Evaluation of eddy dissipation rate within a regional atmospheric model (MetUM) using radar retrievals

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Introduction

Effects of turbulence on cloud morphology remain unclear in both observations and numerical weather prediction (NWP) models. Eddy dissipation rate (EDR) is the rate of energy transfer through the inertial sub-range of isotropic turbulence. EDR can be retrieved from Doppler radar scans for evaluating parametrisation of turbulence in NWP models.

In this study, we compare radar-retrieved EDR with that simulated within high resolution regional atmospheric model simulations. We develop an evaluation framework for investigating the spatial extent of EDR in relation to strong updraft regions within convective cells.

Data and Methods

- Doppler retrievals of eddy dissipation rate from range-height indicator scans of The Chilbolton Advanced Meteorological Radar (CAMRa) as in Feist et al. (2019)
- Regional atmospheric model simulations within the Met Office Unified Model (MetUM) running its turbulence scheme that blends 3D Smagorinsky (Lilly, 1962) with a 1D Boundary Layer scheme (Lock et al., 2001)

Model Configuration

The model suite runs its own global simulation to drive the UKV. This is then used to initialise the WMV and WMV100 with one-way nesting. Both models use a variable-resolution grid to mitigate spin-up issues. The Wessex55 model is of fixed resolution and is nested within the WMV100. Lateral boundary conditions for all sub-kilometre resolution models are updated every 15 minutes. All regional models use a physics configuration that implements double moment microphysics and the bimodal diagnostic cloud scheme.

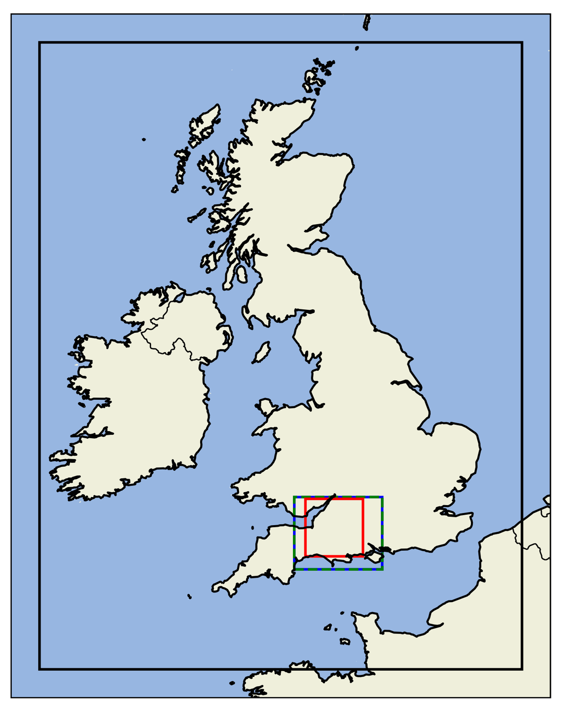

Figure 1. Map showing the inner spatial domain of the UKV (black) covering the United Kingdom. The WMV and WMV100 models share the same inner domain (blue, green). The Wessex55 model (red) is nested within the WMV100.

Table 1. Table showing the domain names, grid lengths, number of vertical levels and timestep length used. Grid lengths in parentheses are the maximum grid resolutions of the stretching region beyond the inner domain.

Domain	Grid Length (km)	Levels	Timestep (s)
UKV	1.5 (4.0)	70	60
WMV	0.3 (1.5)	70	12
WMV100	0.1 (1.5)	120	4
Wessex55	0.055	120	2

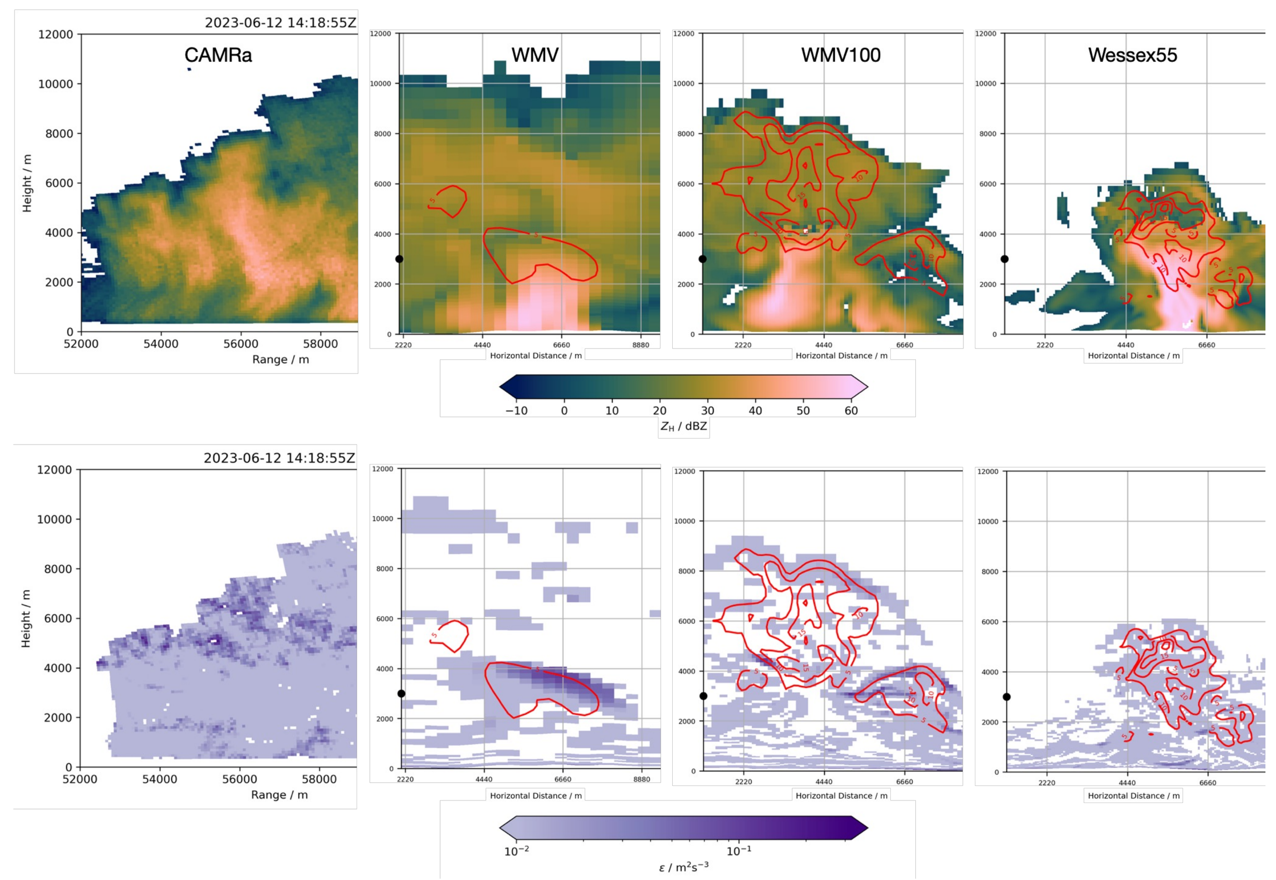

Figure 2. Chosen cross sections of radar reflectivity (top) and eddy dissipation rate (bottom) from radar retrievals (first column), WMV (second column), WMV100 (third column), and Wessex55 (fourth column) simulation outputs for 12 June 2023. Red lines show the contours of upward air velocity every 5 ms^{-1}.

Sensitivity to resolution

Cross sections of reflectivity and EDR show intense regions of EDR near tops of reflectivity cores in both observations and models. Areas of intense EDR decrease in size with increasing model resolution.

EDR statistics within convective clouds (where $Z > 0$ dBZ) were binned in vertical layers of 100 m depth from CAMRa observations and model simulation outputs. Simulated EDR from WMV matches most closely with radar observations. EDR intensity in WMV100 and Wessex55 decreases with height, in contrast to an increasing trend in radar observations. EDR magnitudes decrease with finer model grid resolution.

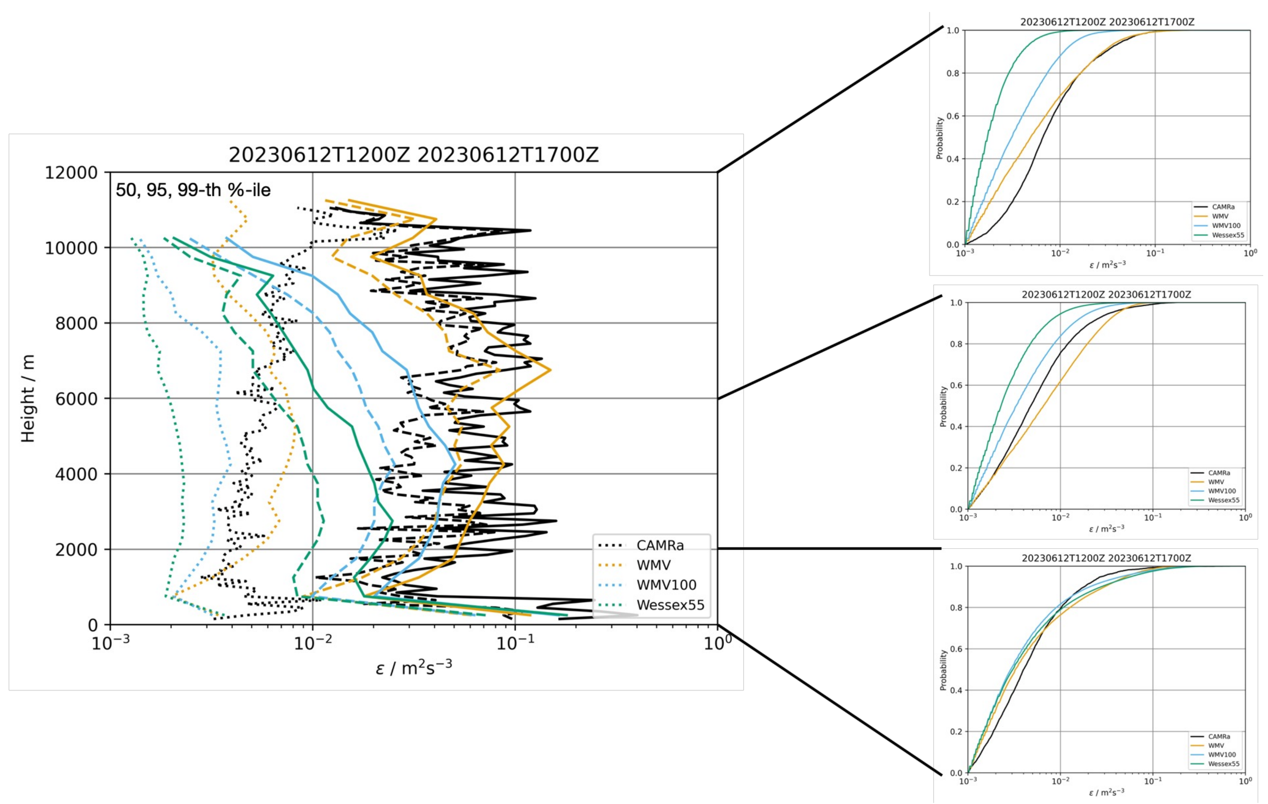

Figure 3. Vertical profiles of 50th (dotted), 95th (dashed) and 99th (solid) percentiles of eddy dissipation rate at each height. Grid points within 0 dBZ reflectivity from all radar retrievals (black), WMV (orange), WMV100 (blue), and Wessex55 (green) hourly simulation outputs for 12 June 2023 between 1200 and 1700Z. Panels on the right depict cumulative distribution functions of eddy dissipation rates for grid points between 0 to 2 (bottom), 2 to 6 (middle) and 6 to 10 km (top) in height.

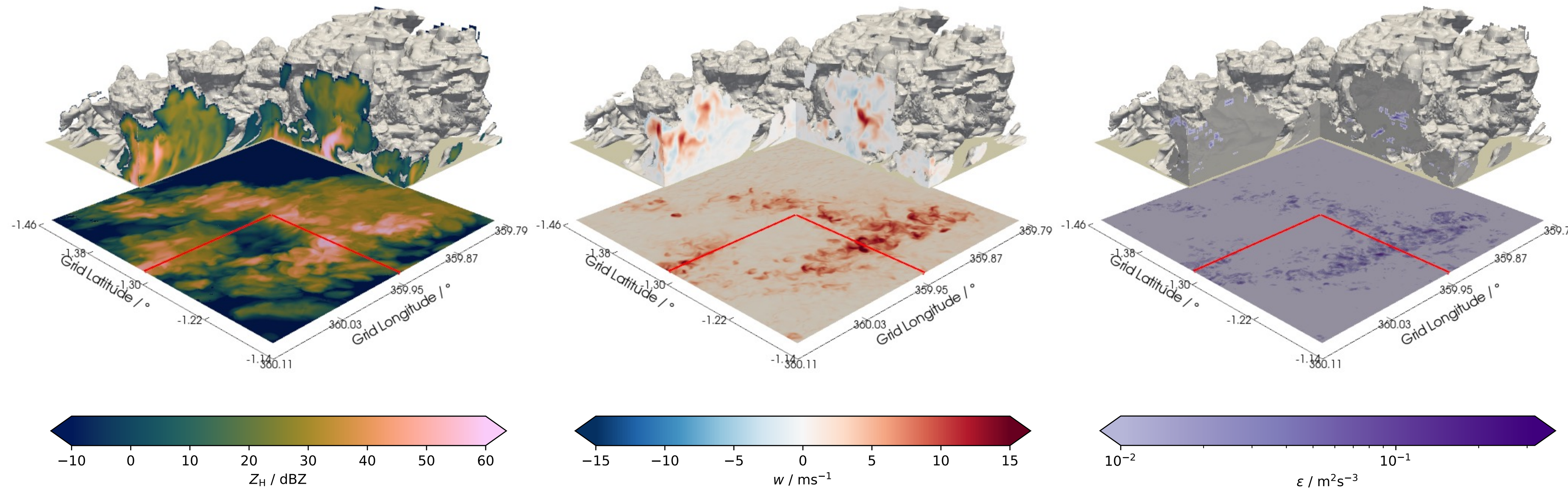

Figure 4. Three-dimensional render of the WMV100 model output for 12 June 2023 showing the 0 dBZ simulated reflectivity iso-surface with cross-sections of simulated reflectivity (left), upward air velocity (middle), and eddy dissipation rate (right). Bottom plots show the vertical maximum of each quantity. Red lines mark the locations of the vertical cross sections.

Structures of updrafts and EDR

Modelled clouds in the WMV100 have 0 dBZ echo tops reaching beyond 10 km in height. Strongest updraft magnitudes are positioned above most intense reflectivity values. Updraft-downdraft couplets are seen within the mid-levels of the clouds, where there are regions of strong horizontal wind shear and where intense EDR is expected.

Three-dimensional renders of WMV100 output reveal intense cap-shaped EDR regions to be near the top of reflectivity and updraft cores. These areas are collocated with regions of strong shear and instability, which are associated with turbulence production in the Smagorinsky scheme.

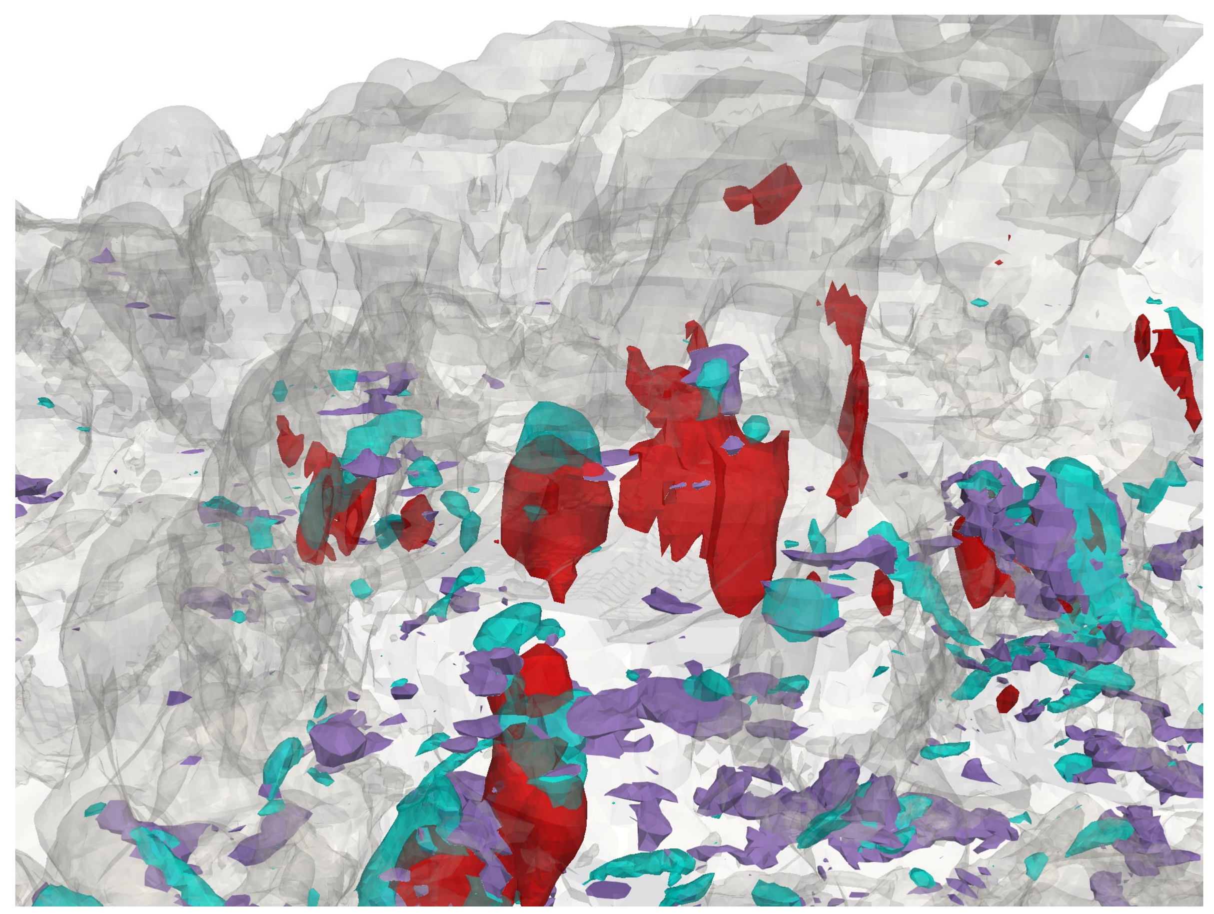

Figure 5. Three-dimensional render of WMV100 model output with 0 dBZ simulated reflectivity (translucent white surface), 10 ms^{-1} updraft (red), 0.02 m^2s^{-3} eddy dissipation rate (purple), and -0.015 Km^{-1} vertical potential temperature gradient (cyan) iso-surfaces.

Conclusions

- Observed EDR magnitudes within clouds increase with height, but simulated values decrease with height
- Intense EDR regions are observed near tops of reflectivity cores and simulated around tops of updraft cores

Next steps

- What is a suitable way to identify cloud and updraft objects for statistical analysis of EDR?
- Are the intense regions of EDR within clouds associated with shear and buoyancy production?
- How well do EDR magnitudes correlate with magnitudes of in-cloud updraft, wind shear and instability?
- How do updraft and EDR statistics of clouds compare between model resolutions and with observations?

This work is taking place as part of the ParaChute programme, in which new turbulence schemes are developed. The evaluation approach presented here will also be used to test how new schemes improve the representation of convective storms and their turbulent structures.

References

Feist, M., Westbrook, C., Clark, P., Stein, T., Lean, H., and Stirling, A.: Statistics of convective cloud turbulence from a comprehensive turbulence retrieval method for radar observations, Q. J. Roy. Meteor. Soc., 145, 727–744, 2019.

Lilly, D. K.: On the numerical simulation of buoyant convection, Tellus A, 14, 148–172, 1962.

Lock, A. P., Brown, A. R., Bush, M. R., Martin, G. M., and Smith, R. N. B.: A new boundary layer mixing scheme, Part I: Scheme description and SCM tests, Mon. Weather Rev., 128, 3187–3199, 2001.

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