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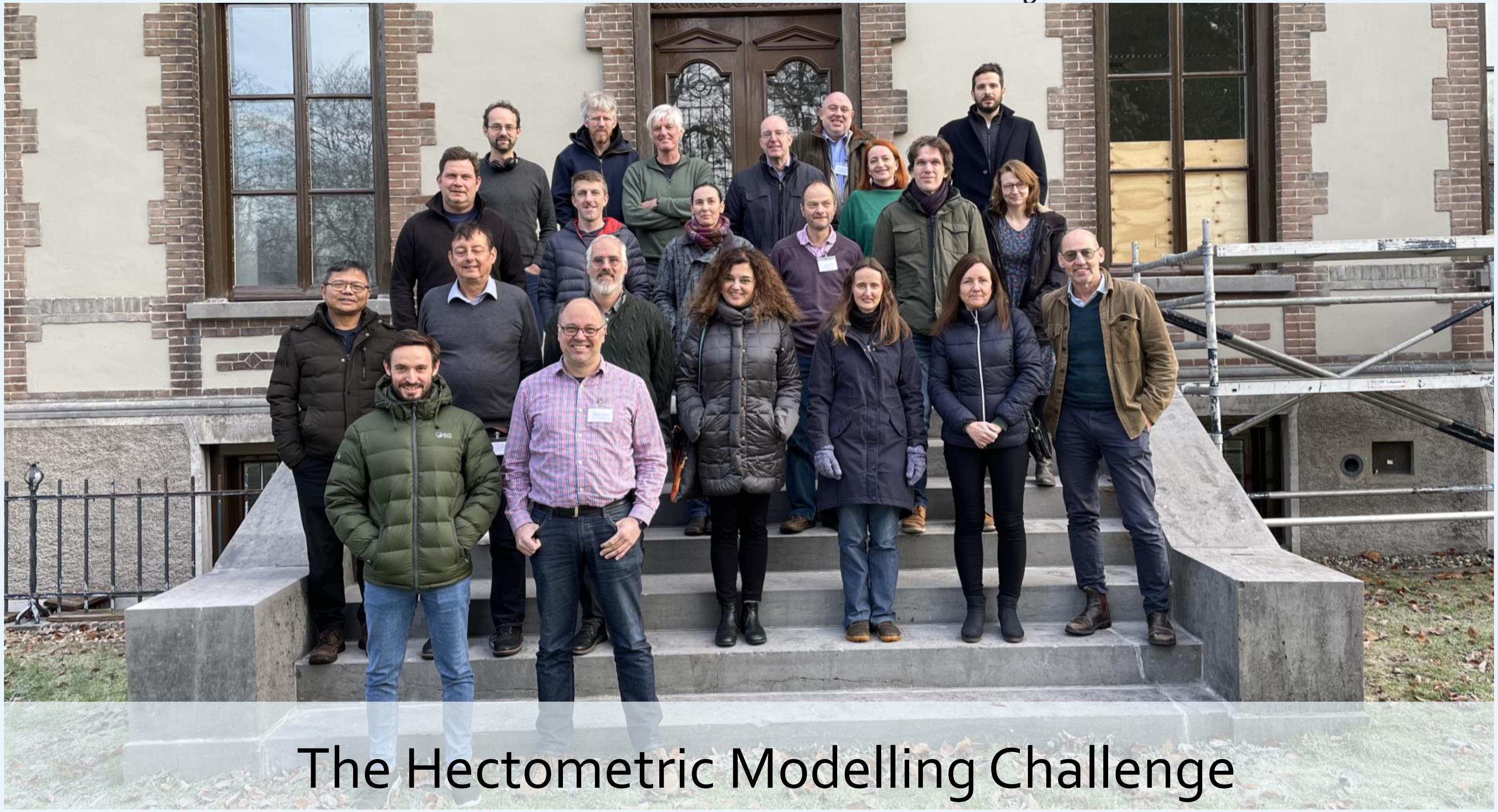

The Hectometric Modelling Challenge

Humphrey Lean (UKMO), Natalie Theeuwes (KNMI), Michael Baldauf, Jan Barkmeijer, Geoffrey Bessardon, Lewis Blunn, Jelena Bojarova, Ian Boutle, Peter Clark, Matthias Demuzere, Peter Dueben, Inger-Lise Frogner, Siebren de Haan, Dawn Harrison, Chiel van Heerwaarden, Rachel Honnert, Adrian Lock, Chiara Marsigli, Valéry Masson, Anne Mccabe, Maarten van Reeuwijk, Nigel Roberts, Pier Siebesma, Petra Smolíková, Xiaohua Yang

Aim to write a paper

- Met service oriented
- European perspective (no travel funding)
- Bring together various NWP components
- Bring in LES experts and academics

The Hectometric Modelling Challenge:

Gaps in the current State of the Art and Ways Forward towards the Implementation of 100 m scale Weather and Climate models

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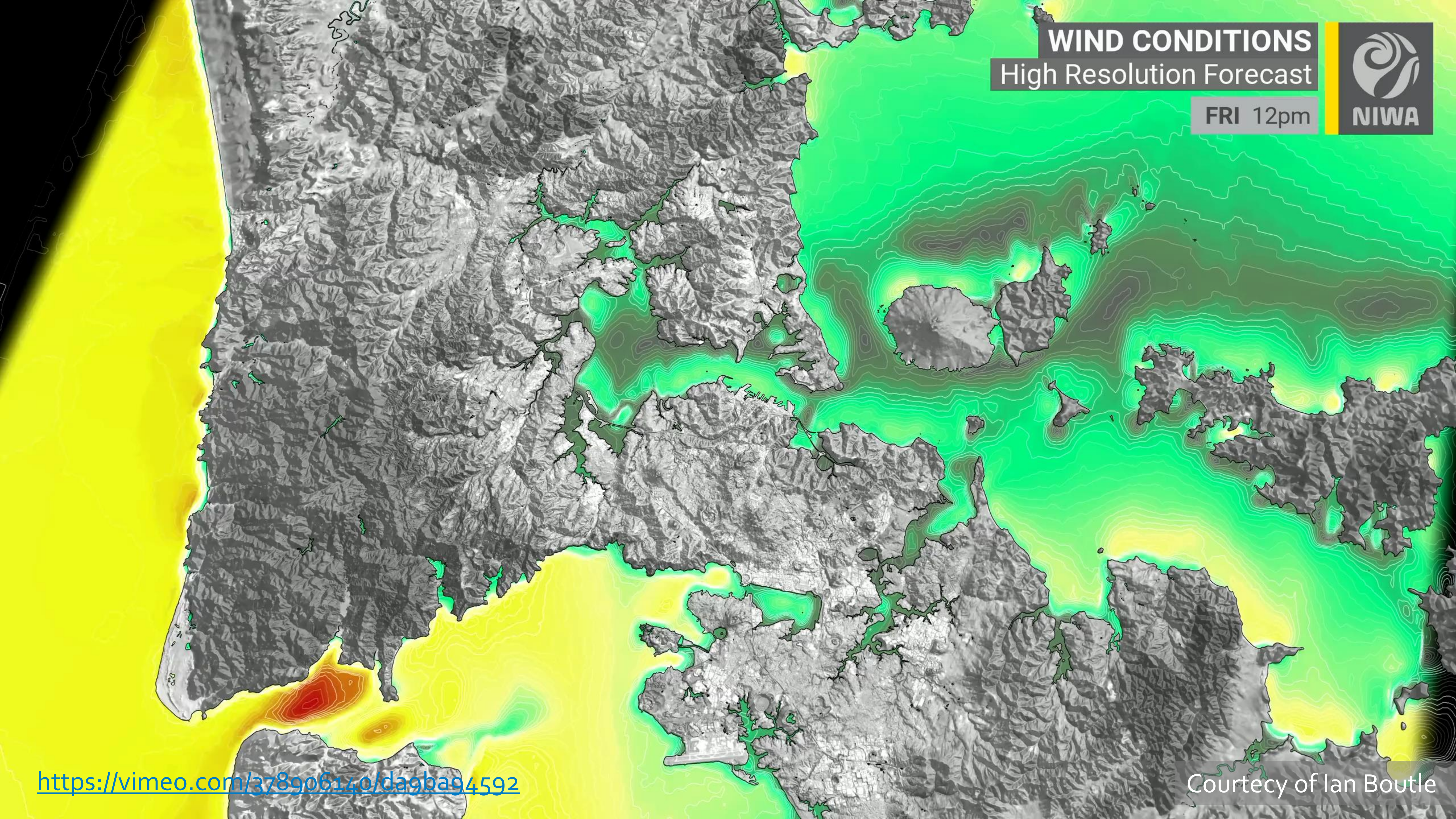
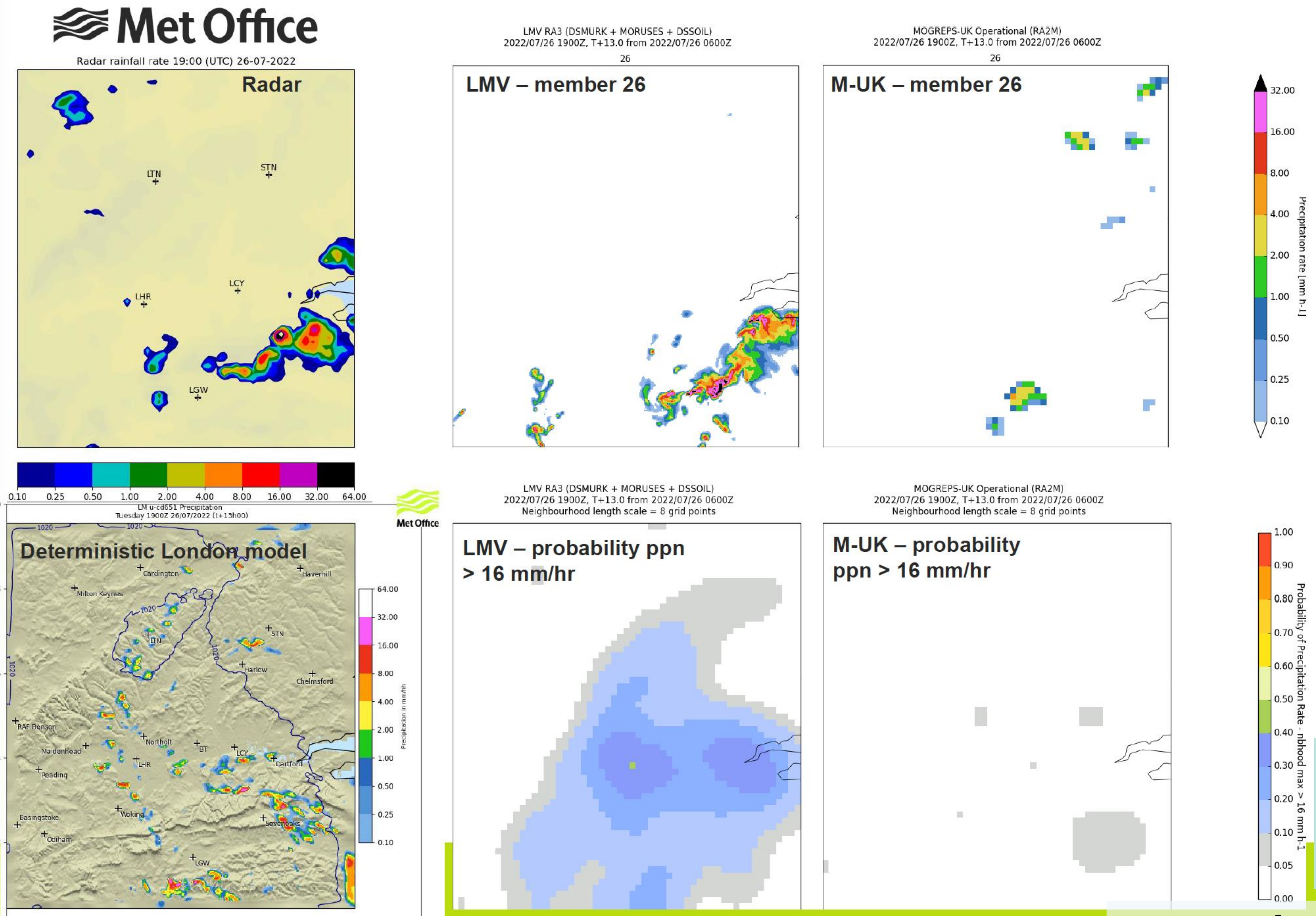


https://vimeo.com/378906140/da9ba94592

Courtecy of Ian Boutle

26 July 2022
1900Z (T+13)



Intense storm over London with ppn rates > 16 mm/hr.

Some LMV members were able to capture the structure and location of this storm better than the equivalent MOGREPS-UK members.

This led to greater probabilities of ppn > 16 mm/hr in the LMV ensemble.

Probabilities are calculated using a neighbourhood length scale of 17.5 km.

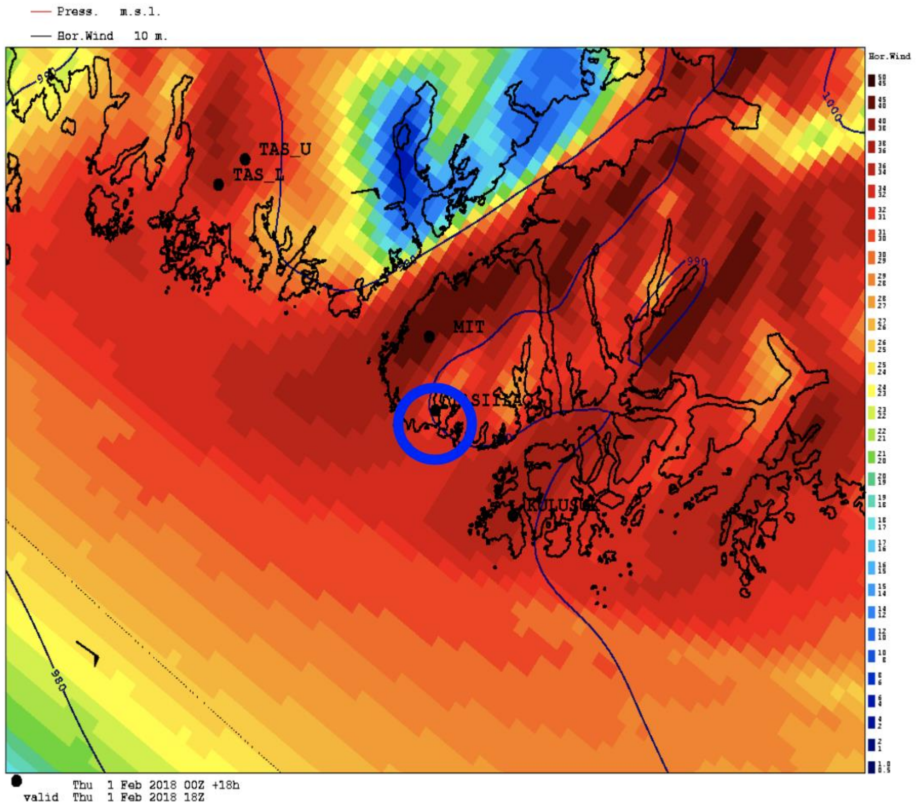
Courtesy of Kirsty Hanley

Flow variability in small scales

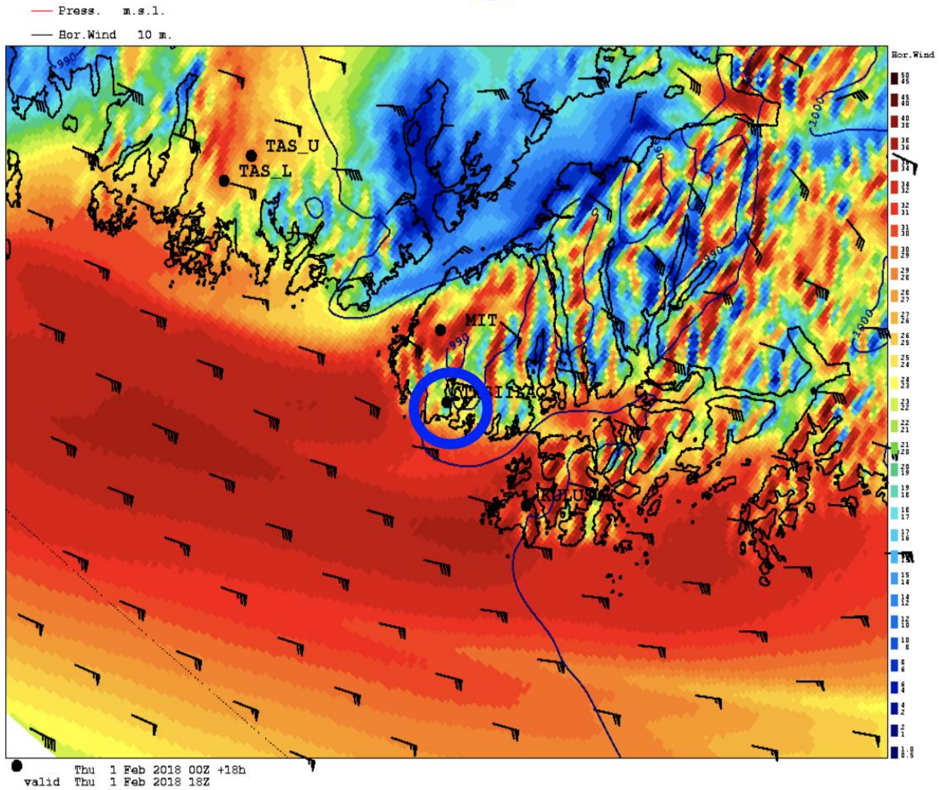
Danmarks Meteorologiske Institut

Tasiilaq, 1 Feb 2018

Ca 5 km radius



IGB@**2.5** km



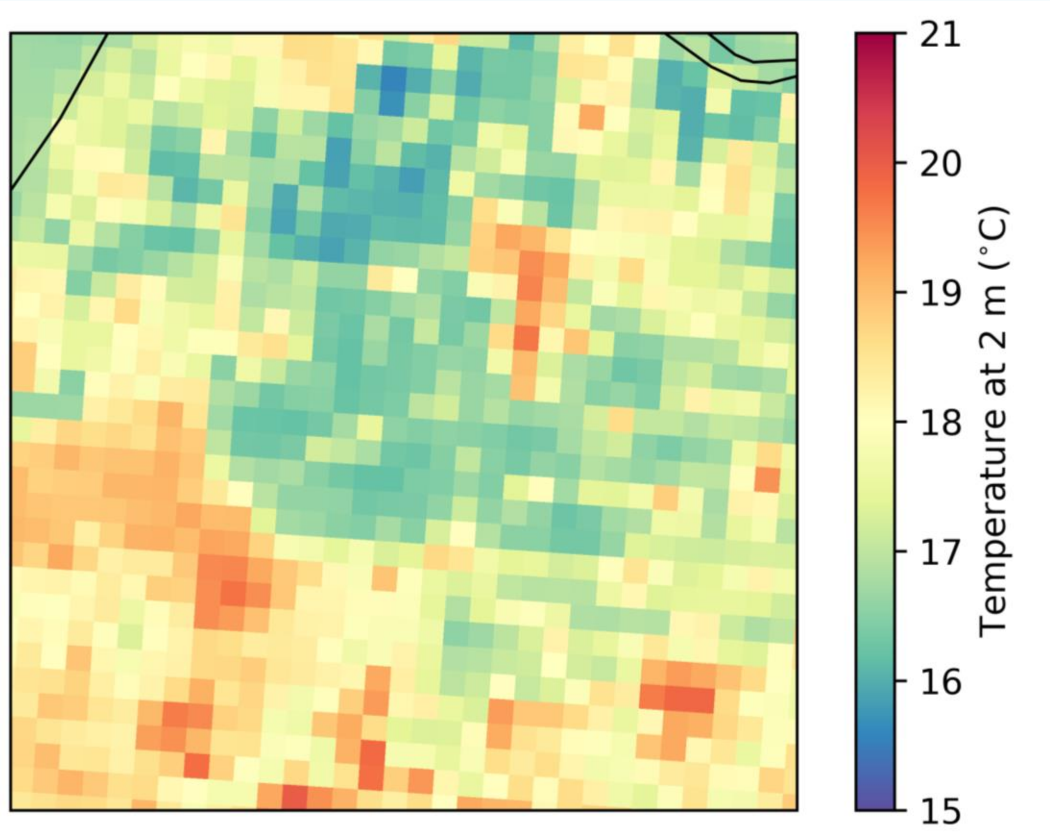
TAS@**750** m

24 h wind speed forecast for Tasiilaq, Greenland. Warm colours for storm scale wind, cold colors for light wind conditions.

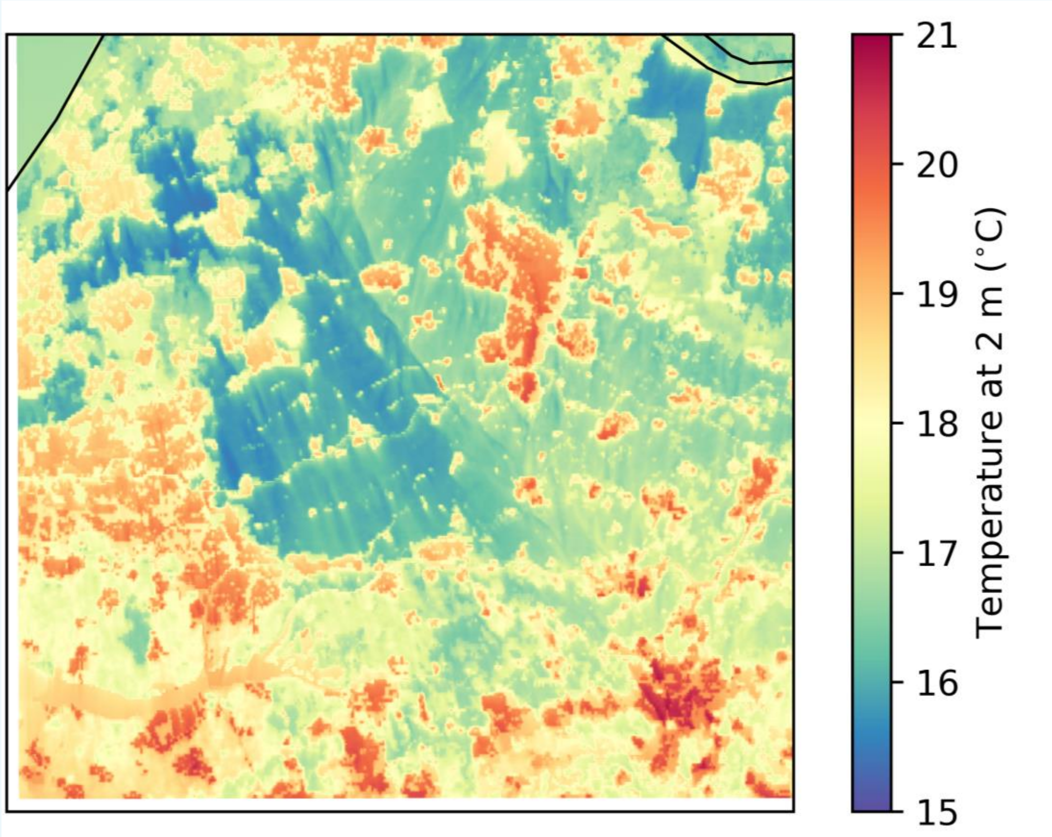
Courtesy of Xiaohua Yang

Better representation of the (urban) surface

HARMONIE-AROME @ Δx = Δy = 2.5 x 2.5 km



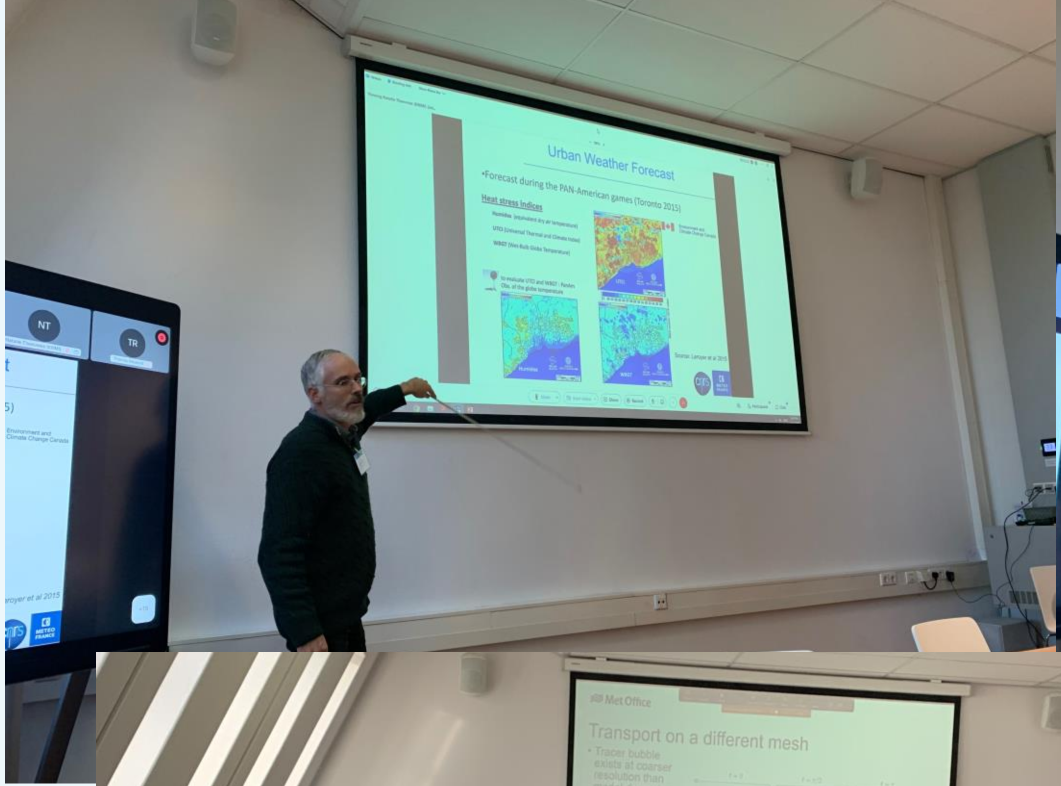
HARMONIE-AROME @ Δx = Δy = 100 x 100 m



Defined sections

- Dynamical core and stability
- Physics-Dynamics coupling
- Parameterisations
- Surface representation
- Surface description
- Data assimilation
- Observations and verification
- Predictability
- Post processing

Overarching: costs, applications, machine learning, research observations



Day 1:

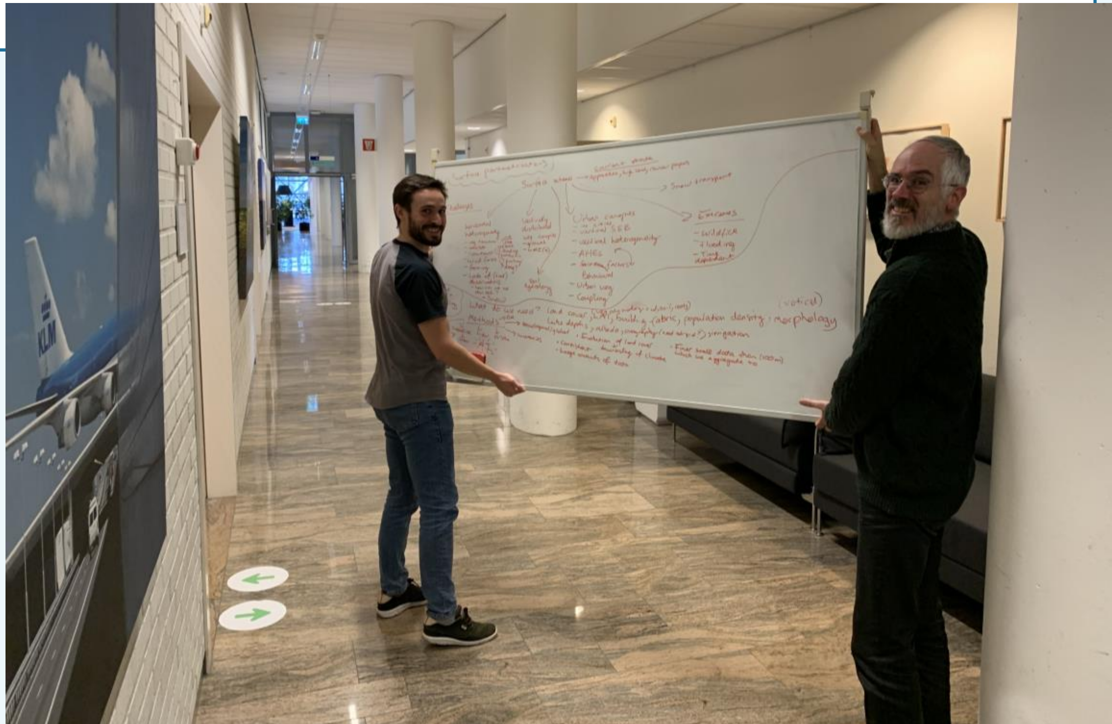
Presentations and discussion

Recording available on request

Day 2:

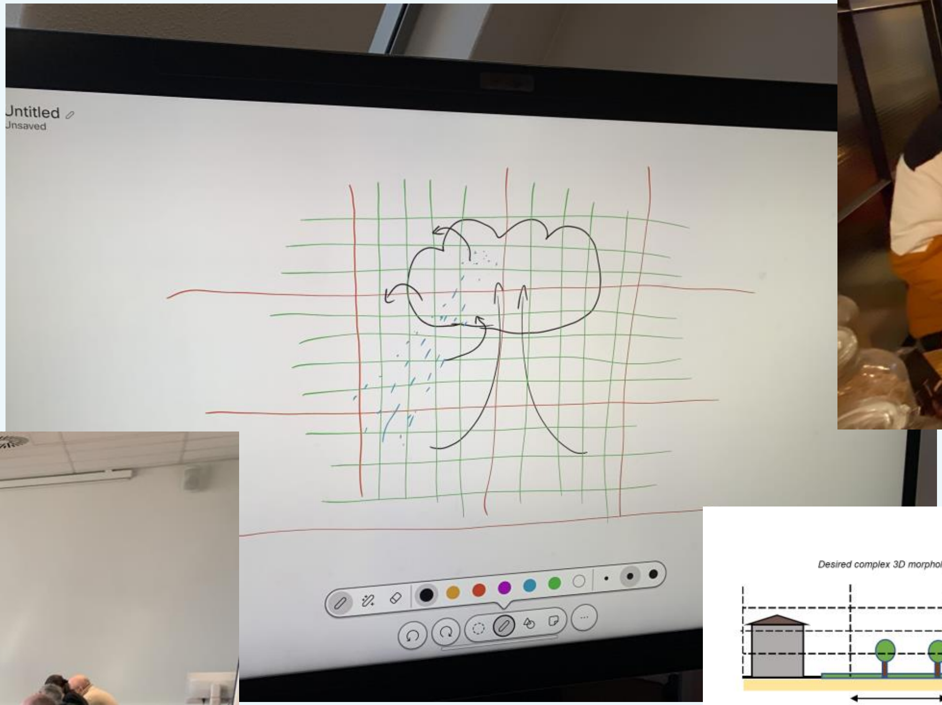
- For each section write in bullets:
  - Current state and research gaps,
  - Short-term plans,
  - Long-term research strategies
- Feedback to the group

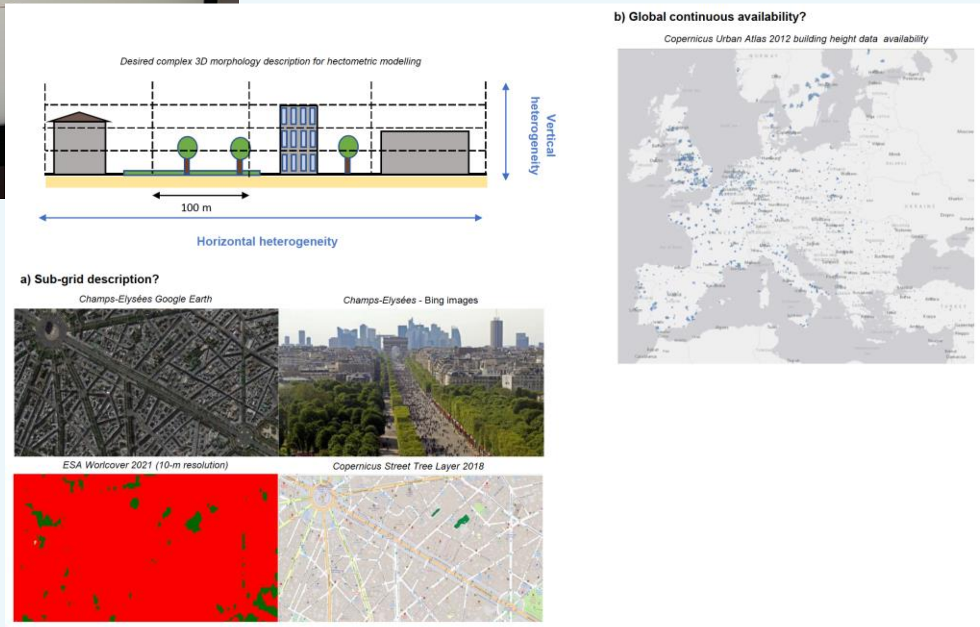
- **Stability and dynamics**
  Petra & **Michael** & Chiel & Maarten & Ian & Adrian & Pier
- **Parameterisation issues**
  Rachel & Chiel & Lewis & Maarten & Peter C & Pier & Valery & Peter D & Adrian & Ian
- **Observations & verification**
  Dawn & Siebren & Jan & **Xiaohua** & Jelena & Chiara & Valery & Matthias & Lewis
- **Data assimilation**
  Jan & Siebren & Xiaohua & Jelena & Pierre
- **Predictability at these scales**
  Anne & Inger-Lise (& Nigel) & Chiara
- **Representation of the (urban) surface**
  Valery & Maarten & Lewis & Matthias & Peter C & Adrian
- **Detailed land-use classification**
  Lewis & **Geoffrey** & Matthias & Valery
- **Postprocessing**
  Nigel & Peter D



Day 3:

- Write! Page limit of three A4's
- Come up with a figure
- Feedback to the group
- *Beer tasting and dinner*





Outcomes … so far

1. Introduction

- Met services have had operational km scale models for a number of years but resolution has not been further increased because there is no clear motivation to do so and extra computer resource has been used on other things such as running as ensembles.
- Much research has been carried out on hectometric scale models demonstrating better representation of many meteorological phenomena, but there are still many obstacles to using them in practical forecasting systems.
- The high cost is the biggest obstacle.
- Need to be clear of the benefits of running hectometric models. For example, for surface forced situations many of the benefits come directly from the high resolution surface information these could be realised without running a full atmosphere model.
- Brief mention of potential applications: Orographic rain/wind, Urban temperatures, Urban winds/turbulence, Air quality/dispersion, Deep convection, fog.
- Add intro to urban meteorology and its benefits (from surface section).
- This paper seeks to understand and present gaps in knowledge which are obstacles to the practical use of hectometric models

2. Dynamical Core and Stability

- Full, un-approximated equation set which are often used today are rather insensitive to resolution (although limitations of other schemes are discussed).
- Steep slopes require higher vertical resolution and are likely to be more of a challenge to stability at very high resolutions. A number of potential techniques to alleviate this need to be investigated.
- One way nesting boundary conditions are a more serious problem at high resolution due to the smallness of the domain compared to the relaxation zone required by the scale of waves in the small model. An important way to ameliorate this is through variable resolution or repeated nesting.
- Once hectometric DA is available, it may be necessary to develop efficient filters to cope with noisy gravity and sound waves excited by the analysis step.

3. Physics Dynamics coupling

- Becomes easier at high resolution in the sense that the short dynamics timestep means that substepping various schemes becomes unnecessary.
- Lack of parallelism in time dimension fundamental constraint with much shorter timesteps however parallelising physics and dynamics.
- Savings may be made by running physics and dynamics on different grids (e.g. physics grid on filter scale of dynamics).

4. Parameterisations

- In principle going to higher resolution should make the parameterisation problem easier because more energy is in the resolved flow so parameterisations of unresolved processes should be simpler.
- At hectometric scales a subgrid cloud condensation scheme and subgrid shallow convection scheme no longer needed but the turbulence scheme becomes more important. With convection (shallow and deep) assumed to be resolved, microphysics also becomes relatively more important, as do 3d radiation schemes.
- We need a grey zone turbulence scheme that moves seamlessly from LES type scheme when well resolved to a column boundary layer when unresolved. Many questions about how best to do this (expand to mention a few?).
- Traditionally work on developing such schemes uses LES as reference "truth" but not clear how correct this is, especially in complex situations and non-standard boundary layer types. Hence need for observations. Hard to understand some processes observationally and relate to models.
- Double moment microphysics schemes show promise but are more expensive so need to be clear about the benefits.
- Similarly, 3d radiation schemes show promise but are expensive so need to elucidate benefits. AI based emulators being explored but cost of producing training data may be a problem.

5. Surface Representation

- An important benefit of hectometric models is likely to be better resolving surface inhomogeneity. Key examples are likely to be urban surfaces and mountains.
- Urban representation is important for applications such as urban heat etc. Important to take into account factors such as the effect of the urban canopy, anthropogenic sources and urban vegetation.
- High resolution is a simplification in the urban context because less likely to need tiled scheme but a complication in that each gridsquare is less likely to be in equilibrium so need to take more account of adjacent points.
- Need to move away from the lowest level being just above the canopy to distributed canopy models with surface scheme interacting with several layers in model for energy balance, turbulence.
- Important question about whether to couple surface scheme implicitly or explicitly, latter easier at high resolutions.
- Hectometric models better represent mountains and valleys so should benefit in representation of anabatic and katabatic winds.
- A full 3d representation of radiation consistent between mountains and clouds will be important.
- Representation of lying snow in mountainous areas may also be an issue
- Some other issues that become relevant at hectometric scales are: changing surface characteristics (e.g. tidally inundated areas), wildfires and wind farms.
- Say something about soil moisture inhomogeneities?

6. Surface Description

- Key to hectometric modelling is to get a good hectometric resolution representation of the surface.
- State of the art datasets are discussed for land cover, urban form and some other parameters (both time varying and fixed).
- For land cover there are plausible global datasets although there are issues with interpretation.
- For urban form the situation is less promising with no freely available global dataset. However, there are promising rapid developments with remote sensing, crowdsourcing and novel interpretation algorithms.
- Potential ways to obtain data for time varying parameters such as land cover (e.g. in the case of inundation and drying), vegetation parameters (including effects of agriculture), soil moisture and lake properties are discussed.
- Datasets are also available for fixed parameters such as soil type and topography.

7. data Assimilation

- Need DA for short range forecast applications (e.g. very short range forecasting of thunderstorms?).
- There is currently almost no experience of DA in sub-km models.
- One issue will be avoiding spin up issues because the usual balance conditions are not valid.
- Key issue is handling DA on different scales – with different types of obs. E.g. length of linear window in 4dvar might ideally be different for different obs types depending on what scales they are constraining.
- Because hectometric model interactions with the surface is often key, surface DA needs to be more closely coupled to atmospheric DA.
- The use of high spatial and temporal observations in hectometer scale analysis demands a more advanced treatment of observation error covariances.

8 Observations and Verification

- Verification against observations is key for the development of hectometric models and observations will also be required for data assimilation.
- Few conventional observations have sufficient spatial resolution for application to hectometric models, in particular the synoptic network is too coarse. Using coarse networks for verification with inappropriate metrics may actually make hectometric models look worse due to the "double penalty" problem.
- There are a number of novel, non-conventional observation types which offer high density observations, in particular remote sensing techniques such as radars, lidars, GPS techniques, commercial aircraft (AMDAR, Mode-S) and satellite instruments (MTG).
- Crowdsourced data (mobile phones, cars etc) is another important category of potential high density observations but suffers from serious quality issues.
- Potential hectometric measurement techniques for a number of parameters are discussed.
- Verification techniques need to be adapted to take into account the higher spatial and temporal variation of the phenomena of interest.

9 Predictability.

- In order to have a reliable ensemble for specific applications it is important to think about the timescales of predictability on different scales. This is particularly important for hectometric models which are able to forecast on previously unresolved scales.
- The balance of the different sources of spread in the uncertainty (boundaries, initial conditions and physics) will be different in hectometric models and (as with other models) depend on domain size, regime etc.
- A number of centres are already experimenting with hectometric scale ensembles – often promising results are from processes being better resolved giving more reliable probabilities.
- Research is needed to understand the benefits of hectometric ensembles compared to convective scale ones.
- In the longer term physics perturbations need to be revisited in the light of new parameterisations at hectometric scales and also the link to data assimilation.

10. Postprocessing.

- It will be essential to use postprocessing systems to efficiently extract the required information from hectometric models.
- At fine grid resolutions representativeness errors disappear so that the model can be more easily related to point observations.
- In contrast the rapid loss of predictability at small scales is more serious than in coarser models so a probabilistic approach is essential.
- An important example of the above is neighbourhood approaches which depending on the application may either give mean or maximum values in the neighbourhood.
- Neighbourhood techniques need further development to avoid smearing out valid detail from the hectometric model. Need to develop algorithms (physical or ML) to detect fine scale weather features of interest (storm mode, heavy rain, tornados etc).
- In a practical forecasting situation there may be hectometric models and km scale models in use with the km scale model likely over a larger area. Depending on the application careful consideration may need to be given to blending seamless products across the two models.

Some highlights

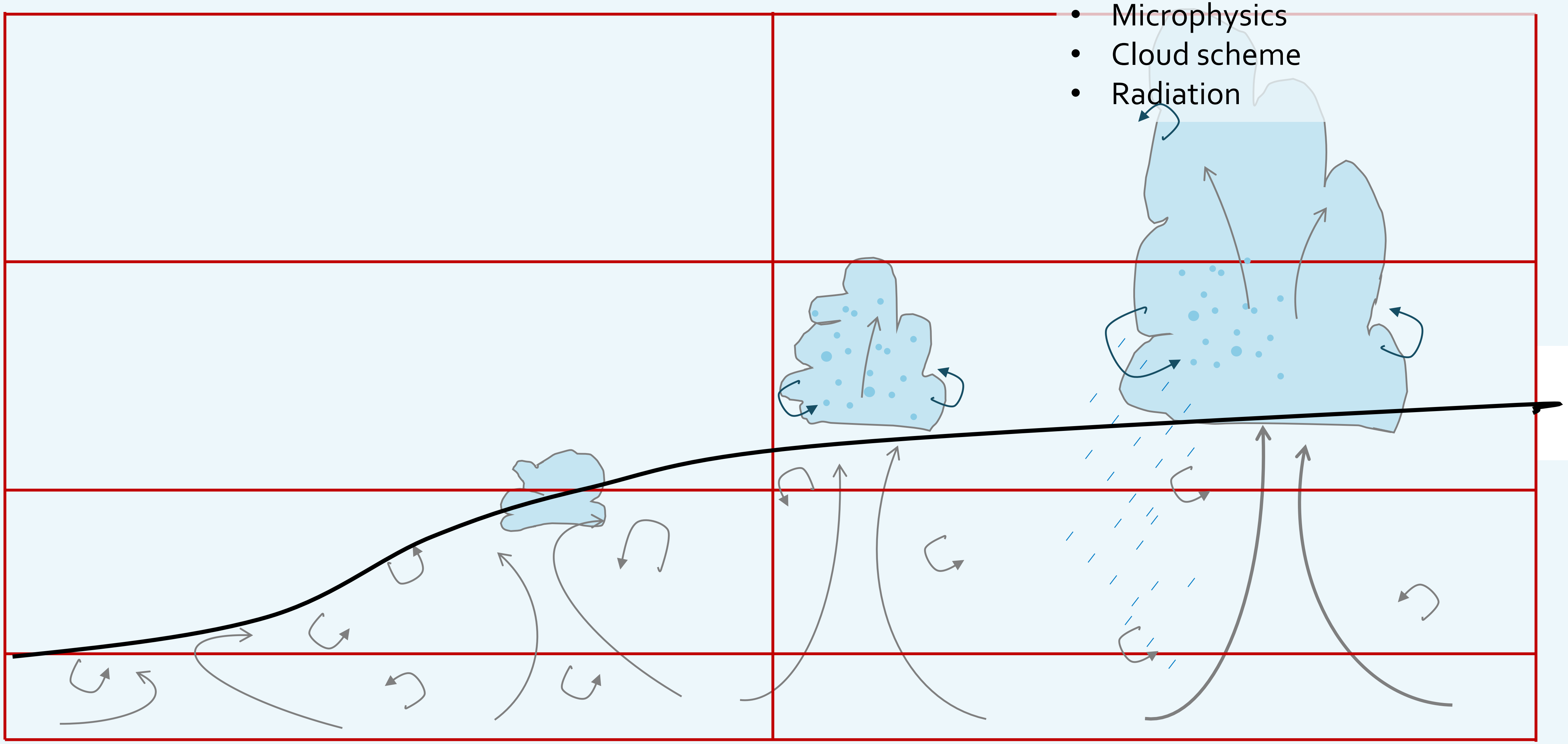
GAIN: Better representation of convection, turbulence, surface heterogeneity

- The high cost is the big obstacle
- Post-processing essential to get the best out of these expensive runs
- Steep slopes
- Running physics and dynamics on different grids
- Need for grey zone, scale aware, physics schemes
- Need to represent smaller scale processes in parameterisations (e.g. surface).
- Representation of 3D processes.
- Scales of predictability longer compared to scales of forecast -> more need for ensembles
- Almost no experience of DA in sub-km models
- Need for non-conventional observations and new verification techniques

Parameterisations

Km-scale models still parameterise:

- (Shallow) convection
- Turbulence
- Microphysics
- Cloud scheme
- Radiation



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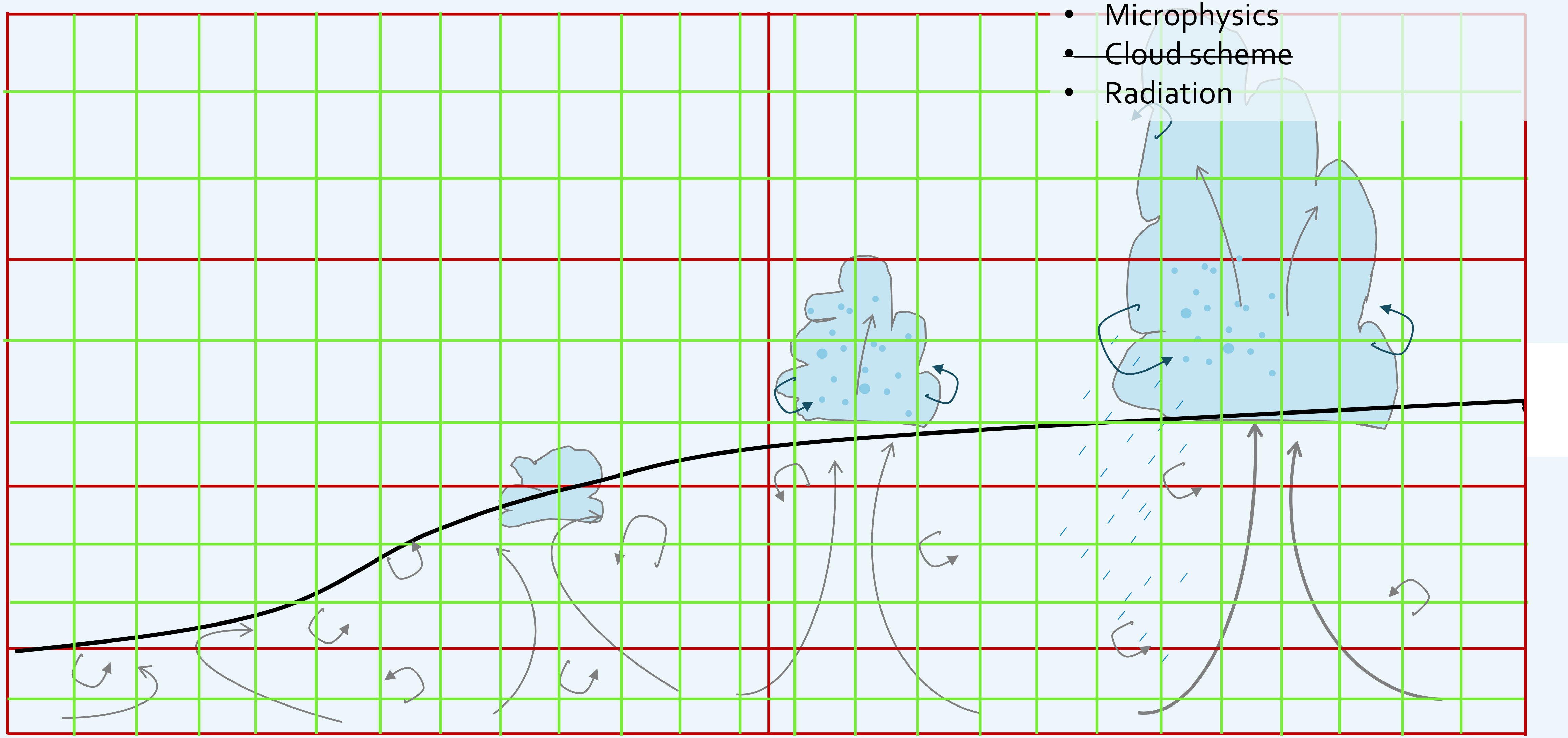

Surface representation

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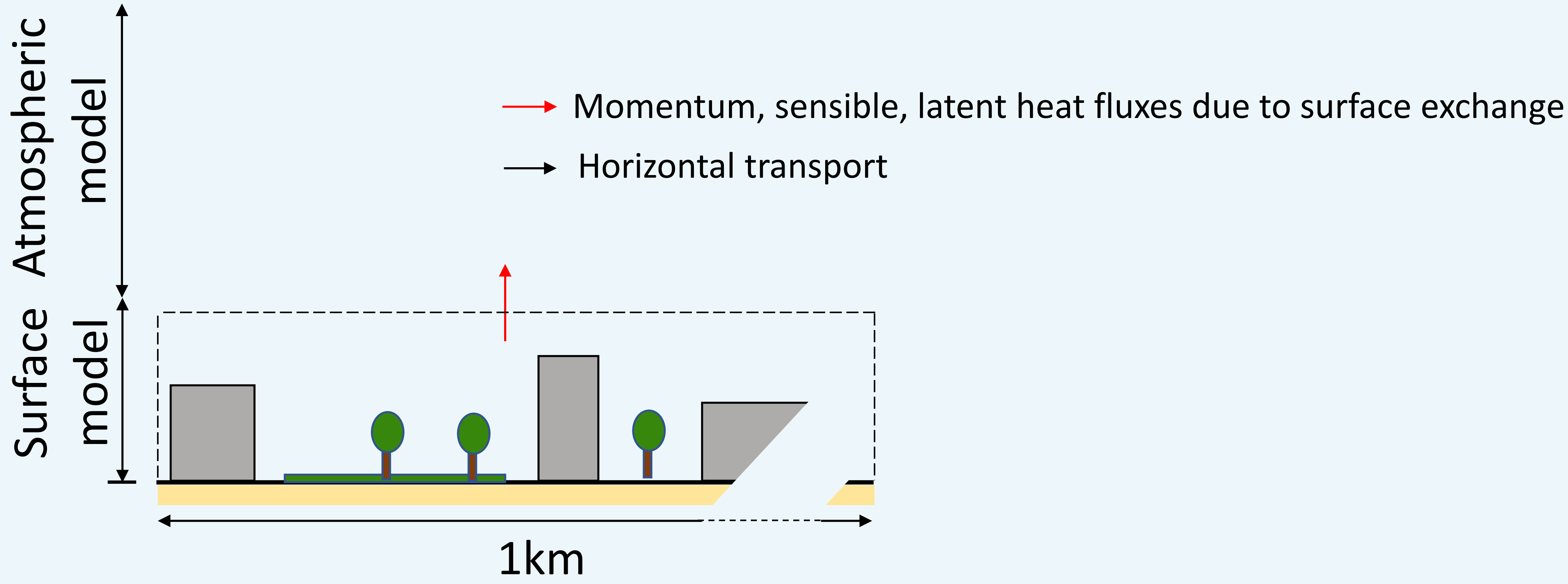

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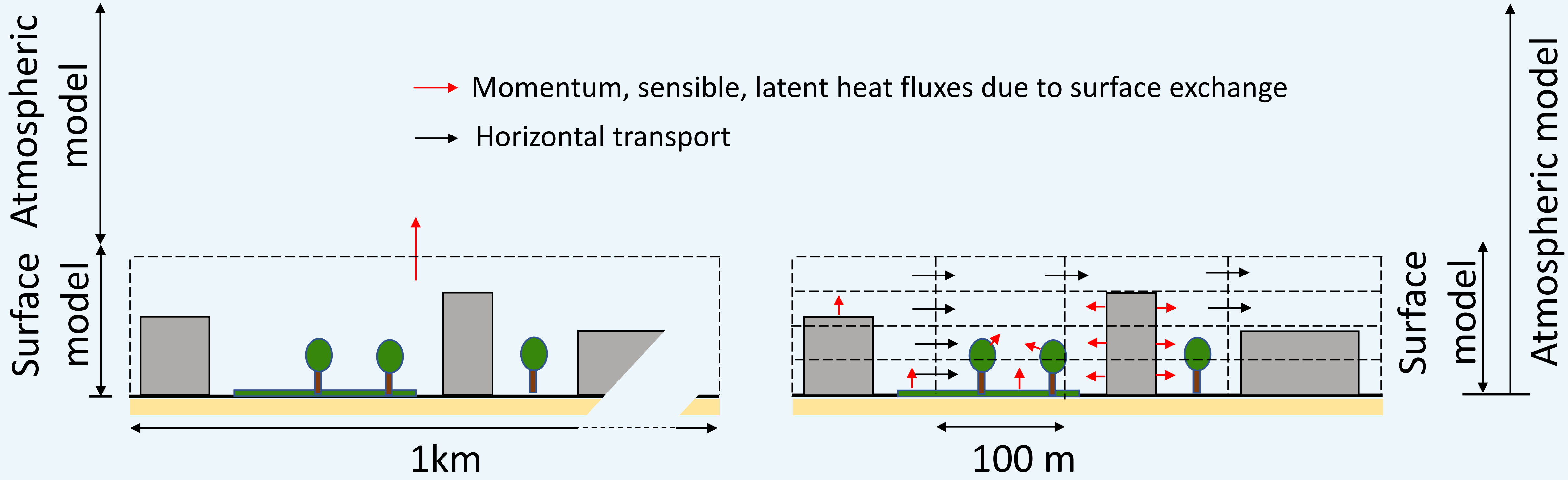

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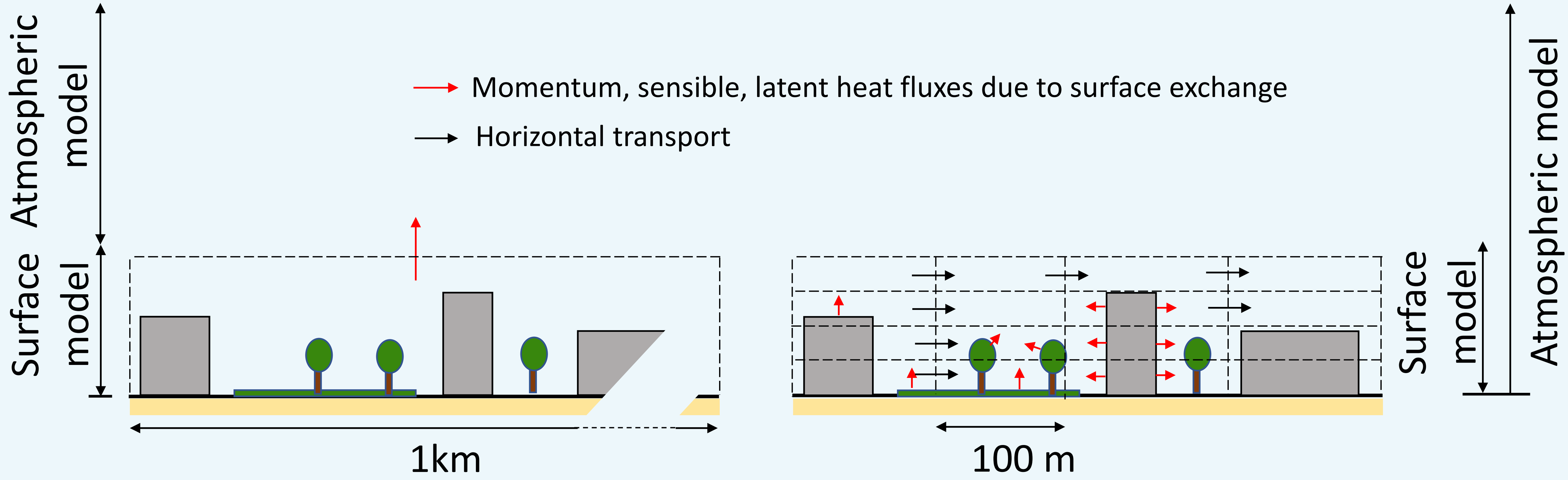
Surface representation



Couple surface scheme implicitly or explicitly?
Explicitly easier at high resolutions → shorter timesteps

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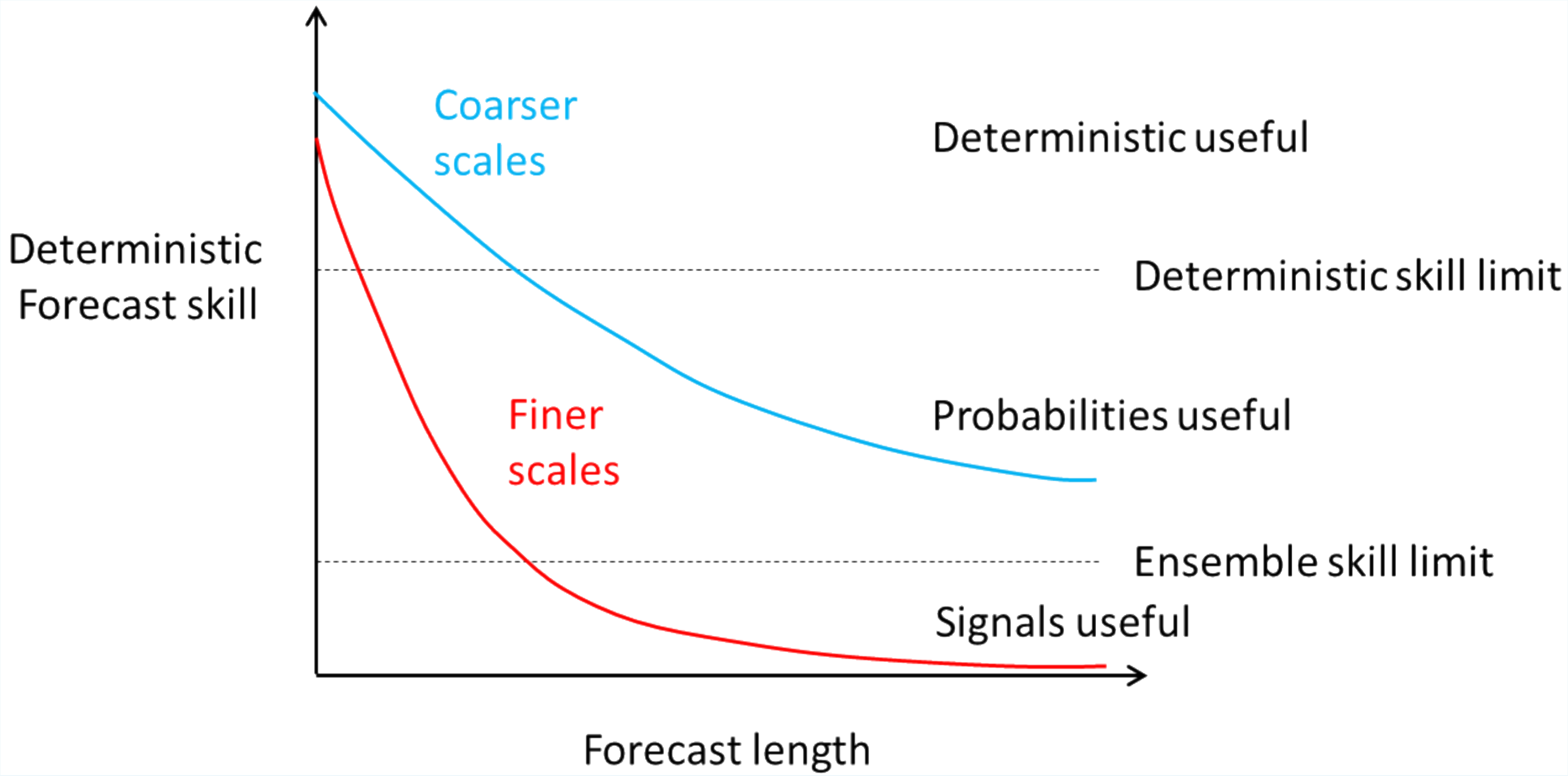

Figure by Nigel Roberts

Summary and next steps

- Many more challenges, thoughts, discussions
- Currently paper with Natalie and Humphrey having had final check through by authors.
- To be submitted to QJRMS ~April??