MPAS-A Sensitivity to Floating-Point Precision, Mesh Configuration, and Interpolation Scheme: Case Studies

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INTRODUCTION

Sensitivity studies for the Atmospheric core of the Model for Prediction Across Scales (**MPAS-A V6.1**) are conducted, to determine its potential as a dynamical core for **medium-range weather forecasting** over the complex terrain of western Canada. We experiment with **three factors** to examine how they affect model solutions. These factors are:

- **Floating-point precision:** double-precision (default MPAS-A build), single-precision
- **Interpolation scheme:** nearest-neighbour, bilinear, patch recovery (using the Earth System Modelling Framework); needed to interpolate to surface stations for verification
- **Mesh configuration:** quasi-uniform (QU) meshes [150 km*, 120 km, 90 km*, 60 km, 30 km], variable-resolution (VR) meshes [150-30 km*, 100-5 km*, 92-25 km, 46-12 km]; ***** indicates self-generated meshes built with a reduced convergence criterion relative to NCAR- generated meshes

Sensitivity to the choice of floating-point precision and mesh refinement configuration is initially explored using a **360-hour dry unperturbed baroclinic jet simulation**. Model performance is further explored using three **120-hour real-data case studies over British Columbia (BC, Canada)**: a **summer high-pressure system**; a **fall low-pressure system**; and a **record-breaking early-winter wind storm**. Forecasts are verified against Environment and Climate Change Canada (ECCC) surface observations and Global Data Assimilation System (GDAS) reanalyses, and the results are compared against control simulations produced by **Version 4.0.3** of the Weather Research and Forecasting (**WRF**) model. All forecasts are initialized with the Global Forecast System (**GFS**), have **55 vertical levels**, and use the **MPAS-A mesoscale physics suite.**

DRY UNPERTURBED BAROCLINIC WAVE TEST

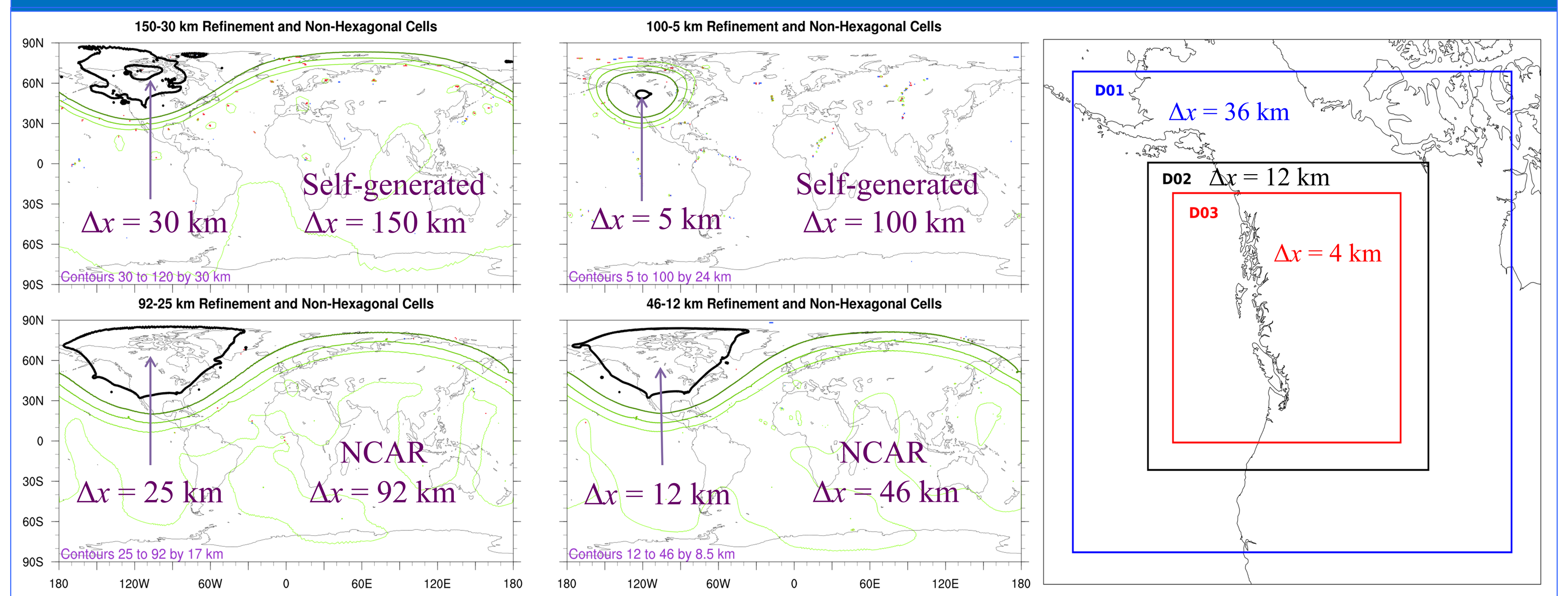
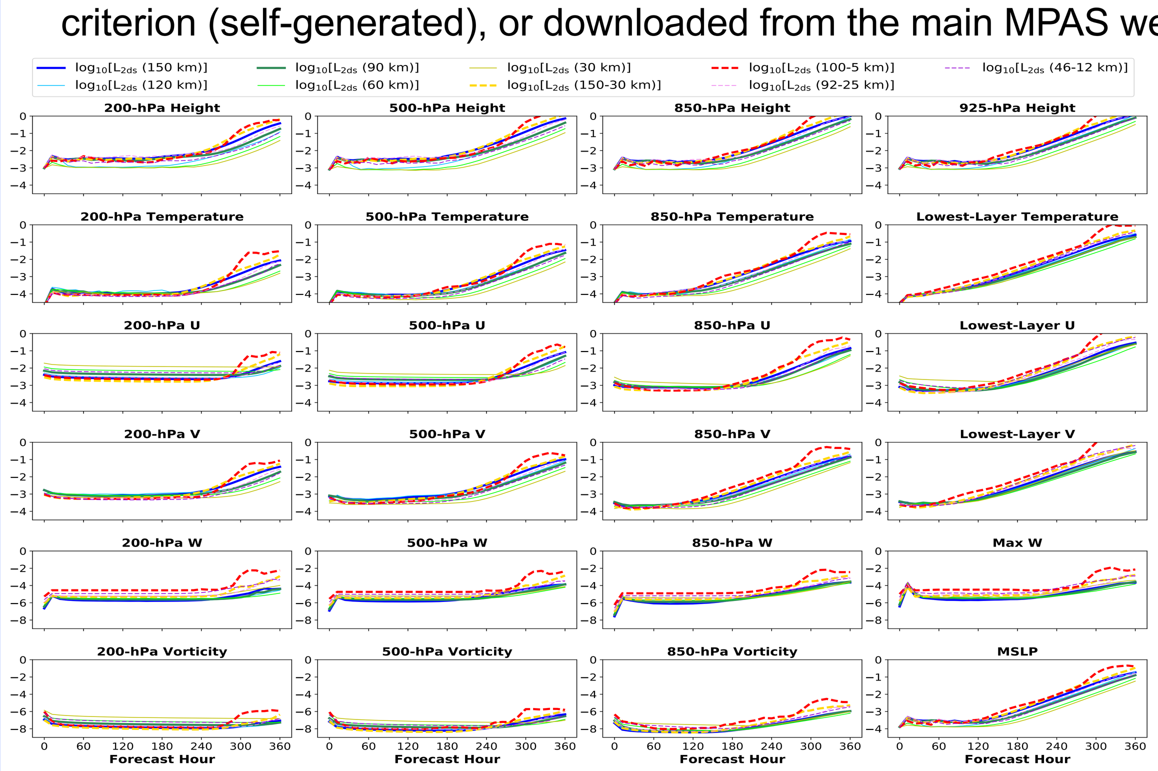


Fig. 1: MPAS-A VR domain refinement regions (left), and WRF nested domains (right). MPAS-A meshes were either built locally with Lloyd's method at a reduced convergence criterion (self-generated), or downloaded from the main MPAS website (NCAR).



$$L_{2di} = \sqrt{\overline{(\text{Forecast}_{double} - \text{Forecast}_{single})^2}}$$

Fig. 2: Semi-log plot of L_2-difference norm growth between double- and single-precision simulations, for multiple variables in the baroclinic wave test. Each colour is a separate MPAS-A mesh. Exponential norm growths occur sooner at lower altitudes.

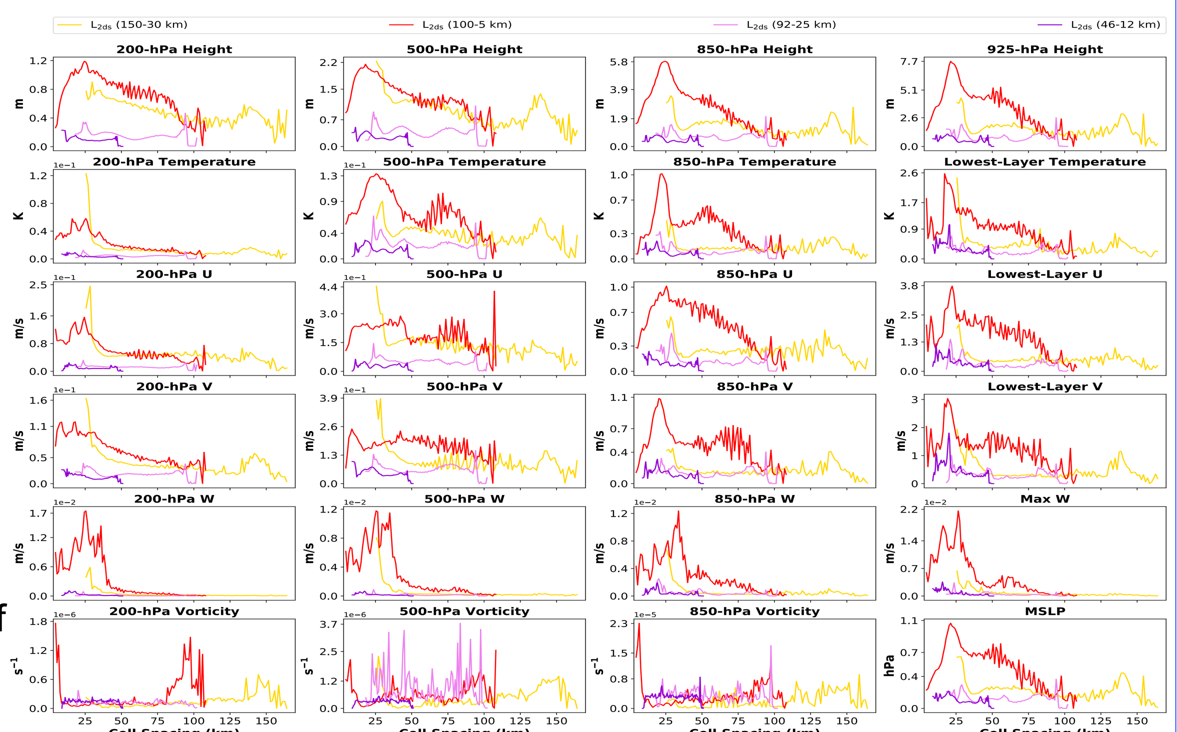


Fig. 3: Length-scale dependence of L_2-norms for the VR meshes, at 360 hours. For most variables, peak difference norms occur at approximately 25 km, regardless of mesh transition zone size or refinement factor. Norms also decrease rapidly within the refinement region of each mesh for most variables.

2018-12-20 WINTER WIND STORM [Init: 2018-12-18 0000 UTC]

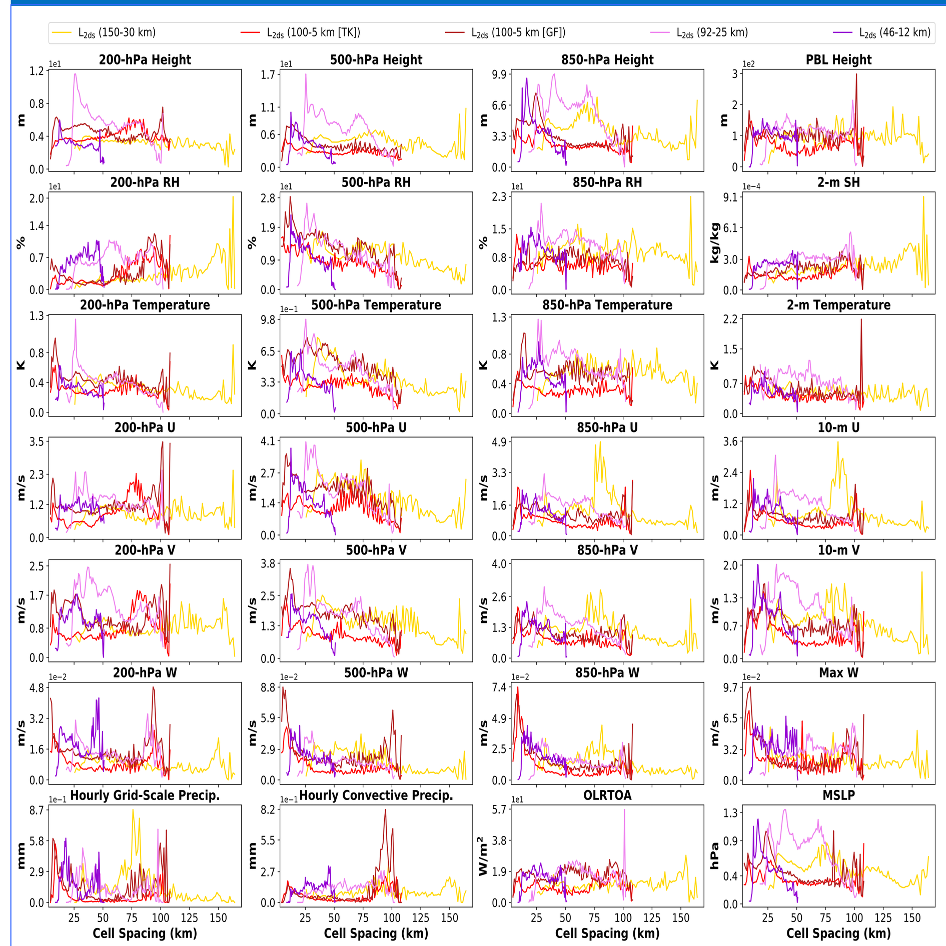


Fig. 4: Length-scale dependence of L_2-norms for the VR meshes, at 120 hours for the December 2018 wind storm case study. With the inclusion of physics, peak difference norms occur more frequently near the edges of transition zones. Norms remain small within the refinement region of most variables.

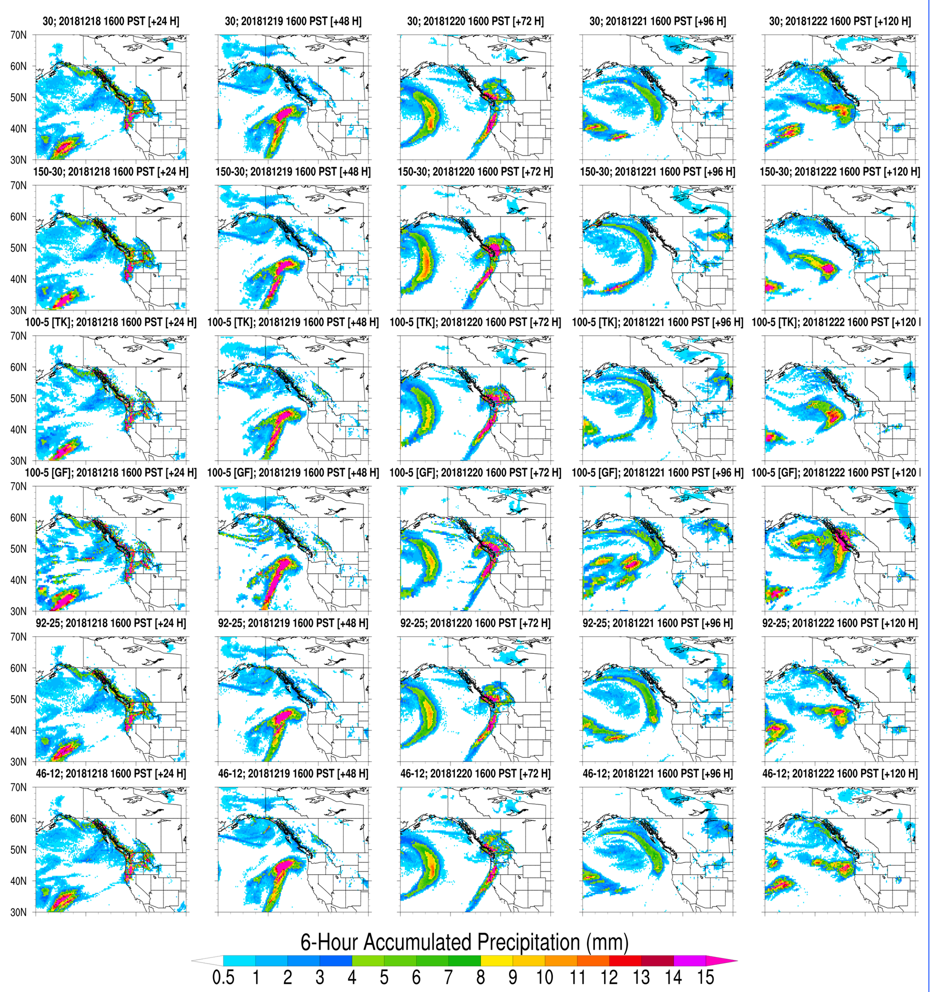


Fig. 5: 6-hr single-precision accumulated precipitation forecasts for lead times of +24 H, +48 H, +72 H [near peak of storm], +96 H, +120 H horizons, for select MPAS-A meshes. Double-precision plots are visually very similar.

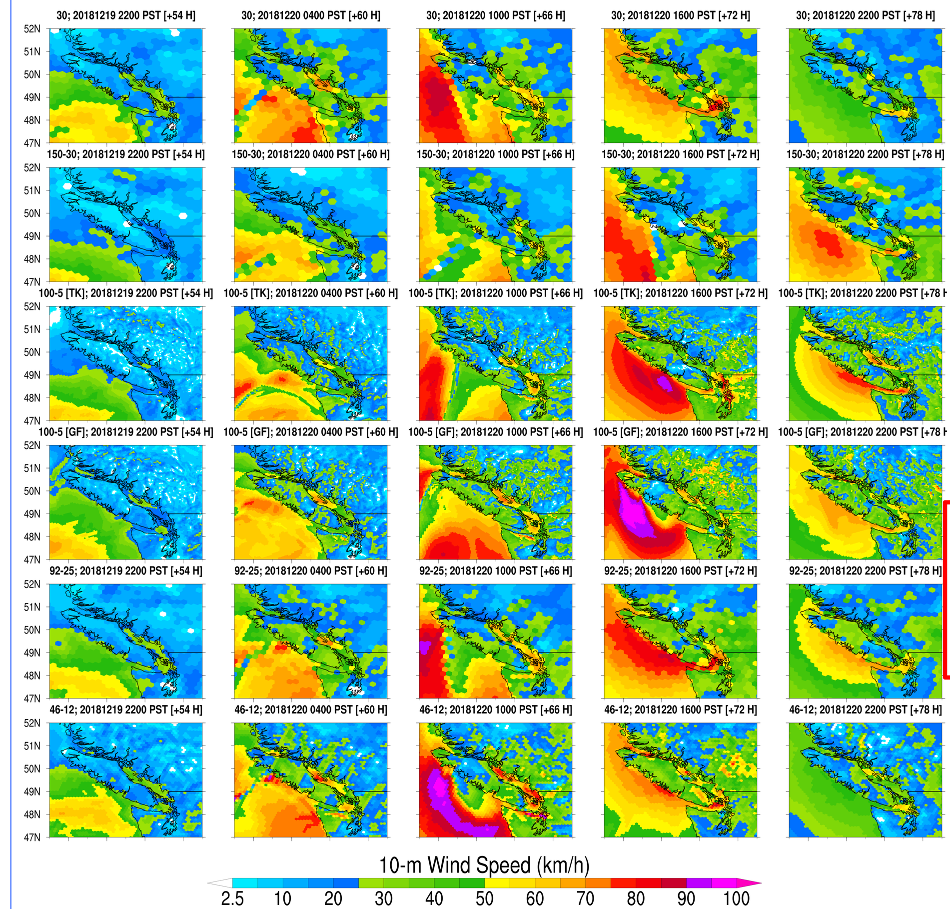


Fig. 6: 10-m single-precision wind speed forecasts for lead times of +54 H, +60 H, +66 H, +72 H, and +78 H, for select MPAS-A meshes near times of peak winds. Double-precision plots are visually very similar.

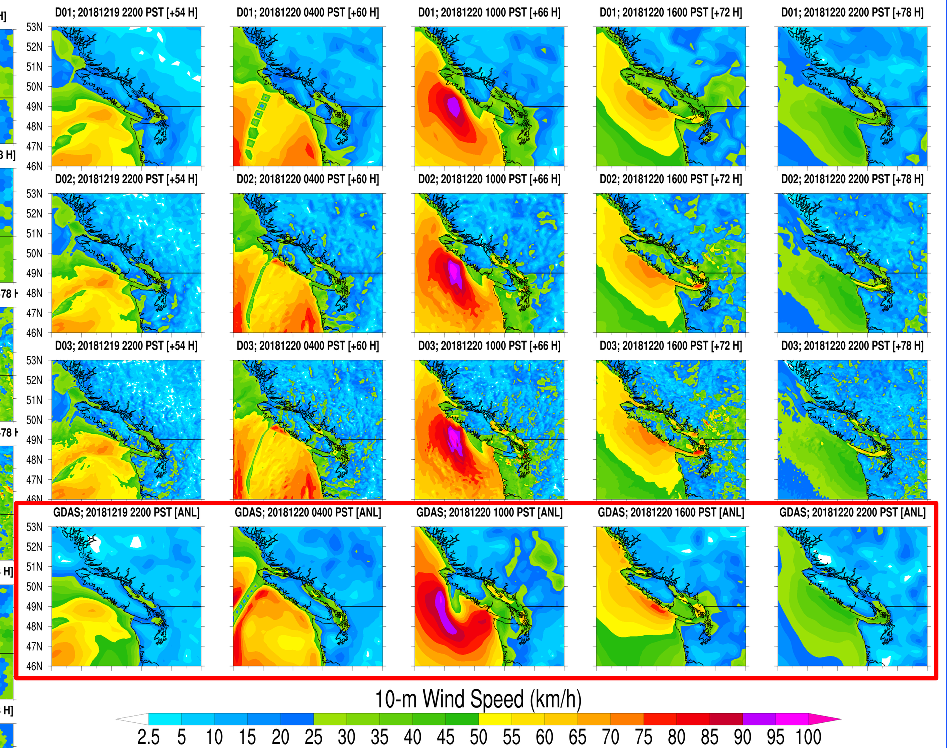


Fig. 7: 10-m wind speed WRF forecasts and GDAS analyses (comparison field; boxed), for the same lead times as in Fig. 6. All WRF domains are able to predict winds similar in structure and magnitude to the GDAS analyses. Only the **46-12 km MPAS-A** forecast in Fig. 6 is able to replicate the correct timing and magnitude of peak winds.

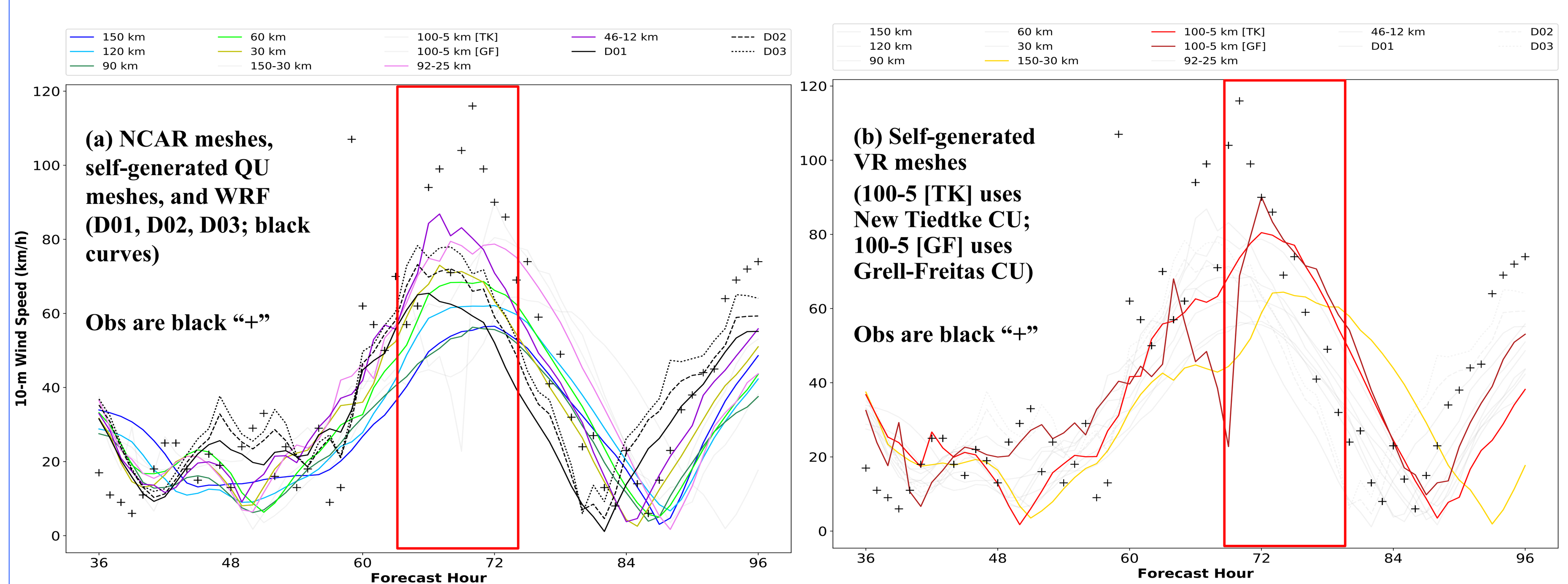


Fig. 8: 10-m wind speed MPAS-A and WRF forecasts, plotted with surface wind speed observations on **Solander Island** [+] (strongest recorded winds during the wind storm). **(a)** NCAR meshes, self-generated QU meshes, and WRF forecasts are able to capture the timing of wind ramp-up, though magnitudes are underpredicted. **(b)** Self-generated VR meshes exhibit ~6 h lag of ramp-up and peak winds. Lag may be due to poorer mesh quality, steep refinement ratios, or difficulties with the transition zone.

VERIFICATION AND TIMING OF CASE STUDIES

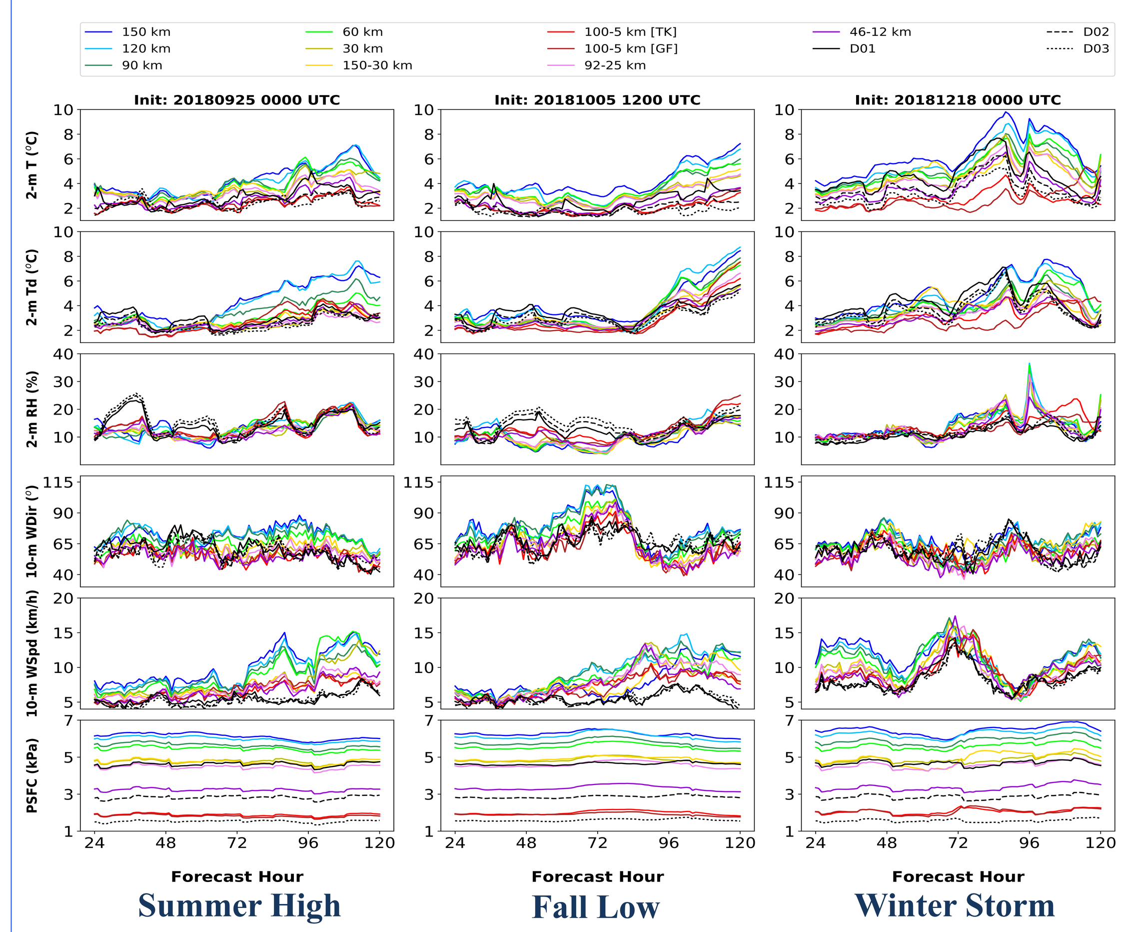


Fig. 9: Mean absolute error (MAE; lower is better) for single-precision forecasts of surface variables, interpolated to ECCC weather stations using the bilinear method (double-precision forecasts and other interpolation methods are similar). WRF forecasts (in black) generally outperform MPAS-A for wind speed. Meshes with smaller grid spacing produce better surface pressure forecasts. The best MPAS-A forecasts often outperforms WRF for all other variables.

Initialization	Variables	MAE η^2 (%)
20180925 0000 UTC (high-pressure system)	2-m Temperature	P: 0.00, I: 0.73, M: 98.95, R: 0.32
	2-m Dewpoint	P: 0.01, I: 0.90, M: 98.44, R: 0.64
	2-m Relative humidity	P: 0.04, I: 33.89, M: 59.78, R: 6.29
	10-m Wind direction	P: 0.00, I: 0.18, M: 99.76, R: 0.06
	10-m Wind speed	P: 0.00, I: 0.86, M: 98.82, R: 0.33
	Surface pressure	P: 0.00, I: 0.03, M: 99.83, R: 0.14
	24-hour Precipitation	P: 0.27, I: 0.11, M: 96.41, R: 3.22
20181005 1200 UTC (low-pressure system)	2-m Temperature	P: 0.00, I: 0.20, M: 99.70, R: 0.10
	2-m Dewpoint	P: 0.00, I: 1.06, M: 97.86, R: 1.08
	2-m Relative humidity	P: 0.01, I: 9.26, M: 90.15, R: 0.58
	10-m Wind direction	P: 0.00, I: 0.00, M: 99.80, R: 0.20
	10-m Wind speed	P: 0.04, I: 3.56, M: 94.50, R: 1.90
	Surface pressure	P: 0.00, I: 0.03, M: 99.80, R: 0.18
	24-hour Precipitation	P: 0.38, I: 2.60, M: 93.71, R: 3.32
20181218 0000 UTC (rain and wind storm)	2-m Temperature	P: 0.00, I: 0.07, M: 99.72, R: 0.21
	2-m Dewpoint	P: 0.03, I: 0.59, M: 98.37, R: 1.00
	2-m Relative humidity	P: 0.18, I: 27.66, M: 67.65, R: 4.52
	10-m Wind direction	P: 0.12, I: 0.11, M: 99.50, R: 0.37
	10-m Wind speed	P: 0.01, I: 2.33, M: 96.18, R: 1.47
	Surface pressure**	P: 0.00, I: 0.04, M: 99.80, R: 0.15
	24-hour Precipitation	P: 0.05, I: 0.15, M: 99.30, R: 0.50

Fig. 10: Factorial analysis of variance (ANOVA) performed for MPAS-A MAE statistics. η^2 indicates how much a factor affects the variance in MAE. Tested factors are **Floating-point Precision (P)**, **Interpolation method (I)**, and **Mesh configuration (M)**. Residuals are also indicated **(R)**. For all variables and case studies, the choice of mesh affects MAE variance the most; **precision negligibly affects the variance.**

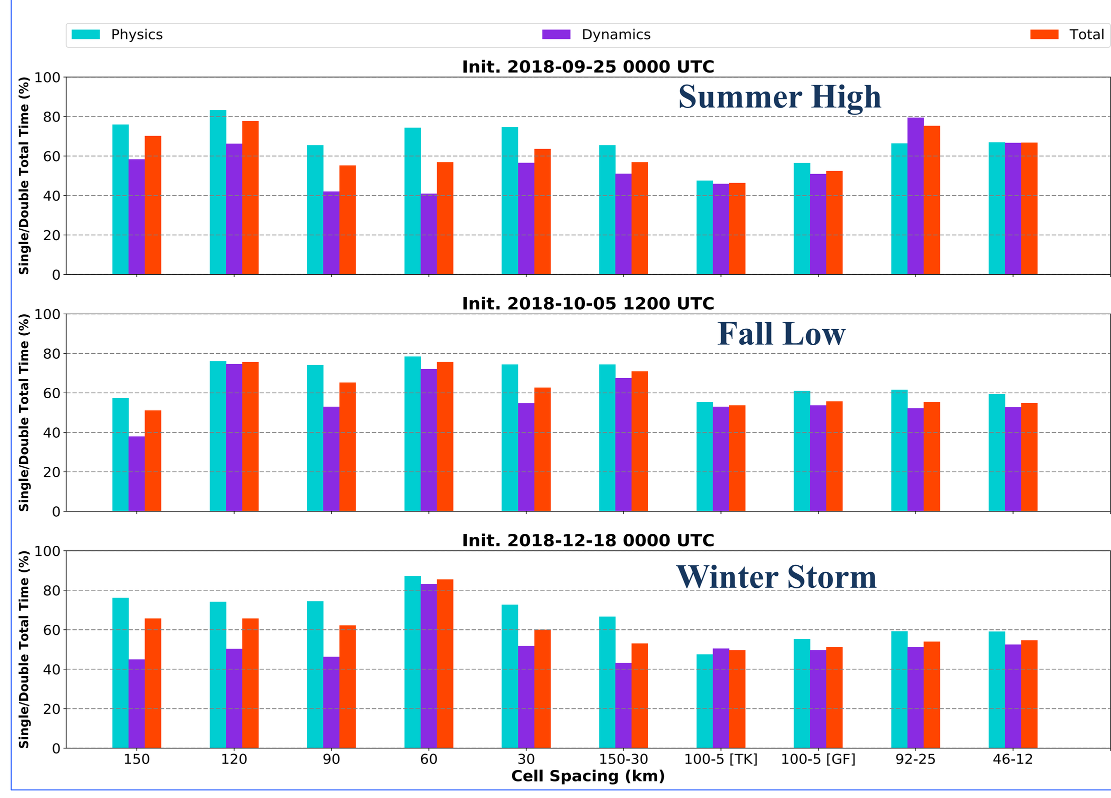


Fig. 11: Ratio of simulation run times between single- and double-precision simulations, for each MPAS-A mesh. Ratios are separated by physics processes, dynamics processes, and total simulation times. **Average reduction in total simulation time = 39%** for single- vs. double-precision.

CONCLUSIONS

The difference in double- and single-precision model solutions for the baroclinic wave test can be substantial at very long forecast lead times. A length-scale dependence for the norm magnitudes also exists. However, for medium-range forecasting (**5-7 days**), the **norms are reasonably small**, especially within the refinement regions of VR meshes. For real-data simulations, **MPAS-A forecasts** with variable-resolution meshes of a given fine-region resolution **perform similarly** to the corresponding **WRF nest with a similar grid resolution**. The **quality of wind speed forecasts can depend strongly on the choice of MPAS-A mesh**; wind forecasts in general remain a challenge. MPAS-A deterministic forecast errors are found to be most sensitive to the choice of mesh refinement configuration, and **less** on the choice of **interpolation scheme** or **floating-point precision**. **Single-precision MPAS-A** builds thus produce medium-range forecasts that are **comparable** to their **double-precision counterparts**, at an average **39% savings in total run time**, indicating their suitability for further experimentation and real-time forecasting in BC.

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