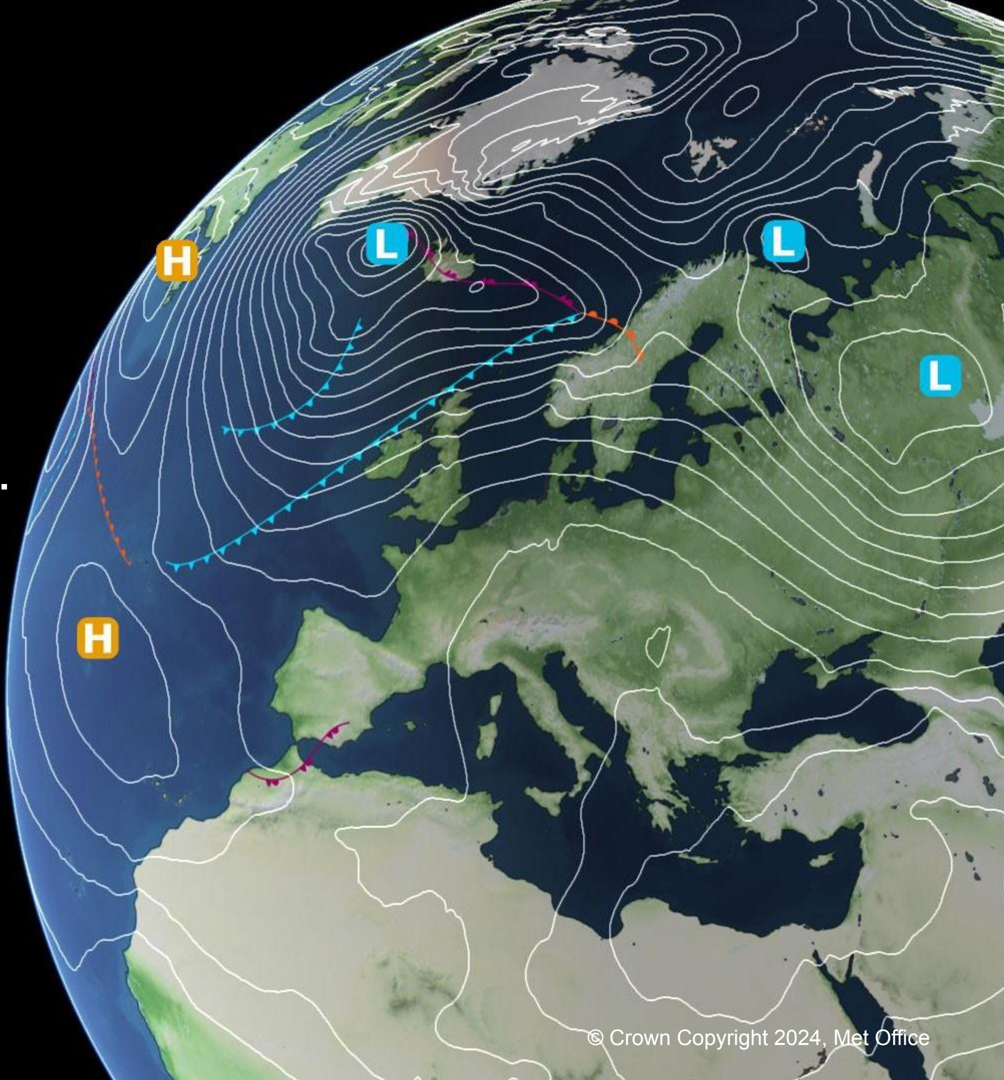
Met Office

ParaChute Programme:
Seamless modelling across the turbulent and convective grey zones.

Alison Stirling

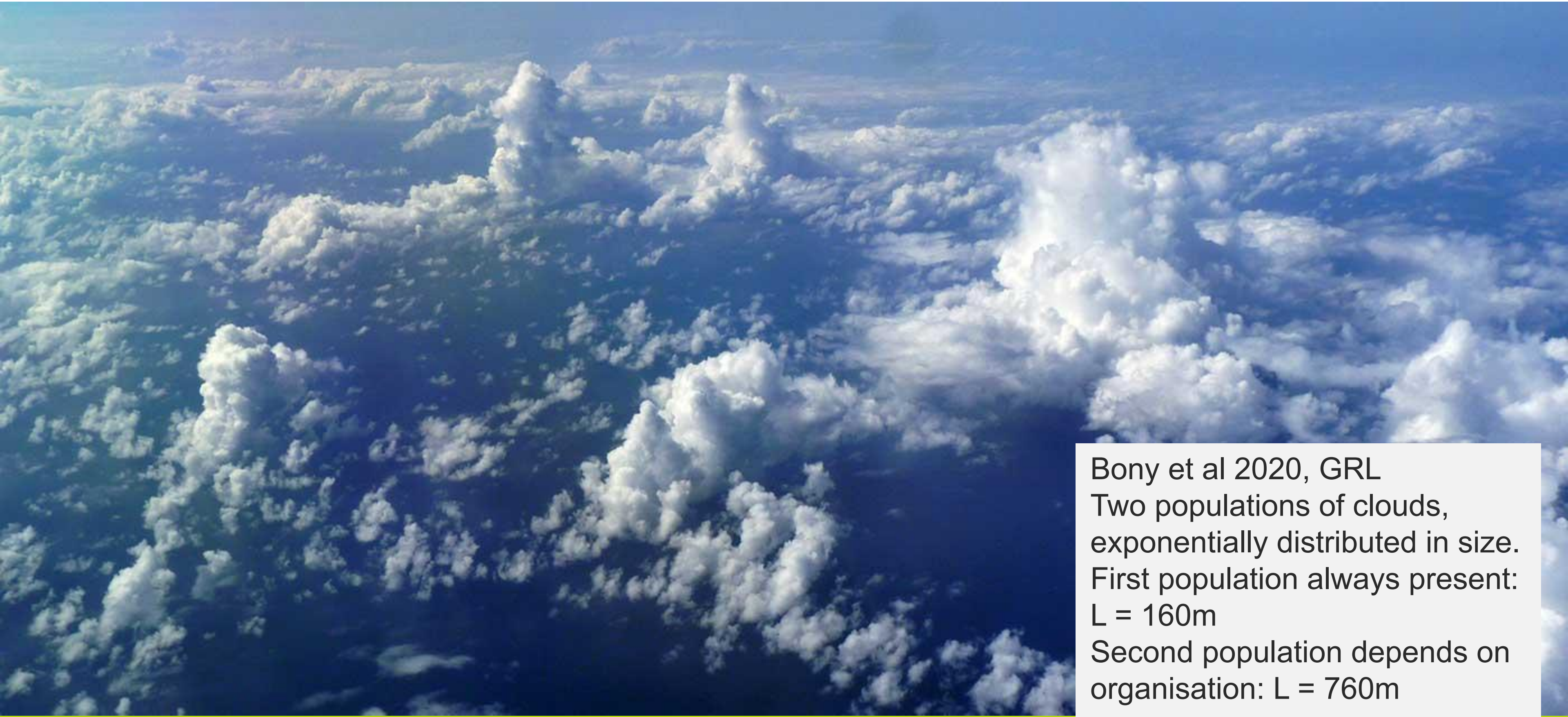
June 2025

Seamless modelling workshop



Met Office

Observed size distributions of trade cumulus in EUREC4A



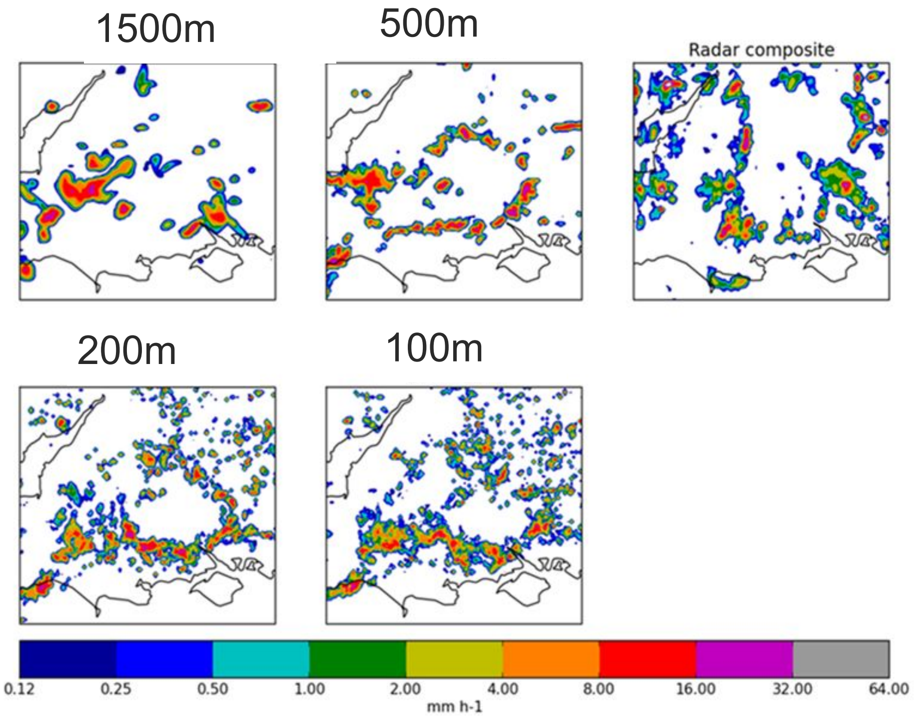
Bony et al 2020, GRL
Two populations of clouds, exponentially distributed in size.
First population always present: L = 160m
Second population depends on organisation: L = 760m

Convection Working Group

Humphrey Lean
Kirsty Hanley

Rank	Performance Improvement needed
1.	Produce too many small showers
2.	Tendency for shallow storms to precipitate too easily
3.	Generally initiate convection too early
4.	Spin-up of convection and turbulence from the boundaries can extend tens of kilometres into the domain
5.	Tendency of convective cells to be unrealistically aligned along the wind rather than across wind.

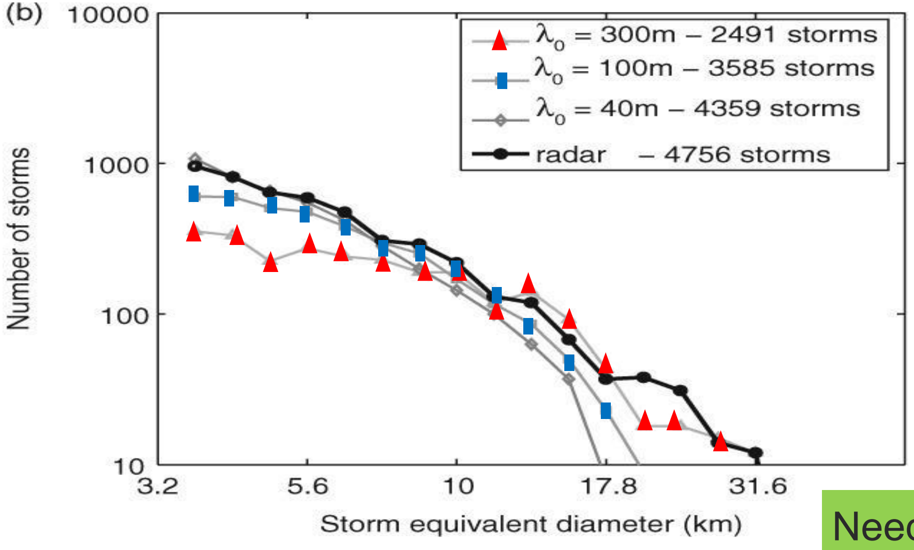
Km and sub-km scale UM over Southern UK



Hanley et al 2015

Cloud Morphology: lessons from DYMECS

UM at 200m for different Smagorinsky mixing lengths compared with radar.



Single mixing lengths allow either the smaller **or** the larger storm statistics to be captured, *but* ***not both*** *at the same time*!

Mixing length needs to be a property of the turbulent flow, also need counter-gradient terms (e.g. Sullivan & Patton 2011)

Need improved turbulence representations in grey zone

Met Office

New Obs → New Theory → New parametrisations → High res. models

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Exeter
MANCHESTER 1824
UNIVERSITY OF LEEDS
UKCEH
University of Reading
Imperial College London
UKRI
Natural Environment Research Council

Partnership and Opportunities Programme: £11m over four years, joint funding from NERC and Met Office (Feb 2023-2027)

Met Office: `Path to High Resolution'
UKRI strategic theme: 'Building a secure and resilient world.'

Aim: To improve the understanding and representation of turbulent processes in km to sub-km scale models.

ParaChute

Parametrizing **C**onvective [turbulence] at **H**ectometric [and km] scales, and **U**nderstanding the **T**urbulent **E**nvironment

Met Office | UK Research and Innovation

ParaChute Programme

Met Office

Met Office | UK Research and Innovation

ParaChute Programme

Aim: To improve the understanding and representation of turbulent processes in km to sub-km scale models.

Goals

- To improve the realism of precipitation structures in Met Office k... and sub-km models, so that they possess similar spatial characteri... observations.

- To improve the accuracy of the ti... ...gth of precipitation forecasts, so that greater value ca... ...the forecasting of severe weather, and associated floodi...

- To produc... ...predictions of the uncertainty in a forecast, so that a better range of p...ssible outcomes can be provided to decision makers.

Provide **trusted** training datasets for AI?

Name	PI	Themes
Hi-Fi	George Efstathiou	Turbulence model development
Umbrella	Andrew Ross	Turbulence and BL scheme evaluation
MORPH	Bob Plant	Km-scale convection scheme development
Cloudy Time	Thorwald Stein	Convective microphysics and hierarchies of evaluation
WOEST	Ryan Neely	Observations to complement WesCon

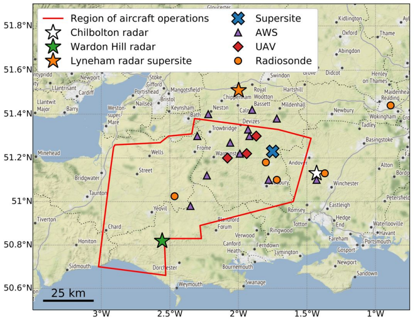
+

Name	Lead	Themes
MMG	Humphrey Lean	Hectometric and turbulence, WesCon
Convection	Alison Stirling	Convection modelling
BL	Adrian Lock	Boundary layer and turbulence
Microphysics	Paul Field	Microphysics
Dynamics	Ian Boutle	Dynamics
OBR	Paul Barrett	WesCon
RMED	Anne McCabe	Predictability

=

WG	Name	Met Office Leads	NERC Leads	External expert
1	WesCon-WOEST observations	Paul Barrett, Humphrey Lean	Thorwald Stein, Ryan Neely	**Cathy Hohenneger**
2	Turbulence Grey Zone	Adrian Lock, Humphrey Lean	George Efstathiou Andrew Ross	Didier Ricard
3	Convective Grey Zone	Alison Stirling	Bob Plant	Dan Kirshbaum
4	Turbulent Microphysics	Paul Field	Steef Boeing	Axel Seifert
5	Physics-Dynamics Coupling	Ian Boutle	Bob Beare	Colin Cotter
6	Predictability	Anne McCabe	Sue Gray	Inger-Lise Frogner

WesCon WOEST. 5th June - 25th August 2023



Aircraft

- FAAM - 12 flights, >70 hours
- DIMONA - 16 Flights, >45 hours

Radars

- CAMRa, Kepler, NXPol1 & 2,
- Chilbolton, Lyneham, Wardon Hill
- 25+ Days scanning

Radiosonde

- Larkhill, Chilbolton, Ash Farm, Spire View, Reading.
- Extras: Camborne, Herstmonceux, Aberporth
- >350 in total.

WxUAS

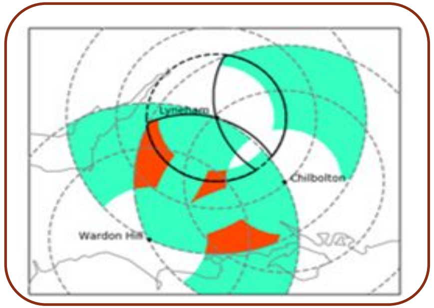
- Breach Hill, Heytesbury, Chilbolton, Wherwell Forest.
- ~120 flight hours.
- ~700 flights.
- First 2 km BVLOS.

Supersites

- Netheravon, Lyneham, Chilbolton
- Lidars,
- wind profilers,
- microwave radiometers,
- stereo cameras
- Masts

AWS sites

- 12 stations 24/7 operation



Doppler Radar network
Lyneham, Chilbolton, Wardon Hill

#WesCon2023

UK scientists to improve forecasting of extreme weather events

1 June 2023

Scientists are working on ways to improve the forecasting of extreme weather events.

£11 million funding is being invested by the Met Office and the Natural Environment Research Council (NERC), including the funding of five projects that will each investigate key scientific questions.

https://www.ukri.org/news/uk-scientists-to-improve-forecasting-of-extreme-weather-events

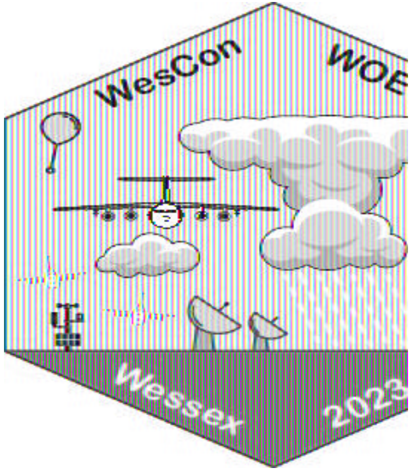
https://www.itv.com/news/2023-09-25/the-scientists-taking-to-the-skies-to-improve-extreme-weather-forecasting

Met Office

WesCon-WOEST campaign provides the focus for ParaChute observational evaluation

- Process-level analysis, e.g.
  - Evolution of pre-convective environment
  - Initiation of convection
  - Cloud morphology
  - Turbulence strength within clouds (Eddy dissipation rates)
  - Vertical velocities within updrafts
  - Cold pool representation

- Model evaluation at different resolutions over the WesCon area
  - Ensemble simulations at 300m over the region the ‘Wessex Model at Variable resolution’ (WMV)
  - Focus for new model physics simulations



Data Paper ready for submission to ESSD: Barr et al 2025

Modelling Path for ParaChute

Improved representation of turbulent processes in km and sub-km scale models leading to improved predictions for weather and climate.

Want to do that through …

- More consistent boundary layer representation across turbulence-grey zone, and taking into account heterogeneous conditions
- Inclusion of a scale-aware convection scheme (building on CoMorph)
- Understanding how to represent microphysics on these scales
- Inclusion of stochastic processes integral to physics schemes, aiming for a more realistic ensemble spread
- …with a longer-term goal for a unified BL-convection scheme from 100m to 100km

Met Office

Turbulence grey zone

Produce a new representation of turbulent mixing that better represents the transfer of energy across the grey-zone.

- Development of **a new turbulence scheme with a dynamically derived mixing length scale for sub-km scales** (Hi-Fi, BL group):

1. Smagorinsky with fixed length scale
2. Dynamic length scale based on properties of flow
3. Inclusion of tilting terms
4. Dynamic approach into prognostic 3DTE scheme
5. Explore inclusion of stochastic variability

- Evaluation of different boundary layer schemes performance over UK using multi-year Doppler lidar observations (Umbrella: Helen Dacre, Natalie Harvey)

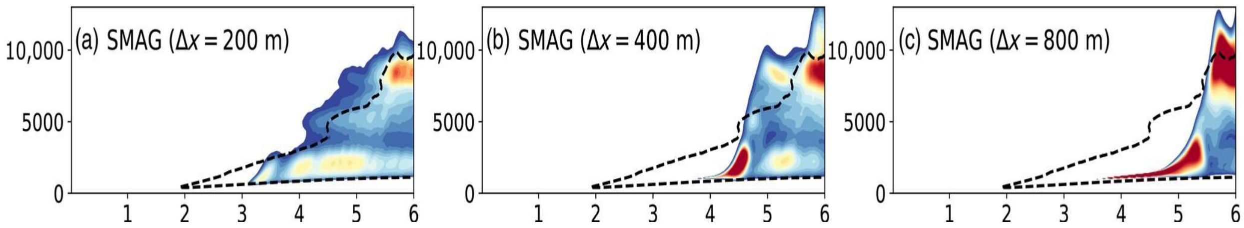
- Modelling and refinement of boundary layer behaviour over heterogeneous surfaces (both typical over UK and tropical Africa) (Umbrella: PI Andrew Ross, **Michael Baidu**)

- WesCon observations to measure the Eddy Dissipation Rate and length scales of coherent structures and compare with modelled predictions

Grey-zone simulations of shallow-to-deep convection transition using dynamic subgrid-scale turbulence models

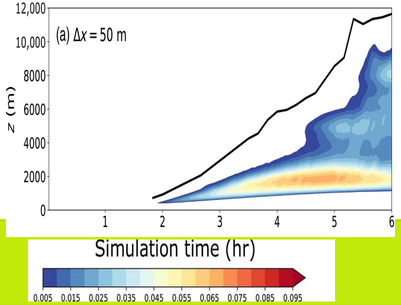
Efstathiou et al 2024, QJ

Smagorinsky with fixed length scale



Dynamic length scale based on properties of flow

Inclusion of tilting terms



Quart J Royal Met. Soc, Volume: 150, Issue: 764, Pages: 4306-4328 DOI: (10.1002/qj.4817)

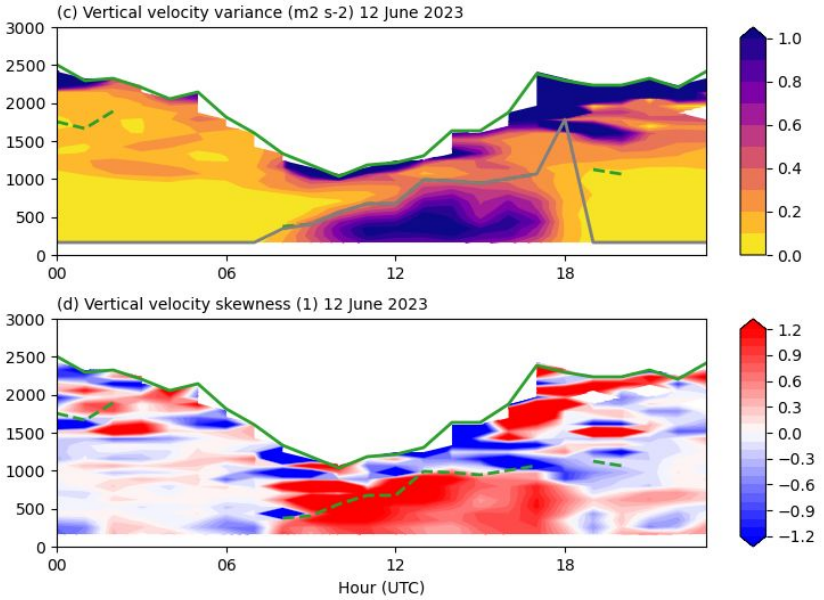
Doppler lidar and sonic anemometer to create a three-year dataset of BL structure for model evaluation

Natalie Harvey
Helen Dacre
University of Reading

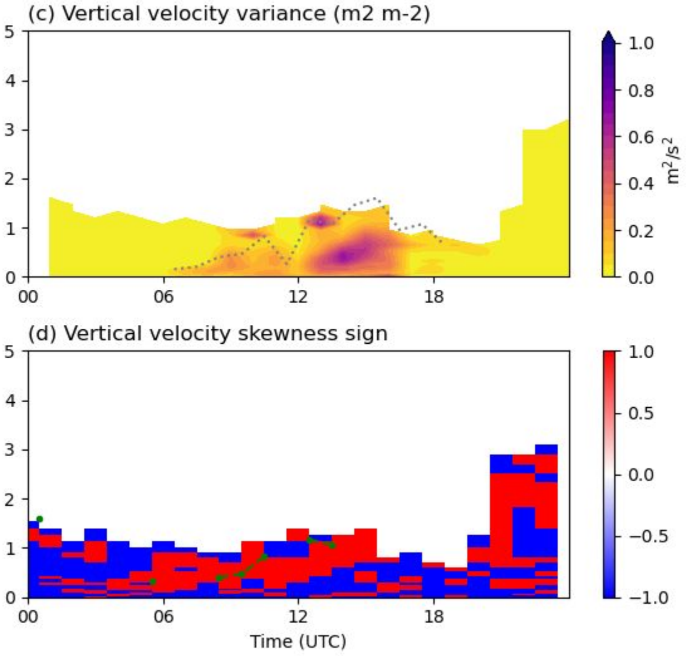
Compare observations and simulations

Exploiting simulated timeseries data

Observations



Control Simulation - WMV (300m, 12s)



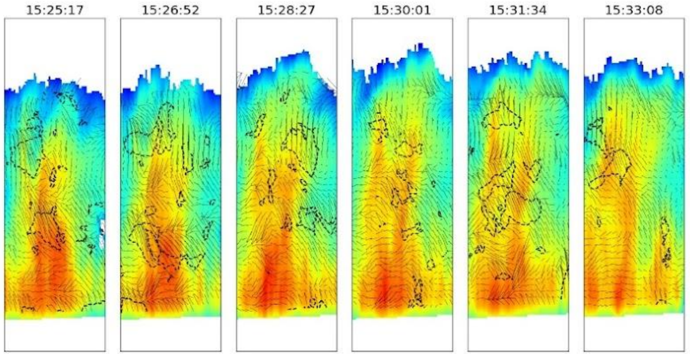
Representing convection at km scales

Extend CoMorph convection scheme to operate at km scales (MO convection group, MORPH project):

CoMorph-B (global models) → Turn down scheme as becomes resolvable by grid. → Introduce stochastic triggering → Introduce stochastic entrainment, detrainment → Ensure works smoothly with boundary layer scheme → CoMorph-C

Evaluation in Regional Atmosphere configurations
CloudyTime: Compare predictions with WesCon-WOEST observations of:

- Pre-convective environment
- Boundary layer perturbations leading to:
- Initiation of convection, leading to:
- Cloud morphology
- Vertical velocities within updrafts
- Cold pool representation



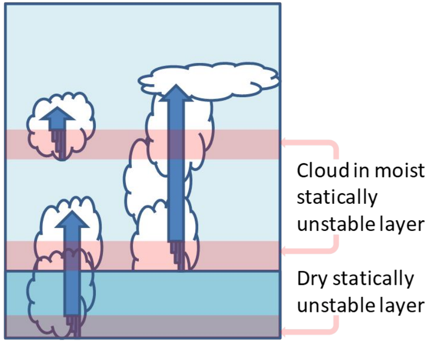
Colours show radar reflectivity, dashed contours are w > 4m/s (courtesy Liam Till, Thorwald Stein).

Met Office

CoMorph properties for scale-aware behaviour

CoMorph – Generalised / Unified approach:

- Convecting parcels launch from any height where there is local vertical instability.
- Plumes from different unstable layers integrated independently.
- Single parcel ascent / descent code for all plumes.
- Updraft radius (entrainment rate = 0.2/R) depends on the turbulent mixing-length in the parcel's source-layer.



- Implicit detrainment term gives smooth timestep behaviour.
- This enables more consistent coupling to the dynamics, making it easier to hand-over between explicit and parametrised convection, or for them to coexist.
- Has a prediction for convective length scale, making it straightforward to turn down as this length scale approaches the grid-scale.

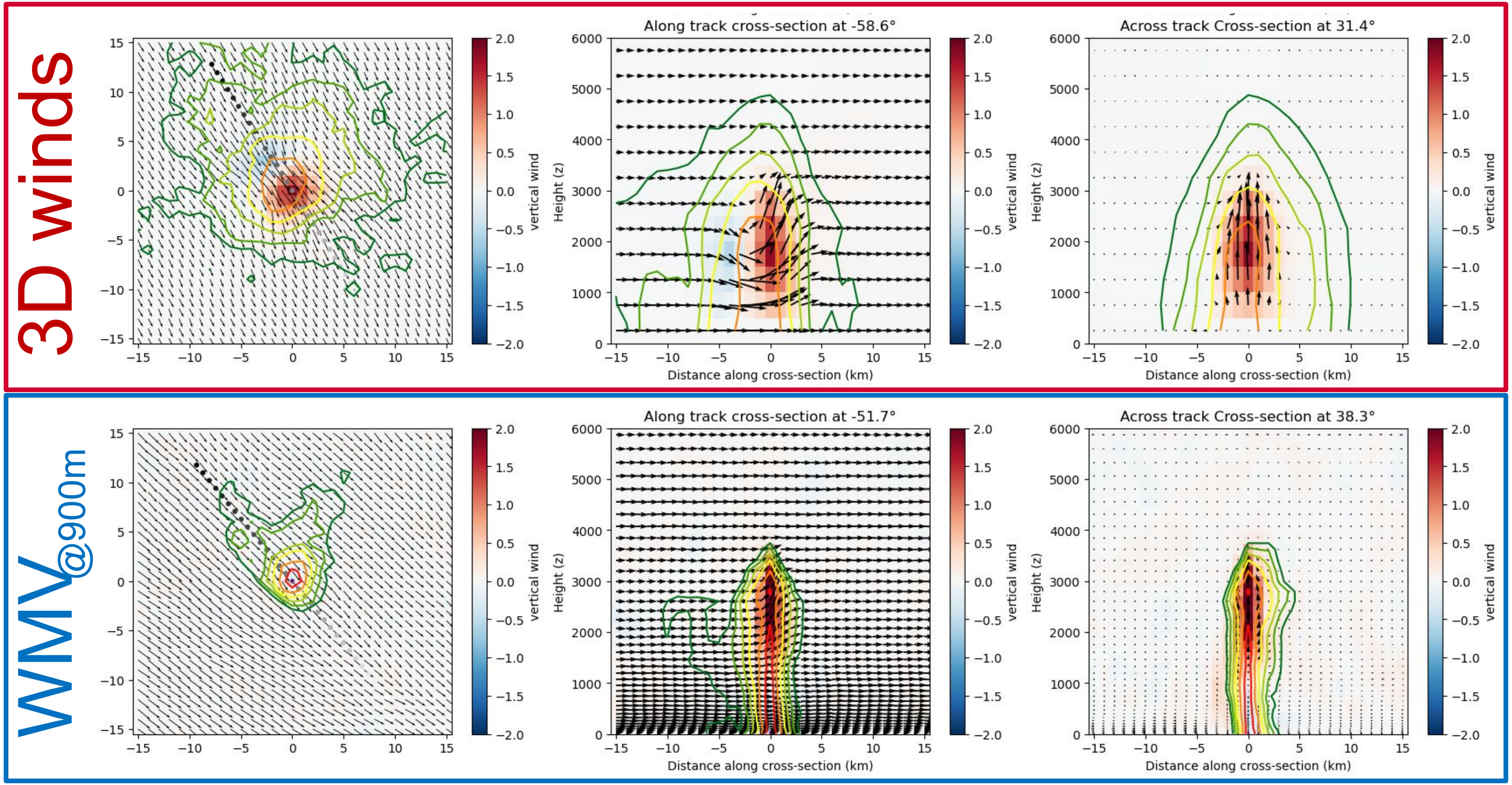
First km-scale formulation uses CoMorph-A (see Sally Lavender's talk)

Initial length scale analysis using CoMorph-B (see Sam Smith's poster)

Mike Whitall

Use radial velocities from multiple radars to deduce full wind vector. Can then compare with modelled cloud systems.

Rob Thompson
Thorwald Stein
University of Reading



Next steps

Turbulent grey-zone scheme

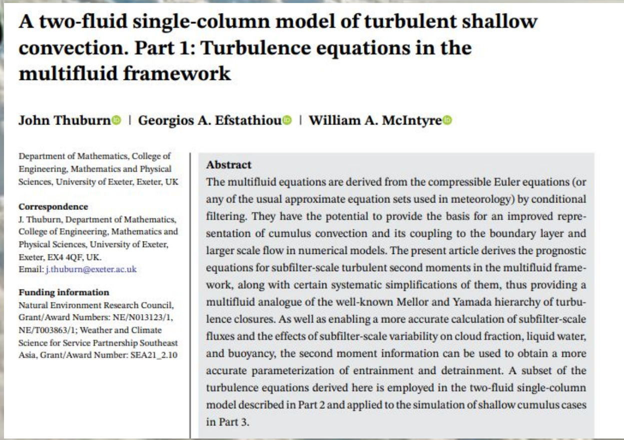
- Continued implementation, evaluation in idealised and real cases from WesCon
- Port to LFRic

1. 3DTE scheme

Scale-aware convection scheme

- Continued evaluation of CoMorph-A trailblazer
- Continued implementation, evaluation in idealised and WesCon case studies, global models
- Port to LFRic

2. CoMorph-C



A two-fluid single-column model of turbulent shallow convection. Part 1: Turbulence equations in the multifluid framework

John Thuburn | Georgios A. Efstathiou | William A. McIntyre

Department of Mathematics, College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, UK

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J. Thuburn, Department of Mathematics, College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, EX4 4QF, UK.
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Funding information
Natural Environment Research Council, Grant/Award Numbers: NE/N013123/1, NE/T003863/1; Weather and Climate Science for Service Partnership Southeast Asia, Grant/Award Number: SEA21_2.10

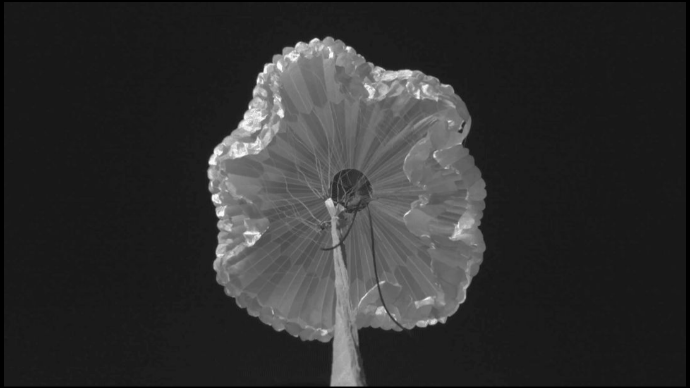
Abstract
The multifluid equations are derived from the compressible Euler equations (or any of the usual approximate equation sets used in meteorology) by conditional filtering. They have the potential to provide the basis for an improved representation of cumulus convection and its coupling to the boundary layer and larger scale flow in numerical models. The present article derives the prognostic equations for subfilter-scale turbulent second moments in the multifluid framework, along with certain systematic simplifications of them, thus providing a multifluid analogue of the well-known Mellor and Yamada hierarchy of turbulence closures. As well as enabling a more accurate calculation of subfilter-scale fluxes and the effects of subfilter-scale variability on cloud fraction, liquid water, and buoyancy, the second moment information can be used to obtain a more accurate parameterization of entrainment and detrainment. A subset of the turbulence equations derived here is employed in the two-fluid single-column model described in Part 2 and applied to the simulation of shallow cumulus cases in Part 3.

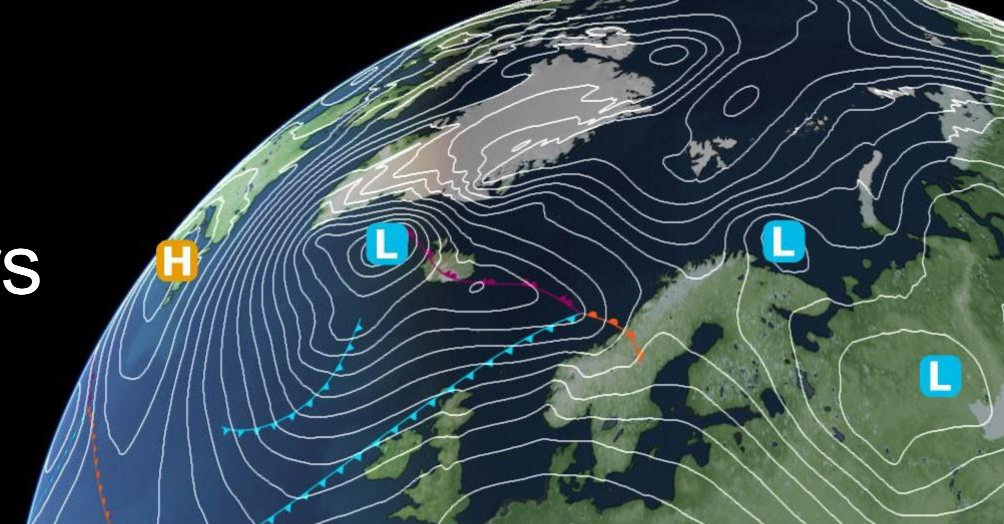
3. Unifying the schemes

Enables us to write both schemes in the same framework and compare terms

Met Office

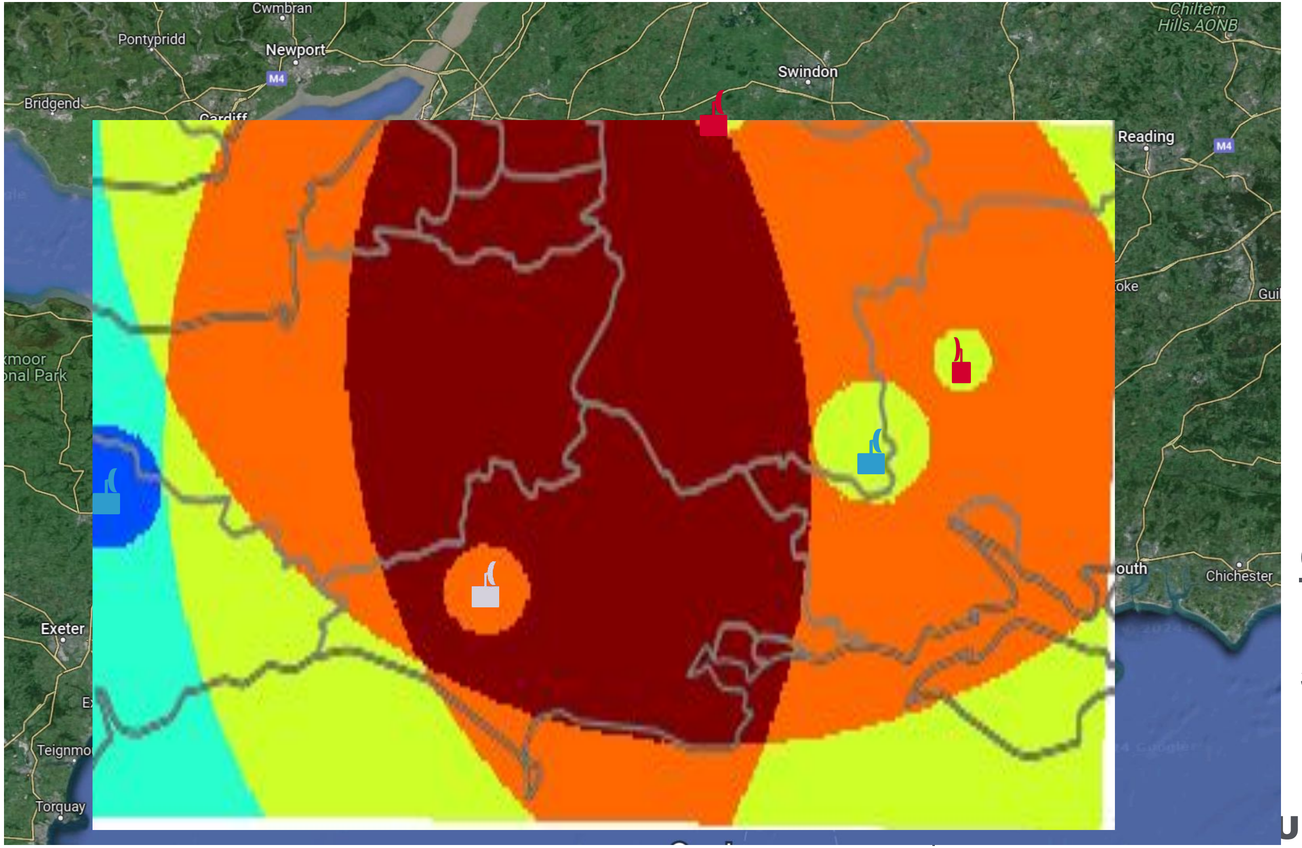
Questions and Answers





THE WOEST RADAR SETUP

University of Reading



NX Pol (mobile X-band)

- 1. Lyneham
- 2. Chilbolton

MO Research (C-band)

- Wardon Hill

MO Network (C-band)

- Dean Hill
- Cobbacombe

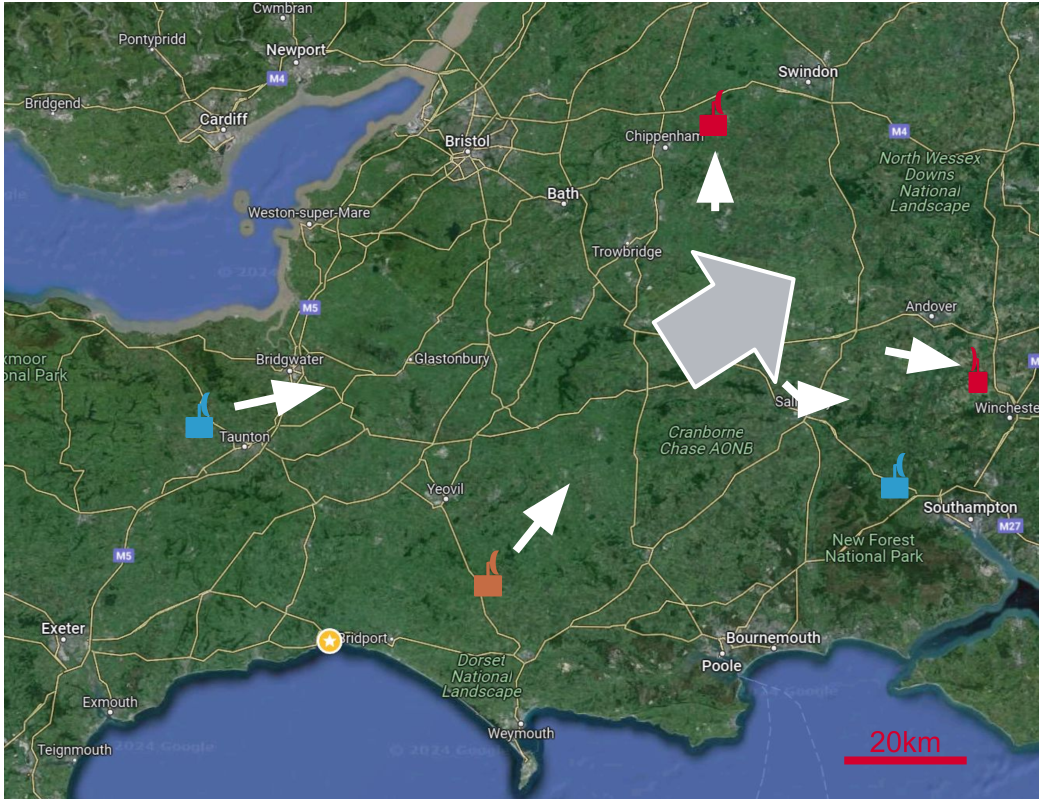
GRID:

189x132 1km horiz.

500m res. to 10km vert.

RELATING RADIAL VELOCITY TO THE TRUE WIND

Rob Thompson
Thorwald Stein
University of Reading



- Use the vectors of line of sight winds from multiple radars to define the wind vector.
- Using PyDDA (ex MultiDop)

  Iterate to minimise a cost function:

$$J = c_o J_{obs} + c_m J_{mass} + c_s J_{smooth} + c_w J_w$$

$$J_{obs} = \Sigma_{radar} \Sigma_i [w_i (V_{ar} - V)]^2$$

$$J_{mass} = \nabla . \boldsymbol{V} + w \, {}^{dP}\!/_{dz}$$

$$J_{smooth} = \nabla^2 \boldsymbol{V}$$

NEW !

$$J_w = \begin{cases} no\ obs\ \& > 2km: & w^2 \\ else: & 0 \end{cases}$$

Turbulent droplet collisions in rainfall

Include sensitivity of collision-coalescence to turbulence in CASIM

New model called EPIC can capture motions at 5m resolution. Use to evaluate turbulent flows in clouds and precipitation production.

Frey et al 2022, J. Comp Phys:X

Domantas Dilys