A Multi-scale Study of the 23 October 2022 Southern England QLCS

Kenneth Pryor, David Smart, David Flack, Matthew Clark

Abstract

During the afternoon of 23 October 2022, a quasi-linear convective system (QLCS) developed and intensified over the English Channel and tracked north-northeastward into southern England, producing widespread damaging downburst winds. The highest measured downburst wind gusts of the event occurred at 1) Army Aviation Centre (AAC) Middle Wallop, Hampshire (55 miles SW of London), with a wind gust of 54 kt (62 mph) recorded between 1500 and 1600 UTC and generated by a prominent bowing segment of the QLCS; 2) London Colney, Hertfordshire, with a wind gust of 56 kt (64 mph) recorded at 1640 UTC and generated by a pulse-severe cell east of the bowing segment of the QLCS. In general, as shown in Figure 1, the early afternoon (1222 UTC) NOAA-20 NUCAPS sounding qualitatively indicated the strongest signal for severe thunderstorm and downburst occurrence over southern England:

1. It resolved a shallow elevated mixed layer detected by the closest downstream RAOB sounding at Nottingham.

2. Indicated more significant lower-middle tropospheric temperature lapse rates and CAPE than the adjacent AIRS sounding.

3. NUCAPS surface temperature (66°F/18°C) matched the temperature recorded at Herstmonceux, the closest observing station to the retrieval.

Mapped SSMIS imagery with UKMO rain radar overlays (see Figure 2) and a mid-day NUCAPS sounding profile over Leicestershire (~90 miles NW of London) provided the strongest signal for severe downburst winds in the pre-storm environment over the Midlands. Close agreement is noted between the boundary layer structure ("inverted-V") as resolved by the NUCAPS soundings and WRF profiles and the microburst windspeed potential index (MWPI) gust potential calculated from NUCAPS and the WRF model. A strong relationship between high rain rates, as indicated by UKMO radar, and the very low MW brightness temperatures (BTs) is apparent in both the consecutive F-18 and F-16 overpasses. Low BTs also correspond well with the high integrated graupel values, suggesting that intense downdrafts and resulting downbursts were forced by ice precipitation loading and melting and unsaturated air entrainment into the mixed-phase precipitation core. In addition, a trailing stratiform precipitation region with possible embedded elevated convective storm cells enhanced the severity and longevity of the QLCS during its track through the greater London area and southeastern England. The favorable thermodynamic and dynamic factors revealed in this study warrant further investigation into the potential role of elevated convection and the development of a rear-inflow jet during the most intense phase of the system. Comparison of LEO satellite microwave imagery to Doppler radar reflectivity patterns and cross-sections of WRF-model derived thermodynamic parameters (i.e., equivalent potential temperature) should further strengthen the evidence for QLCS structure and the presence of a rear-inflow jet.

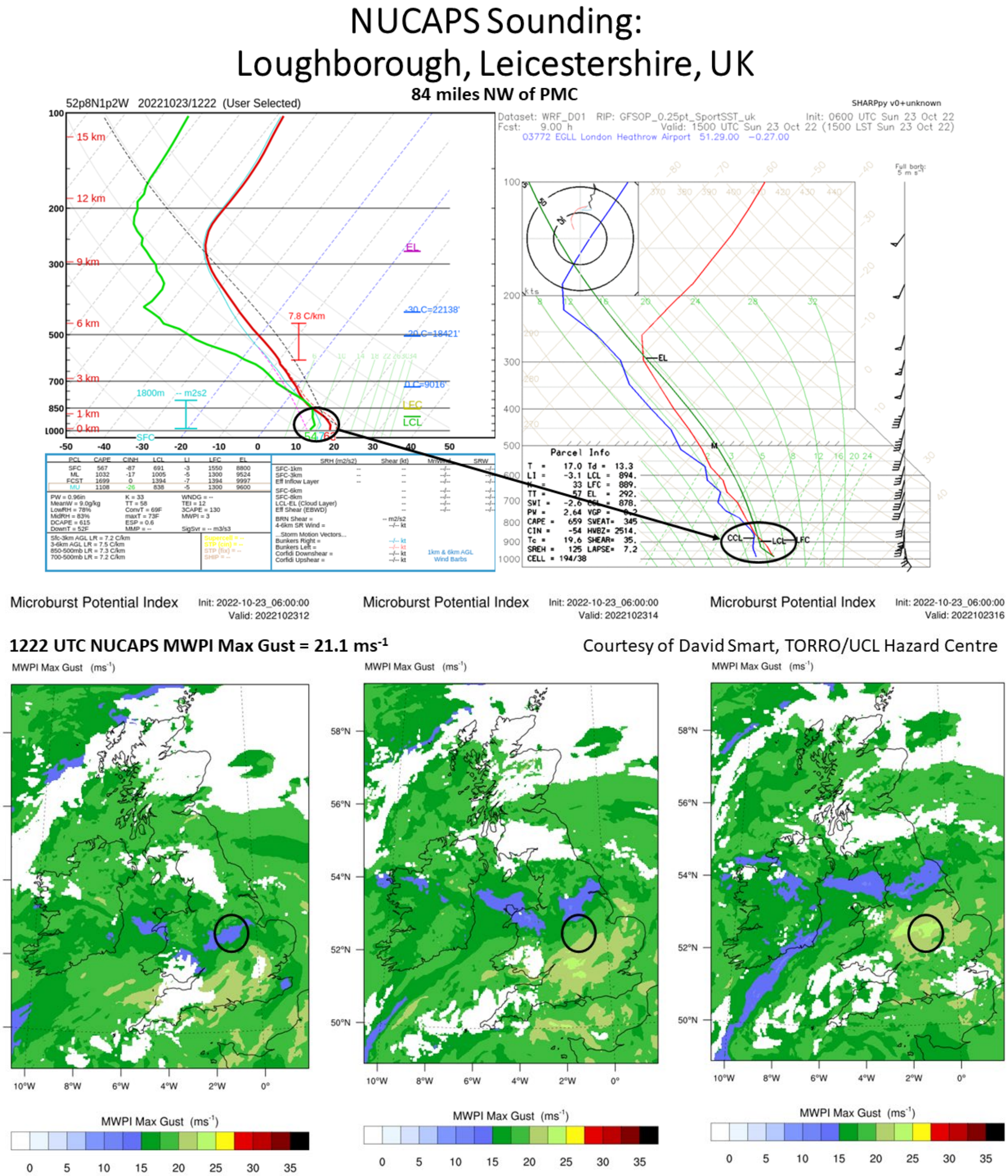

Figure 1. Comparison of the NUCAPS sounding profile over Leicestershire, UK to the WRF sounding profile over London Heathrow Airport during the afternoon of 23 October 2022 (top); WRF model-derived MWPI product over the UK between 1200 and 1600 UTC 23 October 2022 (bottom).

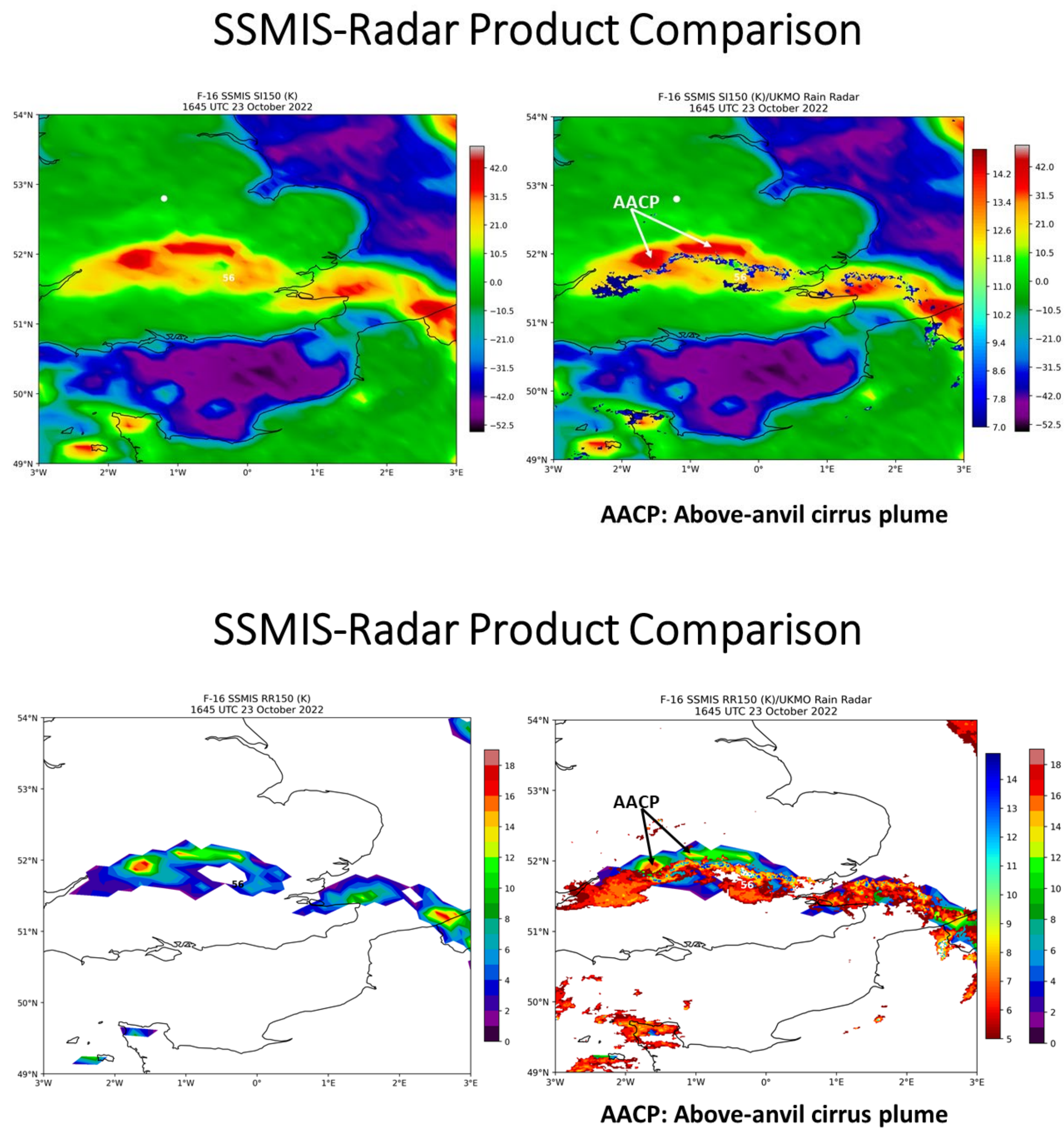

Figure 2. Comparison of DMSP SSMIS-derived scattering index ("SI") and calculated rain rate (mm/hr, top) to UKMO radar-derived rain rate (mm/hr, bottom) at 1645 UTC 23 October 2022.

1. Introduction

Cool-season convective storms over northwestern Europe and Great Britain continues to be a forecasting challenge as well as a public safety hazard. During the afternoon of 23 October 2022, a quasi-linear convective system (QLCS) developed and intensified over the English

Channel and tracked north-northeastward into southern England, producing widespread damaging downburst winds. The highest measured downburst wind gusts of the event occurred at 1) Army Aviation Centre (AAC) Middle Wallop, Hampshire (55 miles SW of London), with a wind gust of 54 kt (62 mph) recorded between 1500 and 1600 UTC and generated by a prominent bowing segment of the QLCS; 2) London Colney, Hertfordshire, with a wind gust of 56 kt (64 mph) recorded at 1640 UTC and generated by a pulse-severe cell east of the bowing segment of the QLCS. The favorable thermodynamic and dynamic factors revealed in this study warrant further investigation into the potential role of elevated convection and the development of a rear-inflow jet during the most intense phase of the system. Comparison of LEO satellite microwave imagery to Doppler radar reflectivity patterns and cross-sections of WRF-model derived thermodynamic parameters (i.e., equivalent potential temperature) should further strengthen the evidence for QLCS structure and the presence of a rear-inflow jet. Figure 1, a WRF-model simulation of the QLCS during phase 1, summarizes the favorable thermodynamic and dynamic factors that promoted strong outflow wind generation: 1) precipitation loading, 2) latent cooling, 3) negative buoyancy (F_{down}), 4) downdraft acceleration, 5) downshear wake entrainment, and 6) rear-flank circulation/rear-inflow jet. This research effort demonstrates how ground-based and satellite-based observational data for convective storms can be combined for monitoring and forecasting applications. In addition, this paper will highlight the scientific value added by synergistic analysis of satellite and ground-based sensor datasets.

2. Data and Methodology

The NOAA-Unique Combined Atmospheric Processing System (NUCAPS) is an enterprise algorithm that retrieves atmospheric profile environmental data records (EDRs), and is applied and evaluated for both a daytime and nocturnal severe convective windstorm cases. NUCAPS is also the primary algorithm for the operational hyperspectral thermal IR and microwave sounders (i.e. Advanced Technology Microwave Sounder (ATMS), Cross-track Infrared Sounder (CrIS)). The ATMS and CrIS instruments are deployed on the NOAA-operational low earth orbit (LEO) Joint Polar Satellite System (JPSS)-series satellites. Figure 2 graphically summarizes the structure of the NUCAPS enterprise algorithm.

Figure 3 illustrates the rigorous inter-comparison process employed to infer and extract the most important physical processes that sustained the QLCS and fostered intense outflow winds. The most important steps in the evaluation process entail pattern recognition, parameter evaluation, and feature identification applying coincident sounding retrieval and satellite, radar and NWP model 2-D plan-view images to build a three-dimensional conceptual model.

The Met Office/Jules Regional Atmosphere and Land configuration version 2 (RAL2M; Bush et al. 2023) of the Unified Model (UM) was used to create a downscaled 2.2 km grid length with 90 vertical levels simulation of the event initiated at 0300 UTC 23 October 2022. The UCL WRF-model run configuration is described in Figure 4.

3. Phase I: Hampshire, UK Bow Echo and Supercell

The first phase of the QLCS lifetime over southern England, denoted in Figure 5, entailed its track from the English Channel northward into Dorset and Hampshire between 1430 and 1500 UTC. As shown in Figures 6 and 7, the QLCS developed a prominent bowing segment on its western (left) flank over the English Channel that persisted during its track through south-central

England. The squall line bow echo ("SLBE") merged with a supercell storm over Bournemouth near 1445 UTC and then proceeded north-northeastward into Hampshire, producing a series of tornadoes and severe downbursts. Figure 8, a qualitative comparison of NUCAPS and WRF model soundings over Hampshire and Sussex, revealed favorable conditions for intense storm downdraft generation and resultant strong outflow winds with close agreement between the boundary layer structure ("inverted-V") as resolved by the NUCAPS soundings and WRF profiles and the microburst windspeed potential index (MWPI) gust potential as calculated from NUCAPS and the WRF model. Various NWP model diagnostic products displayed in Figures 9 and 10, including the CAPE ratio and MWPI maximum wind gust potential, respectively, indicated a high likelihood of surface-based convective storm development that would produce damaging downburst winds, especially near the bow echo apex.

4. Phase II: London and Southeastern England Bow Echo

The second phase of the QLCS lifetime entailed its track from Wiltshire-Berkshire-Kent, merger with a supercell over Greater London, and then northward into the Midlands between 1600 and 1800 UTC. As shown in Figures 11 – 13, the QLCS developed a prominent bowing segment west of London that persisted during the remainder of its track. The QLCS-supercell merger resulted in a cluster of pulse-severe storms that produced a succession of downbursts over Hertfordshire between 1640 and 1740 UTC. During this period, a prominent stratiform precipitation region, with embedded elevated convective storm activity, propagated in the wake of the pulse storm cluster. In a similar manner to the sounding analysis for phase I, Figure 14 signified the favorable conditions for intense storm downdraft generation and resultant strong outflow winds with close agreement between the boundary layer structure ("inverted-V") as resolved by the NUCAPS and RAOB soundings and WRF profiles. The NWP model convection diagnostic products visualized in Figures 15 and 16, including the CAPE ratio and maximum column integrated graupel, echo the patterns and magnitudes displayed in the satellite and radar imagery in Figures 11 – 13. This associative relationship suggests that expanding areal extent of the trailing stratiform region with elevated convective storm development and increasing ice-phase precipitation content resulted in an enhancement in cold pool strength and rear-inflow jet (RIJ) intensification during the track of the QLCS of the greater London region.

5. Discussion and Conclusions

The strategic application of polar-orbiting meteorological satellite and ground-based microwave (radar) datasets allowed for the comprehensive tracking of the QLCS through most of its lifecycle. In addition to application of high-resolution, convection-allowing numerical prediction models, coordinated monitoring of the thermodynamic structure and associated stability of the lower troposphere with co-located satellite and ground-based sounding retrievals provided an effective operational demonstration.

In general, the early afternoon (1222 UTC) NOAA-20 NUCAPS sounding qualitatively indicated the strongest signal for severe thunderstorm and downburst occurrence over southern England: Close agreement between the boundary layer structure ("inverted-V") as resolved by the NUCAPS soundings and WRF profiles and the MWPI gust potential as calculated from NUCAPS and the WRF model. Strong relationship between high rain rates as indicated by UKMO radar and the very low MW brightness temperatures (BTs) apparent in both the consecutive F-18 and F-16 overpasses. Low BTs also correspond well with the high integrated graupel values, suggesting that intense downdrafts and resulting downbursts were forced by ice precipitation loading and melting, as well as unsaturated air entrainment into the mixed-phase precipitation core.

Diagnostics to determine the environment that the convection formed in, from Flack et al. (2023), show that the event was initially surface-based. However, as time progressed and the convective cores stabilized the environment the rear of parts of the QLCS had elements of elevated instability influencing the convection. This elevated instability may help explain the increased precipitation rates within the stratiform region of the QLCS and investigations are still ongoing. Future work will consist of further exploration of the role of squall line-supercell mergers in the enhancement and promotion of severe straight-line winds and tornadogenesis in close proximity. This phase of the study will likely entail higher resolution model simulations that are more sensitive to precipitation phase and concentration and boundary layer turbulence.

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Figures

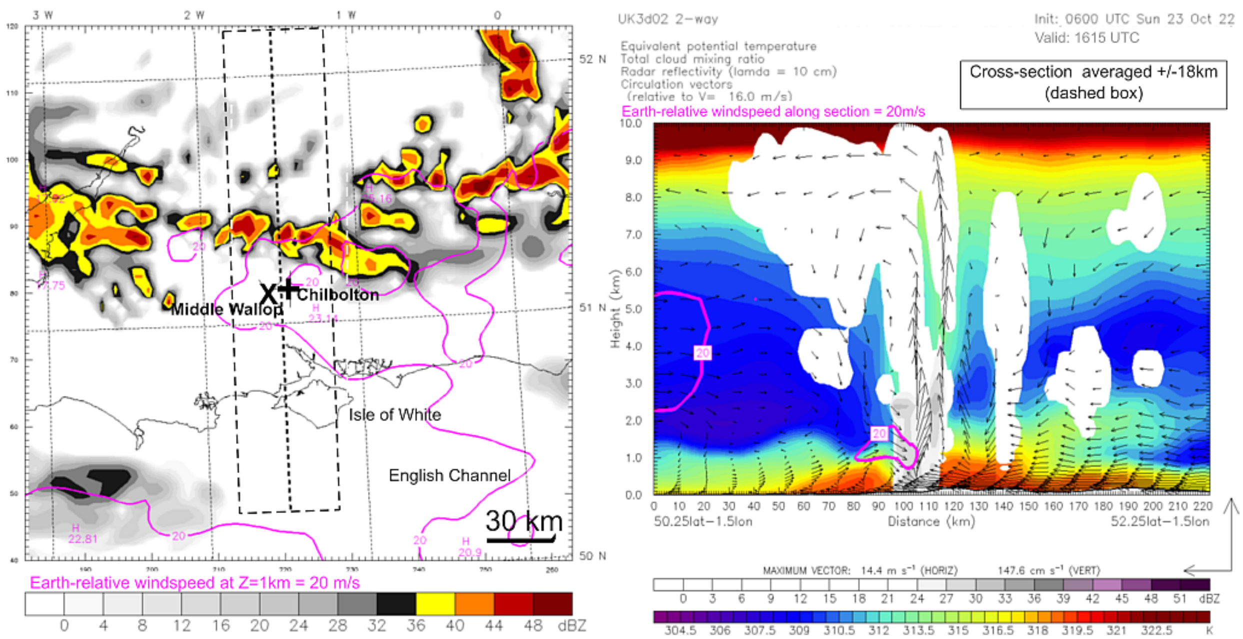

Figure 1. A deep convective storm with the potential to generate intense downdrafts and damaging downburst winds: plan view of WRF model-simulated radar reflectivity over southern England (left) and cross-section (right) at 1615 UTC 23 October 2022. Figure generated from a 2-way nested 9-3km/38 level convection-permitting WRF run initialised with Global Forecast System data. The cross-section is averaged over a 36km-wide box.

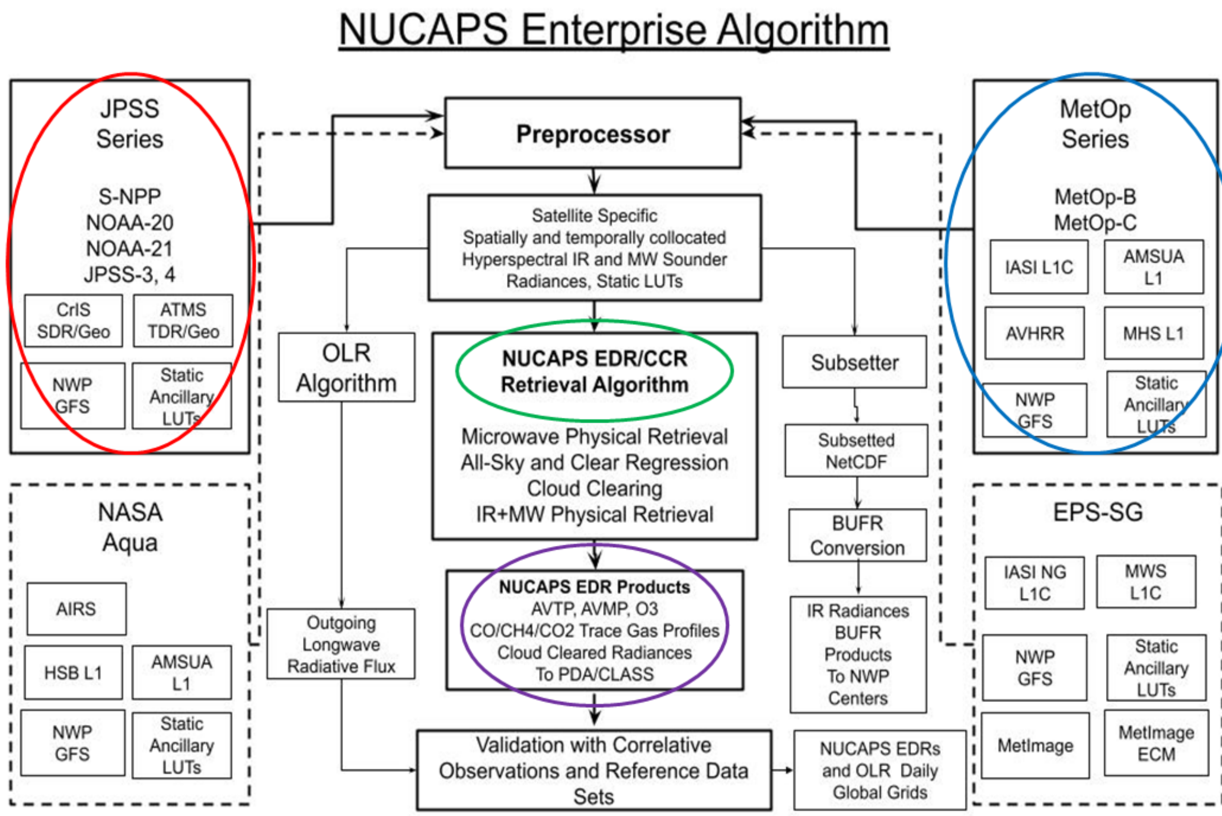

Figure 2. Graphical summary of the NUCAPS enterprise algorithm.

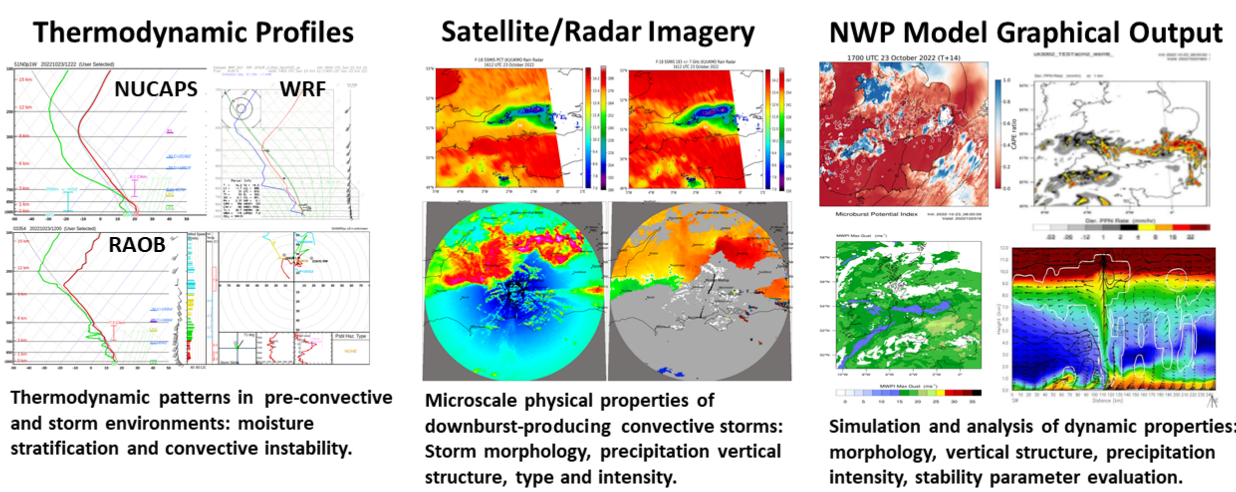

Figure 3. Graphical summary of data analysis and methodology for this study.

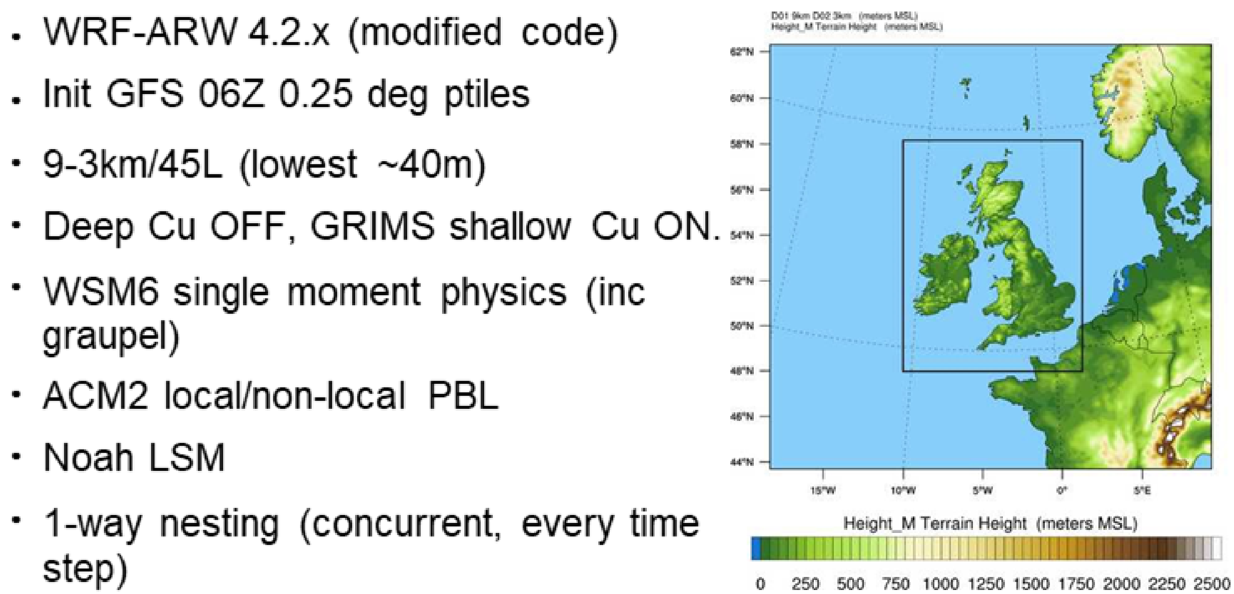

Figure 4. Specifications for the WRF model configuration employed for this study (courtesy of D. Smart, UCL Hazard Centre, Univ. College London).

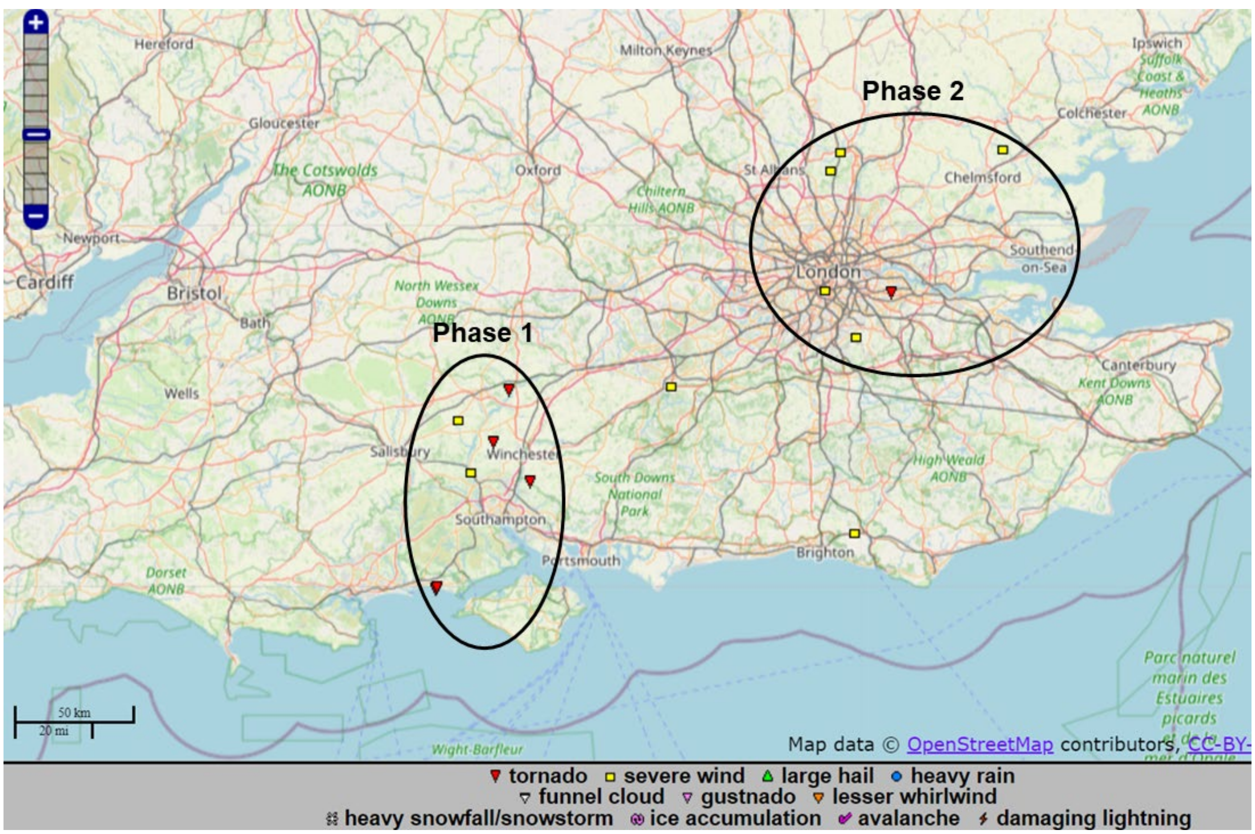

Figure 5. European Severe Weather Database (ESWD) storm reports over Great Britain on 23 October 2022.

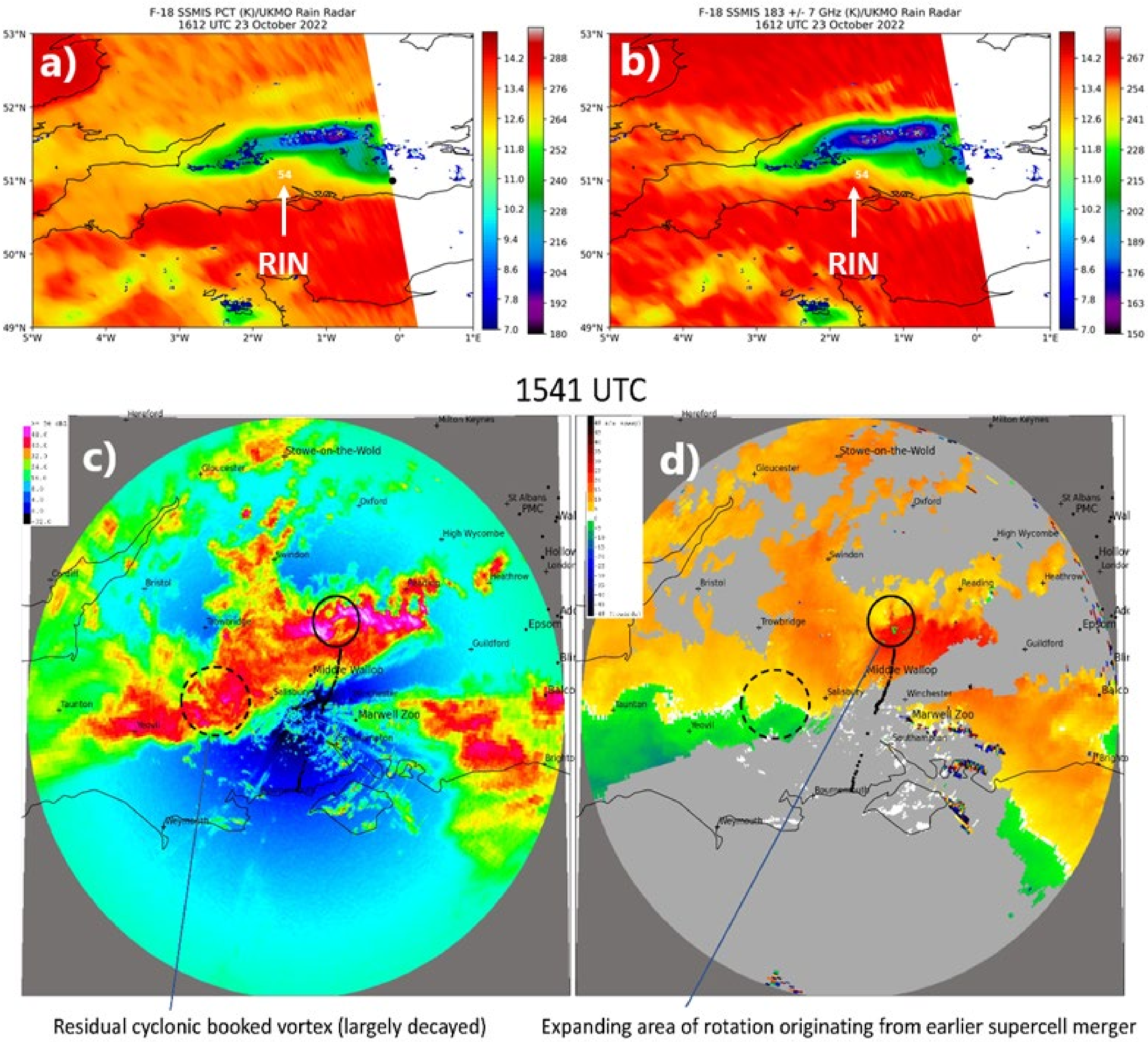

Figure 6. F-18 SSMIS a) polarization-corrected temperature (PCT, K) and b) 183 +/- 7 GHz brightness temperature with overlying UKMO radar rain rate at 1612 UTC and Dean Hill, UK c) radar reflectivity and d) radar velocity at 1541 UTC 23 October 2022. “RIN” denotes a rear-inflow notch.

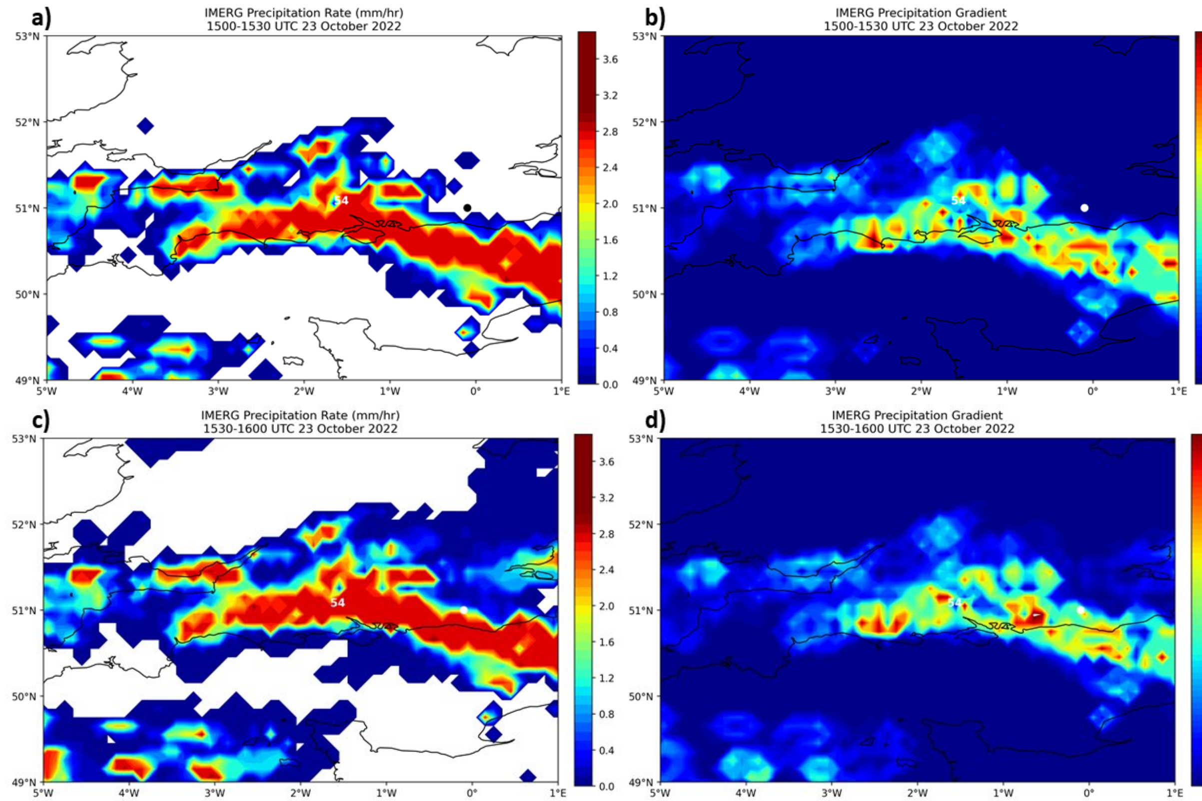

Figure 7. Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation rate (mm/hr) on 23 October 2022 at a) 1500-1530 UTC and c) 1530–1600 UTC; and IMERG precipitation rate gradient at b) 1500-1530 UTC and d) 1530-1600 UTC.

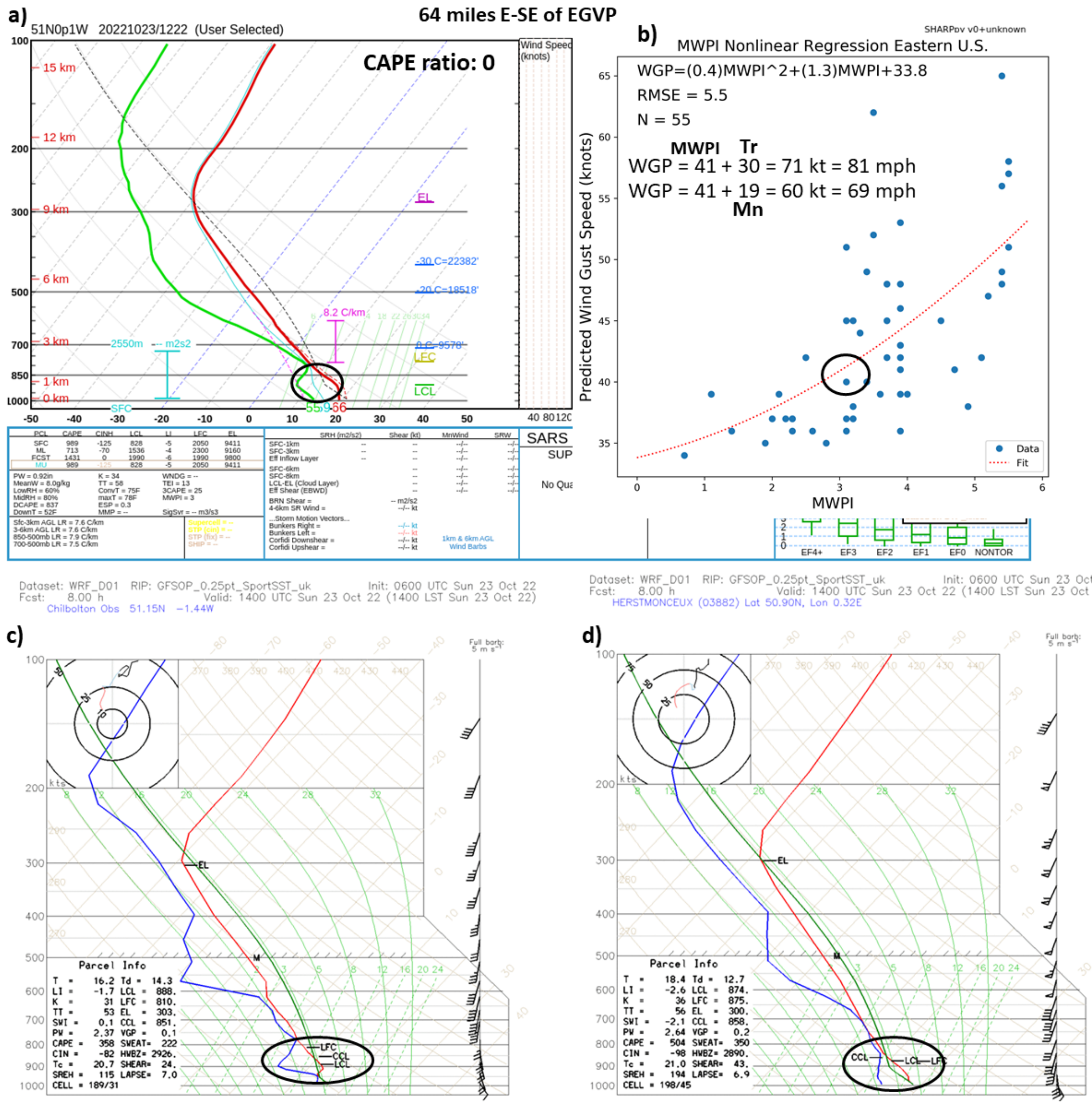

Figure 8. NUCAPS and WRF model sounding comparison: a) NUCAPS sounding profile over Haywards Heath, West Sussex at 1222 UTC with the b) MWPI regression chart demonstrating the wind gust potential calculation technique, and WRF-model generated sounding profiles over c) Chilbolton Observatory, Stockbridge, Hampshire and d) Herstmonceux, East Sussex at 1400 UTC 23 October 2022.

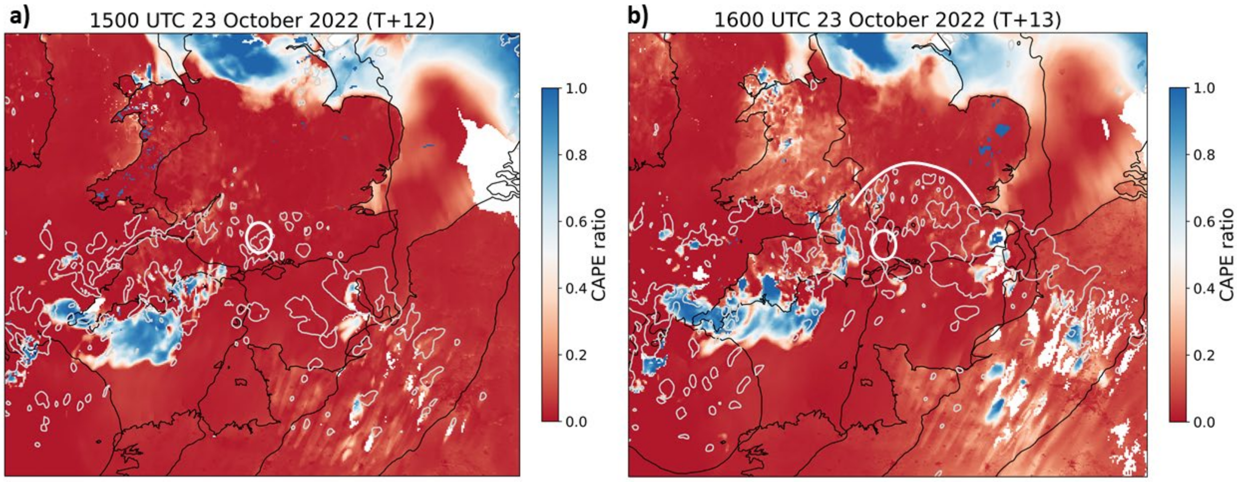

Figure 9. CAPE ratio diagnostic (1 - (SBCAPE/MUCAPE)) map from the UM forecasts of the 23 October 2022 QLCS: a) 1500 UTC and b) 1600 UTC. Reds indicate environments suitable for surface-based convection, blues indicate environments suitable for elevated convection. The gray contours show the 30 dBZ model reflectivity, and the black contours the MSLP. The white circle marks the location of downburst occurrence at Middle Wallop while the white arc represents the leading edge of the bowing segment of the QLCS over the Midlands.

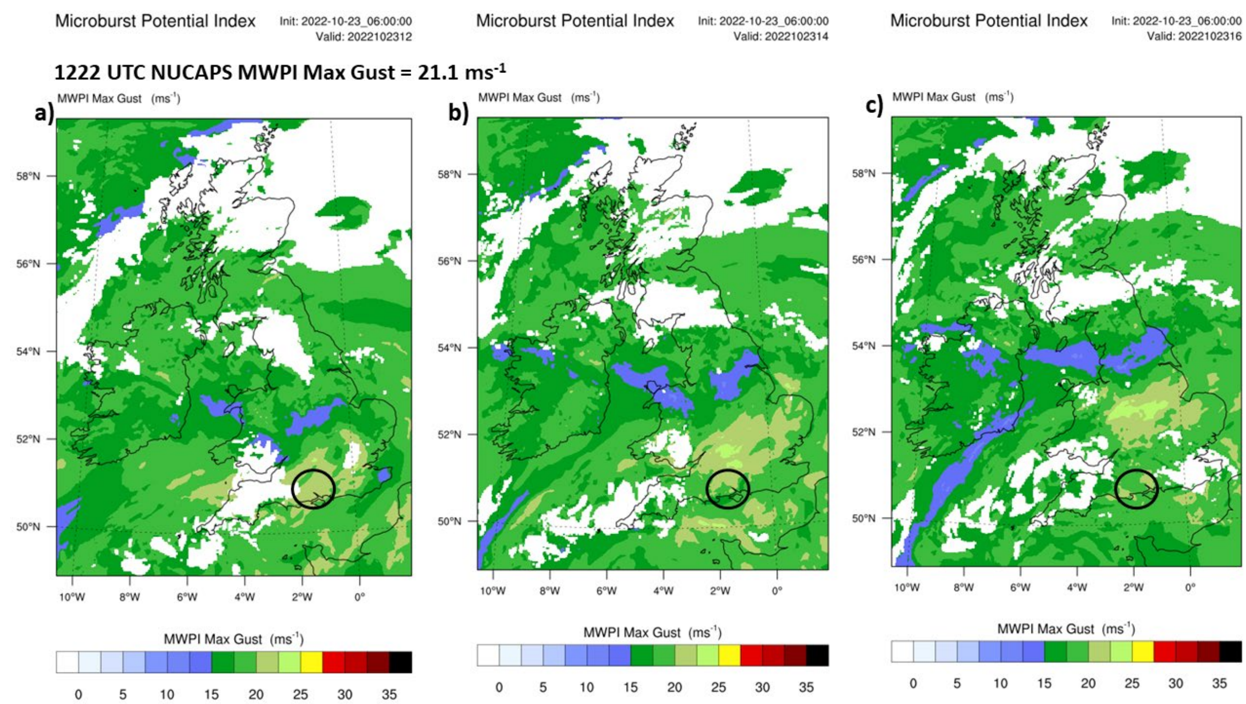

Figure 10. UK sector WRF model-derived MWPI maximum wind gust potential maps at a) 1200 UTC, b) 1400 UTC, and c) 1600 UTC 23 October 2023 (courtesy of D. Smart, UCL Hazard Centre, Univ. College London).

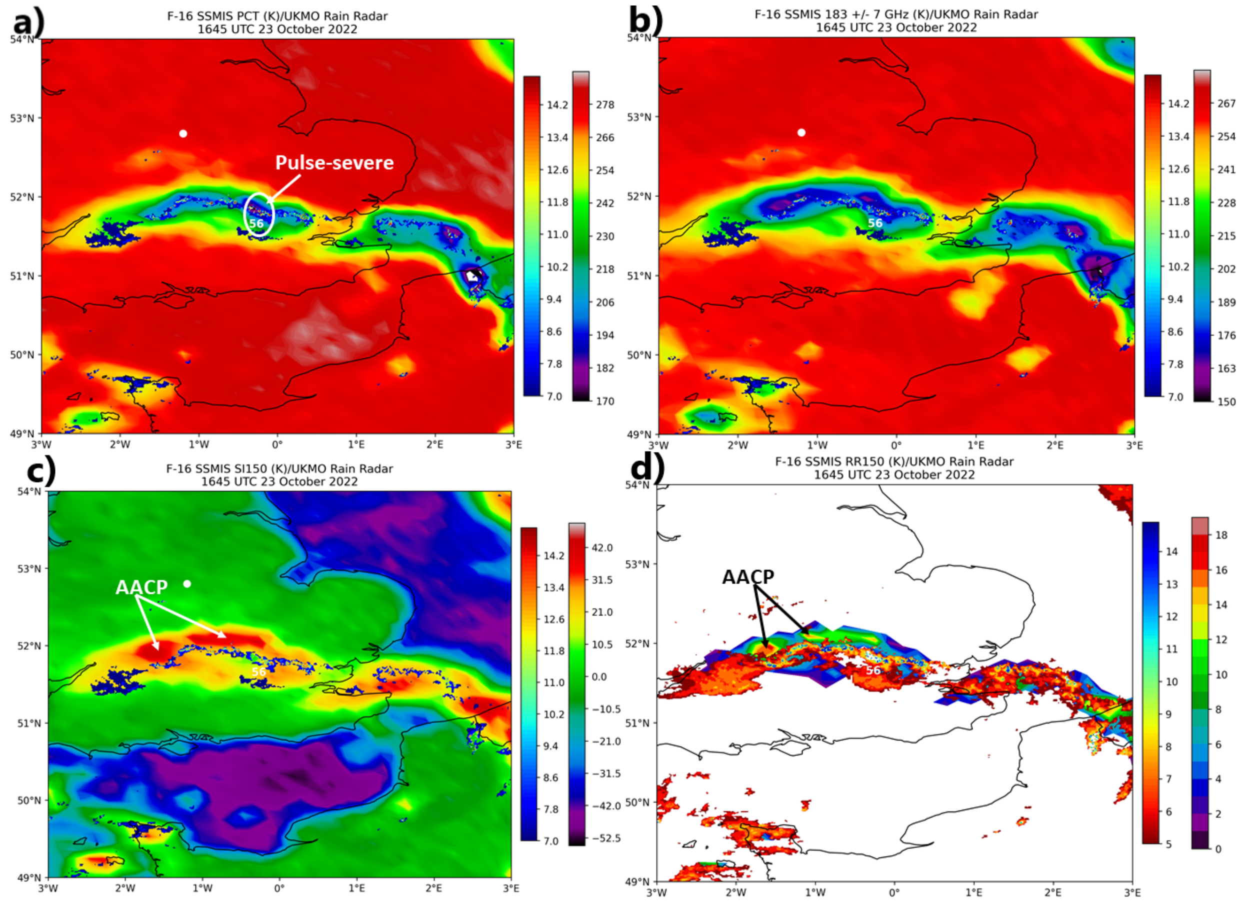

Figure 11. F-16 SSMIS a) polarization-corrected temperature (PCT, K), b) 183 +/- 7 GHz brightness temperature (K), c) 150 GHz scattering index (SI), and d) 150 GHz-channel derived rainfall rate (RR150) with overlying UKMO radar rainfall rate at 1645 UTC 23 October 2023.

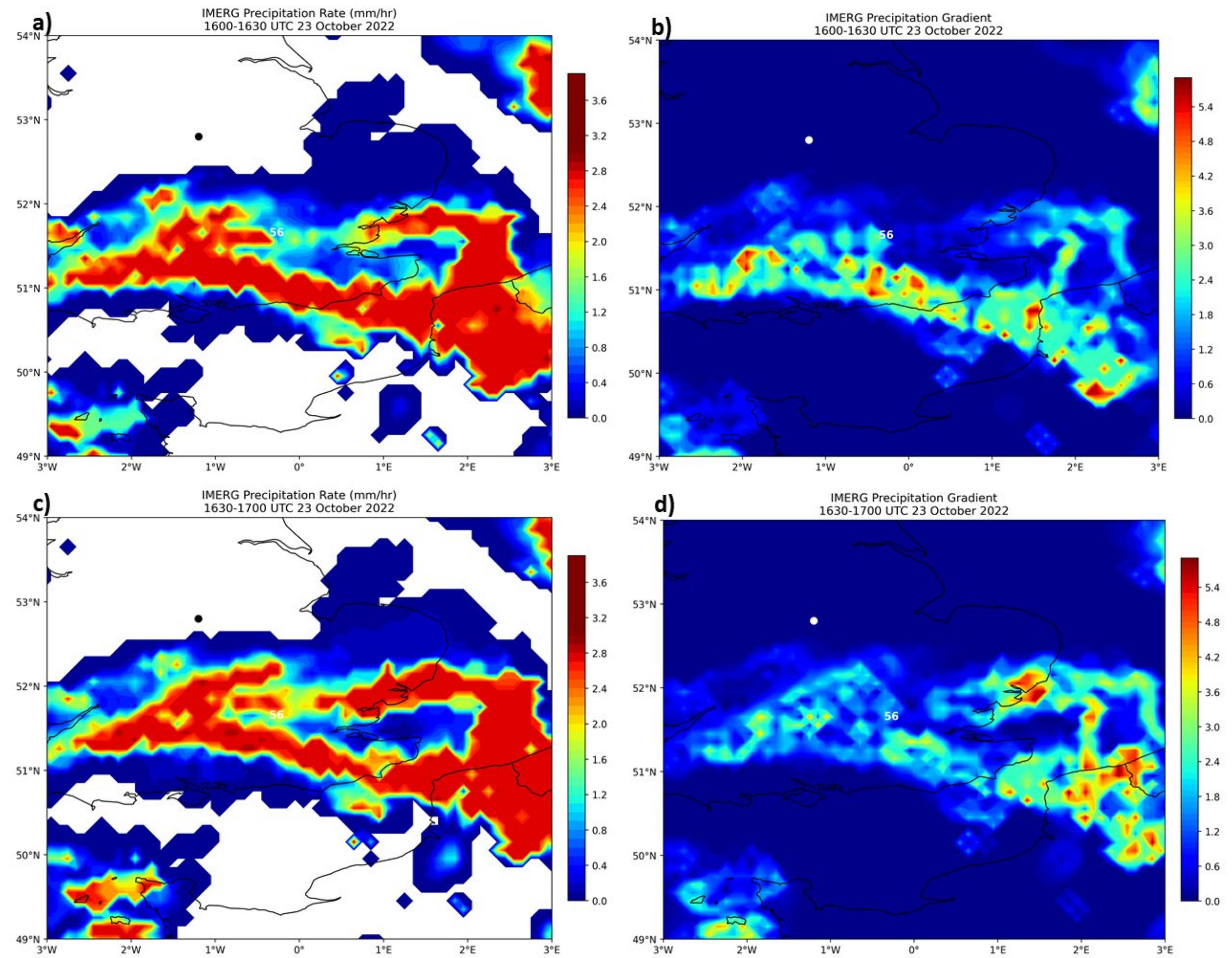

Figure 12. Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation rate (mm/hr) on 23 October 2022 at a) 1600-1630 UTC and c) 1630–1700 UTC; and IMERG precipitation rate gradient at b) 1600-1630 UTC and d) 1630-1700 UTC.

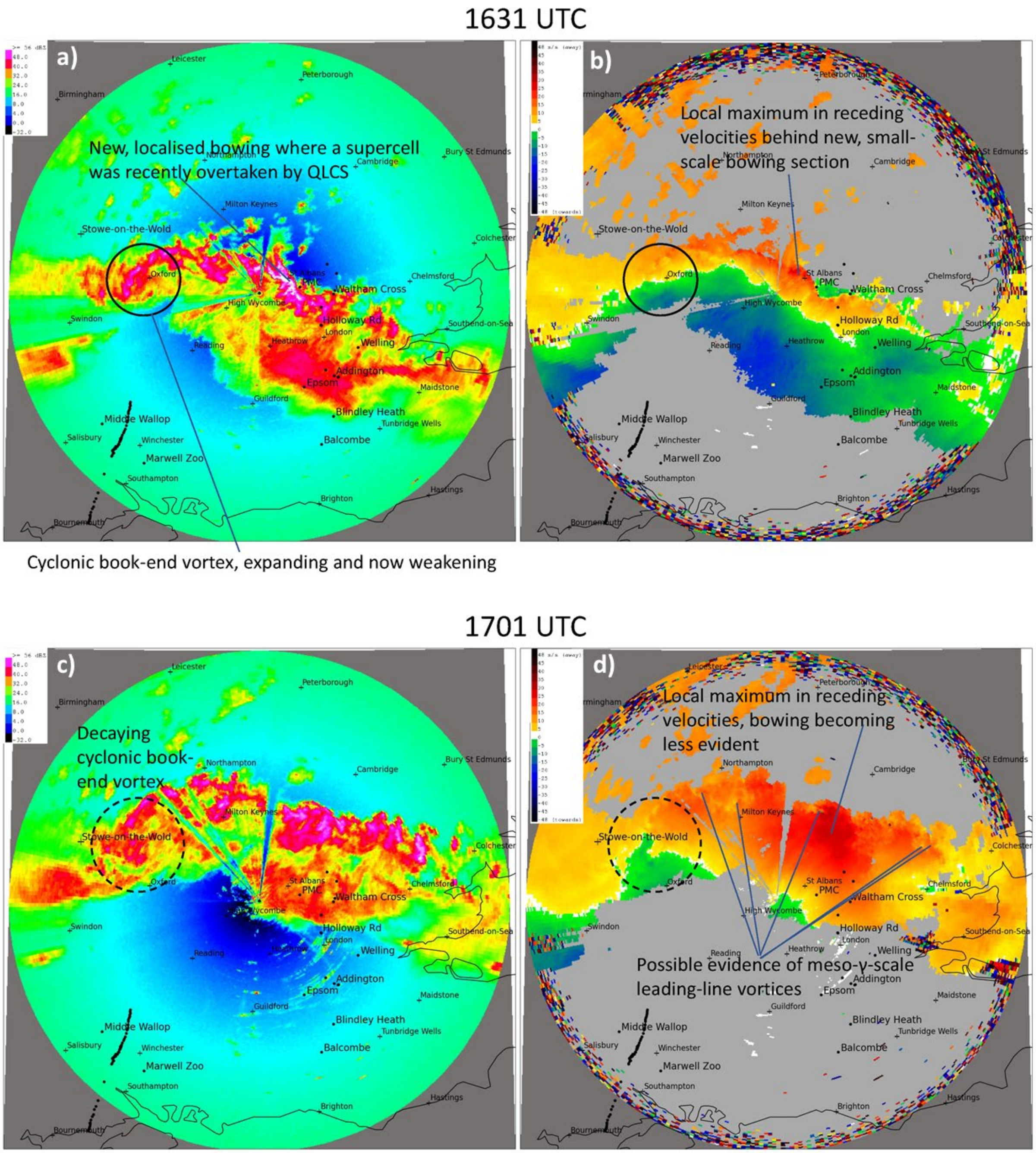

Figure 13. Chenies, UK radar reflectivity (left) and velocity (right) at 1631 UTC 23 October 2022. Black dots mark the location of reported damage.

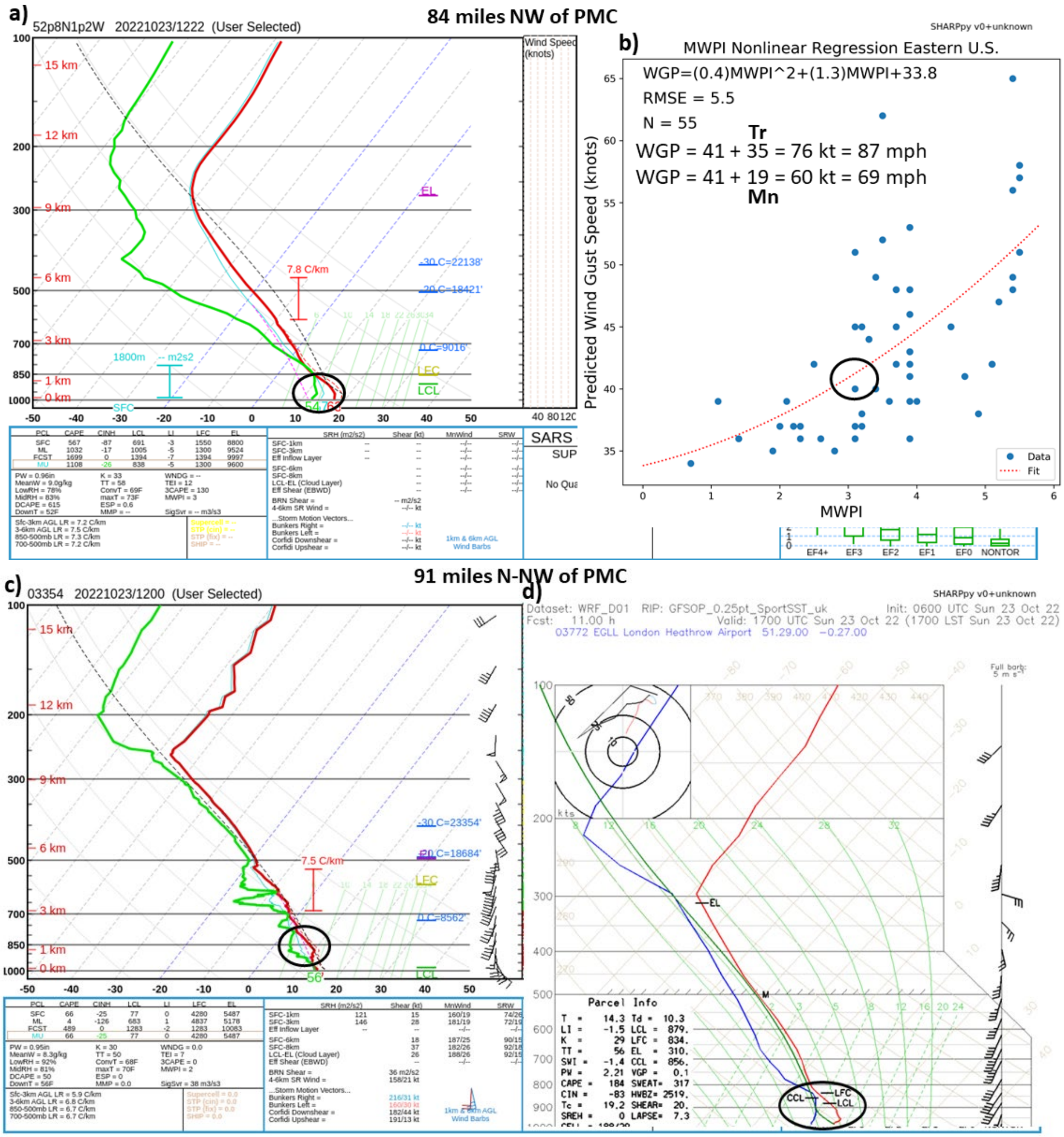

Figure 14. NUCAPS, WRF model, and RAOB sounding comparison: a) NUCAPS sounding profile over Loughborough, Leicestershire at 1222 UTC with the b) MWPI regression chart demonstrating the wind gust potential calculation technique; c) Nottingham RAOB profile at 1200 UTC, and d) WRF-model generated sounding profile over London Heathrow Airport at 1700 UTC 23 October 2022.

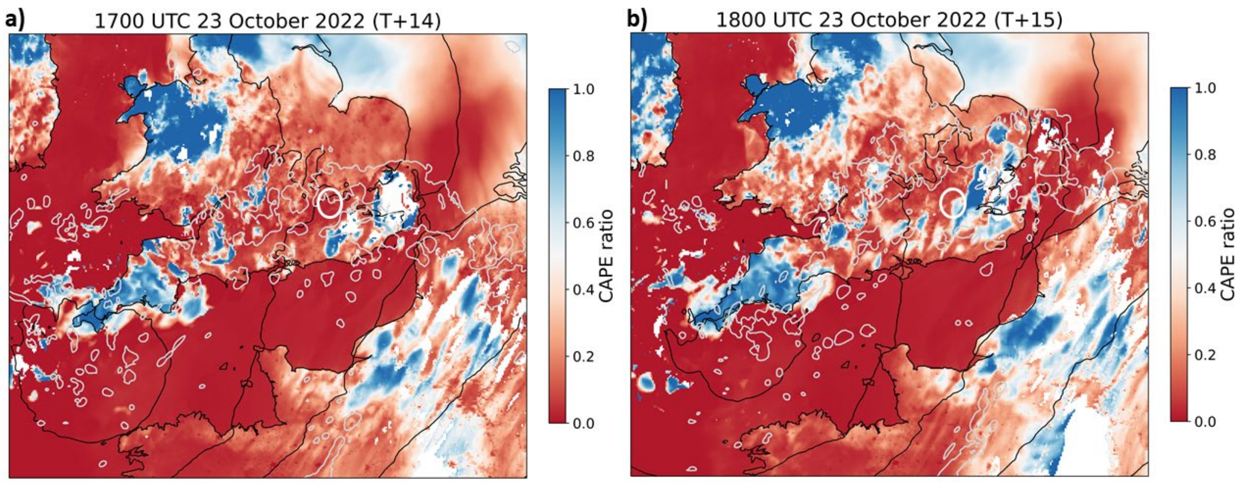

Figure 15. CAPE ratio diagnostic (1 - (SBCAPE/MUCAPE)) map from the UM forecasts of the 23 October 2022 QLCS: a) 1700 UTC and b) 1800 UTC. Reds indicate environments suitable for surface-based convection, blues indicate environments suitable for elevated convection. The gray contours show the 30 dBZ model reflectivity, and the black contours the MSLP. The white circle marks the location of downburst occurrence at London Colney, Hertfordshire.

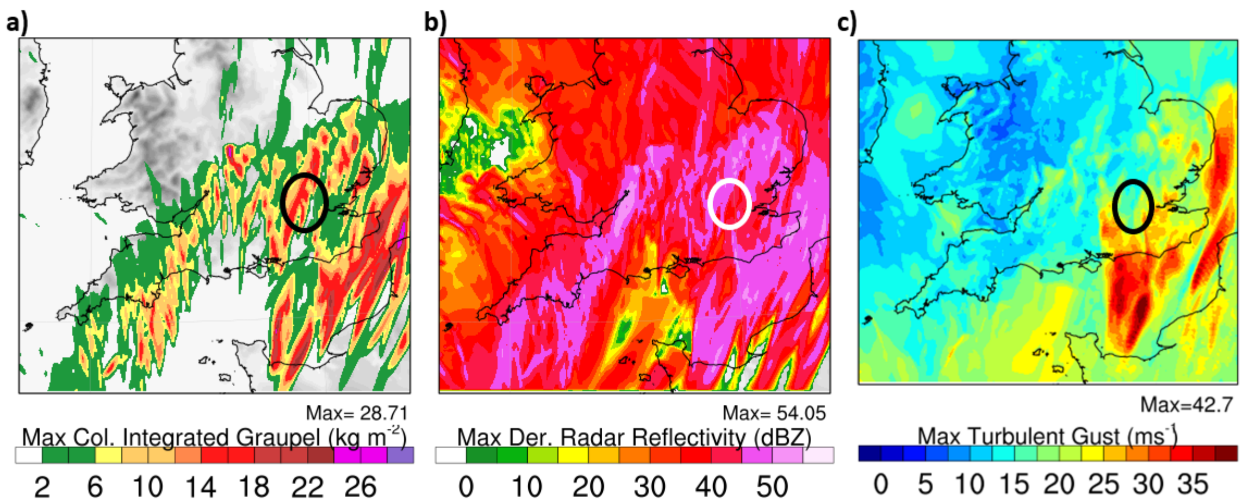

Figure 16. WRF model (UK3 D02)-derived convection diagnostic maps valid at 1800 UTC 23 October 2022: a) maximum column integrated graupel, b) maximum derived radar reflectivity, and c) maximum turbulent gust.