Preliminary evaluation of systematic biases in a FV3--powered global cloud- permitting model

S.-J. Lin
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ
“Super FV3” developed while on sabbatical at Academia Sinica, Taipei, Taiwan

Outgoing Longwave Radiation: 1 AUG 2016 – 10 SEP 2016

DYAMOND Project:

- “Super FV3”, C3072_L79 (3.25 km)
- Very large time step:
- No cumulus parameterization

2016-08-01 01:00Z
001 Forecast Hours
FV3 3km

超有限體 動力核心
Visualization
Xi Chen@FV3 team

5th ENES HPC workshop on “HPC for high-resolution weather and climate modeling” , May 17, 2018, Lecce, Italy

Status of the current FV3

Weather Applications:

- The GFDL FV3 "dynamical core" (動力核心) was selected in June 2016 as the "engine" for the Next Generation Global Prediction System (NGGPS)

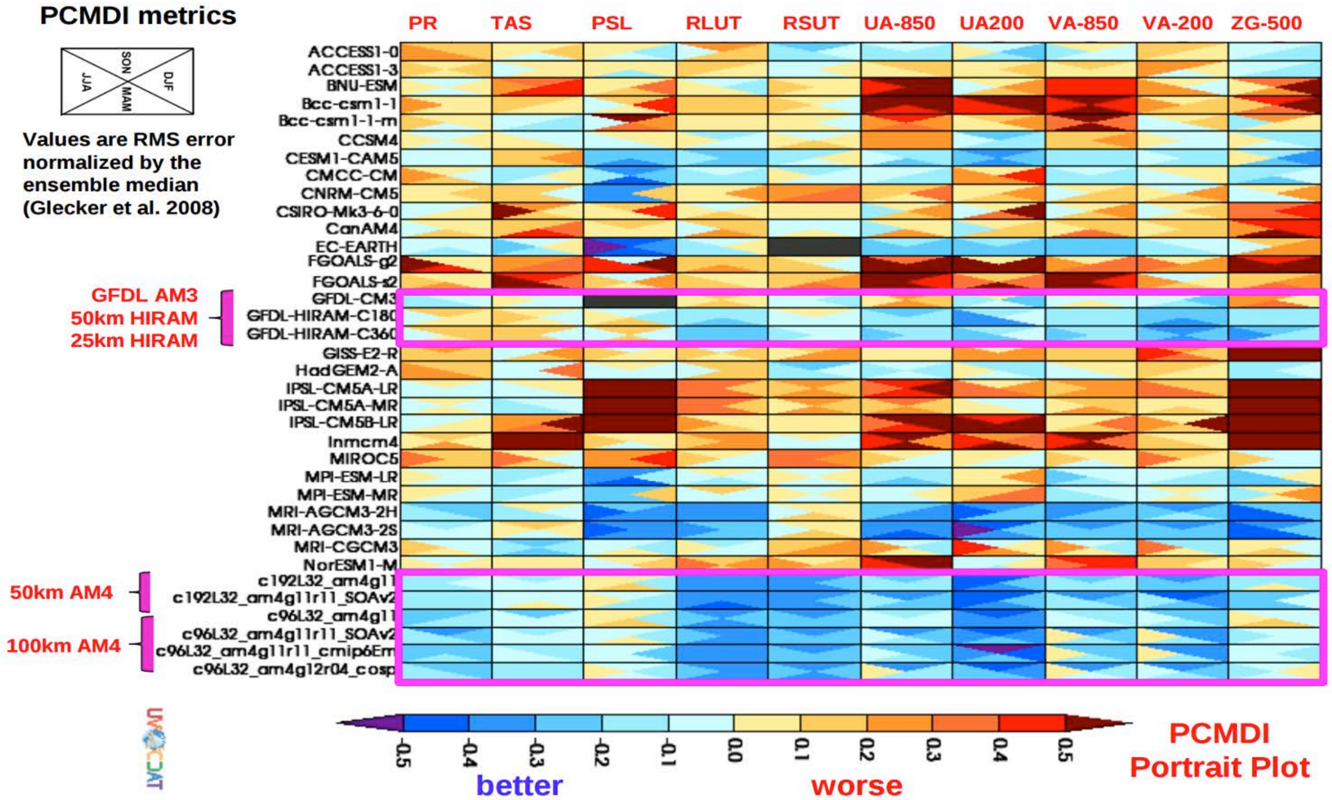
- Since Jan 2018, supported by sufficient evidence on the storm-scale, NOAA is developing a **U**nified **F**orecast **S**ystem (**UFS**) around FV3 – **the unification between the Global models for weather, space weather, S2S, and all regional forecast systems in the US -- the one system to unify all prediction systems**

Climate Applications:

- **All** NOAA/GFDL models developed since 2005 are based on the FV3
- **All** climate modeling centers in the US contributing to IPCC AR4/AR5 (NASA GMAO and GISS, NCAR, GFDL) adopted either the old FV core or the current FV3

Quality of Climate simulations

(Zhao et al., 2018, JAMES)



GFDL AM4 is a BIG improvement over AM3

Powered by FV3

What's next after FV3?

Introducing the "Super FV3": 超有限體 動力核心

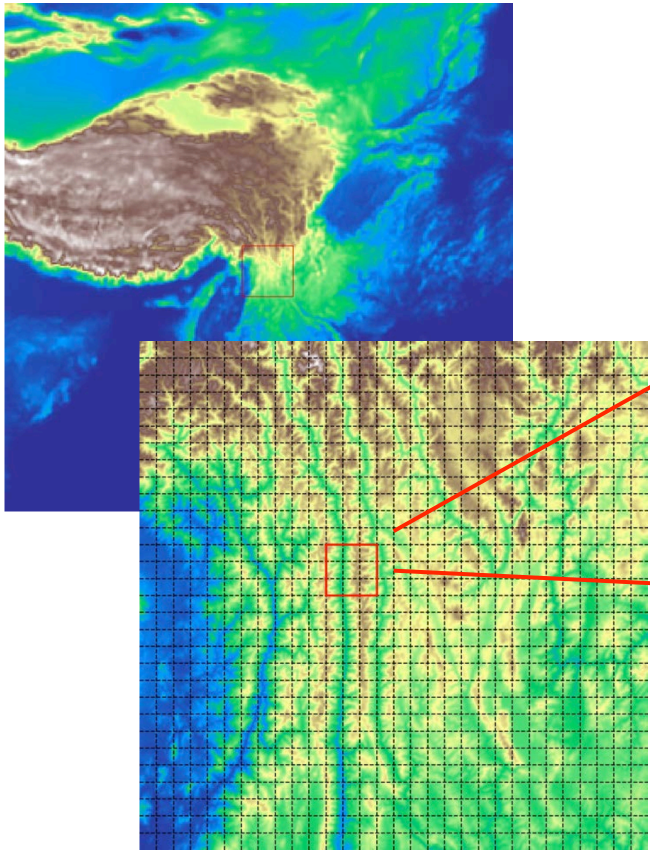
- "Dynamics" and "physical parameterizations" are traditionally separated within a modeling framework (*e.g.*, GFDL CM4, NCAR CESM, NASA GEOS). To make progress, we need to tear it apart

- As model resolution increases, particularly within the gray-zone (1-10 km), the dynamics needs to "see" better the various water substance to allow better physics-dynamics interaction, and for higher computational efficiency (by using only small-time-step for "fast physics")

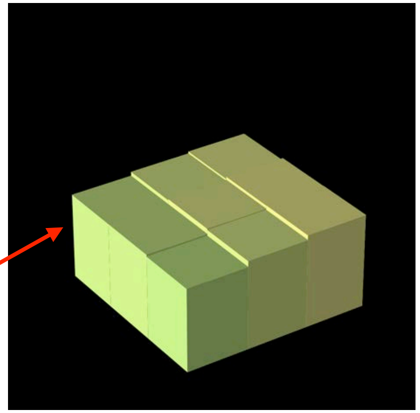
- What exactly is "super FV3"?

FV3 with built-in 1) A thermodynamically consistent cloud microphysics, 2) Mountain blocking by Sub-Grid Orography (SGO), 3) Shear-induced turbulence, 4) SGO-induced turbulence, 5) work-in-progress: parameterized 3D radiation and 3D "gray-zone" gravity-wave-drag

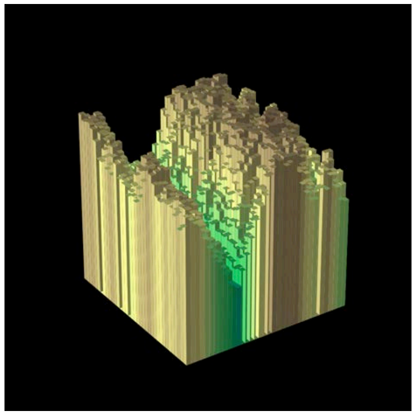
The “super FV3” uses the 1-km sub-grid orography, regardless of the true resolution



C768 (Δx~12 km) model Mean orography



Hi-resolution orography (1-km)

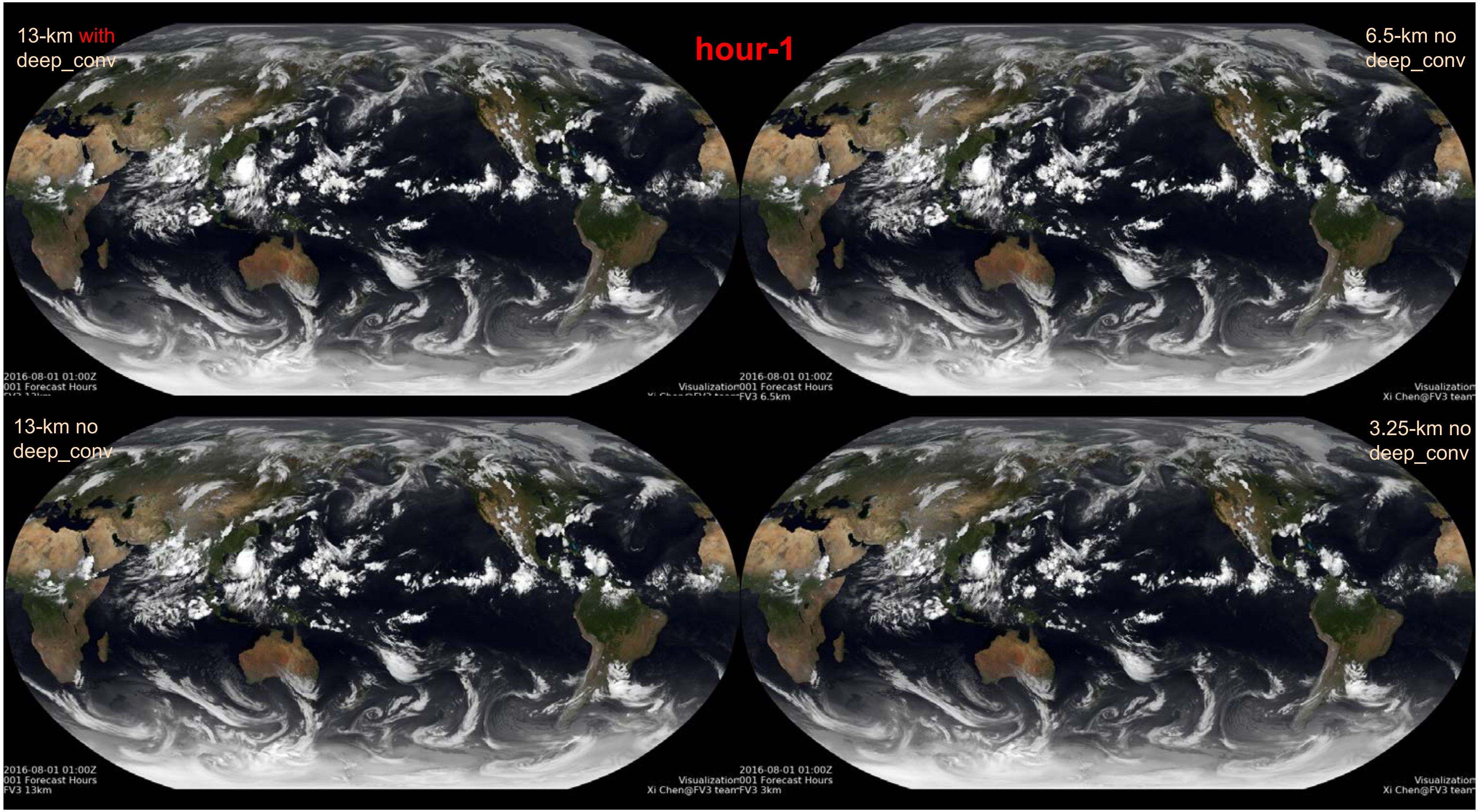


For each 12x12 (km) ”finite-volume” (grid box), there are 12x12=144 sub-grid columns

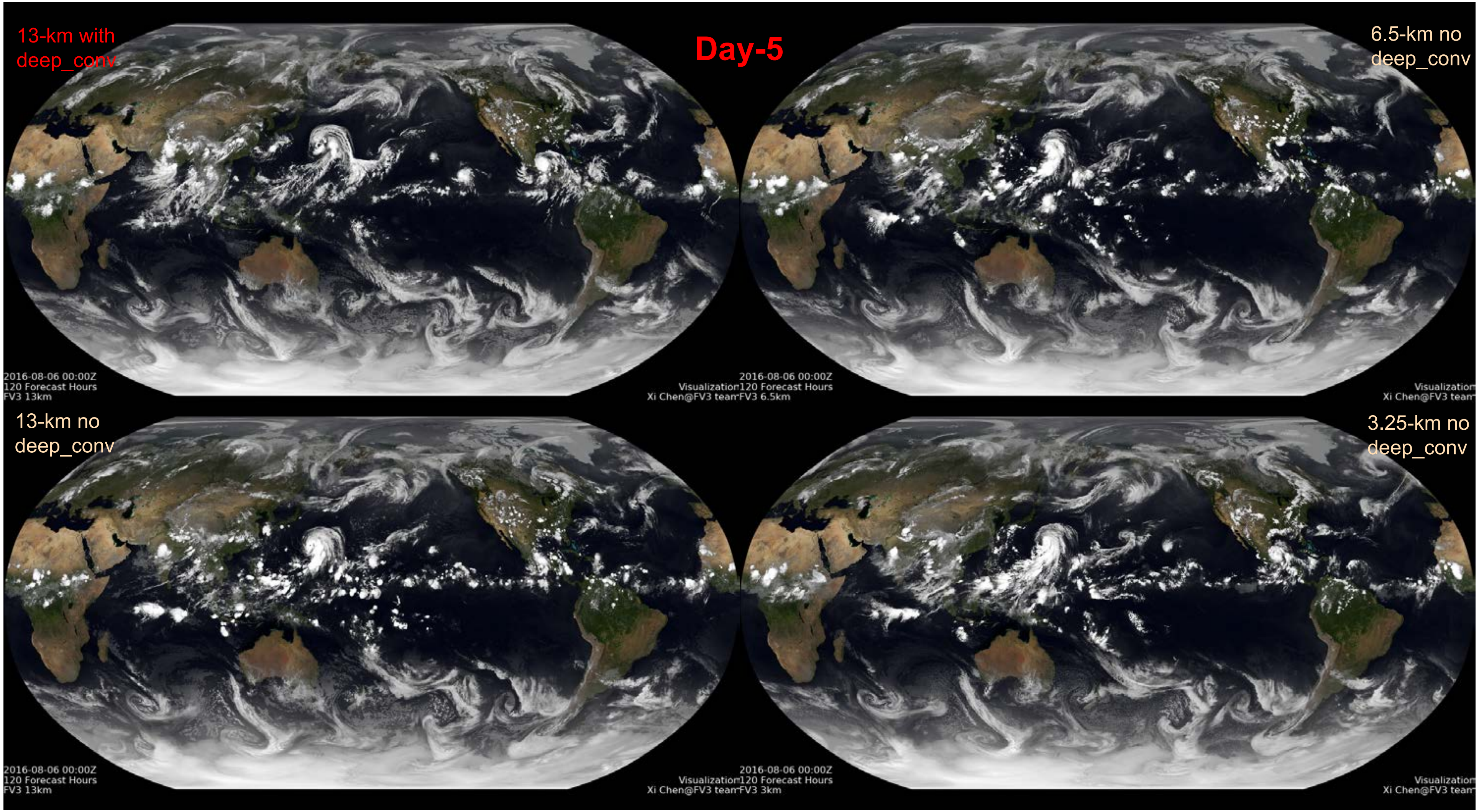
Evaluating the Super FV3 in the Gray-Zone

The "DYAMOND Project" *(https://www.esiwace.eu/services/dyamond)*

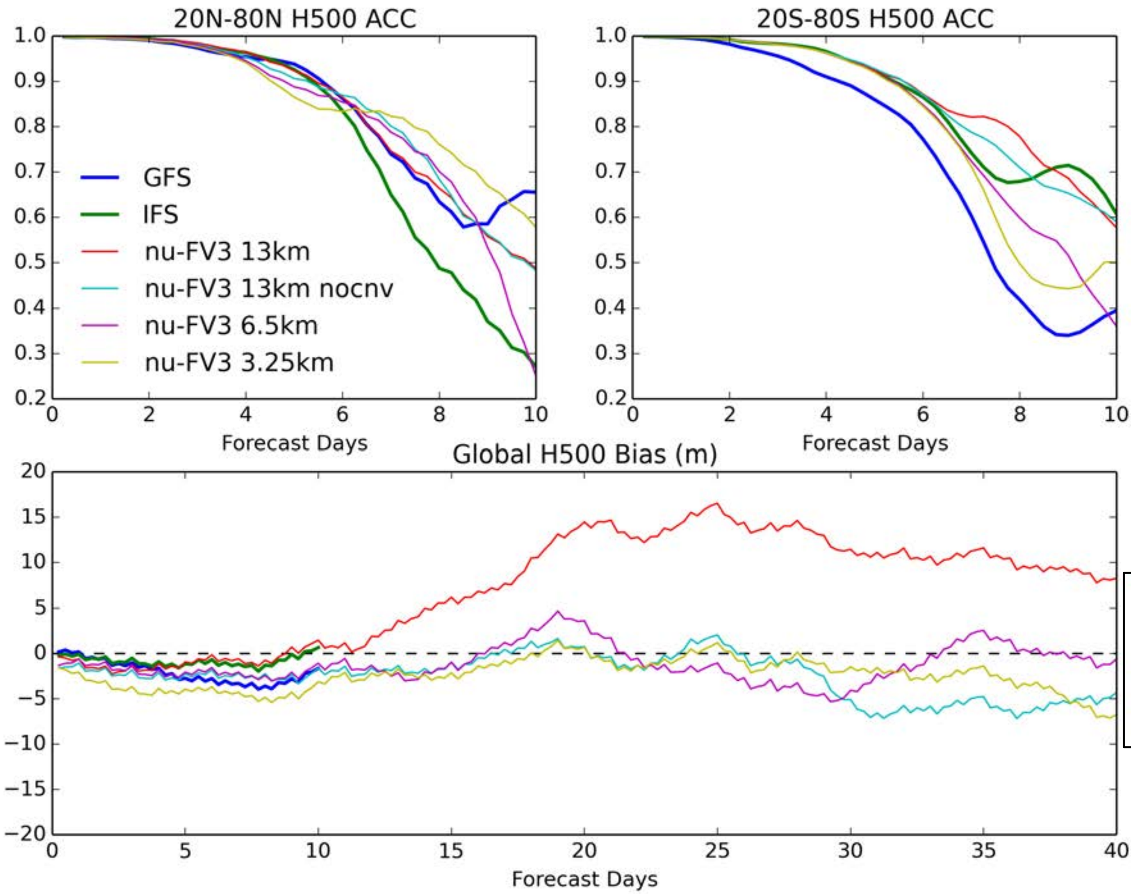
- First International inter-comparison of global cloud-resolving models
- Participants: nu-FV3, NASA-GOES-5, NICAM, ICON, UK HadGEM3, MPAS, and SAM
- One of the goals is to reduce the uncertainty associated with convective parameterization by brute force (e.g., 1-km global) or by Artificial Intelligence-aided hybrid parameterization



hour-1
13-km with deep_conv
6.5-km no deep_conv
13-km no deep_conv
3.25-km no deep_conv
2016-08-01 01:00Z
001 Forecast Hours
2016-08-01 01:00Z
001 Forecast Hours
FV3 6.5km
Visualization
Visualization
Xi Chen@FV3 team
2016-08-01 01:00Z
001 Forecast Hours
FV3 13km
2016-08-01 01:00Z
001 Forecast Hours
FV3 3km
Visualization
Xi Chen@FV3 team
Visualization
Xi Chen@FV3 team

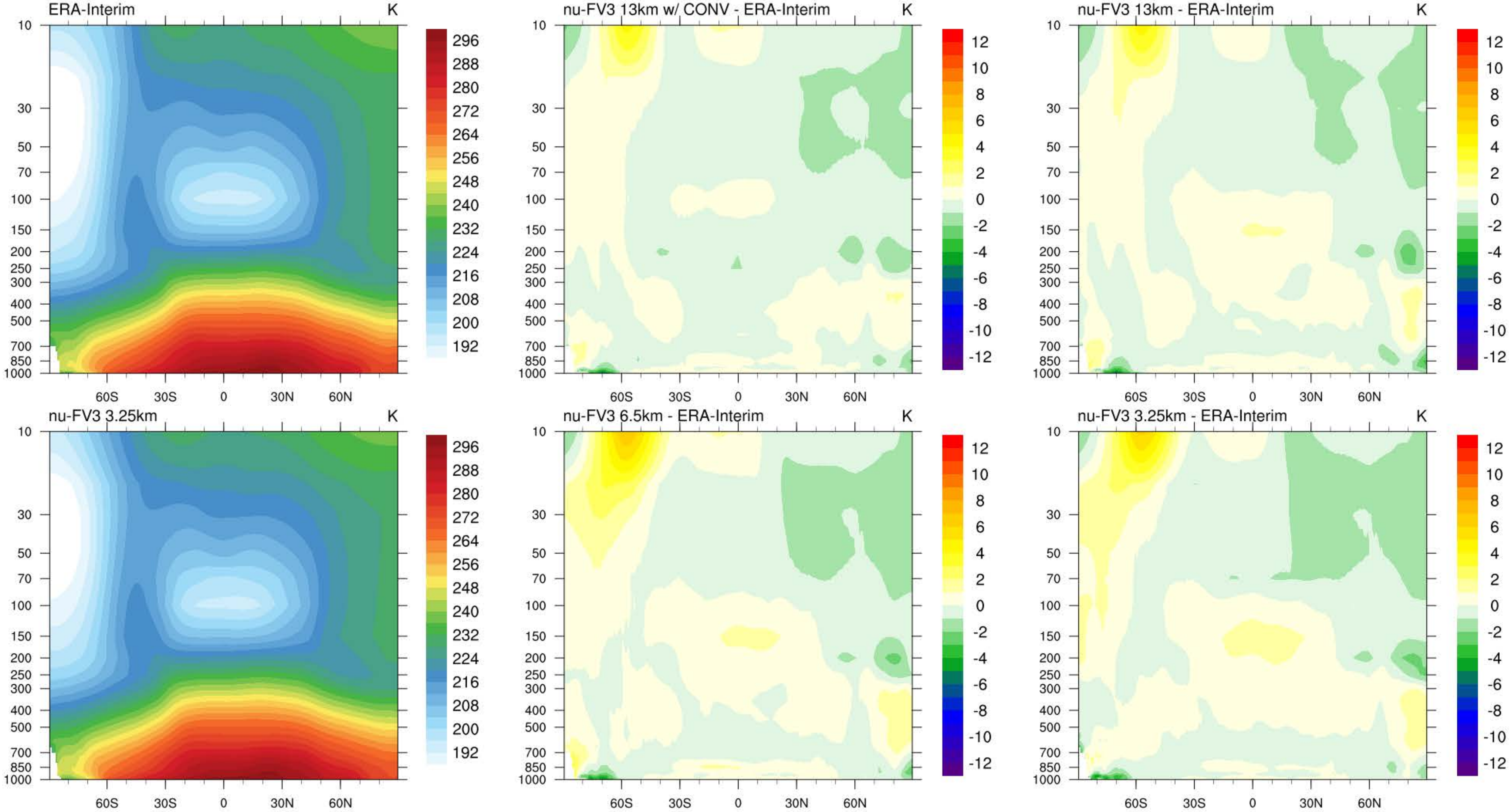

13-km with deep_conv
Day-5
6.5-km no deep_conv
13-km no deep_conv
3.25-km no deep_conv
2016-08-06 00:00Z
120 Forecast Hours
FV3 13km
Visualization
Xi Chen@FV3 team
FV3 6.5km
FV3 3km

Anomaly Correlation Coefficient (ACC): 500-mb Height

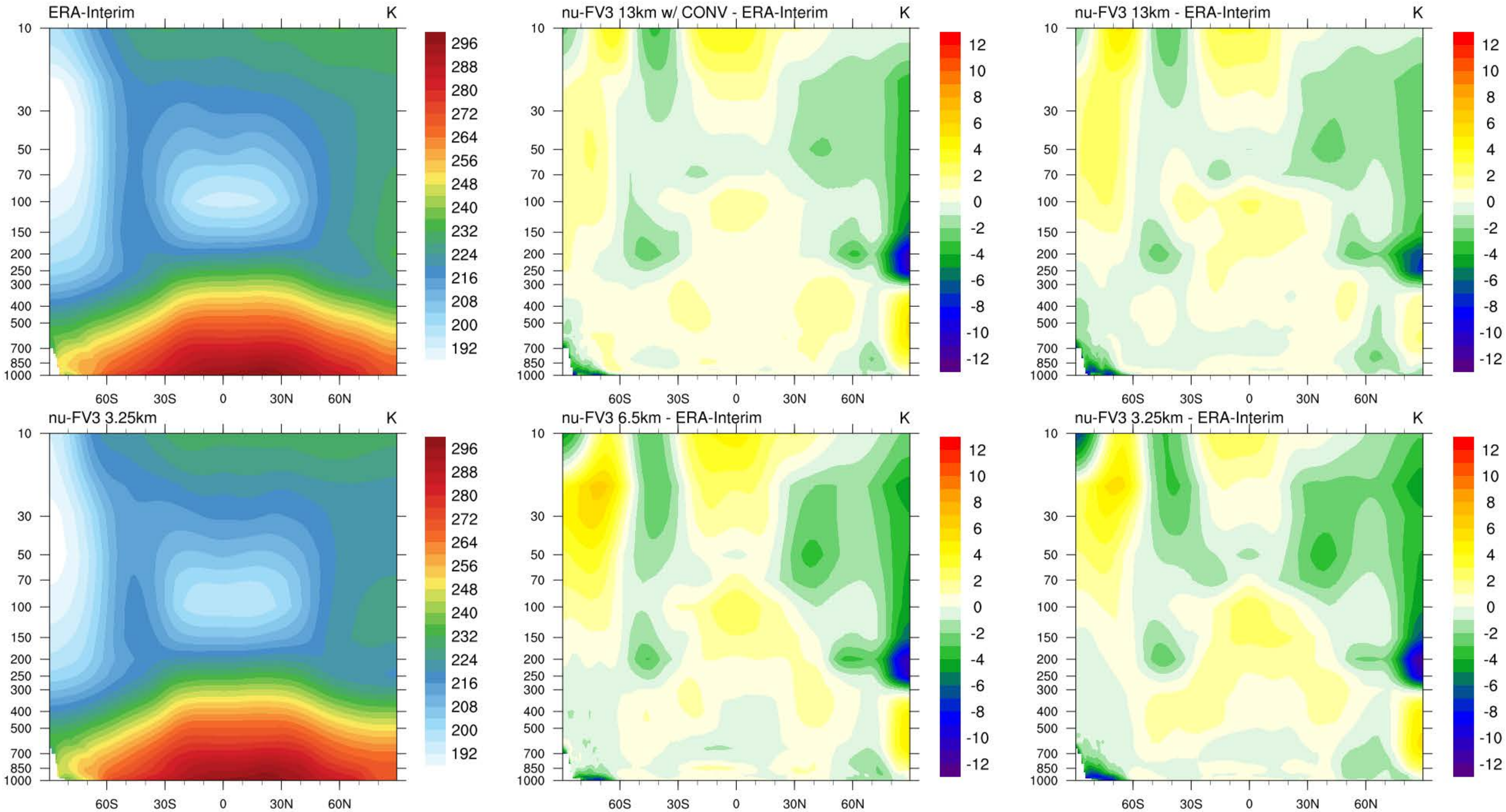


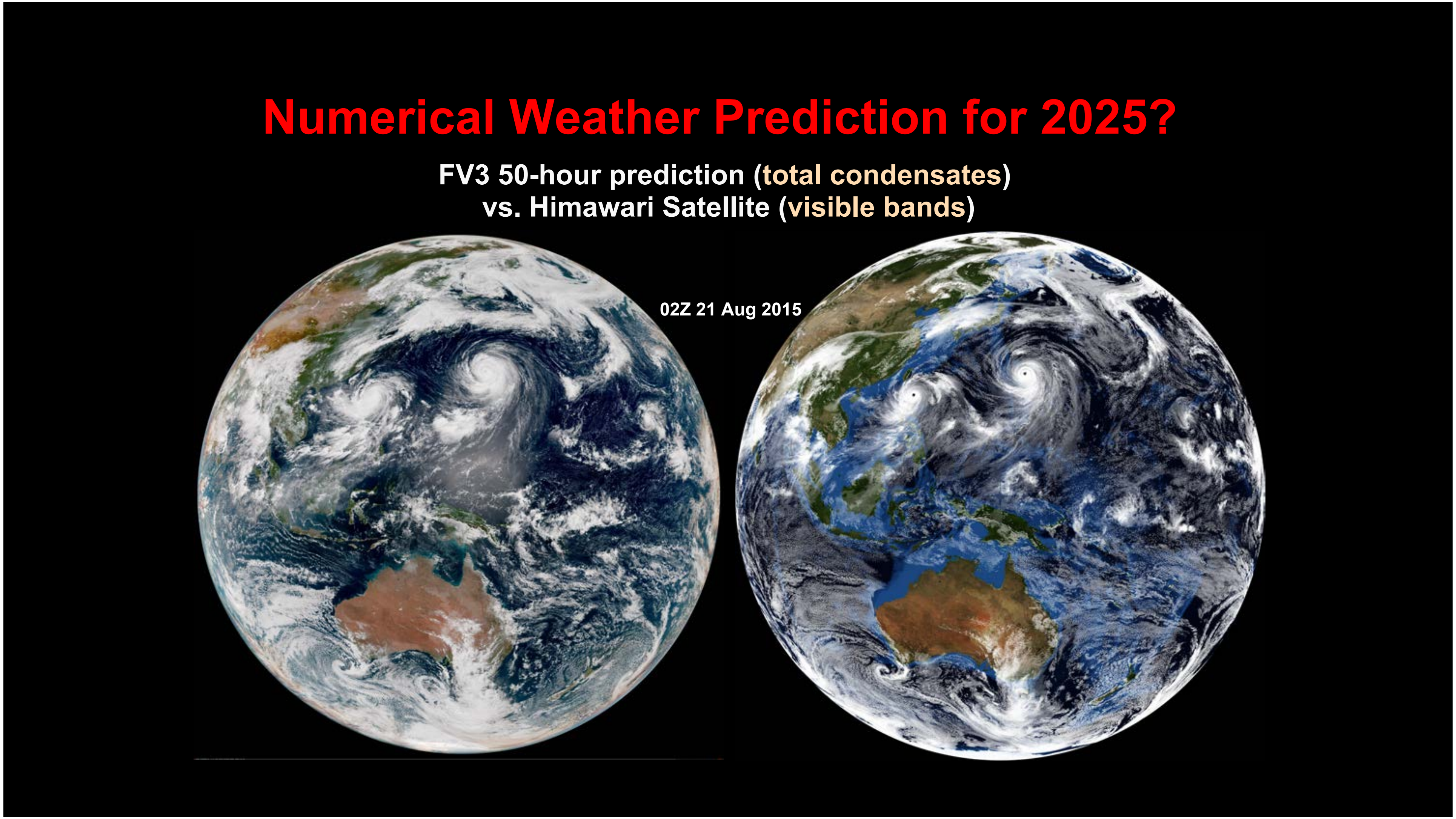
The C1536 (6.5 km) has the smallest bias in 500-mb HGHT over the 40-day period

The first 10 days



The last 30 days



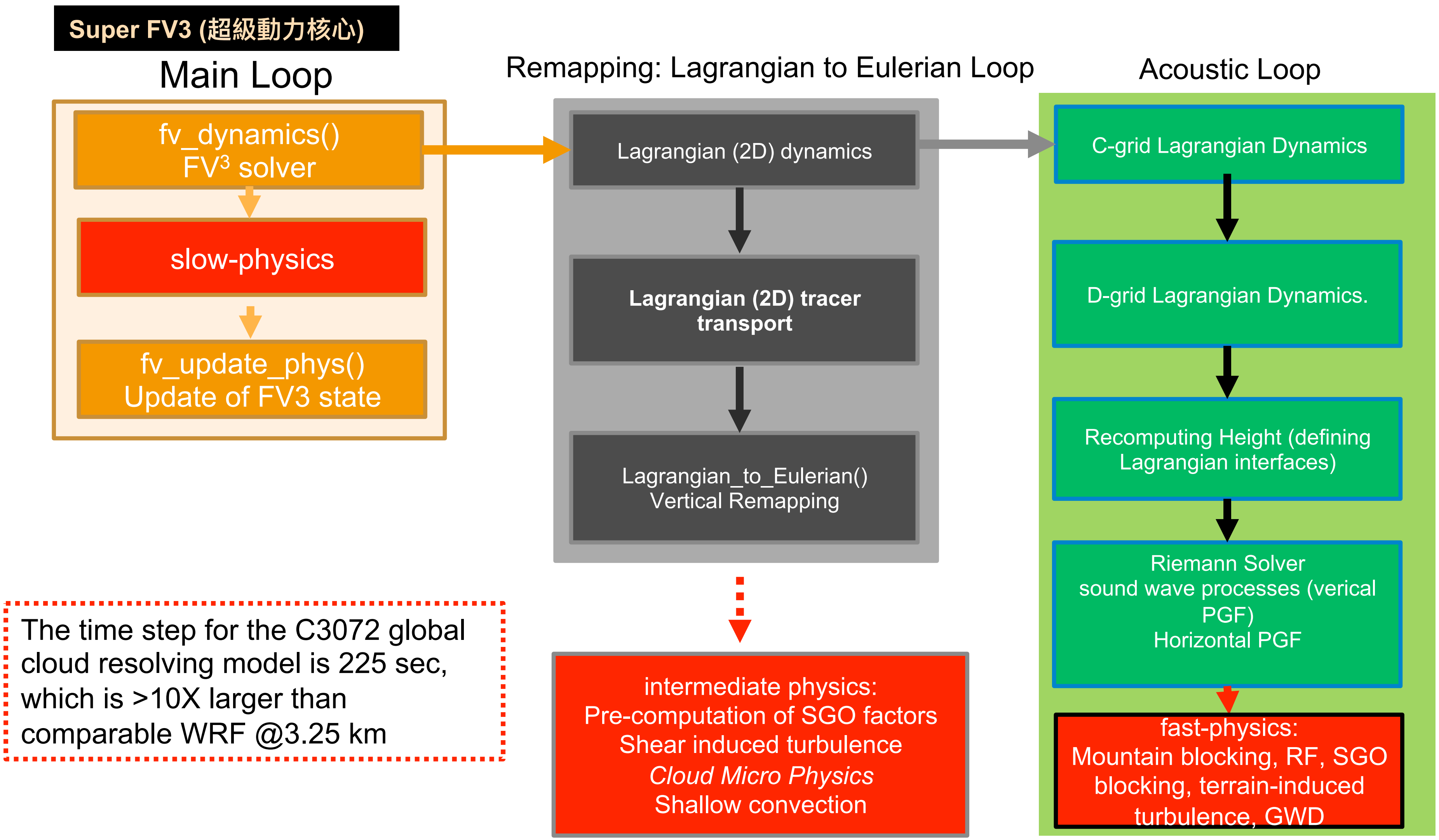

Numerical Weather Prediction for 2025?
FV3 50-hour prediction (total condensates)
vs. Himawari Satellite (visible bands)
02Z 21 Aug 2015

Summary:

- ❑ To unify weather-climate modeling systems, we've recently developed a nearly self-contained modeling framework: a FV3 based "super dynamics" with built-in Sub-Grid physics for gray-zone (1-10 km)

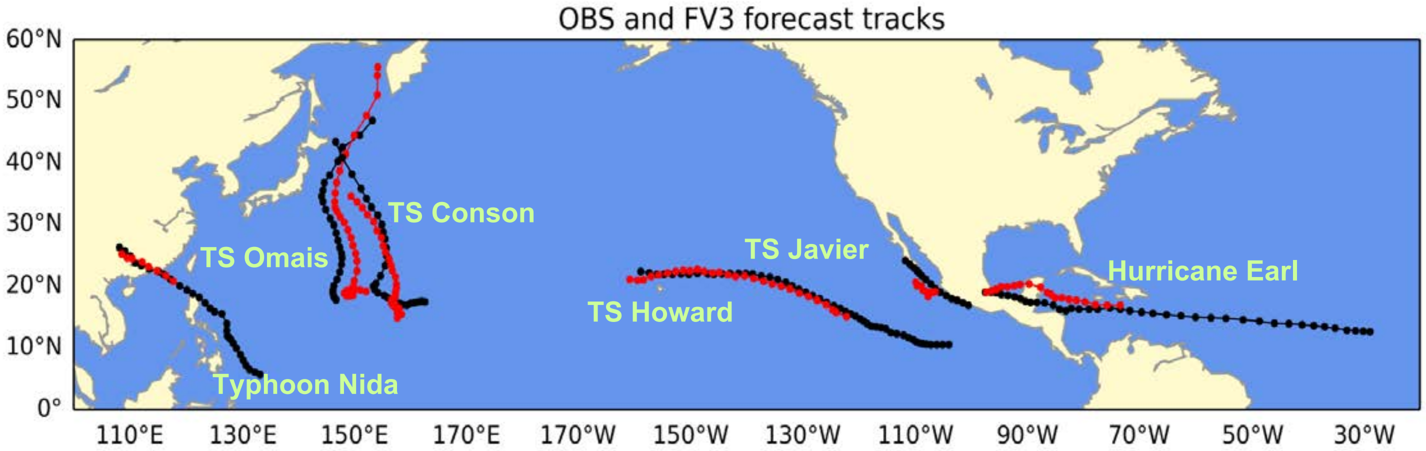
- ❖ We evaluated the new modeling system at three different horizontal resolution across the gray-zone (13, 6.5, and 3.25 km).

- ❖ At 6.5 (or finer) resolution the model appears to be sufficiently resolving tropical deep convection, and would be a good candidate for S2S due to its scientific & computational performance.
  Computational performance: to finish a 40-day sub-seasonal prediction, it takes under 6 hours with ~55K cores(Cray XC40)


Super FV3 (超級動力核心)
Main Loop
fv_dynamics()
FV³ solver
slow-physics
fv_update_phys()
Update of FV3 state
Remapping: Lagrangian to Eulerian Loop
Lagrangian (2D) dynamics
Lagrangian (2D) tracer transport
Lagrangian_to_Eulerian()
Vertical Remapping
intermediate physics:
Pre-computation of SGO factors
Shear induced turbulence
Cloud Micro Physics
Shallow convection
Acoustic Loop
C-grid Lagrangian Dynamics
D-grid Lagrangian Dynamics.
Recomputing Height (defining Lagrangian interfaces)
Riemann Solver
sound wave processes (verical PGF)
Horizontal PGF
fast-physics:
Mountain blocking, RF, SGO blocking, terrain-induced turbulence, GWD
The time step for the C3072 global cloud resolving model is 225 sec, which is >10X larger than comparable WRF @3.25 km

TCs forecasts in the first 10-day

C1536 (6.5 km)



WP: Typhoon Nida:
2016/07/29-08/03
TS Omais:
2016/08/02-08/09
TS Conson:
2016/**08/07**-08/15

EP: TS Javier:
2016/**08/07**-08/09
TS Howard:
2016/07/31-08/03

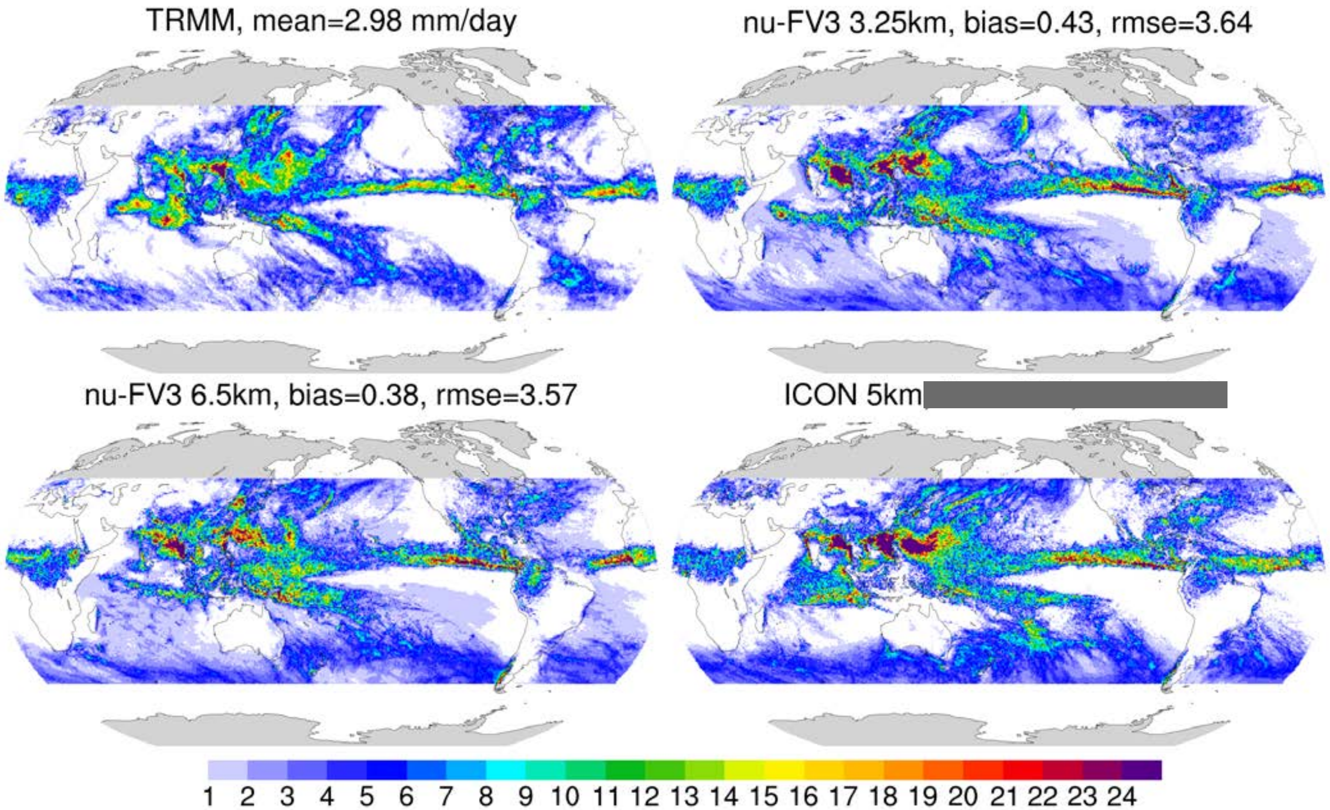
AL: Hurricane Earl:
2016/08/02-08/06

Computational requirements for 40-day sub-seasonal predictions

Configurations	Resolution (km)	Time Step (seconds)	Cores (Cray XC40)	Wall Time (hours)
C1536_L79	6.5	225	6,912	47.6
C1536_L79	6.5	225	55,296	6 (estimated)
C3072_L79	3.25	225	13,824	50
C3072_L79	3.25	225	110,592	6 (estimated)

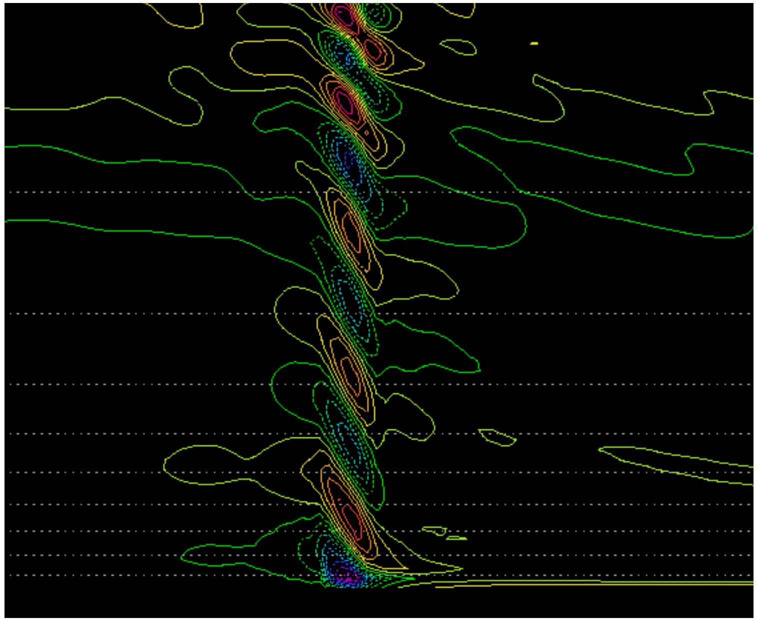
Storage: for each C3072_L79 (3.25 km) 40-day experiment, the total size of output is **~100 TB** (Output frequency: 15-min for 2D, 3-hr for 3D fields)

Million-core scalability: hybrid MPI, OpenMP, and hyper-threading (on Intel chip)

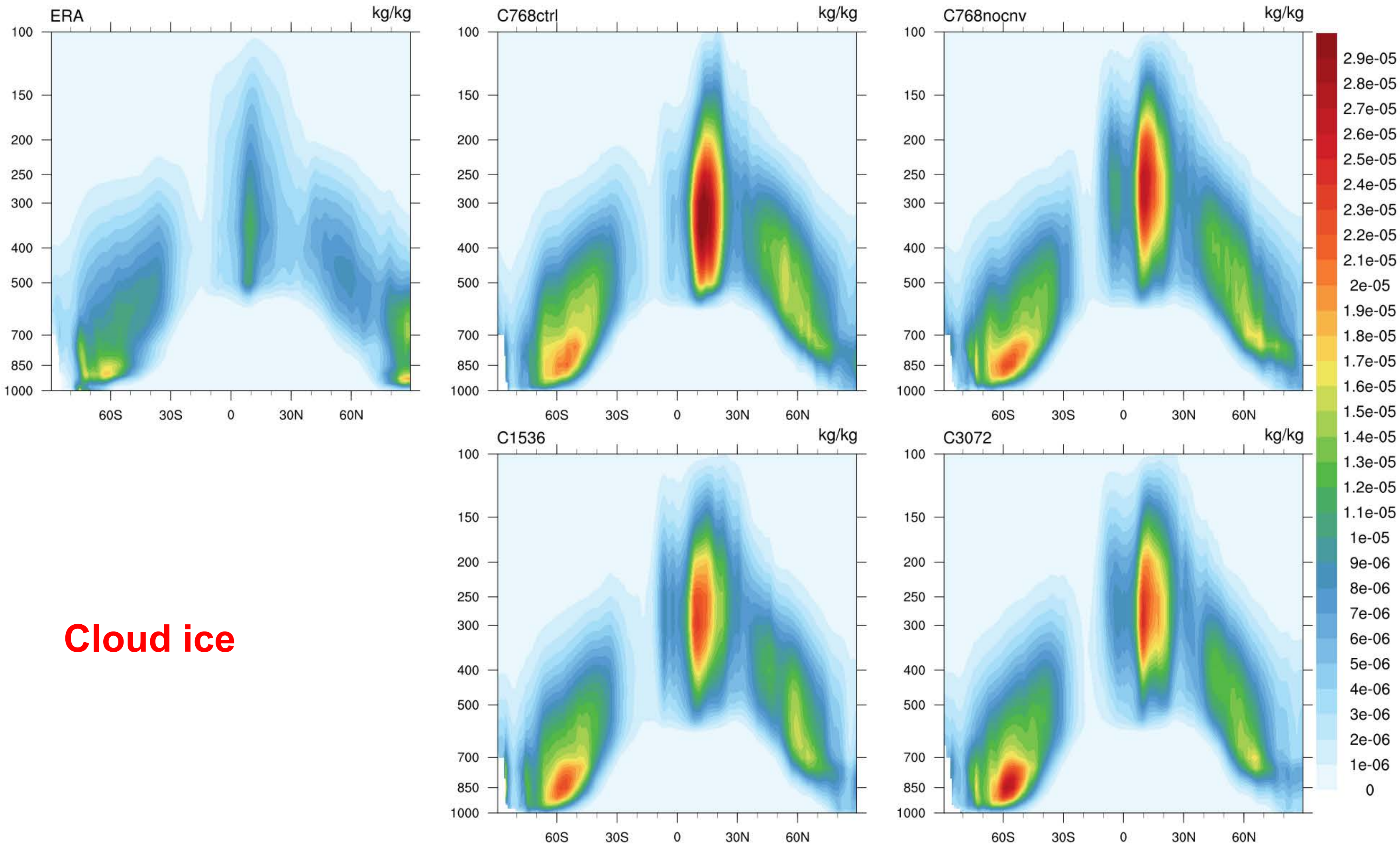

TRMM, mean=2.98 mm/day
nu-FV3 3.25km, bias=0.43, rmse=3.64
nu-FV3 6.5km, bias=0.38, rmse=3.57
ICON 5km [redacted]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

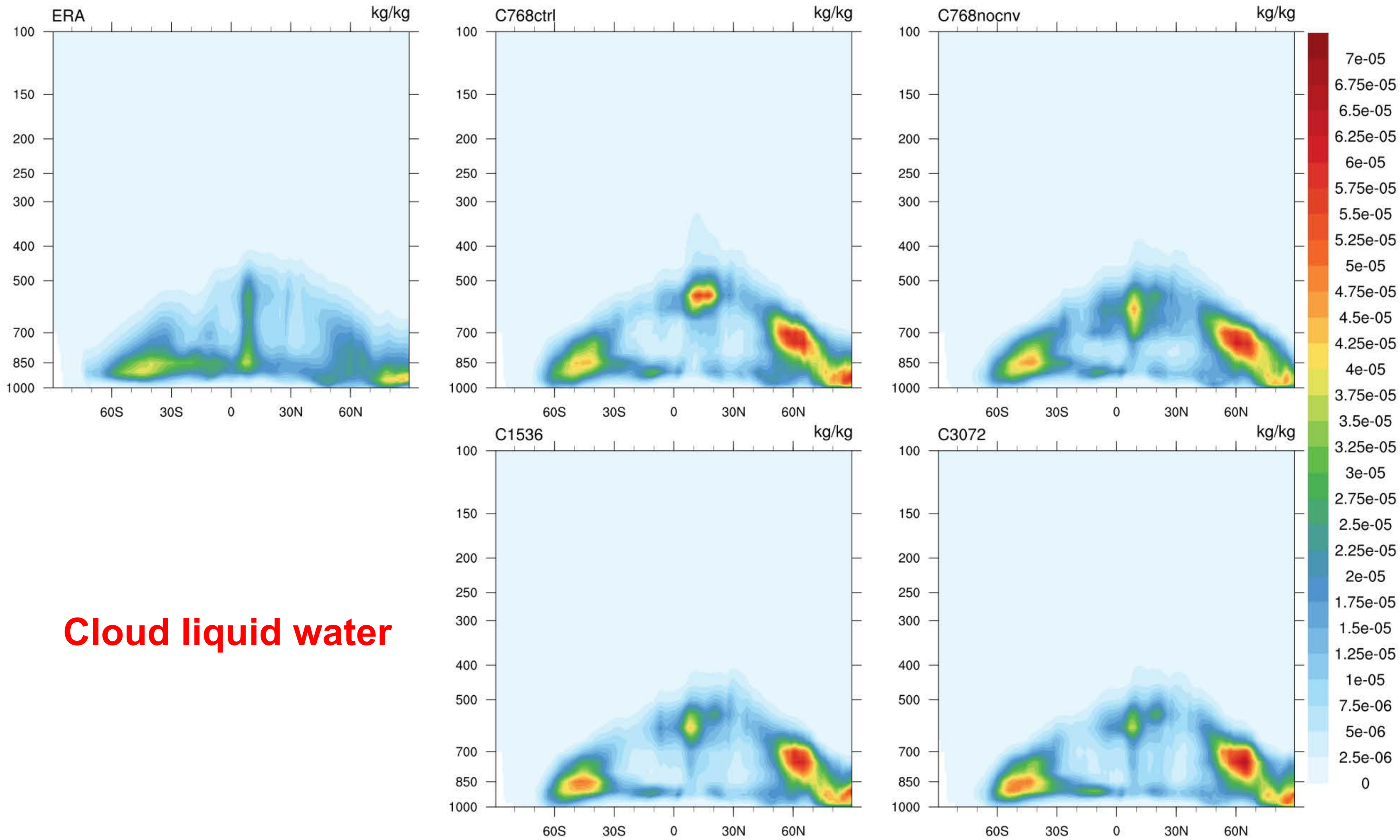
Testing the built-in SGO "mountain blocking"

Simulated mountain waves via built-in SGO in super FV3



- Idealized test: isothermal atmosphere with the Sub-Grid Orography assumed to be a "sine-wave". Therefore, the mean terrain is identically ZERO
- Forced by a constant u-wind above the SGO

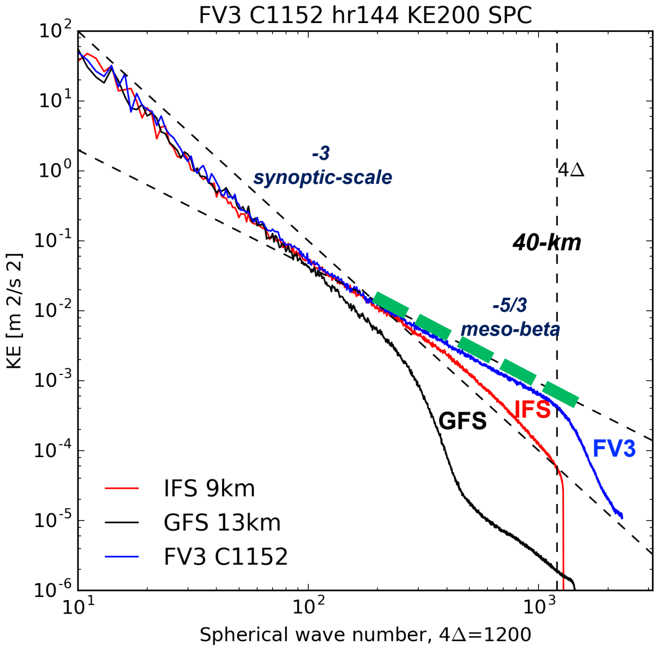

ERA
C768ctrl
C768nocnv
C1536
C3072
kg/kg
100
150
200
250
300
400
500
700
850
1000
60S
30S
0
30N
60N
2.9e-05
2.8e-05
2.7e-05
2.6e-05
2.5e-05
2.4e-05
2.3e-05
2.2e-05
2.1e-05
2e-05
1.9e-05
1.8e-05
1.7e-05
1.6e-05
1.5e-05
1.4e-05
1.3e-05
1.2e-05
1.1e-05
1e-05
9e-06
8e-06
7e-06
6e-06
5e-06
4e-06
3e-06
2e-06
1e-06
0
Cloud ice



Cloud liquid water

- **How well do ECMWF-IFS (9-km), NCEP-GFS (13-km), and FV3-GFS (9-km) actually resolve the mesoscale?**

200-mb KE spectra



- FV3 at C1152 (9-km) near perfectly represents the"-5/3" meso-beta (20-200 km) spectrum
- The IFS has lower energy in the meso-scale; but it does follow "-3" spectrum (synoptic scale) well
- The GFS has the least amount of energy in the mesoscale (3 orders of magnitude smaller than FV3 and the theoretical value)

FV3: physically representing the atmosphere by finite control-volumes

1. Vertically Lagrangian control-volume discretization (Lin 2004)
   - Conservation laws solved for the control-volume bounded by two Lagrangian surfaces

2. Physically based forward-in-time "horizontal" transport (only "2D" between two Lagrangian surfaces)
   - Locally conservative and (optionally) monotonic via constraints on sub-grid distributions (Lin & Rood 1996; Putman & Lin 2007) – particularly good for aerosols and cloud micro-physics
   - Space-time discretization is non-separable -- hallmark of a physically based FV algorithm

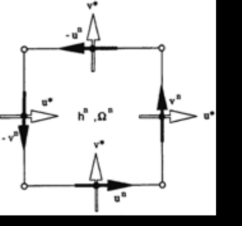
3. Combined use of C & D staggering with optimal **Potential Vorticity** advection and **Helicity** representation

→ important from TC-permitting (100-km) to tornado-permitting (1-km) scale

4. Finite-volume integration of pressure forces (Lin 1997)
   - Analogous to the forces acting upon an aircraft wing (lift & drag forces)
   - Horizontal and vertical influences are non-separable

5. Non-hydrostatic extension: the vertically Lagrangian discretization reduces the sound-wave solver into a 1-D problem (solved by either a Riemann-Invariant method or a semi-implicit solver)

The FV3's C-D grid works like 陰-陽



Helicity