Performance of MPAS-A and WRF in predicting and simulating western north Pacific tropical cyclone tracks and intensities

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1. Motivation

- The Model for Prediction Across Scales - Atmosphere (MPAS-A) is a global model based on the Weather Research and Forecasting (WRF) model but on a staggered unstructured spherical centroidal Voronoi tessellation (SCVT) C-grid (*Skamarock et al. 2012*).
- MPAS-A and WRF were used for simulating historical TCs, and their tracks and intensities were compared.

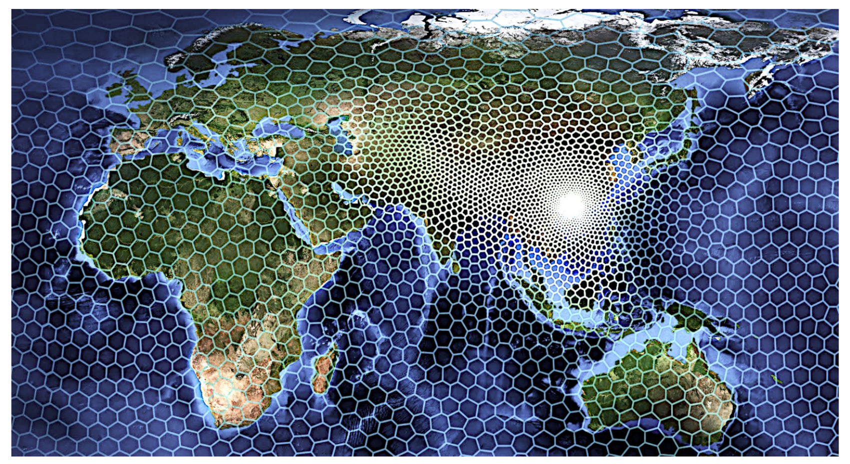


Fig. 1. A sample variable-resolution SCVT for MPAS-A.

- Impacts of IC and grid resolution on MPAS-A's forecast accuracy were also investigated.
- **This is the first study to use customized variable-resolution meshes in MPAS-A for simulating TCs.**

2. Model, data and methodology

Table 1. Model configurations used in WRF and MPAS-A experiments. Note that cumulus scheme is disabled for grids smaller than 9 km in MPAS-A, and in the WRF 3-km domain.

	WRF v4.0.3	MPAS-A v6.1
Description for modeling	Regional with no nudging	Global
Horizontal resolution	15 km/3 km nested domain	(i) 60-to-3 km; (ii) 160-to-2 km
Vertical levels (Top)	55 (10 hPa)	55 (30 km; ~12 hPa)
Radiation	RRTMG (v3.8.1)	as in WRF
Planetary boundary layer	YSU (v3.8.1)	as in WRF
Convection	New Tiedtke (v3.8.1)	as in WRF
Microphysics	WSM6 (v3.8.1)	as in WRF
Land surface	NOAH (v3.3.1)	as in WRF

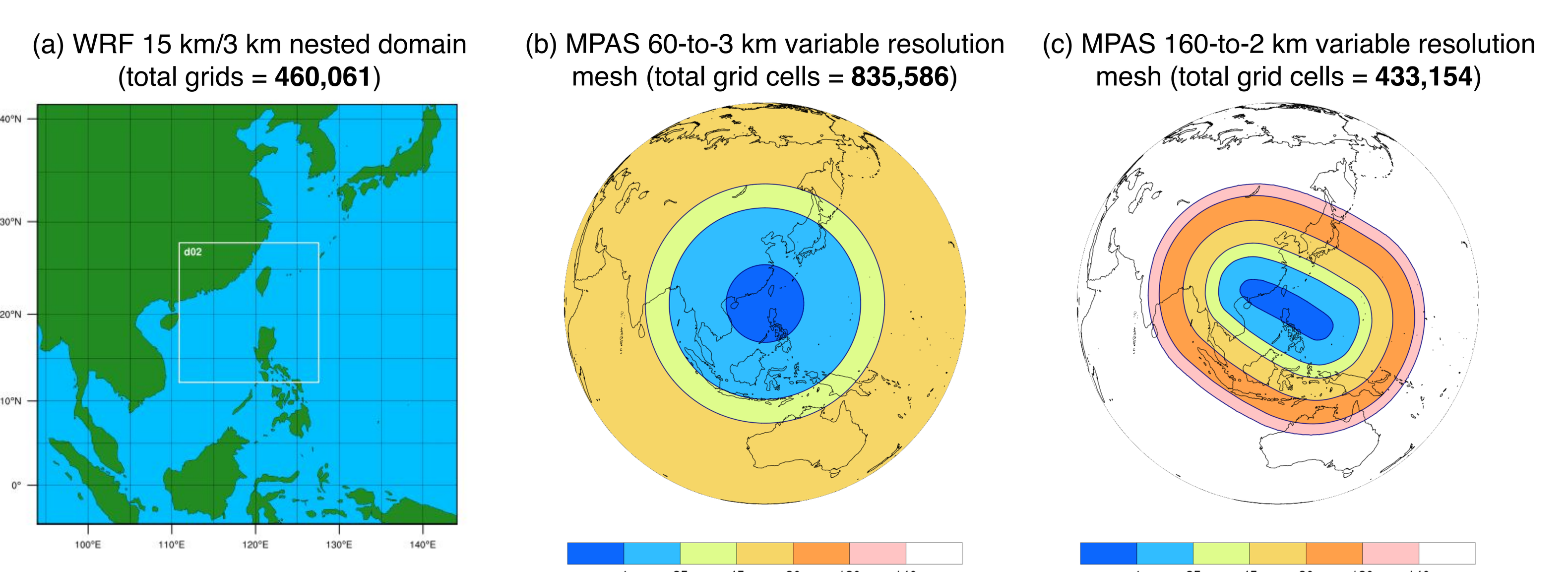


Fig. 2. (a) WRF nested grids at 15 and 3 km resolution for domain 1 and 2 , MPAS-A (b) 60-to-3 km, and (c) 160-to-2 km global variable-resolution meshes (units: km) respectively.

Table 2. Simulation periods, data used and methodology.

Simulation periods for TCs	Hope (1979-07-29 12UTC to 08-03 06UTC); Gordon (1989-07-14 12UTC to 07-18 18UTC); Koryn (1993-06-24 12UTC to 06-27 18UTC); Imbudo (2003-07-21 12UTC to 07-25 00UTC); Dujuan (2003-08-31 00UTC to 09-03 00UTC); Molave (2009-07-16 12UTC to 07-19 12UTC); Hato (2017-08-21 00UTC to 08-24 03UTC); Mangkhut (2018-09-13 00UTC to 09-17 06UTC)
IC (lateral boundary conditions as well for WRF)	ERA-interim (*Dee et al. 2011*); ERA5 (*Hersbach et al. 2018*)
TC tracking method	First, barycentric interpolation (onto a regular 0.025°×0.025° grid); then, Geophysical Fluid Dynamics Laboratory (GFDL) vortex tracker (following *Davis et al. 2016*)

3. The ClusterTech Platform for Atmospheric Simulation (CPAS)

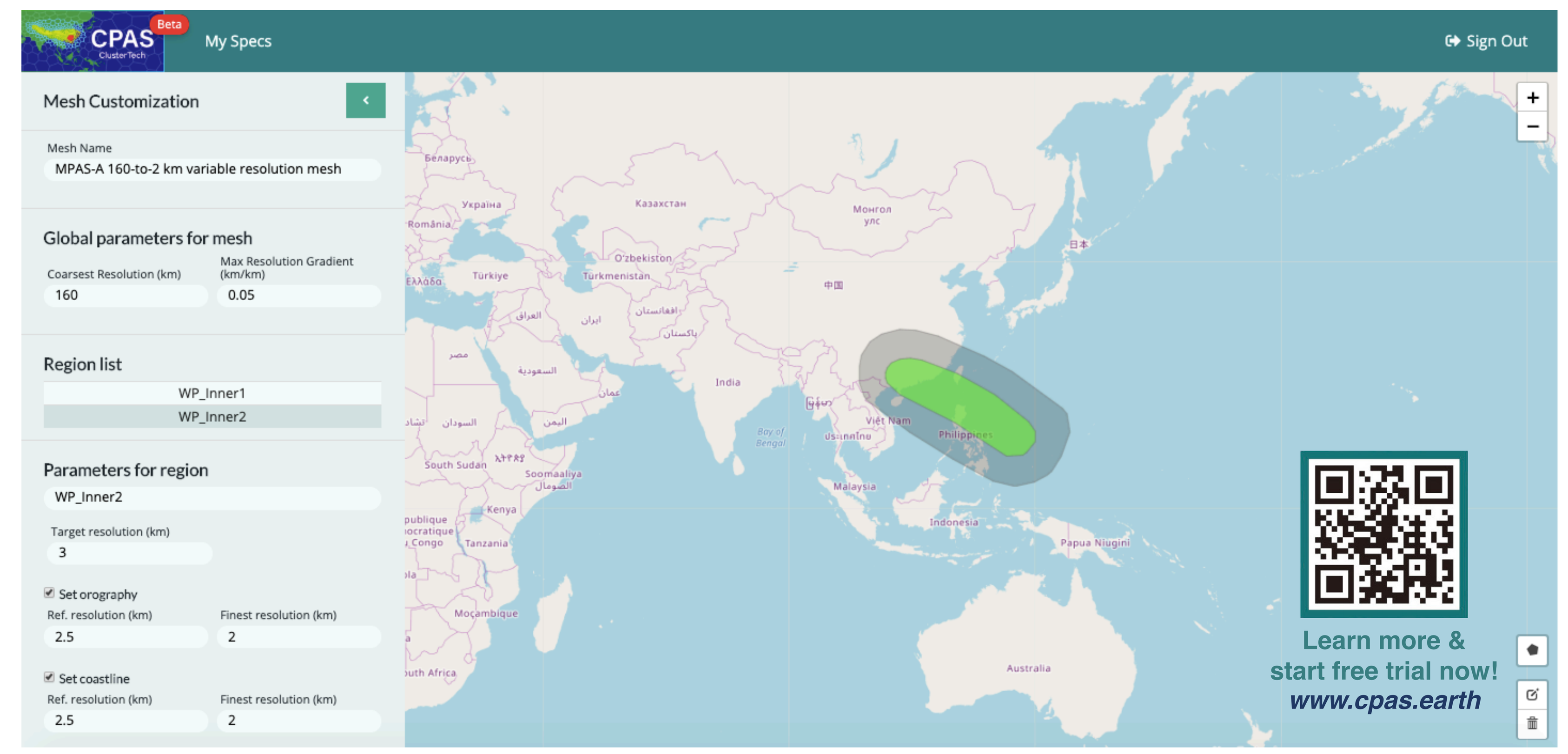
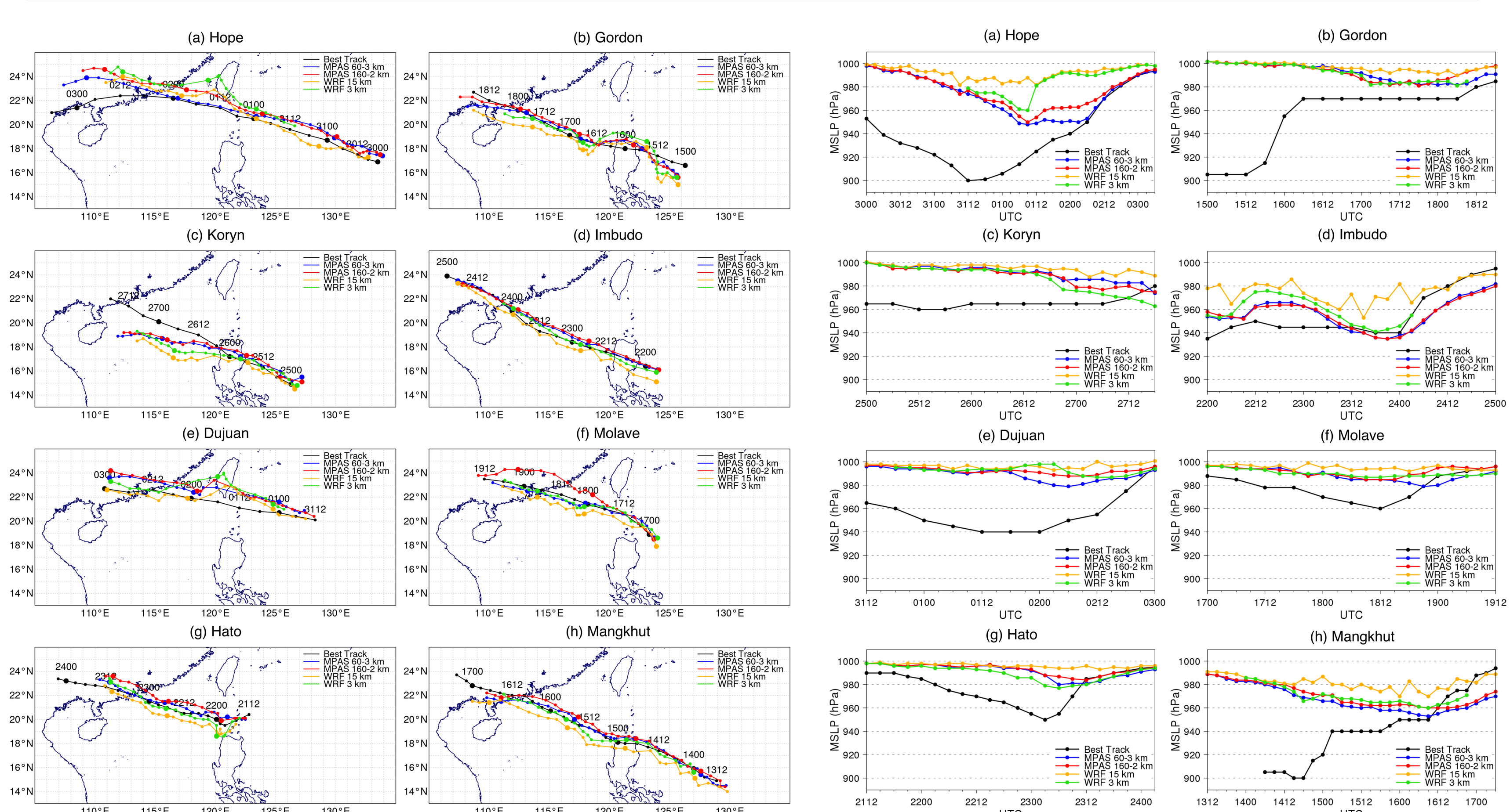


Fig. 3. Customizable unstructured mesh generation (CUMG) with arbitrarily shaped regions of interest and automatic resolution boost for orography and coastline.

- CPAS is a **cloud-based service platform** which offers (i) customizable unstructured mesh generation (CUMG), (ii) MPAS-A simulations with computational resources reduced by hierarchical time-stepping (HTS), and (iii) data visualization.

4. Results and discussions



Figs. 4 and 5. Observed best tracks (left panel) and minimum sea-level pressure (right panel; units: hPa) from HKO (black), and the simulated tracks from the MPAS-A 60-to-3 km (blue), 160-to-2 km (red) experiments, the 15 km domain (orange) and 3 km domain (green) in the WRF experiments, for (a) Hope, (b) Gordon, (c) Koryn, (d) Imbudo, (e) Dujuan, (f) Molave, (g) Hato and (h) Mangkhut.

- **TC tracks were reasonably captured** by the two models configured variously, compared to Hong Kong Observatory (HKO) best tracks (esp. for Gordon, Imbudo and Molave).
- Northward biases were found in Hope's and Dujuan's tracks, whereas southward bias was found in Koryn's track.
- The **translational speed was under-predicted** for Koryn, Hato and Mangkhut.
- MPAS-A reasonably reproduced the location of WNP subtropical high and the steering flow, but it underestimated their strength in comparison to ERA-interim reanalysis (not shown). The **weaker southeasterly steering flow** resulted in a slower TC translational speed in MPAS-A simulations of Koryn, Hato and Mangkhut.
- **TC intensity was generally underestimated**, and its time evolution was poorly captured by both models.

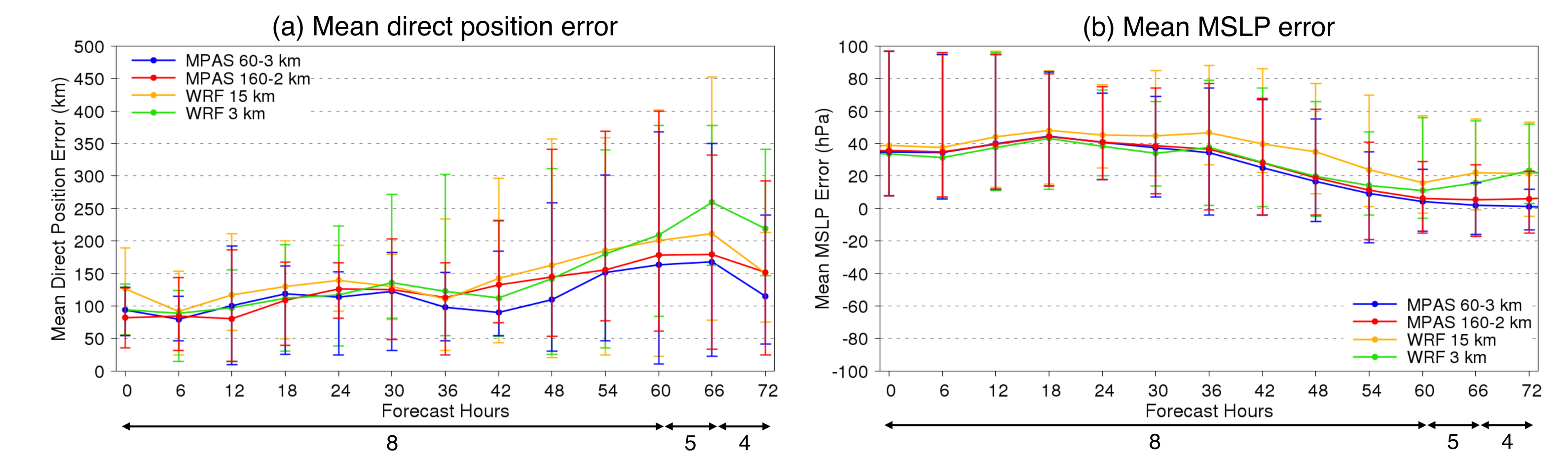


Fig. 6. Time series of (a) direct position errors (units: km), and (b) minimum sea-level pressure (units: hPa) averaged for the TCs from the MPAS-A 60-to-3 km (blue), 160-to-2 km (red) experiments, the 15 km domain (orange) and 3 km domain (green) in the WRF experiments, from lead time of 0 to 72 hours. The sample size for the time series at each lead time is shown at the bottom.

- For predictions of 36 hours ahead, the tracks given by both model simulations were comparable, in which the mean position errors were both smaller than 150 km. **However, with a lead time of 36 to 72 hours, MPAS-A predictions began showing a smaller mean position error than WRF simulations.**
- Similarly, for lead time of more than 60 hours, **the intensity error is smaller in MPAS-A predictions than in WRF** (likely related to the better track performance in MPAS-A).

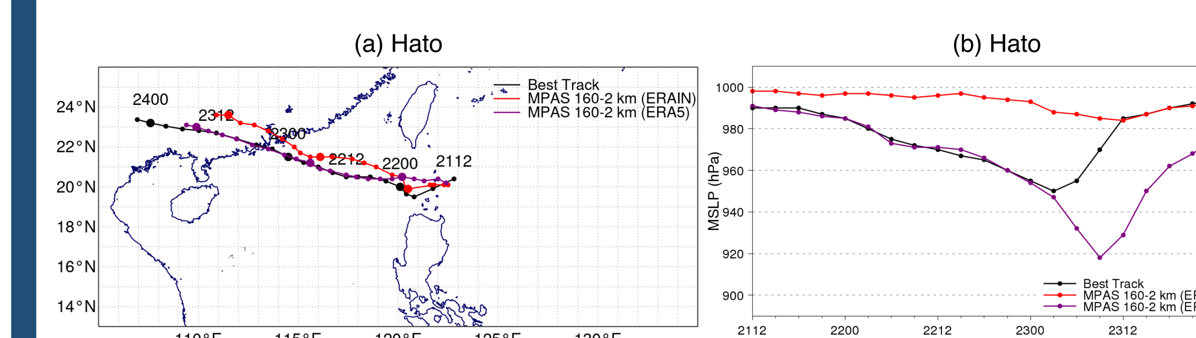


Fig. 7. (a) The track and (b) MSLP (units: hPa) for Hato respectively, from the HKO best track (black), the 0.75° ERA-interim initialized (red) and the 0.75° ERA5 initialized (purple) 160-to-2 km MPAS-A experiments.

- **ERA5-initialized run showed significant improvement in both track and intensity** (though over-predicted at later stage) for Hato, compared to ERA-interim-initialized run.

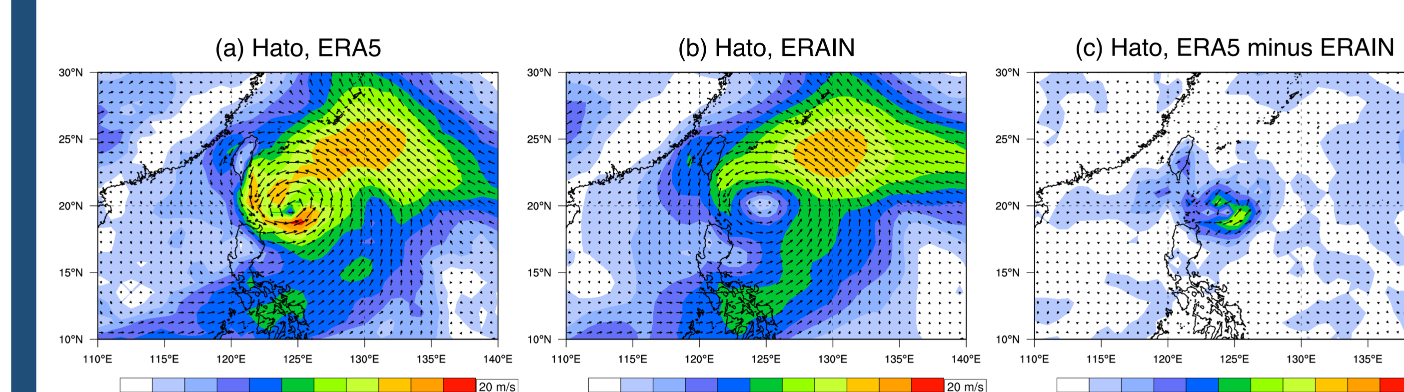


Fig. 8. 850 hPa winds from the 0.75° (a) ERA5 and (b) ERA-interim data at 00 UTC 21 Aug 2017. (c) Their difference.

- ERA5 seemed to have a **stronger and better vortex representation** than ERA-interim.

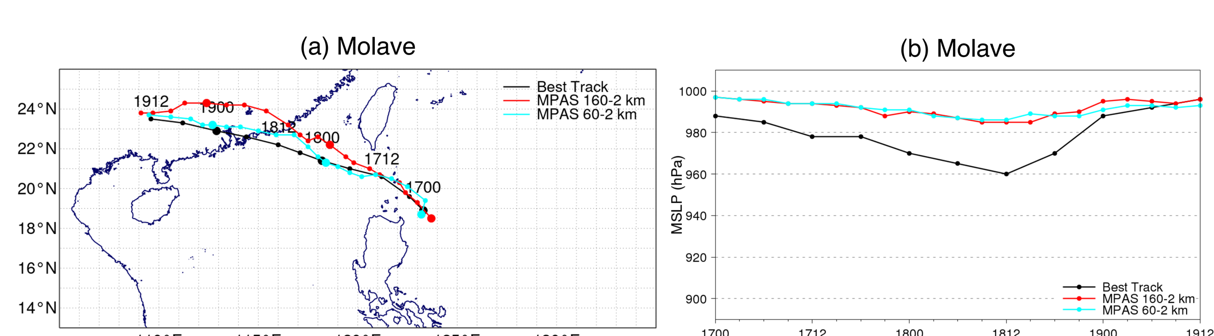


Fig. 9. (a) Track and (b) MSLP (units: hPa) for Molave respectively, from the HKO best track (black), the 0.75° ERA-interim initialized 160-to-2 km (red) and 60-to-2 km (cyan) MPAS-A experiments.

- Improving the coarsest grid resolution from 160 km to 60 km (i.e. 60-to-2 km mesh; not shown) **improved steering flow and reduced northward bias** in Molave's track.

5. Conclusion

- **MPAS-A has performance comparable with (or slightly better than) that of WRF, which is noteworthy**, given MPAS-A runs were initial value predictions whereas WRF runs were dynamically downscaled from reanalysis fields.
- ERA5-initialized runs showed significant (slight) improvement in intensity (track) evolution, suggesting that the underestimated TC intensity is likely related to **inferior representation of storms in the ERA-interim initial fields.**
- The track forecast accuracy of MPAS-A in TC can be **sensitive to the grid resolution in the coarsest part** of the variable-resolution mesh used.
- This study is **a successful demonstration of using customized variable-resolution meshes** for high-resolution regional/local forecasts using MPAS-A.