Numerical Weather Prediction at 200-m Local Resolution Based on the Unstructured Grid CPAS Model

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Abstract

The ClusterTech Platform for Atmospheric Simulation (CPAS) model is based on the Model for Prediction Across Scales - Atmosphere (MPAS-A) and enhanced with additional capabilities such as customizable unstructured mesh generation (CUMG) and hierarchical time-stepping (HTS). CPAS supports flexible use with global meshes featuring large resolution ratios, steep resolution transitions, and high-resolution patches as needed, as well as regional meshes, thanks to its rapid mesh generation process.

For high-fidelity hectometric modeling, CPAS incorporates multi-resolution geographic data processing, utilizing terrain data at resolutions as fine as 3 arc-seconds (90 meters) and up-to-date street map coastlines. To address resolution grey zones, CPAS integrates the Shinhong Planetary Boundary Layer scheme along with other scale-aware parameterizations. The CPAS simulation of Super Typhoon Mangkhut's approach to Hong Kong will be presented.

Customizable Unstructured Mesh Generation (CUMG)

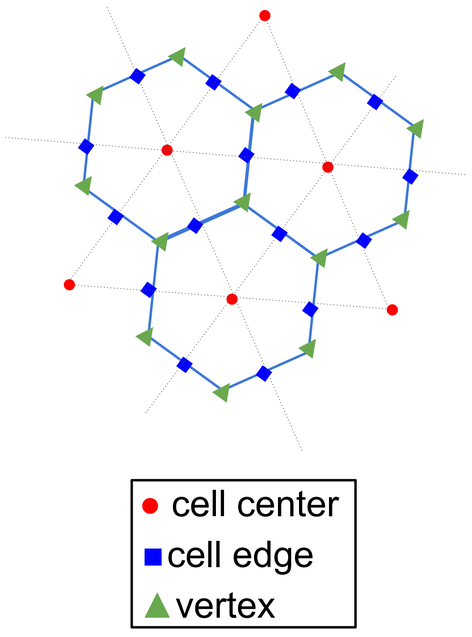

Figure 1. Depiction of the horizontal grids in CPAS. Following MPAS, CPAS uses an unstructured centroidal Voronoi tessellation (CVT). Hexagons in solid lines represent primary cells while dotted triangles show the dual Delaunay triangulation. All scalar fields and reconstructed zonal and meridional winds are defined at the primary cell centers (●) and normal velocities are defined at cell edges (■).

The mesh generation can be done on CPAS's **HPC cloud computing platform**[1] - simply defining regions (dense blue color on Figure 2) on a map panel and setting the target resolutions, it will generate CVT cells accordingly.

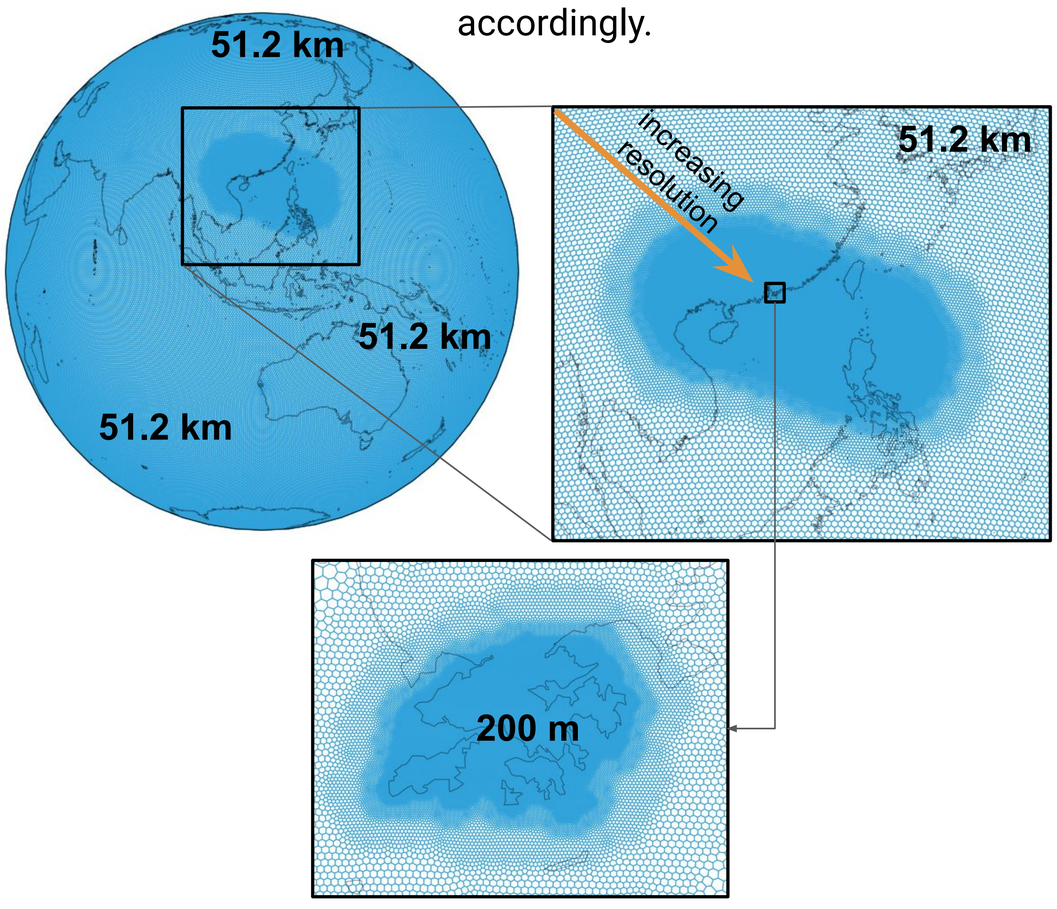

Figure 2. The global mesh generated by CUMG used for the study of Tropical Cyclone (TC) Mangkhut (2018). The globe is covered by 51.2 km resolution grids and the varying refinement of 0.2-3.2 km resolution is applied over the region surrounding South China and Hong Kong (HK) territories.

CPAS provides the implementation of **Hierarchical Time-Stepping (HTS)** in its dynamic core for unstructured CVT grids such that coarse resolution regions use larger time steps and finer resolution regions use smaller time steps, saving computational resources significantly.

CPAS with 200-m Resolution Refinement

Here we perform a 60-hour CPAS simulation for TC Mangkhut with local 200-m refinement[2] over HK territories. The GFS data on 2018-09-14T12Z are used as the initial state.

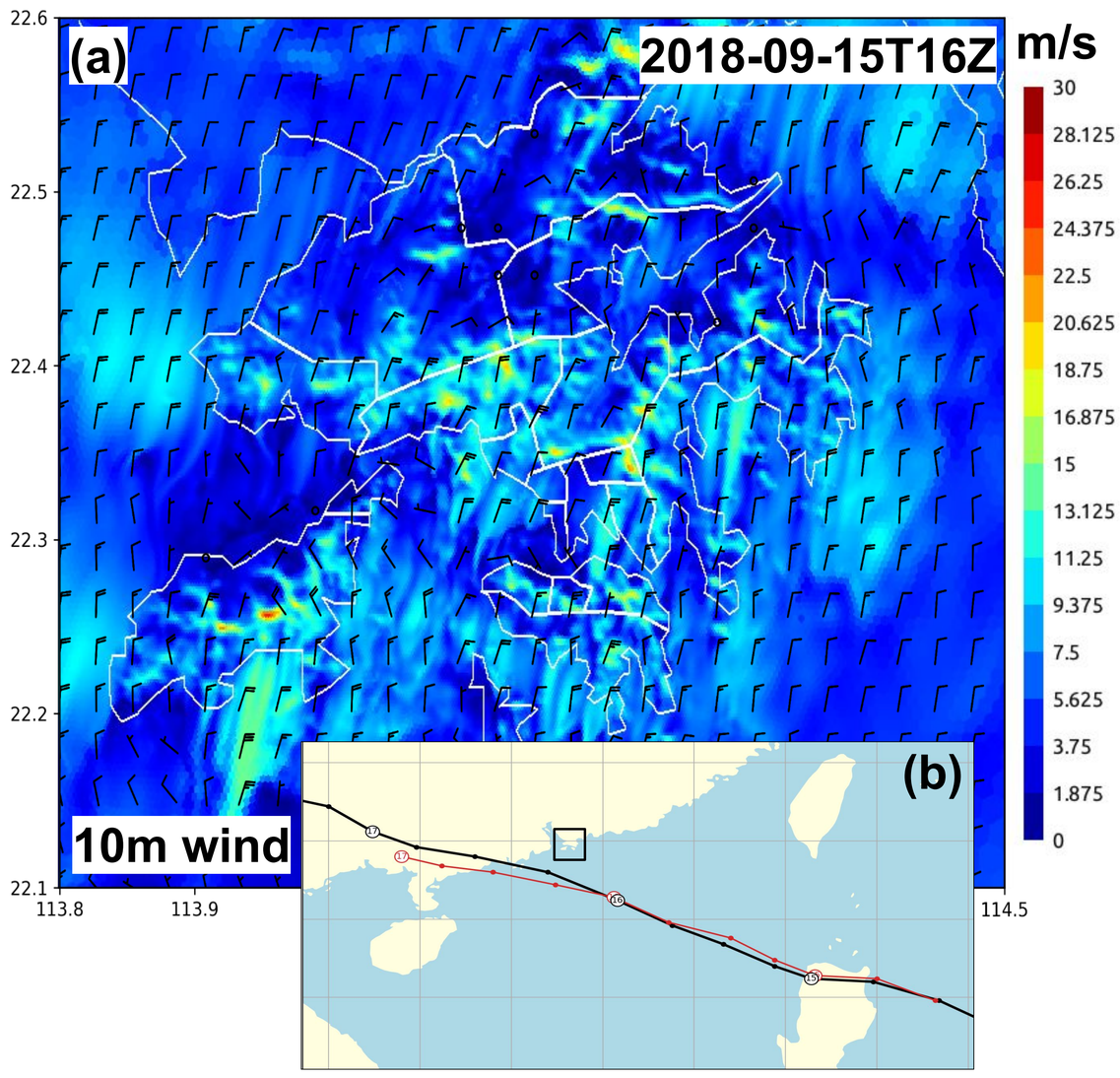

Figure 3. **(a)** The 10-meter wind profile over the HK territories on **2018-09-15T16Z**. The local wind patterns, resolved by 200-m refinement, are consistent with the terrain, demonstrating CPAS with CUMG and HTS can simulate local weather conditions. Note that the white coastlines and administrative district lines are from common shapefile sources which are not updated. **(b)** The track (red) of TC Mangkhut simulated by CPAS from 2018-09-14T12Z to 2018-09-17T00Z, in comparison to the China Meteorological Administration (CMB) best track (black); the black square marks Hong Kong's location.

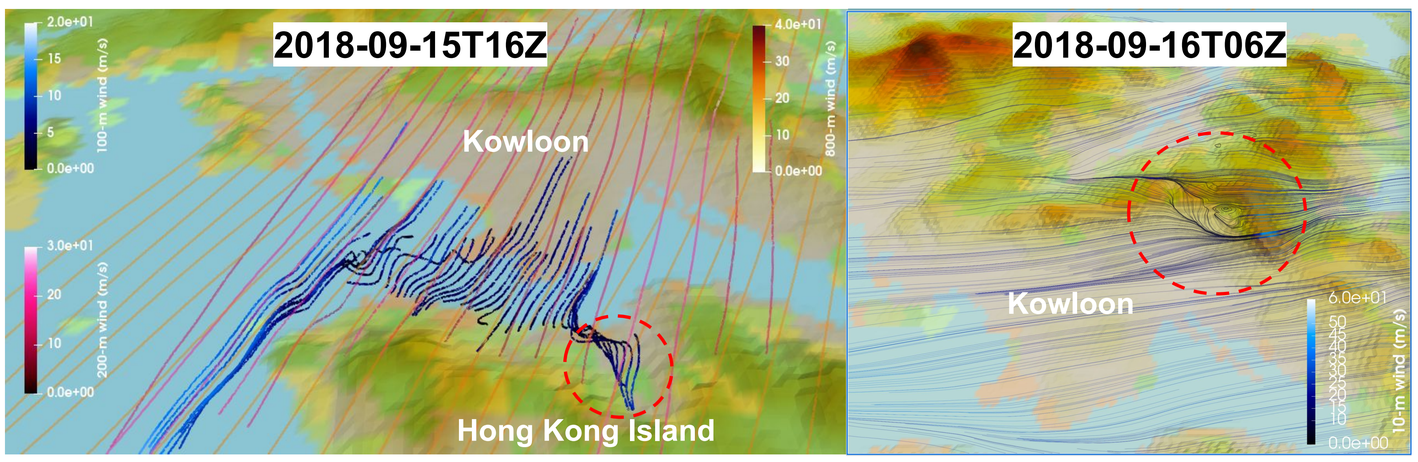

Figure 4. **(left)** A 3D visualization (powered by Paraview) of the streamlines of northerly winds at altitudes of approximately 100 meters (blue), 200 meters (magenta) and 800 meters (yellow) at 2018-09-15T16Z. **(right)** Zooming to Kowloon and its northern hills at 2018-09-16T06Z (14 hours later), streamlines of 10 meters above ground level wind brown dominantly from the east. Note the hills colored in orange and the interesting patterns of low level winds affected by the terrain are marked by dashed red circles.

Remarks. This global CPAS model features a high resolution ratio of 256, achieving local resolutions as fine as 200 meters, comparable to limited-area models. The track of a TC is accurately simulated, along with its localized impact on a coastal hilly city. Among all weather elements forecasted by NWP, wind is simulated with particularly high fidelity, benefiting greatly from the well-resolved terrain. Future work could focus on incorporating the effects of buildings.

Further Reading and Exploration

1. **HPC cloud computing platform**: https://cpas.earth
2. **Sheltering effect in NWP wind prediction and other verification cases**: Sze, W.-P., Tang, S.-C., Cheung, C.-C., & Tam, C.-Y. (2022). Numerical weather prediction at 200 m local resolution based on an unstructured grid global model. Earth and Space Science, 9, e2022EA002342. https://doi.org/10.1029/2022EA002342