



High Performance Computing
CLUSTERTECH

Using hierarchical time-stepping to utilize MPAS-A computational resources for customized extreme variable-resolution meshes

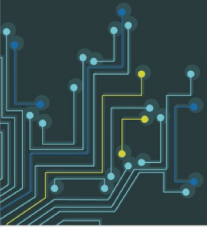
Ng, Ka-Ki

Senior Software Engineer, ClusterTech Limited

11 Jun 2019

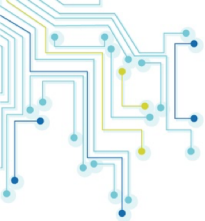
Roadmap

1. Background
2. Introducing CPAS
3. Verification
4. Custom Mesh Example
5. Conclusions



Background



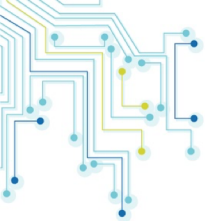


Background

- Want high-resolution regional/local weather forecasts
- Have limited computational resources
- Impractically high computational cost of running MPAS with high resolution in some regions (extreme resolution ratios)
 - Global time step is limited by highest resolution areas due to use of a single time step globally (CFL condition)

Our Objective

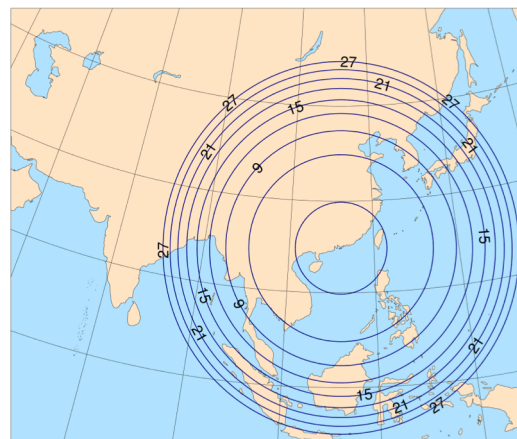
- Make it practical and convenient to use MPAS-A for regional forecasting with extreme resolution ratios



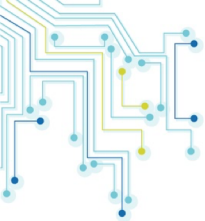
Challenges

- Enable the use of different time step sizes across the global simulation
 - Variable time steps needed with extreme resolution ratios
 - Solution: use Hierarchical Time-Stepping (HTS)
- Efficiently generate a grid with global coverage with desired resolution in the desired areas
 - Solution: A convenient UI backed up by an intelligent grid generation algorithm

Mesh resolution for MPAS-A 60-3km mesh



CONTOUR FROM 3 km to 27 km

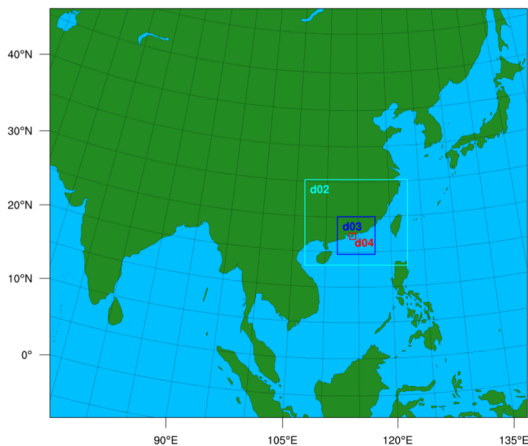


Bridging WRF and MPAS-A

WRF

- Uses an appropriate time-step for each nested domain

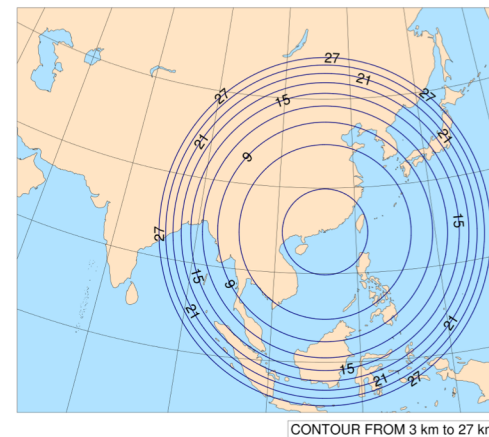
WRF Domain Configuration



MPAS-A

- Global coverage with variable resolution without abrupt change in mesh spacing

Mesh resolution for MPAS-A 60-3km mesh



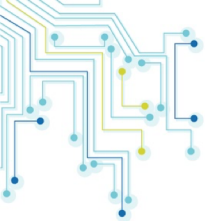
CPAS



**CPAS: The ClusterTech Platform
for Atmospheric Simulation**

Introducing CPAS



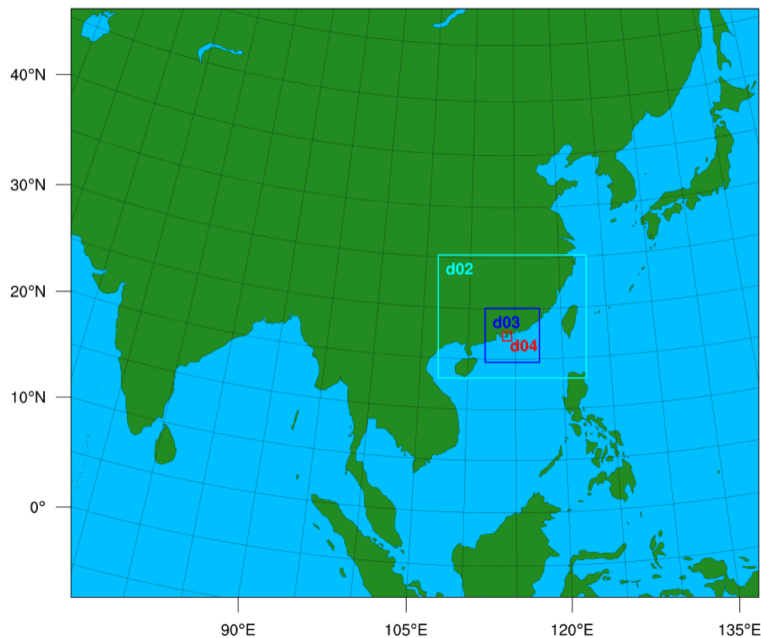


Example from WRF domain

WRF

- Appropriate time-step for each grid size in each nested domain
- e.g. 27km - 9km - 3km - 1km

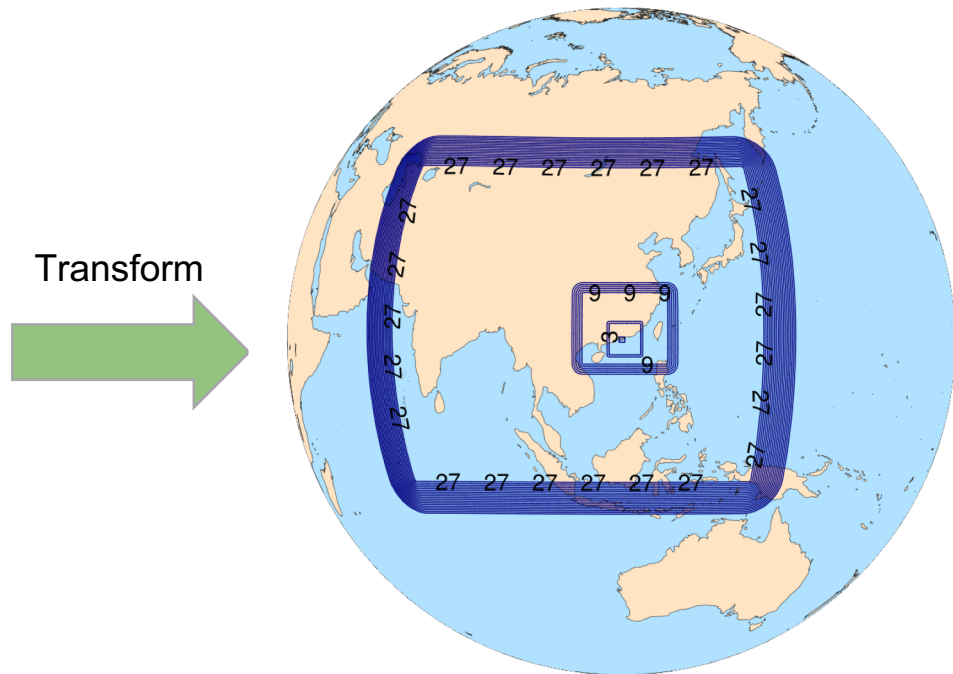
WRF Domain Configuration

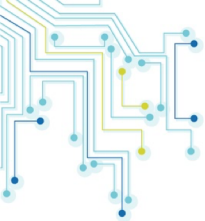


CPAS

- Global coverage with smooth transitions from 160km to 27km - 9km - 3km - 1km in corresponding regions

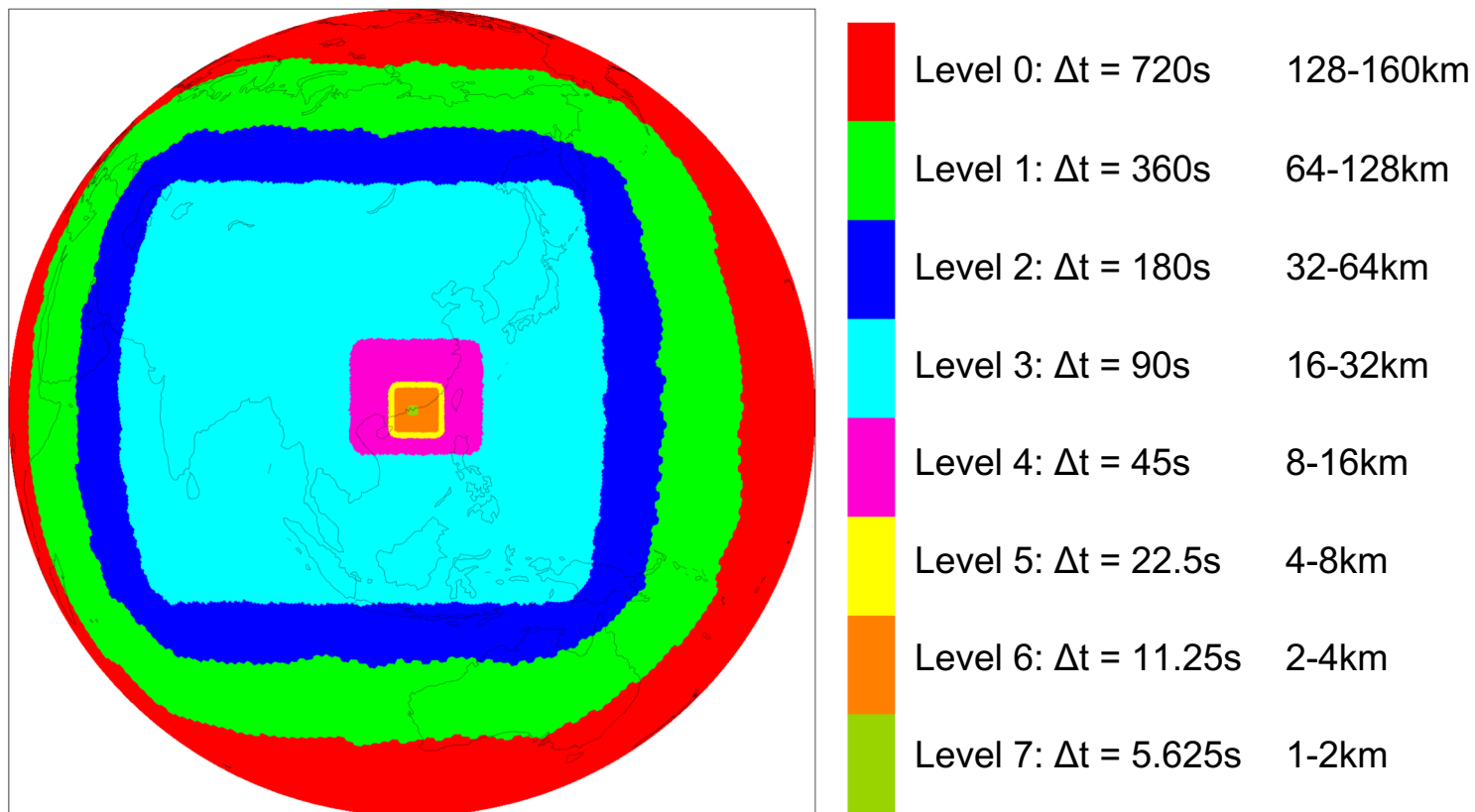
Approximate mesh resolution (km)

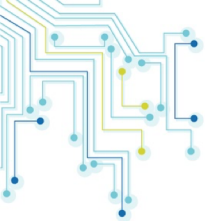




CPAS: Hierarchical time-stepping (HTS)

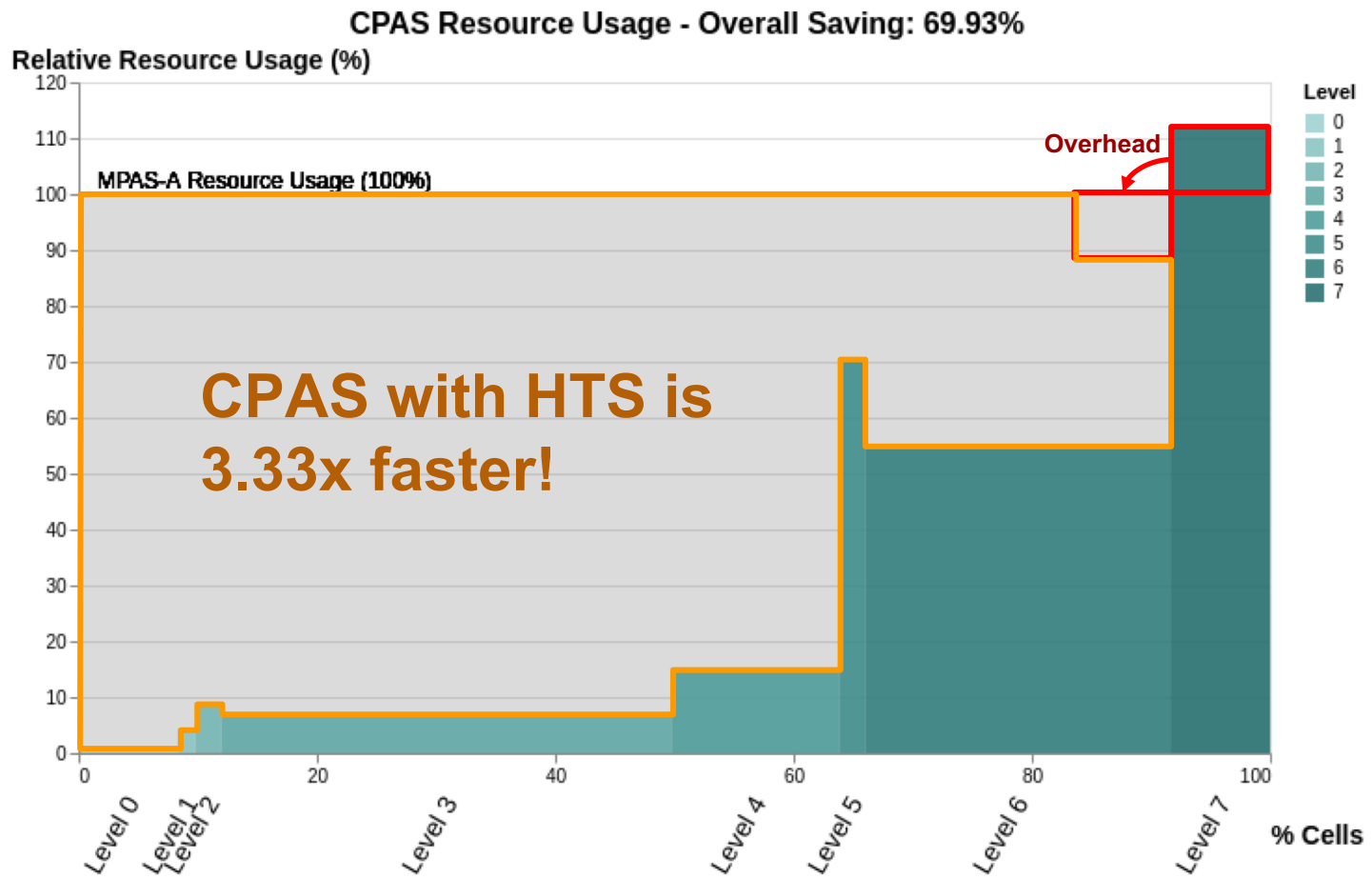
- Partition the mesh into regions
 - Use different time-steps depending on cell size (extreme resolution ratio of 160:1)

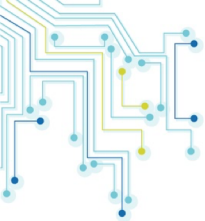




CPAS vs. MPAS: Estimated Resource Savings

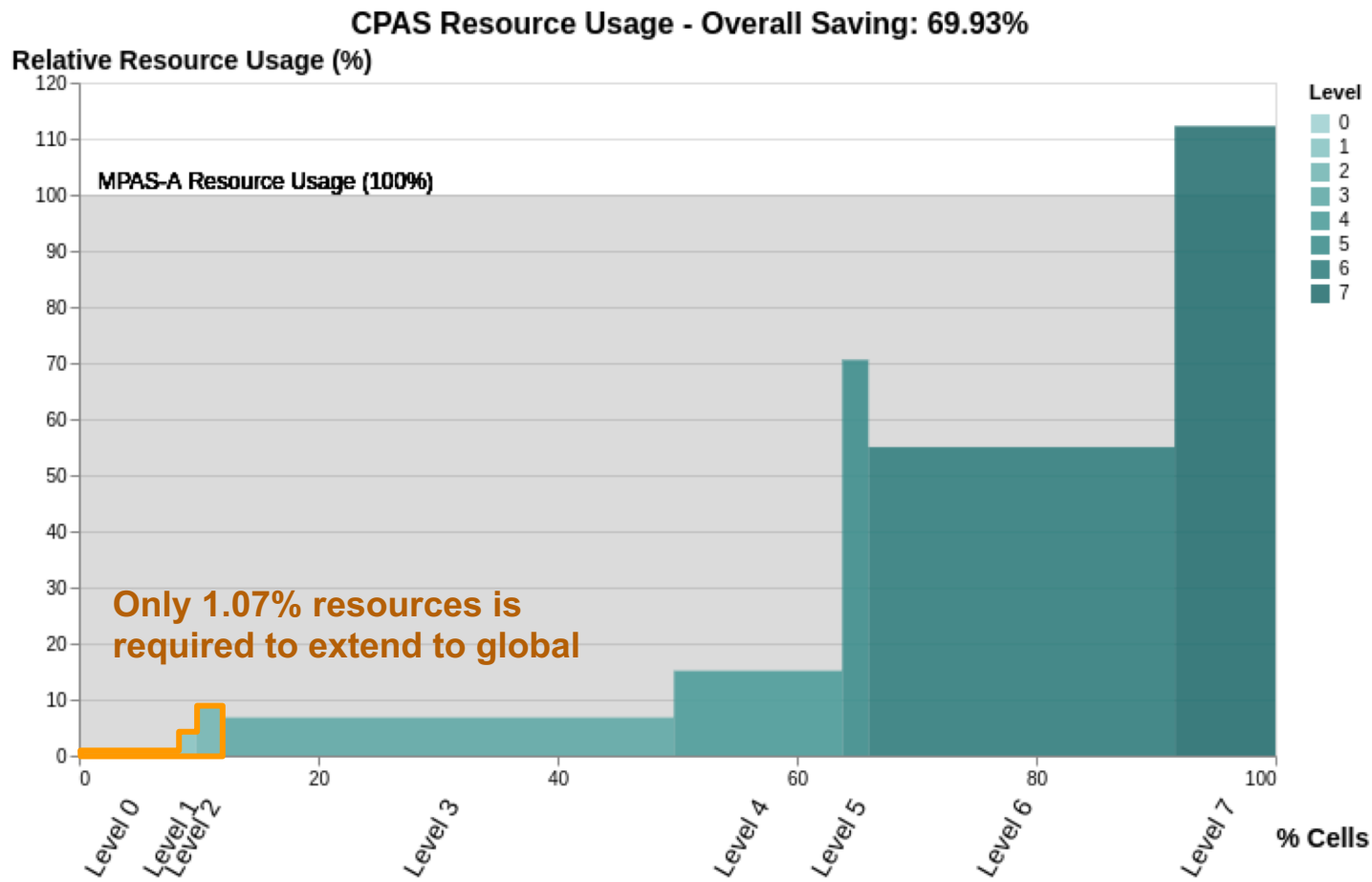
- Reduce resource usage in CPAS after applying HTS





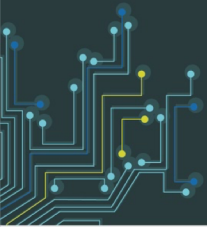
CPAS: Regional Forecast with Global Coverage

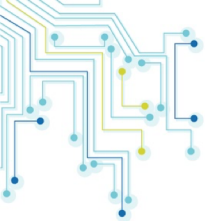
- We can run global model for regional forecast



Verification

(Comparing Results of CPAS and MPAS-A)

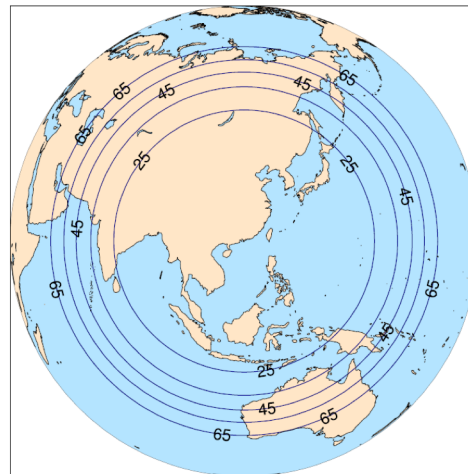




Verification with MPAS Official Meshes

- Use 2 variable-resolution meshes on MPAS' official website to verify forecast results using CPAS with HTS
 - 92-25km variable-resolution mesh (163842 cells)
 - 60-3km variable-resolution mesh (835586 cells)

MPAS Global 92-25km Mesh

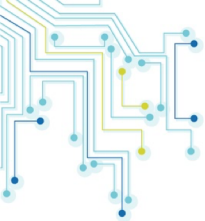


CONTOUR FROM 25 TO 65 BY 10

MPAS Global 60-3km Mesh

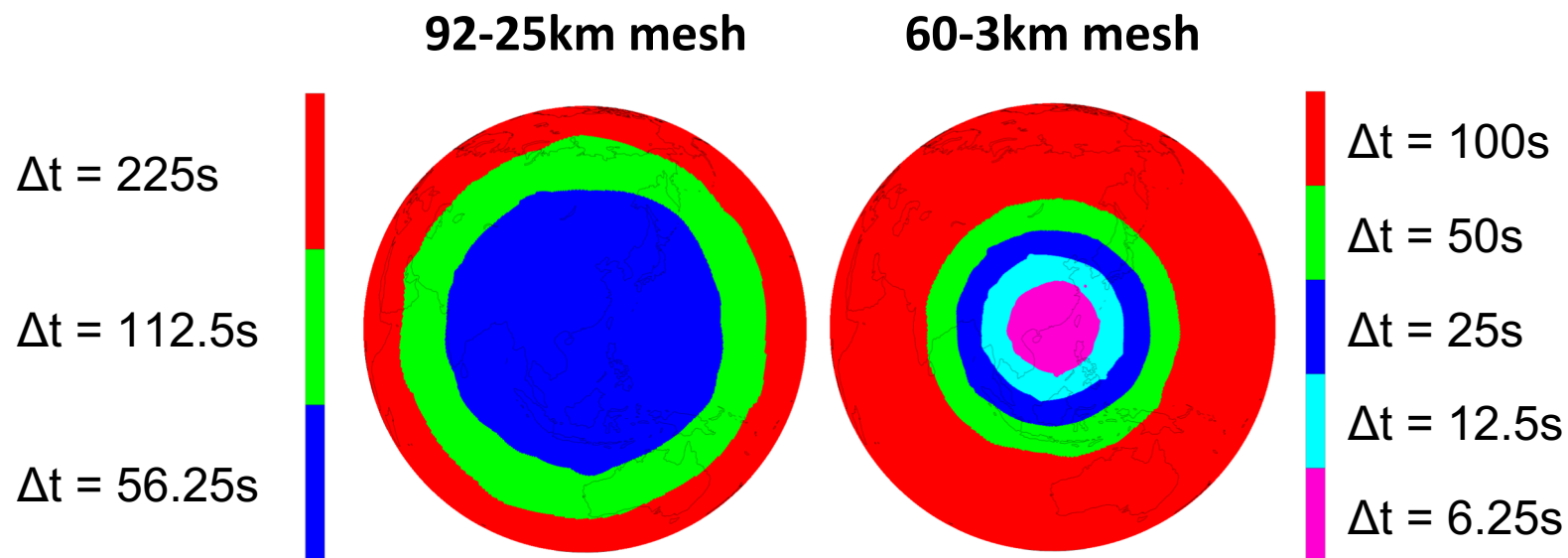


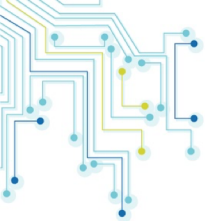
CONTOUR FROM 3 TO 57 BY 6



CPAS: Hierarchical Time-Stepping (HTS)

- Use 2 variable-resolution meshes on MPAS' official website to verify forecast results using CPAS with HTS
 - 92-25km mesh is partitioned into 3 levels
 - 60-3km mesh is partitioned into 5 levels

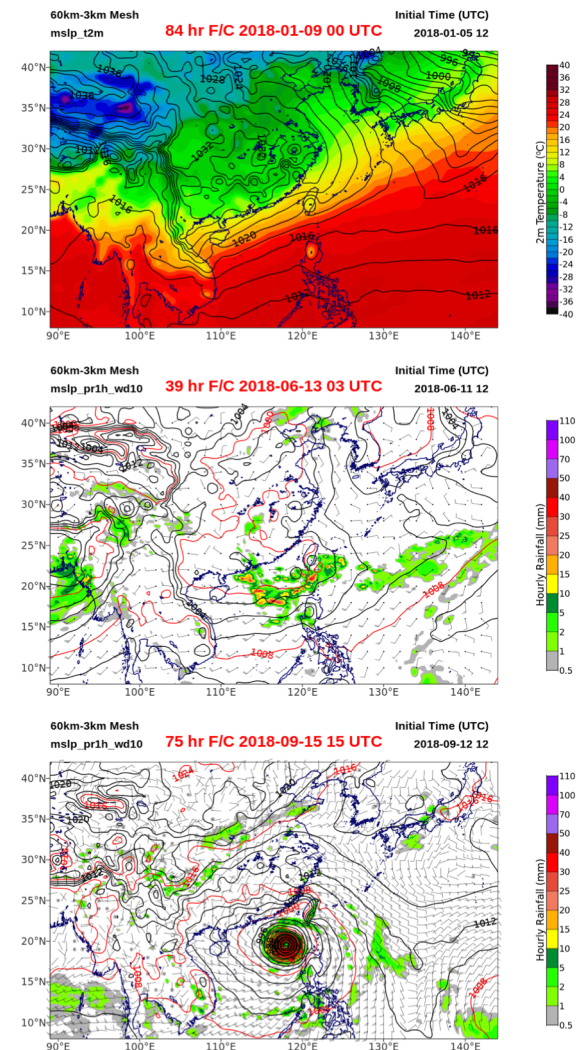




Case Comparison

CPAS (HTS) vs MPAS-A

- 5.5-day simulation
- GFS initial conditions
- **Case 1**
 - Cold front
 - 8 Jan 2018 (Winter)
- **Case 2**
 - Heavy rainfall
 - 13 Jun 2018 (Summer)
- **Case 3**
 - Tropical cyclone
 - 16 Sep 2018 (Autumn)



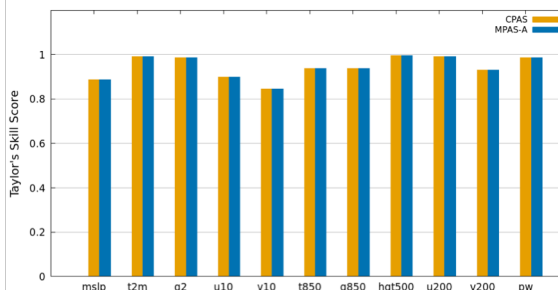
Skill Score (FNL Reanalysis)

● Case 1

- Cold front
- 8 Jan 2018 (Winter)

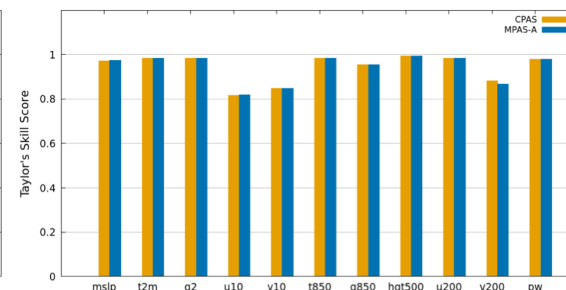
92-25km mesh

CPAS (HTS) vs MPAS-A (non-HTS)



60-3km mesh

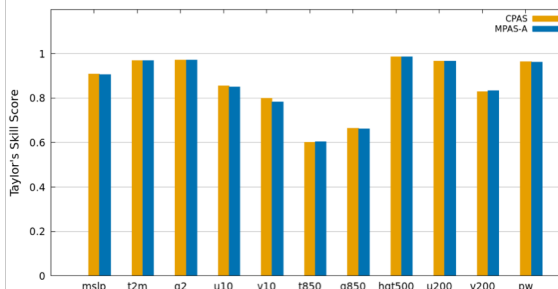
CPAS (HTS) vs MPAS-A (non-HTS)



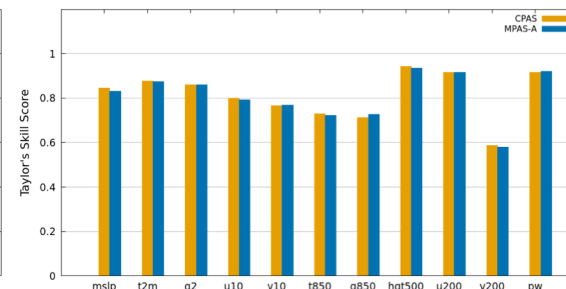
● Case 2

- Heavy rainfall
- 13 Jun 2018 (Summer)

CPAS (HTS) vs MPAS-A (non-HTS)



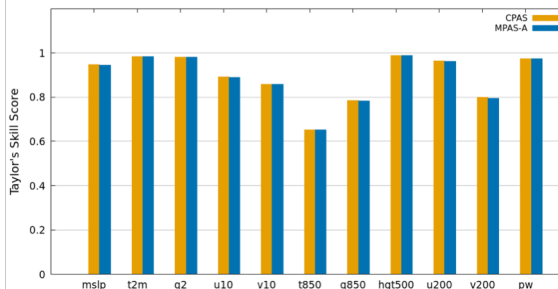
CPAS (HTS) vs MPAS-A (non-HTS)



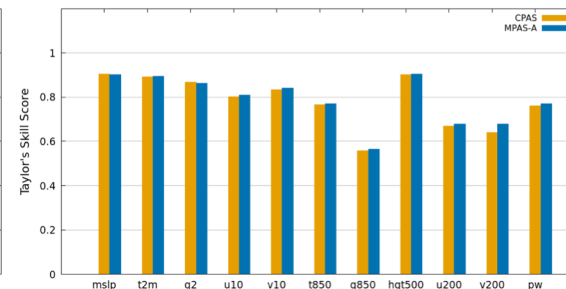
● Case 3

- Tropical cyclone
- 16 Sep 2018 (Autumn)

CPAS (HTS) vs MPAS-A (non-HTS)



CPAS (HTS) vs MPAS-A (non-HTS)

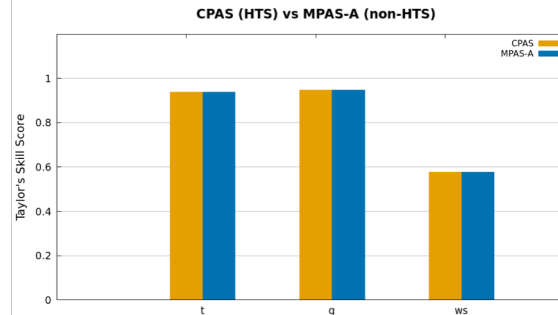


Skill Score (WMO stations)

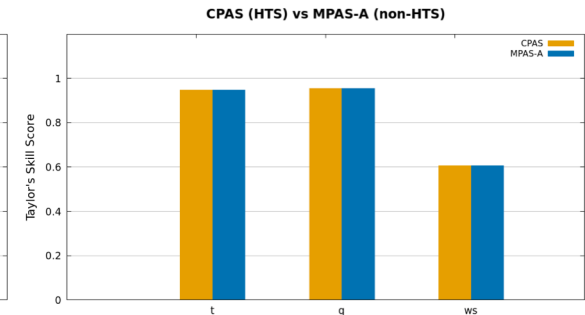
● Case 1

- Cold front
- 8 Jan 2018
(Winter)

92-25km mesh

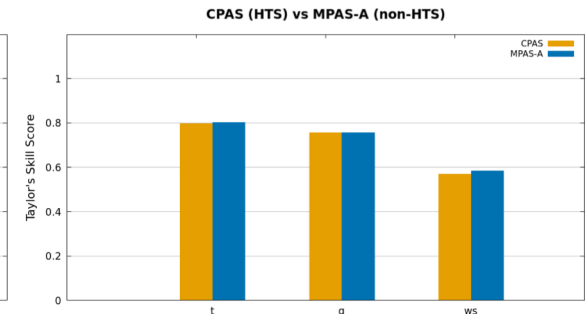
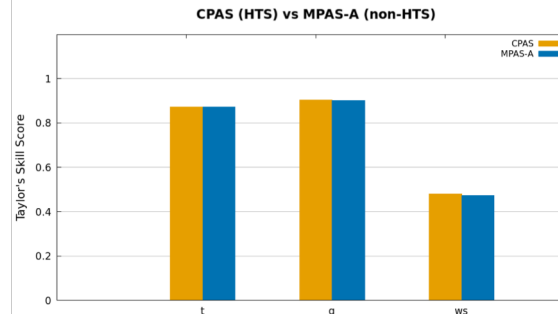


60-3km mesh



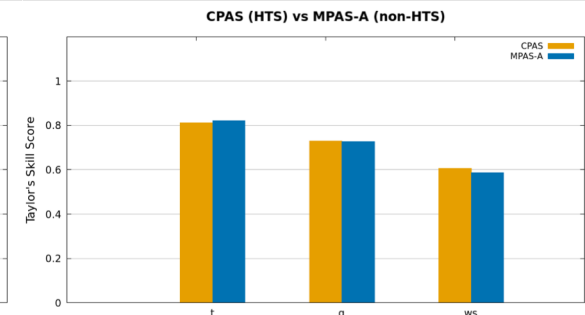
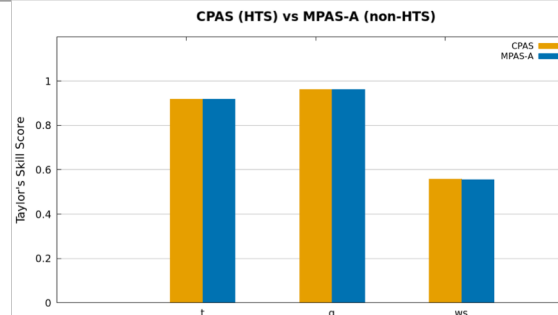
● Case 2

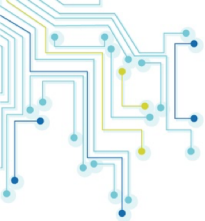
- Heavy rainfall
- 13 Jun 2018
(Summer)



● Case 3

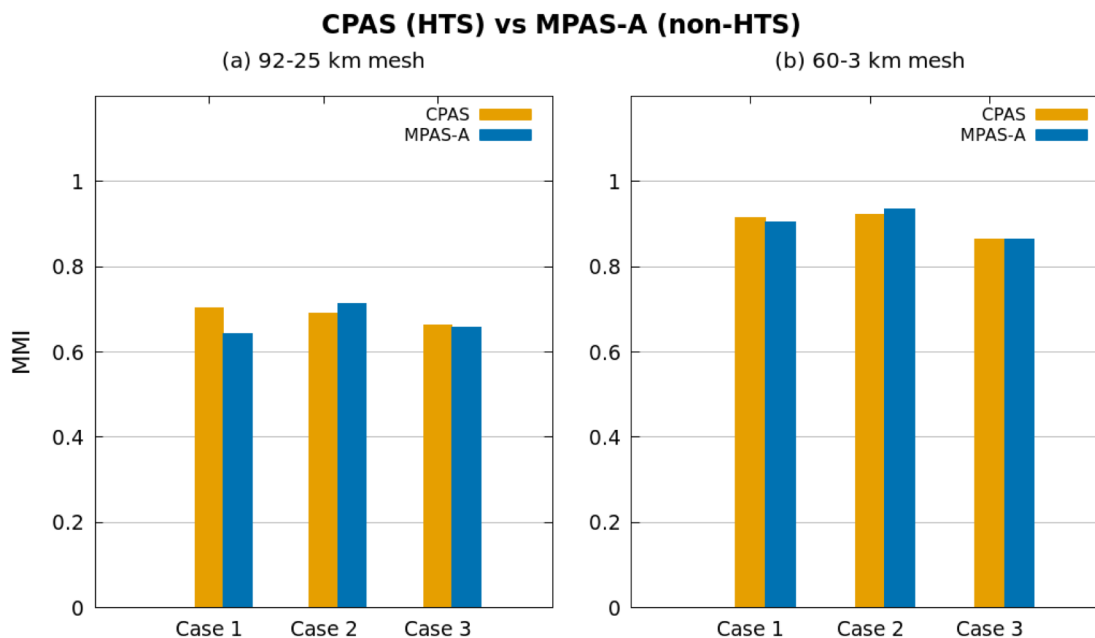
- Tropical cyclone
- 16 Sep 2018
(Autumn)

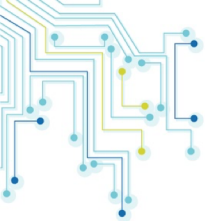




Precipitation (TRMM)

- Precipitation comparison with TRMM
 - Median of Maximum Interest value (MMI) evaluated by Method for Object-Based Diagnostic Evaluation (MODE)

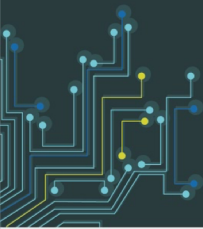


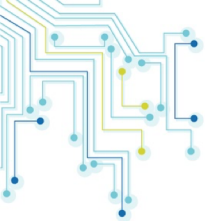


Comparison Results

- CPAS (with HTS), using less computational resources, generates results comparable to MPAS-A at the same resolutions

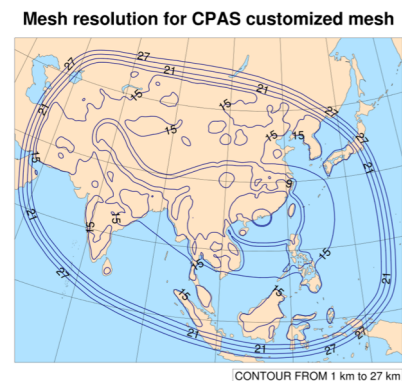
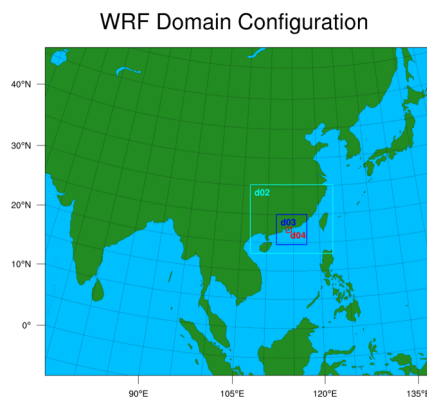
Customized Mesh Example

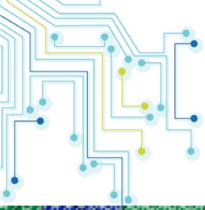




CPAS Advantages: Customized Mesh design

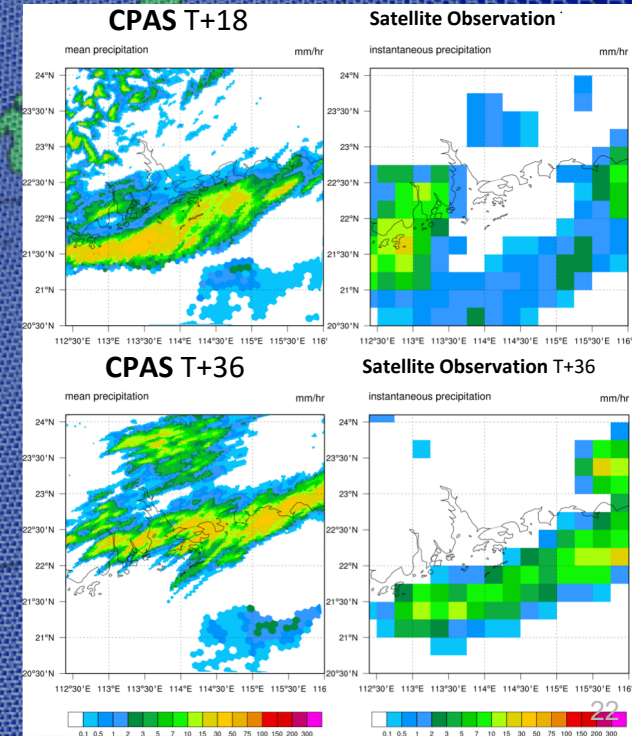
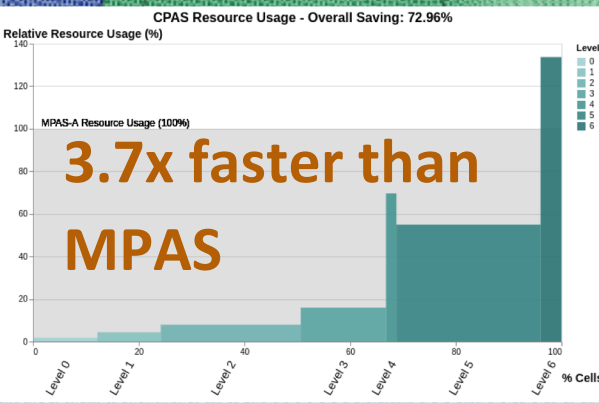
- **CPAS high resolution regions can be arbitrarily shaped**
 - WRF nested domains have limitations on shape and size
- **CPAS enables customized meshes for regional forecasts**
 - Extreme local refinement for target area (~1km)
 - Boost resolution to better resolve:
 - Nearby terrain and coastline
 - Regions with weather affecting target area
- **CPAS comes with tools for convenient mesh generation**
 - Convenient UI backed up by intelligent algorithm

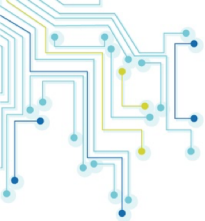




CPAS Customized Mesh Example

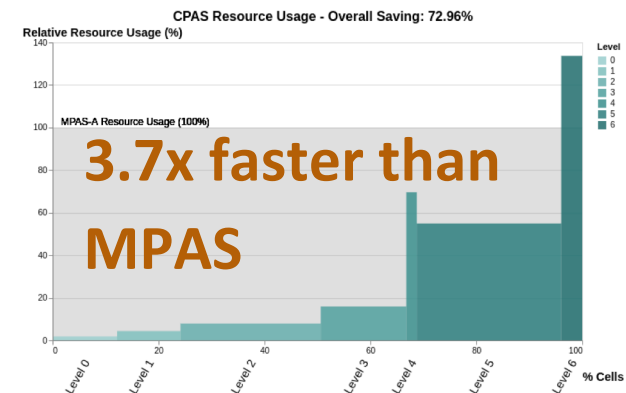
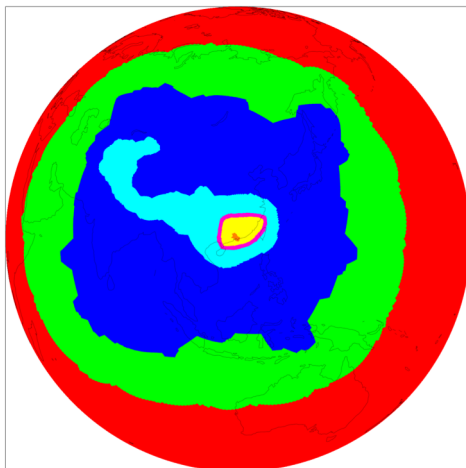
- 160-1km mesh (x160)
 - 1km resolution around target area (Hong Kong)
 - Increased resolution around target area (coastline & mtns)
 - Boost resolution to better resolve Himalayas

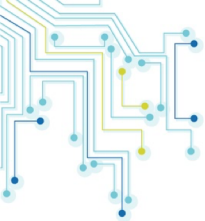




Summary of CPAS with HTS

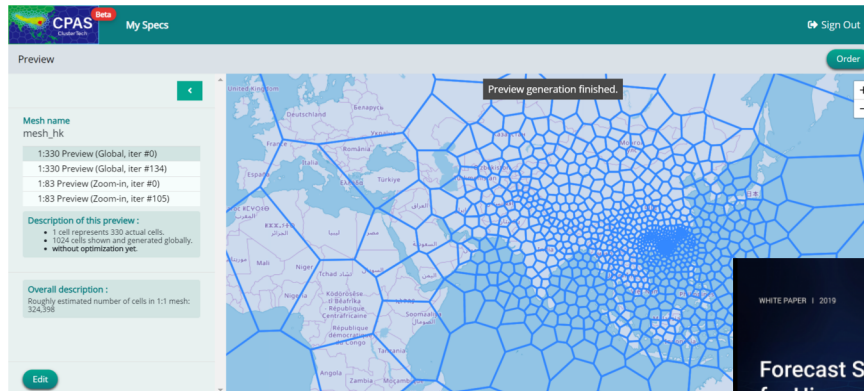
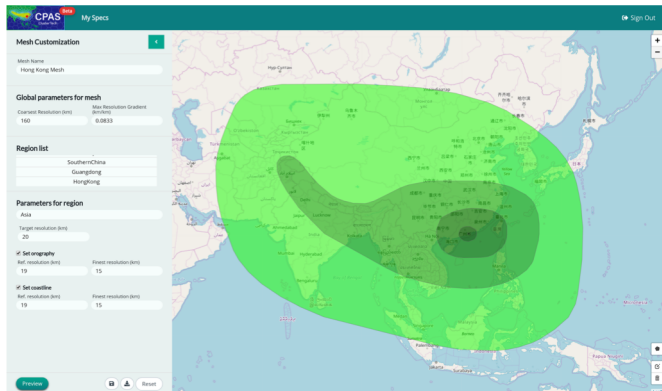
- **HTS speeds up simulation while giving comparable results**
 - Saves computational resources
 - Especially useful for meshes with extreme resolution ratios
 - Making it practical to use a global model for regional forecast





The ClusterTech Platform for Atmospheric Simulation (CPAS)

- **CPAS cloud service** (<https://cpas.earth>)
 - Mesh generation (Free trial)
 - Simulation with HTS (Coming soon)
 - Visualization (Coming soon)

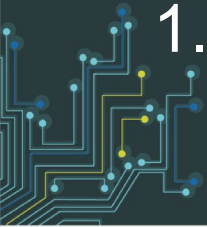


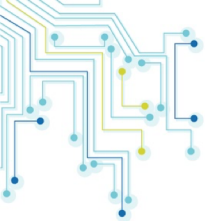
- **More details can be found in whitepaper**
 - <https://cpas.earth/download>
- **Contact:** enquiry@cpas.earth



Conclusions

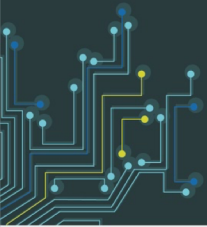
1. CPAS enables fast regional forecasts with global coverage, using extreme resolution ratios.
1. CPAS comes with tools for convenient and intelligent mesh generation to cover regions that need high resolution.
1. Free trial: <https://cpas.earth>

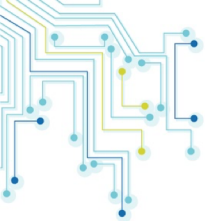




Hierarchical Time-Stepping (HTS)

1. Objective
2. Bridging WRF and MPAS-A
3. Introduction to Hierarchical Time-Stepping (HTS)
4. Saving computational resources
5. Global model for regional forecast





Objective

- **Meshes with extreme refinements**
 - Small time-step for small cell size is required due to CFL condition
 - Use a globally small time-step is too expensive
- **Variable-resolution meshes have wide range of cell size**
 - Small cells requires a small time-step
 - Large cells requires a large time-step only
 - We want to use hierarchical time-stepping (HTS)

