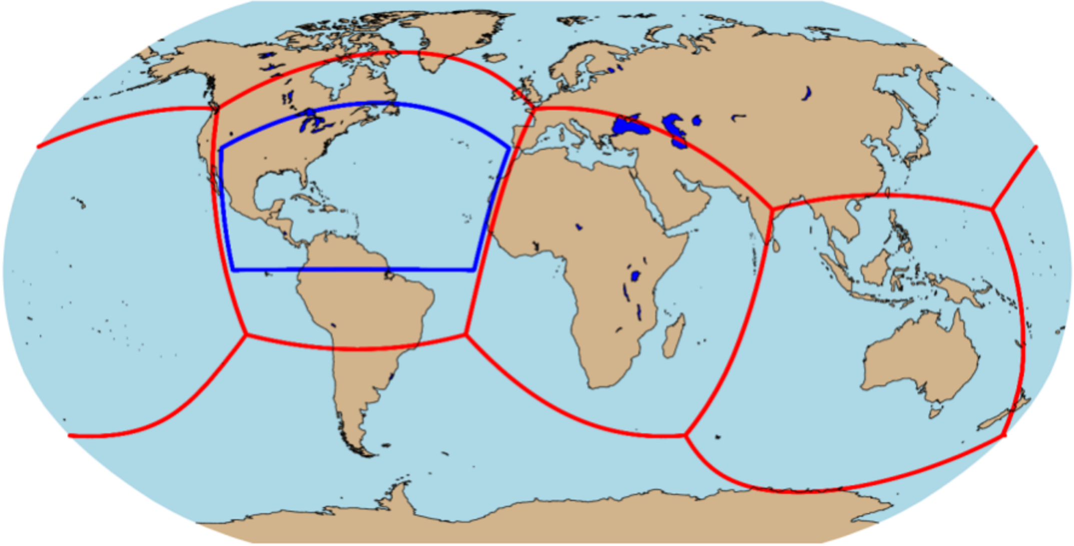
Domain configuration (C96, 1:3 ratio)

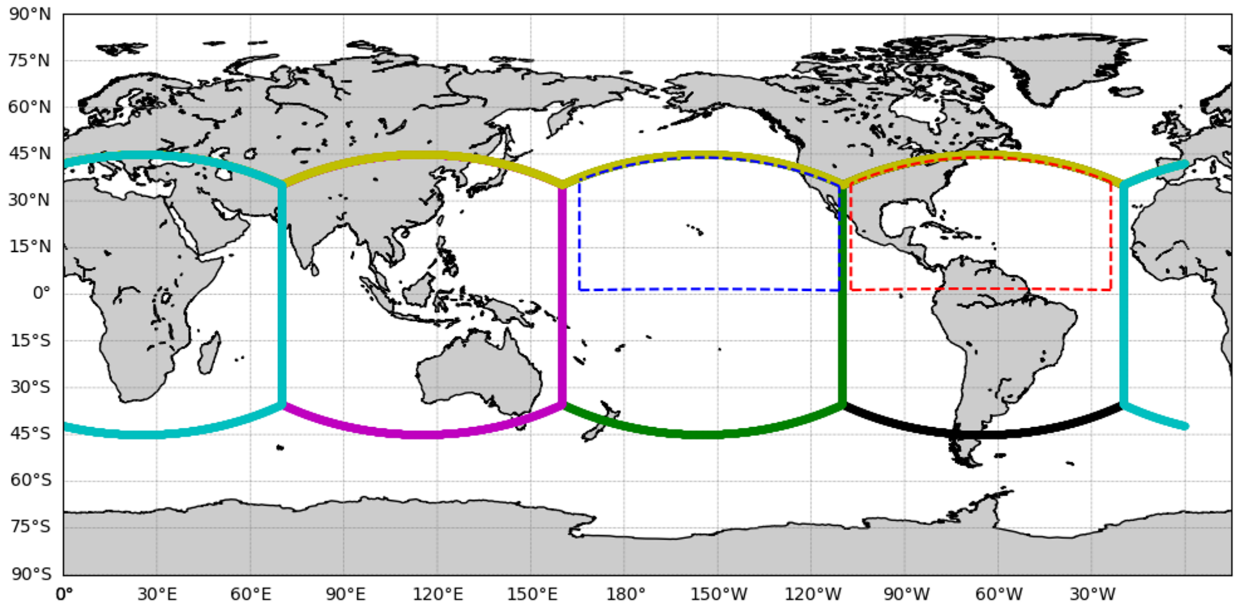


Simulated satellite (column condensed water)

HAFS HFIP Real-time Demo



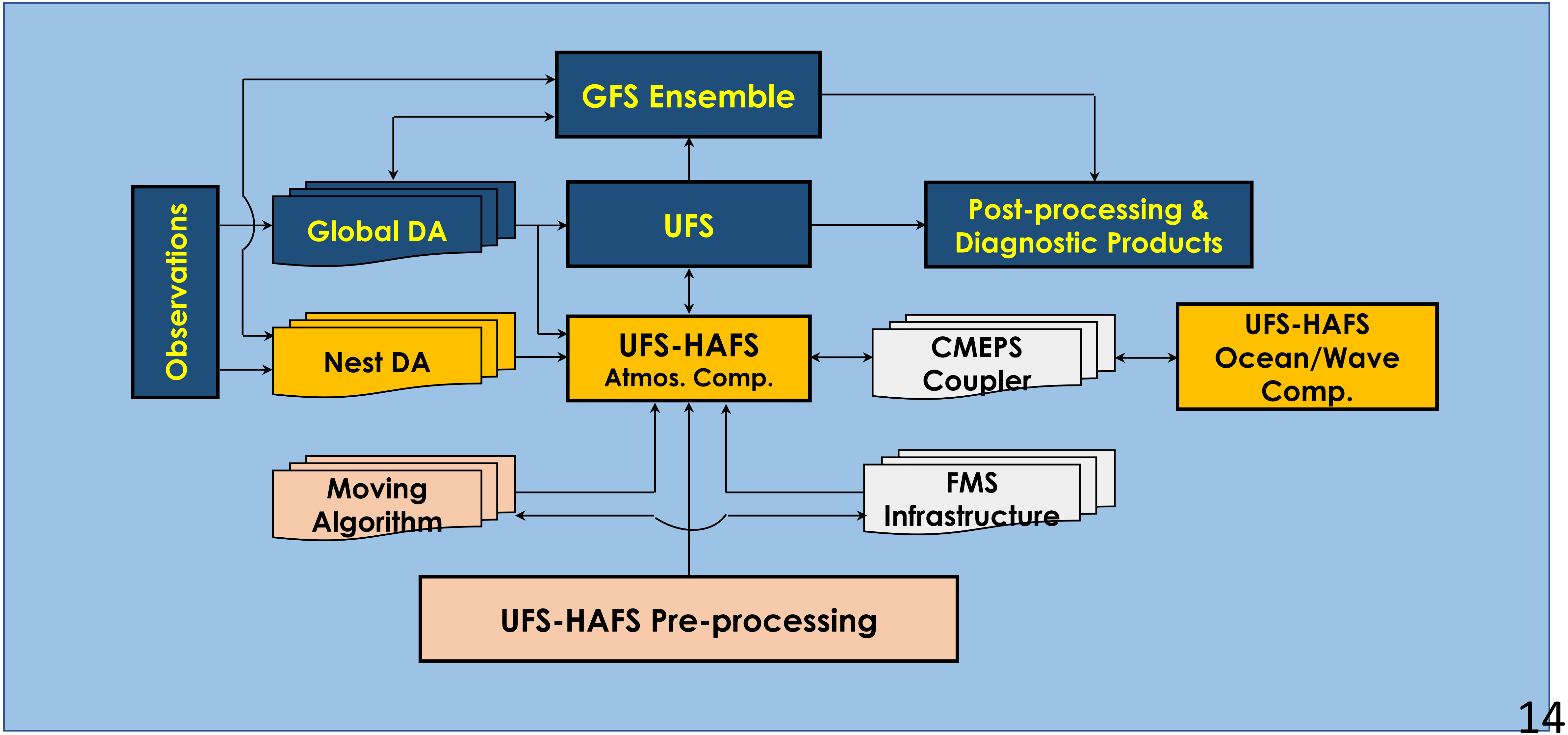




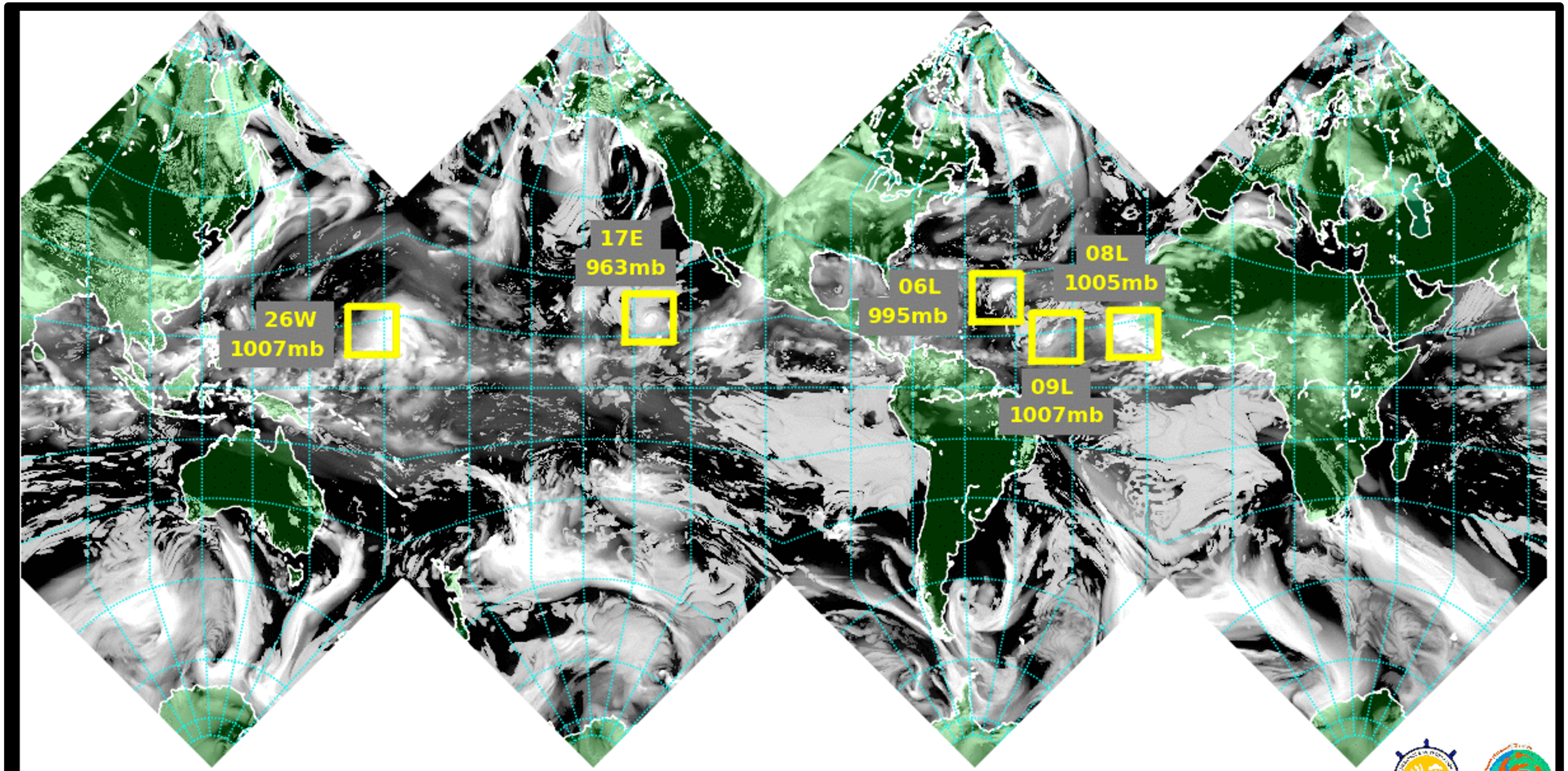
Optimal configuration towards operations

- Three domain setups: Regional, Global single nest, and Global multiple nests
- Different configuration and components: horizontal resolution, vertical resolution, DA strategies, data impacts, ocean coupling etc.
- Different physics parameterizations: convection, PBL, microphysics
- Common research and forecast products
  - https://storm.aoml.noaa.gov
  - https://www.emc.ncep.noaa.gov/gc_wmb/vxt/HAFSv0p1a/tcall.php
  - http://www.hfip.org

UFS-HAFS Strategic Roadmap



The Ultimate HAFS



06L: Florence; 08L: Helene; 09L: Isaac; 17E: Olivia; 26W: Mangkhut

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