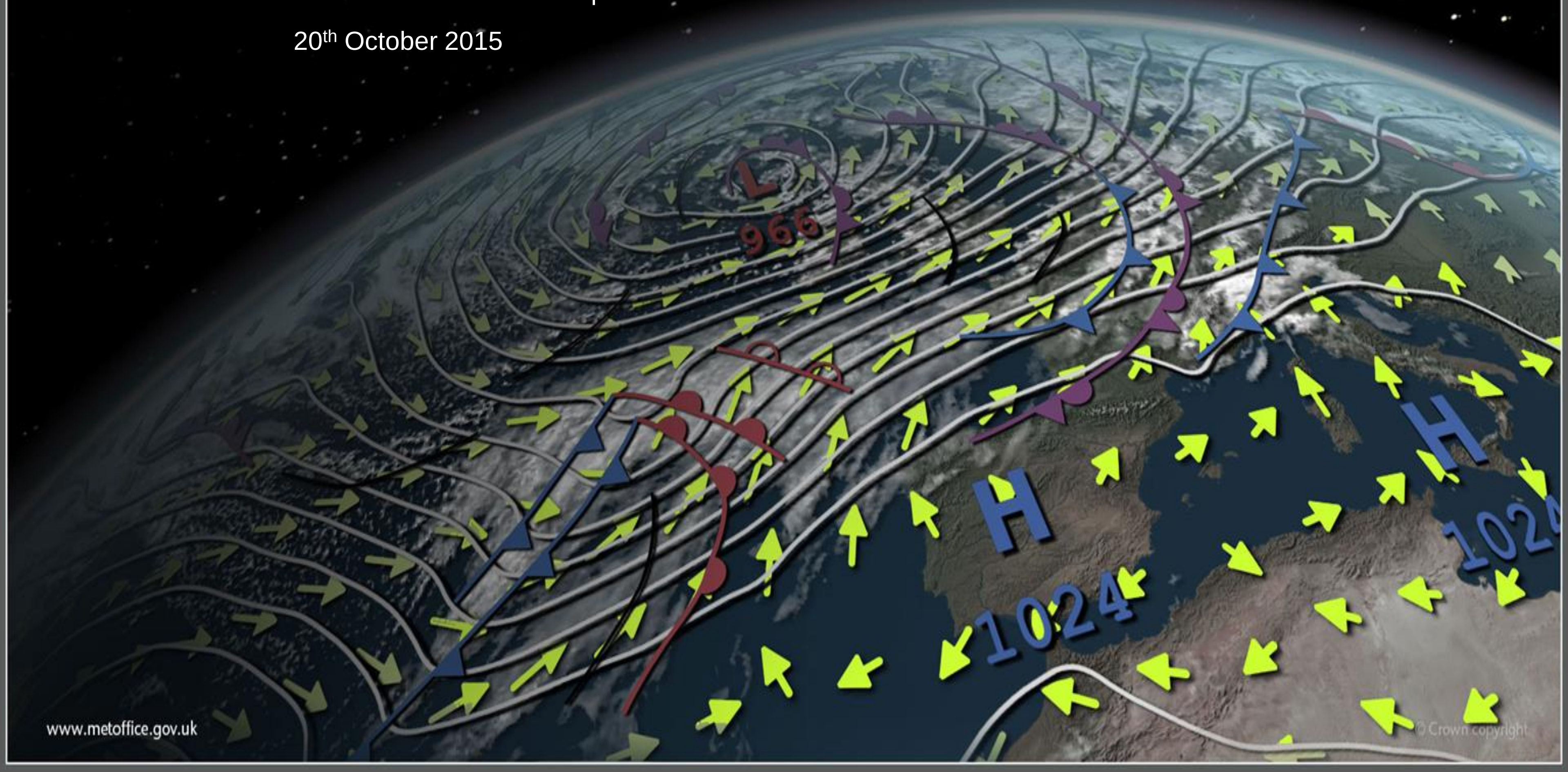
Recent fog forecasting research at the Met Office

Adrian Lock

CAWCR Annual Workshop

20th October 2015



Outline

- Why fog?
- Fog related research
  - LANFEX
  - Higher resolution fog modelling
- Future plans

- Particular acknowledgements to Ian Boutle

Fog – why the interest?

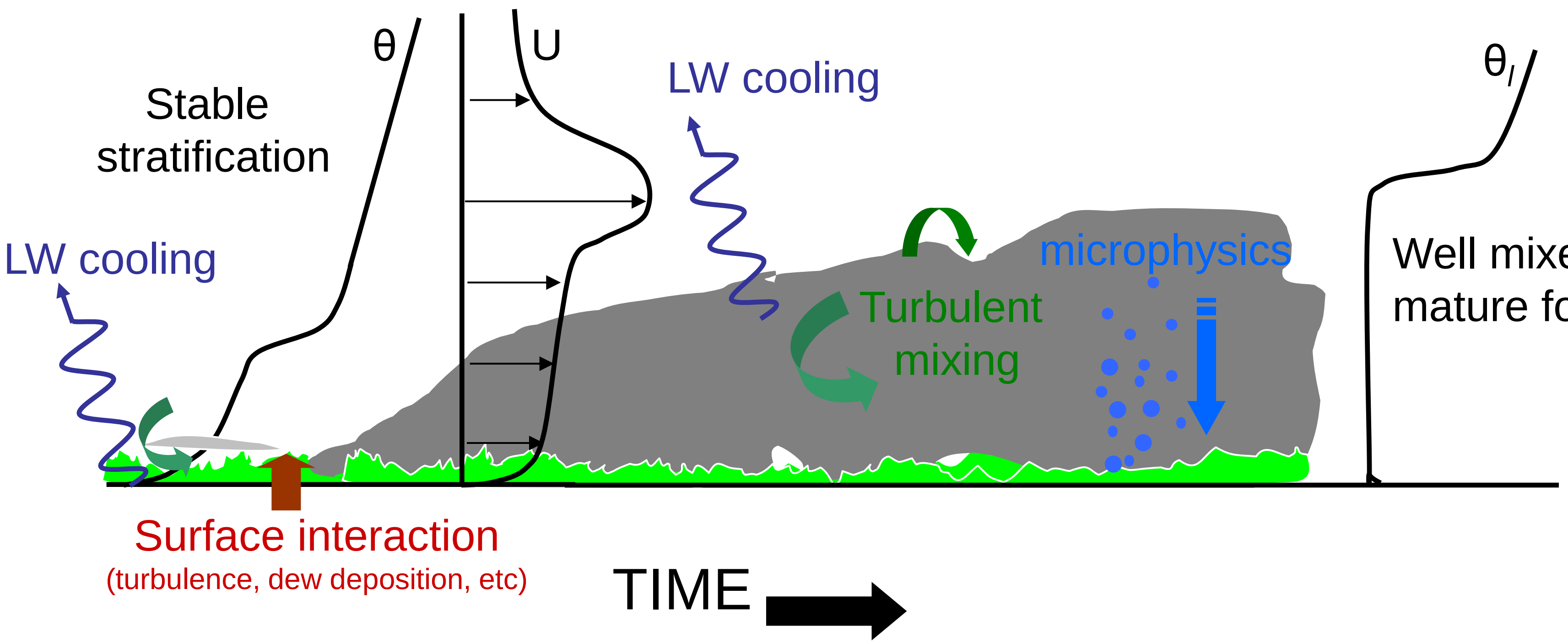
- Significant high impact weather, particularly for transport
- Every year fog causes serious road traffic accidents
- Fog at airports leads to reduced landing and take off rates → flight delays
- At Heathrow, fog → flight cancellations and diversions
  - costs airlines and BAA £millions
  - the Met Office supplies weather services to Heathrow

What makes fog hard to forecast?

- Several “NWP Problem Group” tickets relate to poor fog forecasts
- Physically complicated
  - Result of feedbacks and imbalances between many small scale processes
- Spatial distribution subject to both large scale and local influences
  - Both scales introduce uncertainty

Radiation fog

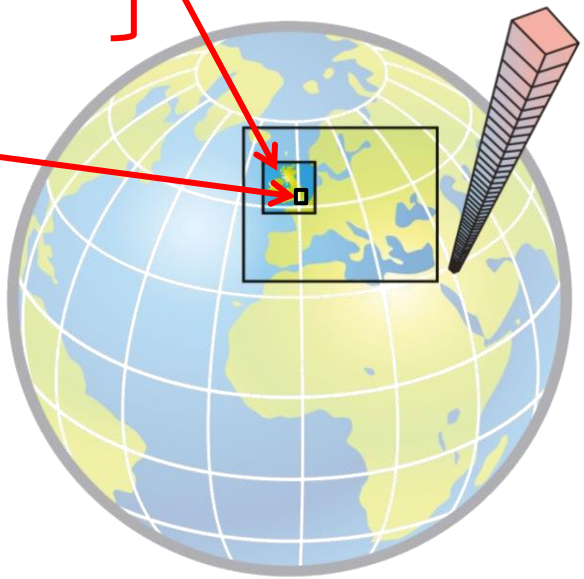
- Initial formation and evolution strongly dependent on fine imbalances between surface, turbulent, radiative and microphysical processes
  - Implies spatially highly variable
- Variability further enhanced by a positive feedback via longwave radiative cooling
  - Potential to transition to “mature”, well-mixed fog layer



Met Office forecast models

(A subset of)

- Global: deterministic N768 (~17km) L70
  - MOGREPS-G= 33km global ensemble, 12 members
- UK: deterministic (“UKV”) 1.5km, L70
  - MOGREPS-UK = 2.2km UK ensemble , 12 members
- London Model, 333m, L70
  - “Downscales” UKV



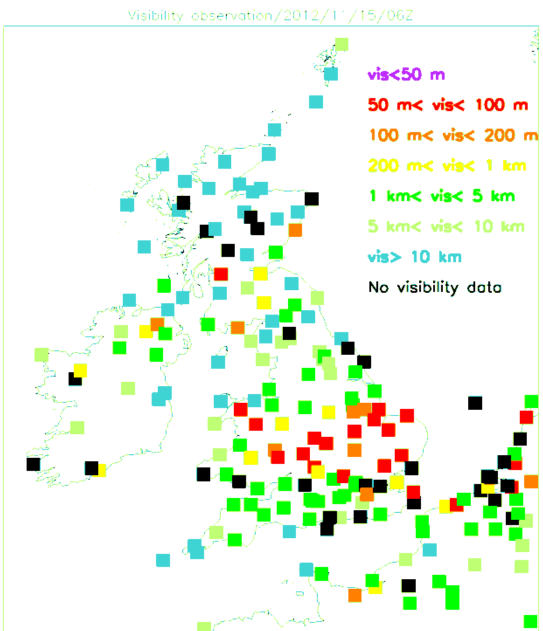
Quantifying uncertainty

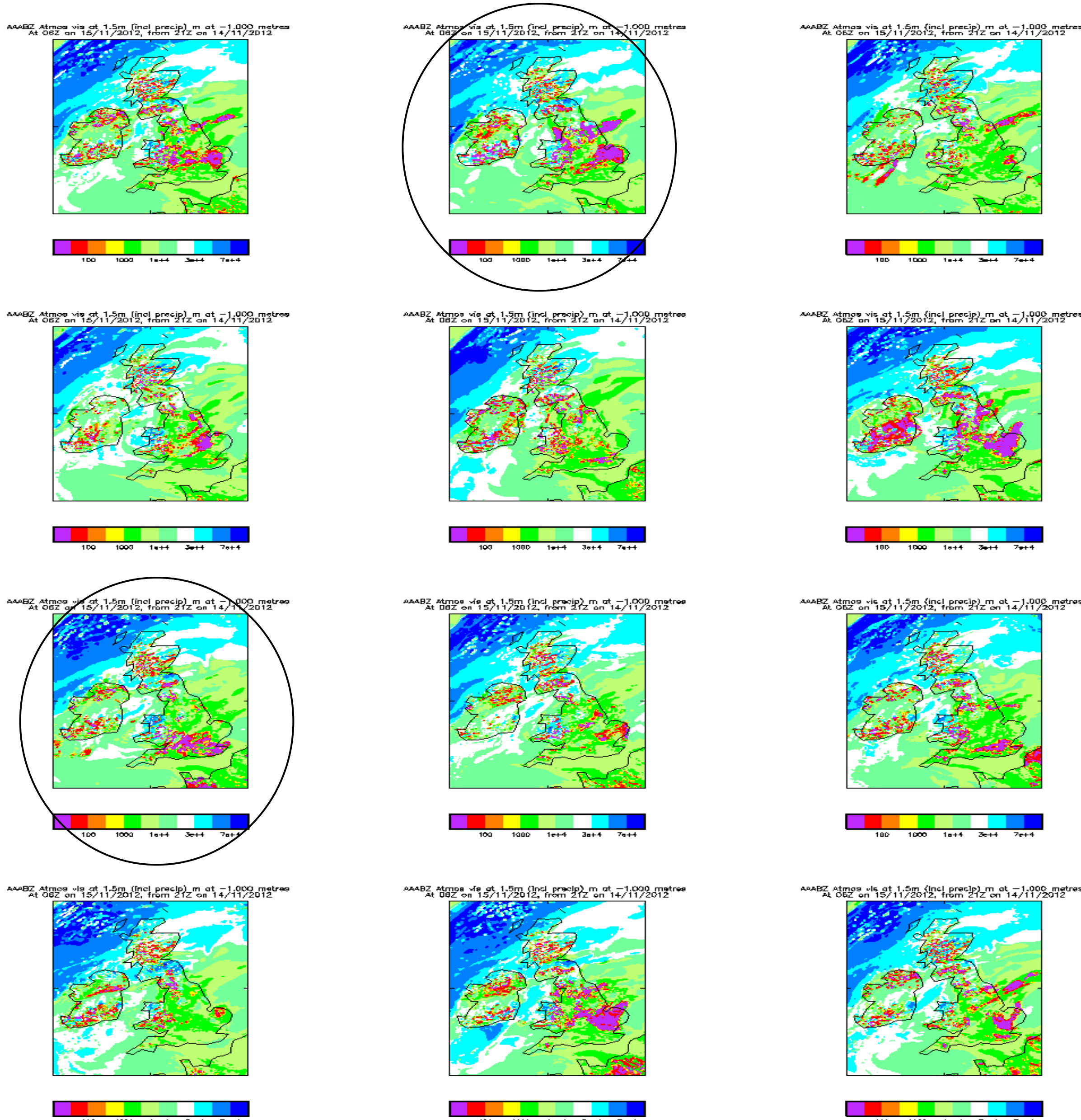
Met Office

- MOGREPS-UK samples a range of plausible solutions
  - 12 members at 2.2km resolution over the UK
  - Currently differ only in their initial conditions and boundary forcing (both direct from global ensemble)
    - So only samples uncertainty in the large scale state of the atmosphere
  - Additional uncertainty should come from variability of small scale processes
    - random parameters to be introduced this winter
- Useful forecast tool for quantifying probability of an event
- Also useful for identifying systematic errors in model physics

MOGREPS-UK visibility postage stamps, T+9

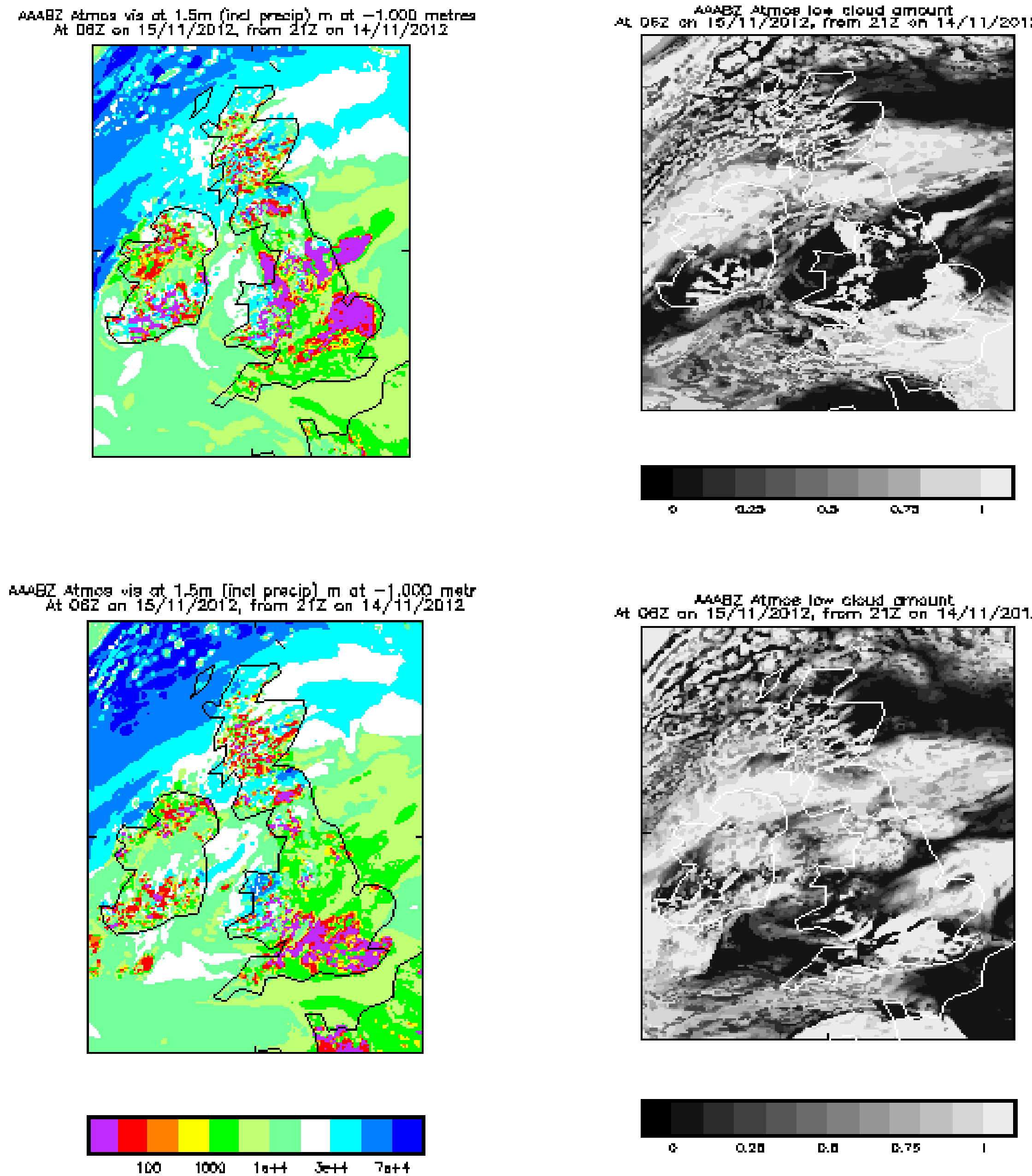
06Z 15th Nov 2012





Met Office

Large-scale differences in low cloud advection dictates location of fog in SE England



Convective-scale (<4km) Met UM physical parametrizations relevant to fog

Met Office

- Scale-aware blending of boundary-layer and Smagorinsky **turbulence** schemes
  - Gives a scale-dependent blend as the flow transitions from unresolved to resolved turbulence
  - Self-adapting for all high resolution configurations
- Scale-aware warm rain **microphysics**
  - Directly represents an appropriate subgrid variability in the warm rain microphysical conversion rates
- “murk” = single variable for total aerosol mass = air mass characteristics
  - Used to diagnose visibility and thence assimilated
  - Has surface sources, is advected by dynamics, mixed by turbulence, rained out,...
  - Sets cloud droplet number for microphysics
    - ...and for radiation, starting this winter (but murk has no direct radiative effect)
- Diagnostic **cloud** scheme with specified distribution width (RH_{crit})
- JULES 9-tile **surface** scheme
- **Radiation**: 2-stream (Edwards & Slingo), accounting for terrain slope
- **No convection scheme**

Fog research

Recent fog studies at the Met Office

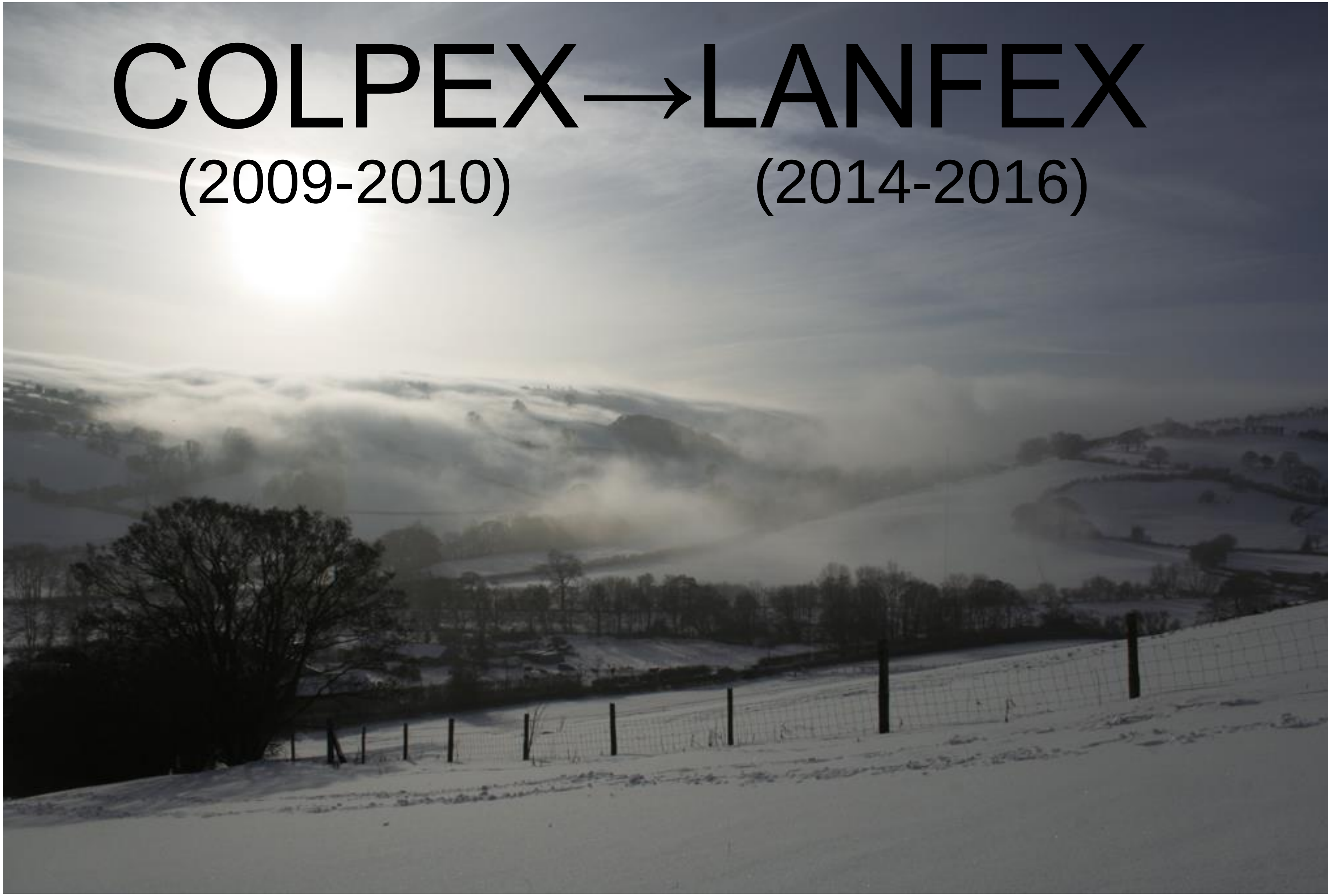
- Ongoing projects since 2006 (e.g. Price 2011, Porson et al. 2011, Price et al 2015)
- Observations in radiation fogs, adiabatic fogs, stratus fogs at Met Office Cardington site
- Combined with modelling studies – LES, SCM and NWP (both deterministic and ensemble)
- Some key observations:-
  - Fog may not form as expected under sustained periods of very high RH (>98%)
  - Suspected importance of (unknown) local heterogeneity
  - Systematic bias in MetUM ensemble to lift fog into low stratus

Science questions
that a focussed field campaign might address

- Heterogeneity: why does fog form in one place and not another?
  - Dynamics (sheltering, cold pools, local turbulence, etc)
  - Thermodynamics (RH of air vs dew competition)
  - Aerosol (high RH but weak activation)
- Understanding fog evolution/propagation
  - Advection or propagation? Role of drainage flows
  - What are the controls on optical thickness and the transition to mature fog?
- Predictability
  - How robust is the heterogeneity?
  - What impact does large scale uncertainty play?
  - Can we quantify local uncertainty?
- Basic MetUM validation and informing parametrization development

COLPEX→LANFEX

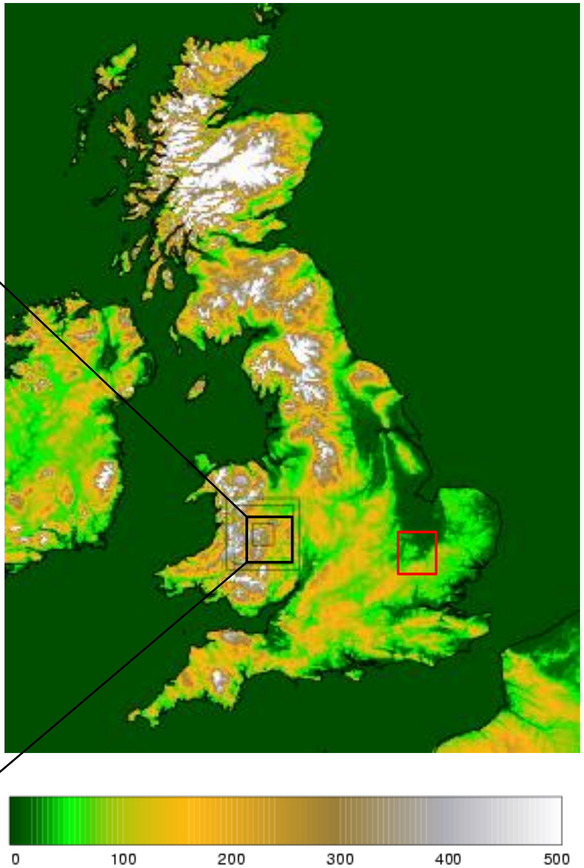
(2009-2010) (2014-2016)



LANFEX

Local And Non-local Fog EXperiment

- 18 month campaign to examine development and evolution of (primarily) radiation fogs (Autumn 2014-Spring 2016).
  - Deploying longterm networks of instruments (flux towers, surface sites, dopler lidar, etc)
  - IOPs with sondes, tethered balloon
- High resolution modelling run in parallel
- Two sites: Met Office Cardington and **Shropshire hills**



Initial modelling studies

- Running high resolution (from 1.5km to 100m or finer) MetUM case studies
  - Identify systematic errors (use of ensembles)
  - Sensitivity tests and coarse-graining to inform parametrization developments
- Examples of recent results, focussing on each parametrization in turn
  - Cloud scheme
  - Orography
  - Stable boundary layer and surface coupling
  - Aerosols and microphysics

The role of the cloud scheme

The London Model (LM)

Met Office

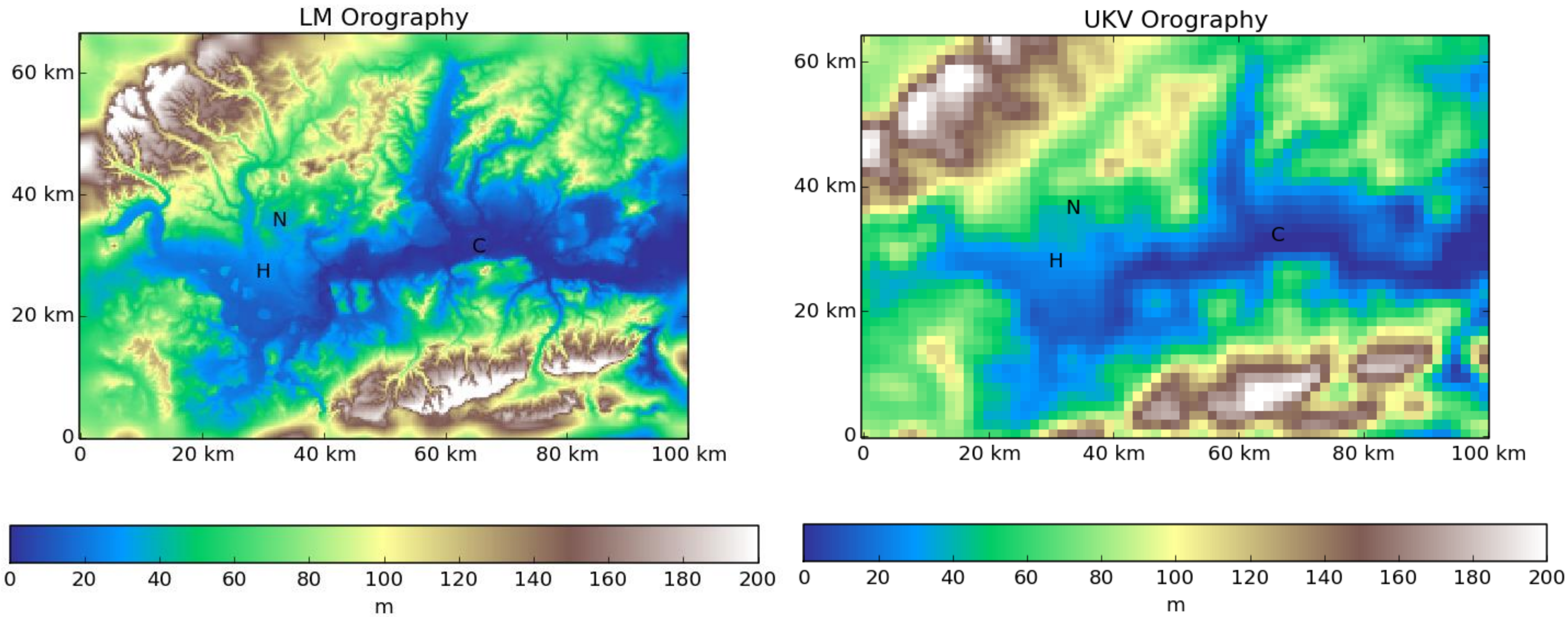
333m grid-length MetUM nested inside the UKV (1.5km)

Better representation of terrain and land surface characteristics

300x200 grid-points (100x66km domain)

Running (at 6Z and 21Z) every day since 2014

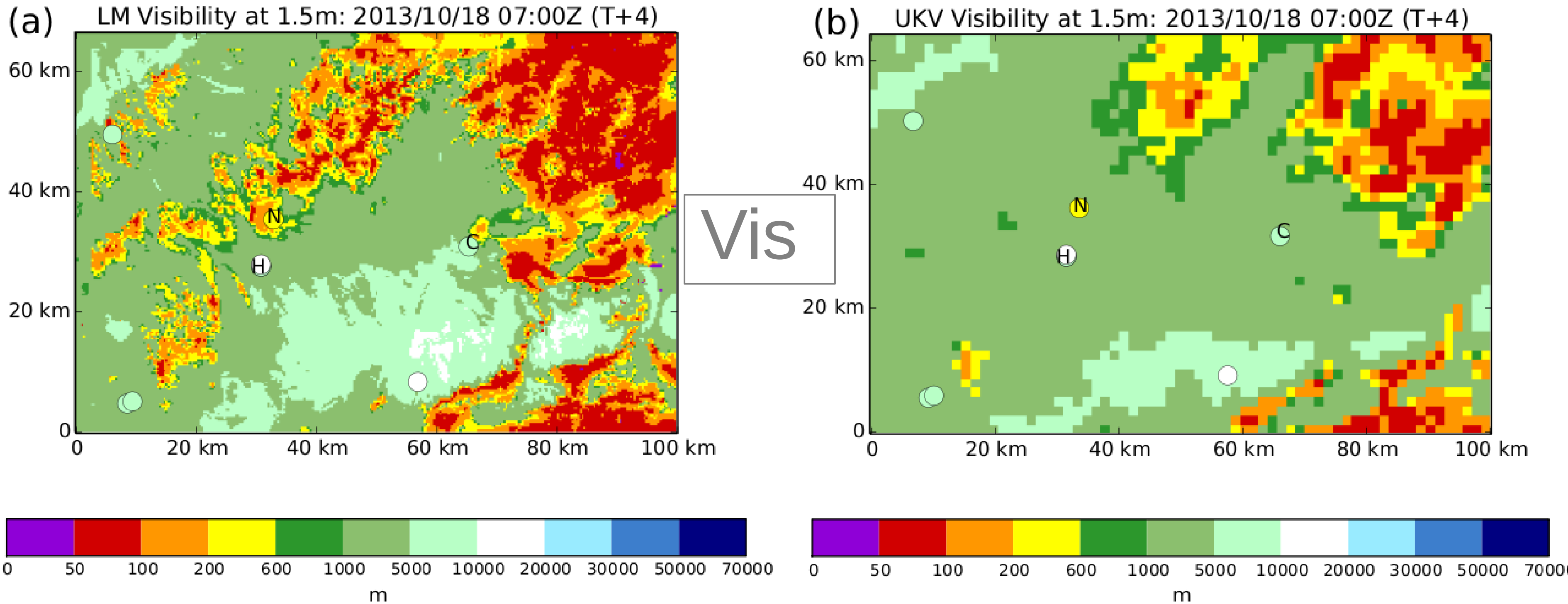
London Model domain



- Parametrizations are the same as UKV except for the cloud scheme
  - diagnostic scheme with specified distribution width (RH_{crit})
  - increase RH_{crit} in LM, consistent with its smaller grid-boxes

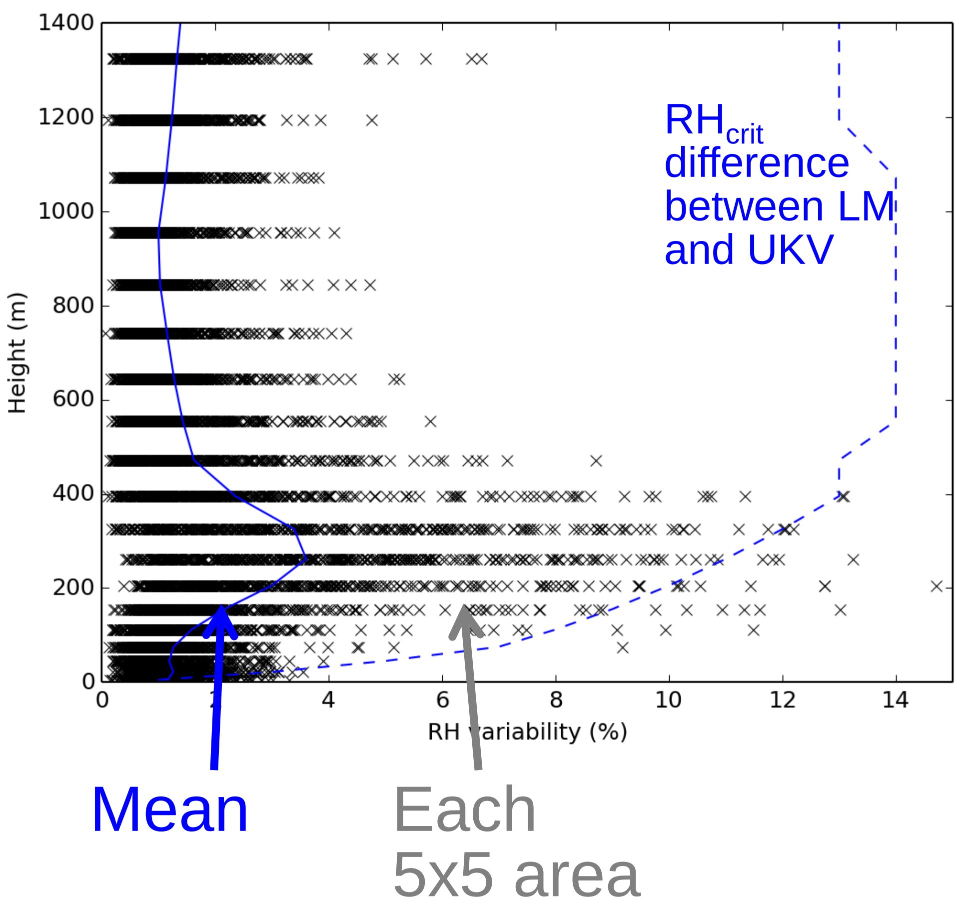
Case Study 18/10/2013

LM control UKV control



- Patchy fog in vicinity of Heathrow (H), fog observed at Northolt (N)
- Fog erroneously absent in UKV, but present in LM
- LM had breaks in a thin low cloud layer earlier in the night where UKV didn’t
    - Allowed surface temperature to cool, and fog to form

Extra LM moisture variability

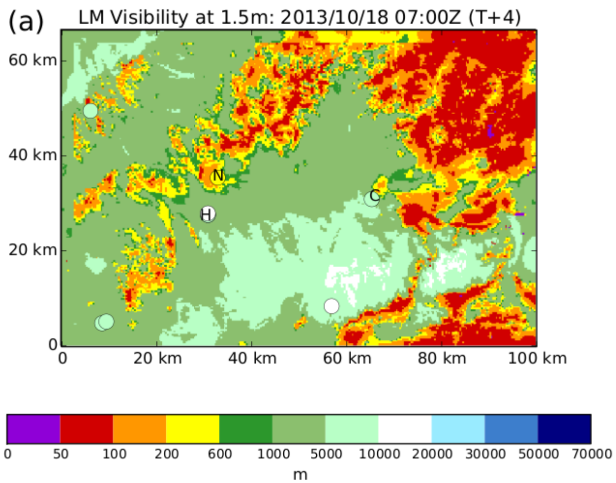


- Calculate resolved variability in RH in a 5x5 grid-point (1.67km) region of the LM
- Equivalent to the additional variability the UKV should need to parametrize
- Additional resolved variability is significantly less than parametrized difference in RH$_{crit}$
- Suggests RH$_{crit}$ should vary less with resolution
- Also shows one single number for RH$_{crit}$ doesn't exist – need a more sophisticated cloud scheme

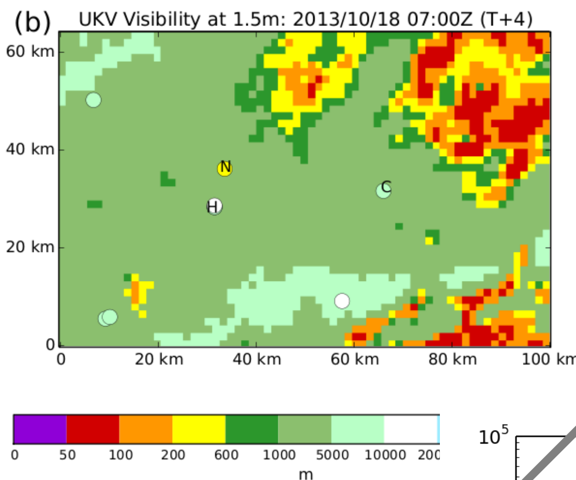
Remove RH_{crit} difference

Met Office

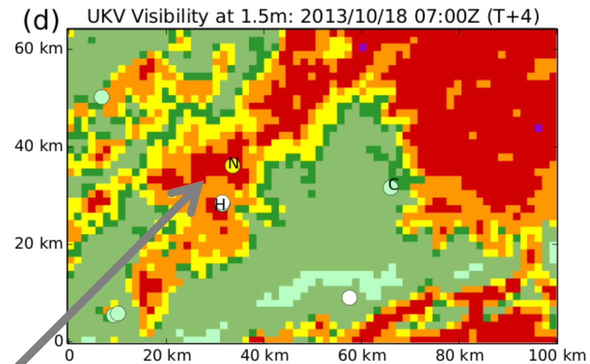
LM control



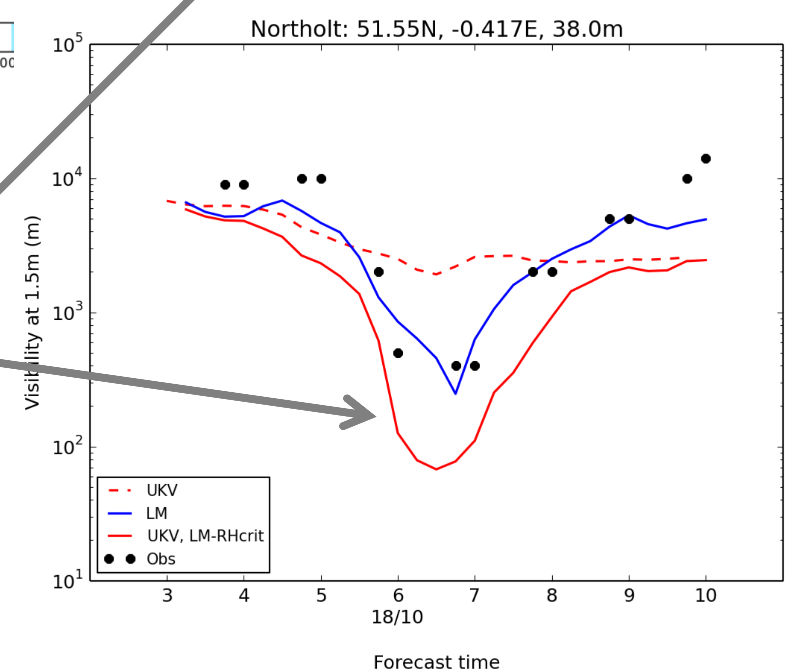
UKV control



UKV with LM RH_{crit}



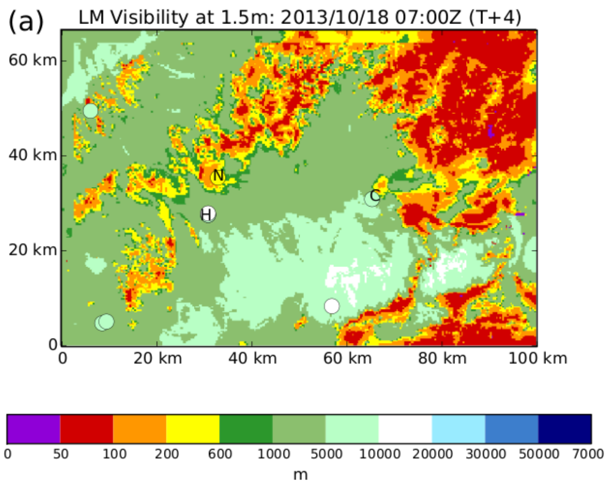
- UKV now breaks cloud between 4.30 and 5.30am similar to LM
- Fog forms, but now too thick and extensive in UKV
  - Something else is different



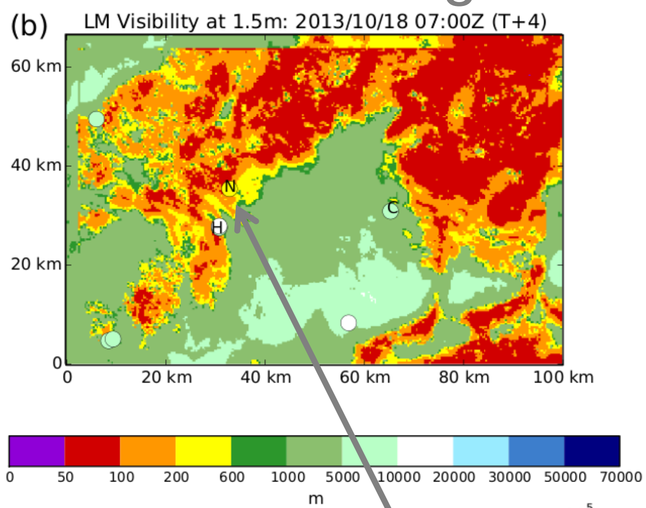
The role of small scale orography

Remove orography difference

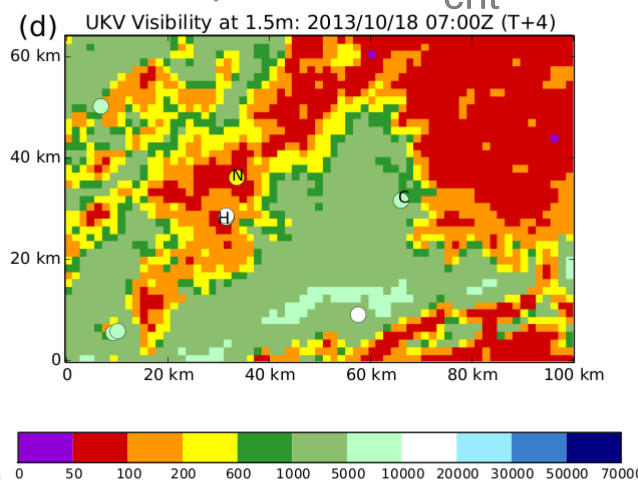
LM control



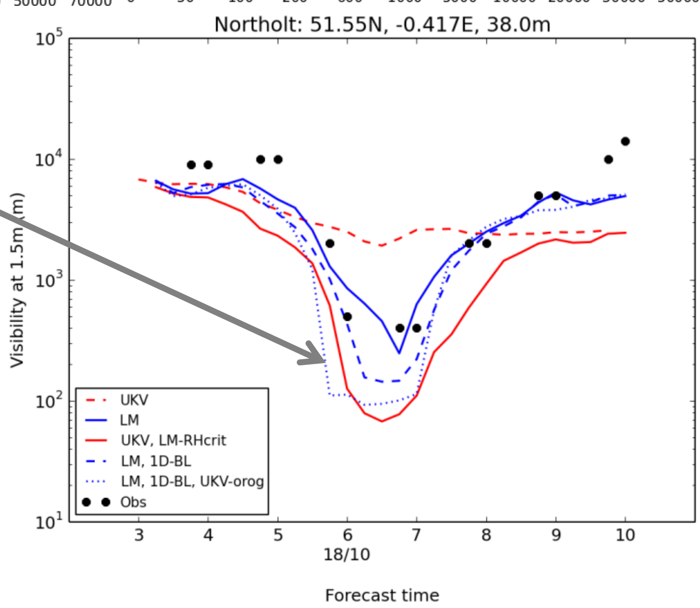
LM+UKV orog



UKV, LM RH_{crit}



- Run LM with (smoother) UKV orography
  - Gives thicker fog in LM, similar to UKV
  - Real effect of enhanced resolution!

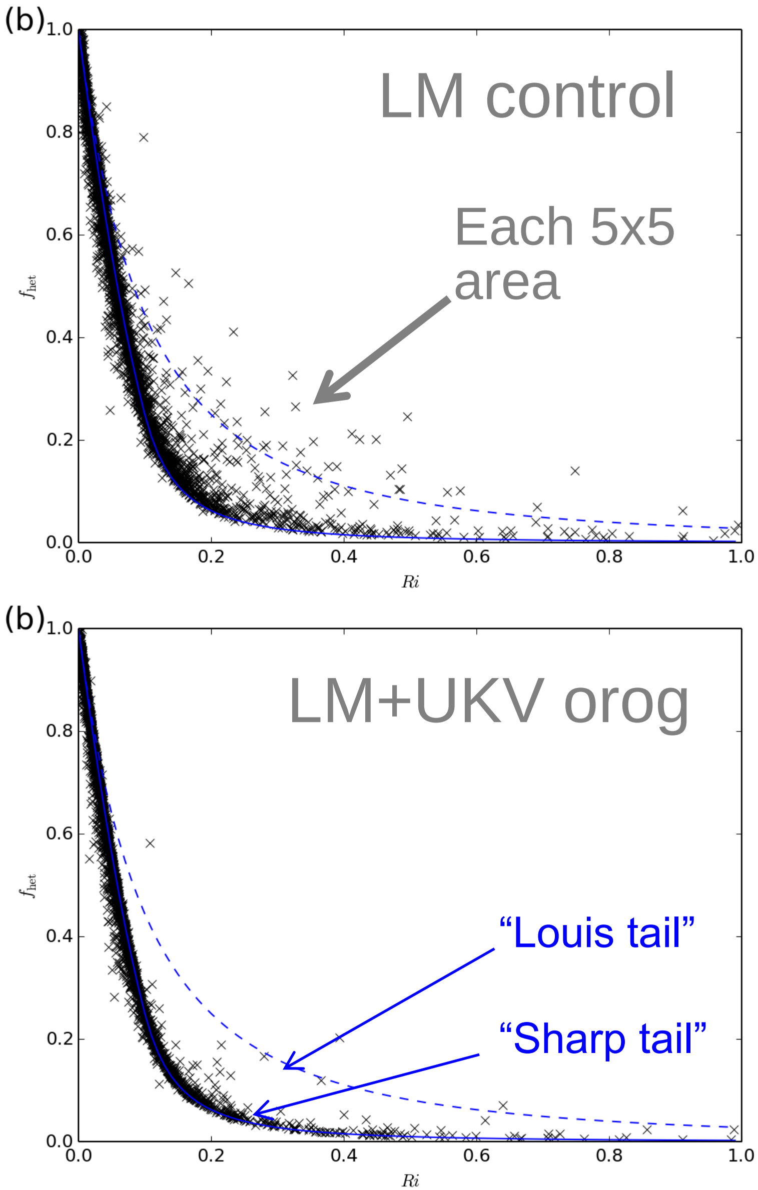


How does the orography affect fog?

- Calculate effective stability function (McCabe & Brown 2007)

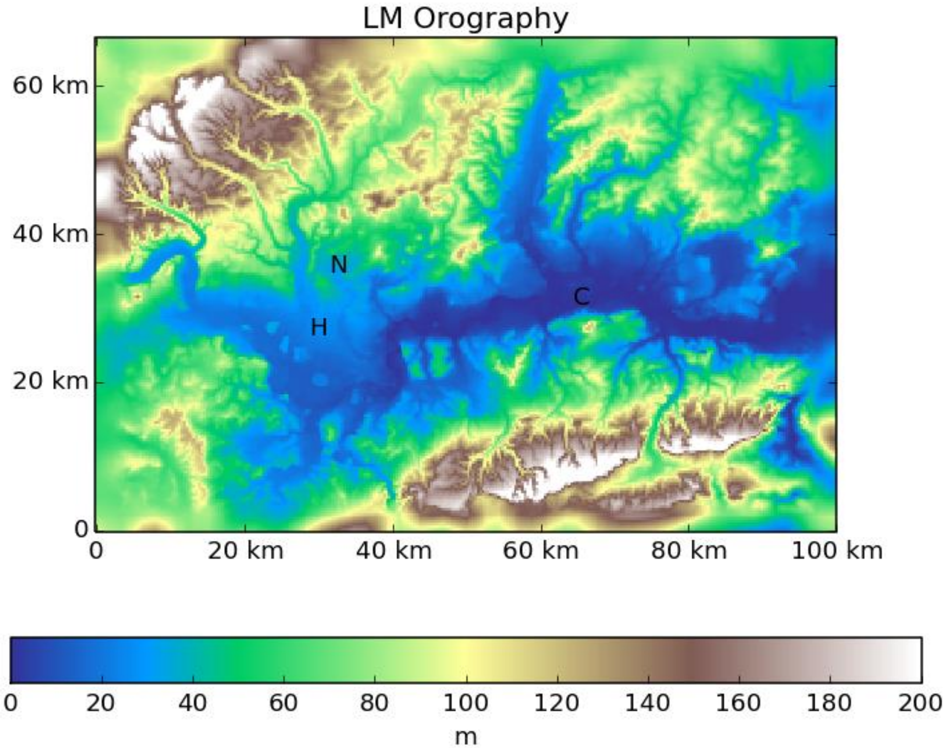
$$f_{het}\left(\langle Ri\rangle\right) = \frac{\overline{wb_{het}}}{\overline{wb_{1.67}}} f\left(\langle Ri\rangle\right)$$

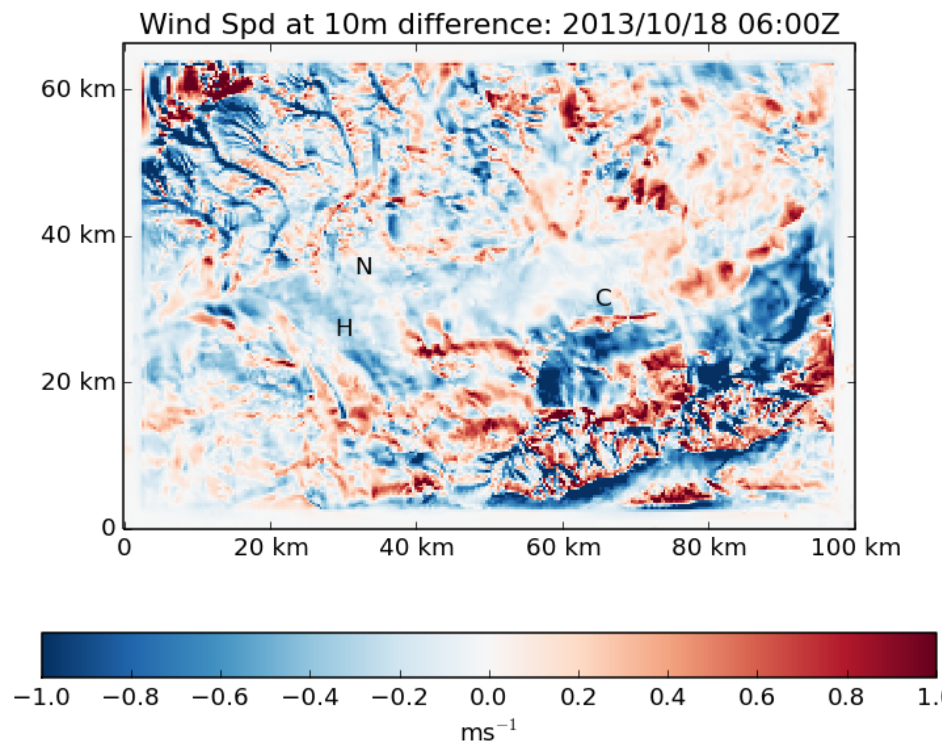
  - *wb*=buoyancy flux, *Ri*=Richardson number
- Quantifies the additional mixing created at 1.67km (5x5 grid points) due to resolved variability in LM
- UKV uses the "sharp-tail" to parametrize stable BL mixing
- More turbulent mixing in LM, less fog



Variability in shear

10m wind difference due to high res orography





- Lots of additional variability in the near surface windspeed seen in LM
  - Closely tied to variability in the orography

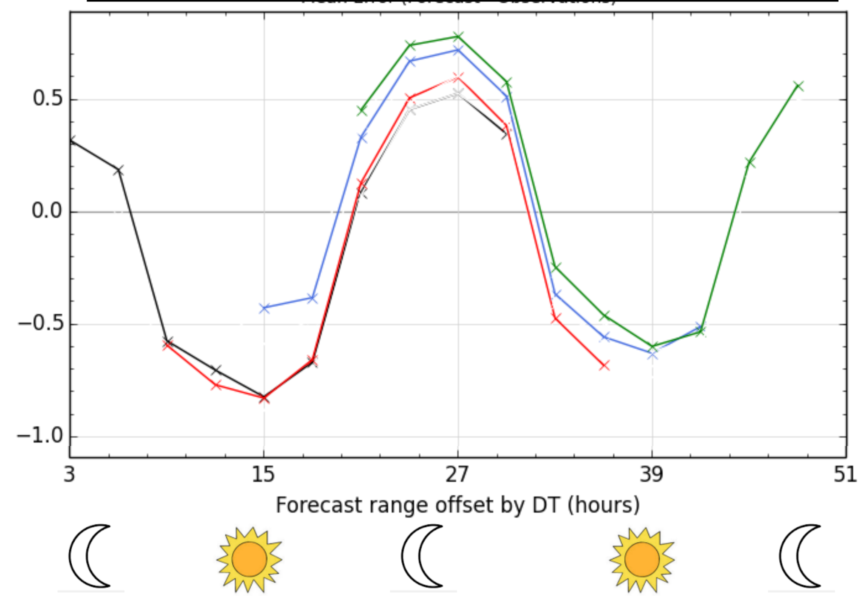
The role of stable boundary layers and surface coupling

UK temperatures

Diurnal cycle verification for June 2014

- Suppressed diurnal cycle (UKV and GM) in near-surface temperature
  - Systematic physics problem
- Biases amplified when sampled over clear sky cases
  - Not simply excessive cloud
- Warm bias at night
  - Excessive SBL mixing?
- Cold bias by day
  - BL depth/entrainment wrong?
  - Surface fluxes/Bowen ratio wrong?
  - Cold bias above SBL?
- Excessive coupling between atmosphere and soil could explain both

1.5m temperature mean error (K)



Comparisons at Cardington

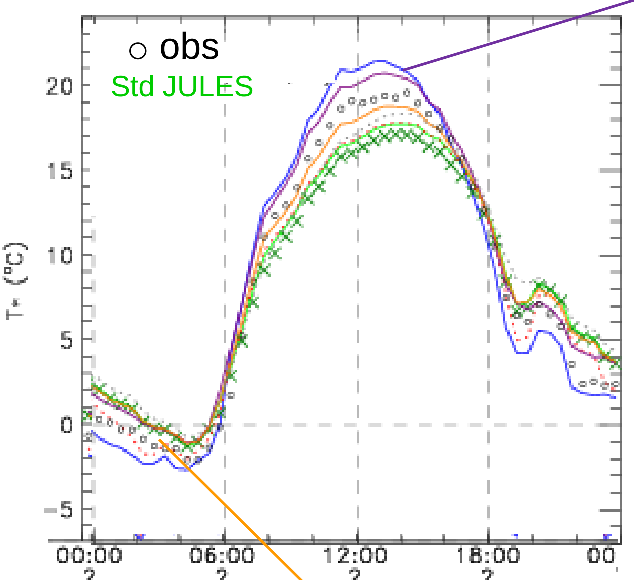
- Off-line JULES (driven by observed T, q, U and down-welling radiation)
  - Reproduces suppressed diurnal range
  - Shows strong sensitivity to land surface properties
- Top soil level (10cm thick) in UKV has greater diurnal range than observations at 1cm
  - Alleviated by reducing the fraction of bare soil

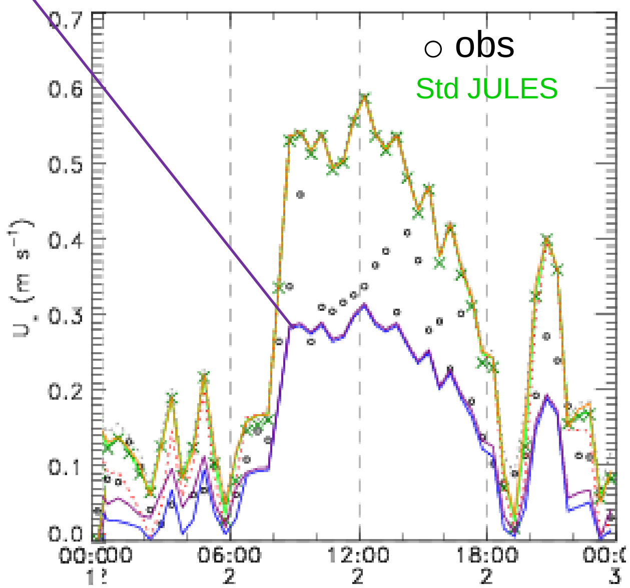
Grass surface T

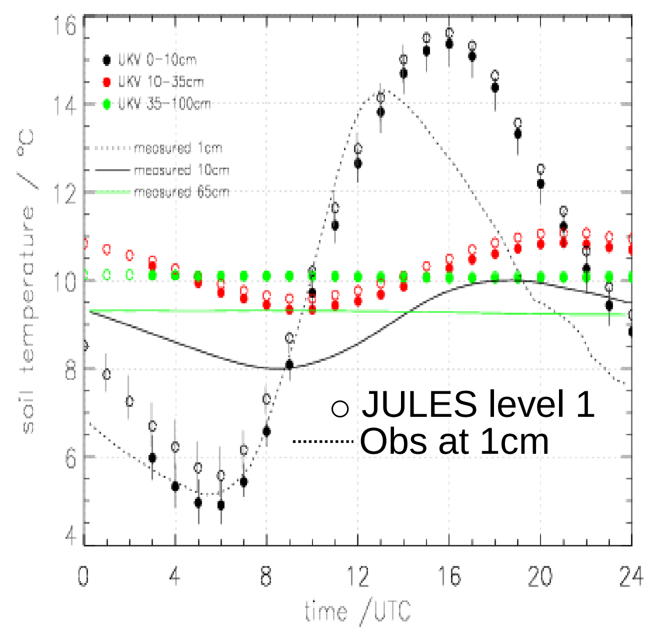
"Realistic" canopy height

Friction velocity

Soil temperatures





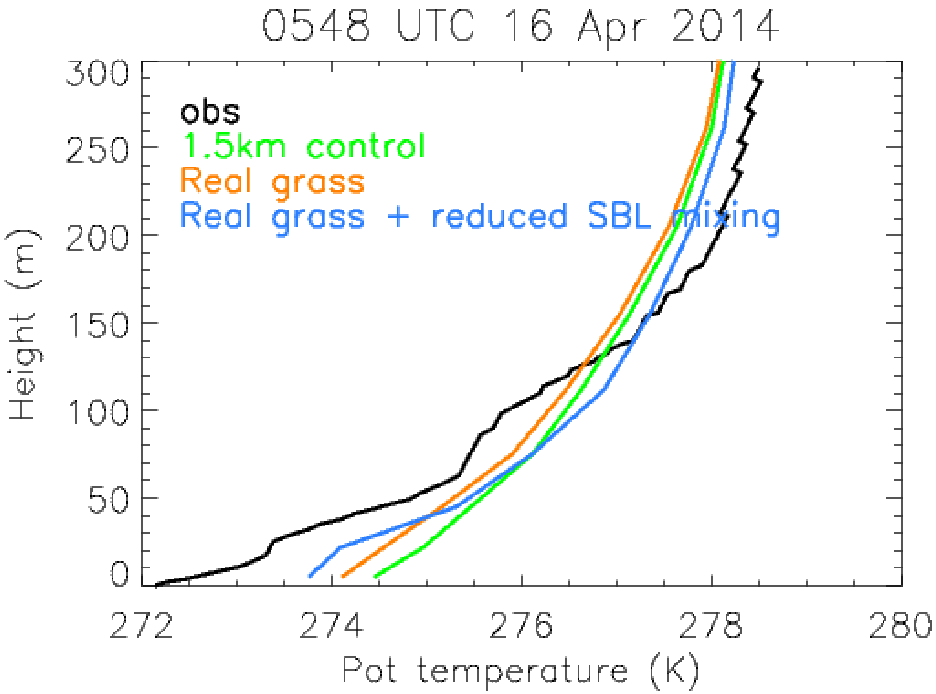


Realistic bare soil fraction

Clear sky sensitivity to SBL mixing

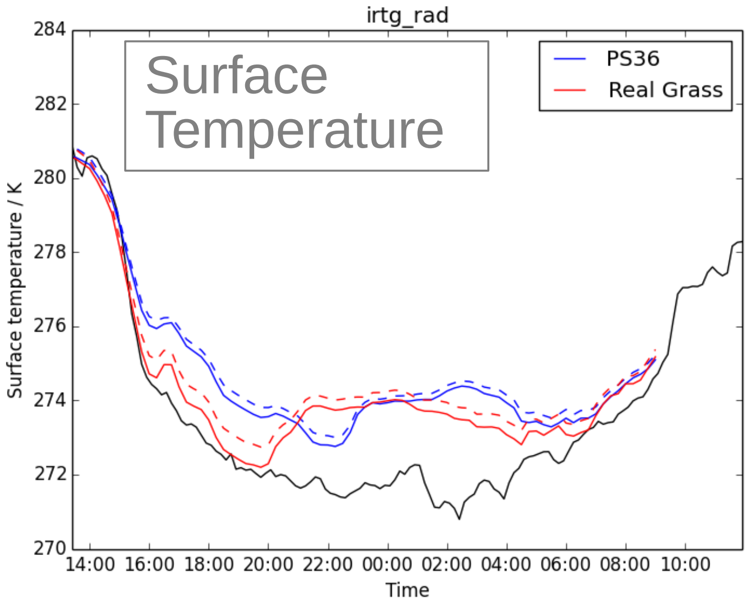
Cardington clear-sky case study, 16th April 2014

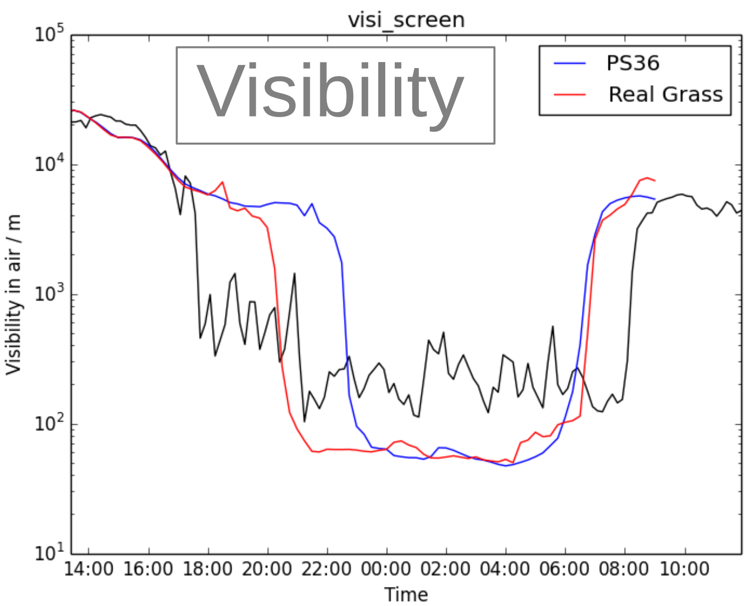
- Reduced mixing in stable boundary layers
  - Minimum mixing length (5m cf 40m)
  - Sharper than "Sharpest" stability function
  - Use surface T in lowest-level Ri
- Improves near-surface T profile
- Enhanced vertical resolution shows little impact

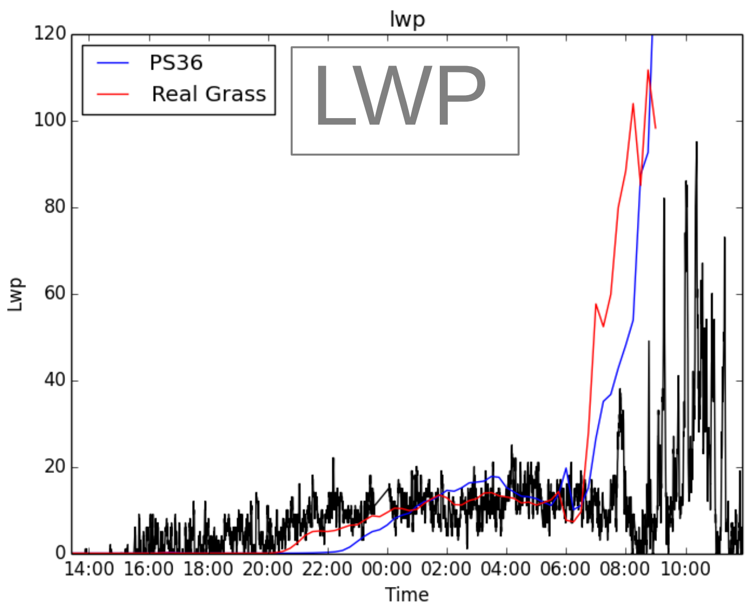


LANFEX case study

- More realistic grass surface and reduced SBL mixing, “Real Grass”, improves surface temperature and fog formation
- But soon after fog forms the model’s becomes *optically* thick and spuriously warms the surface



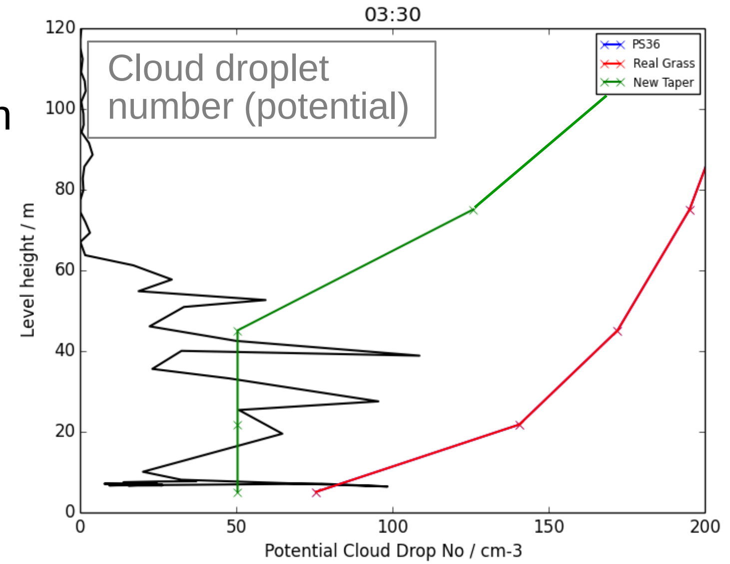


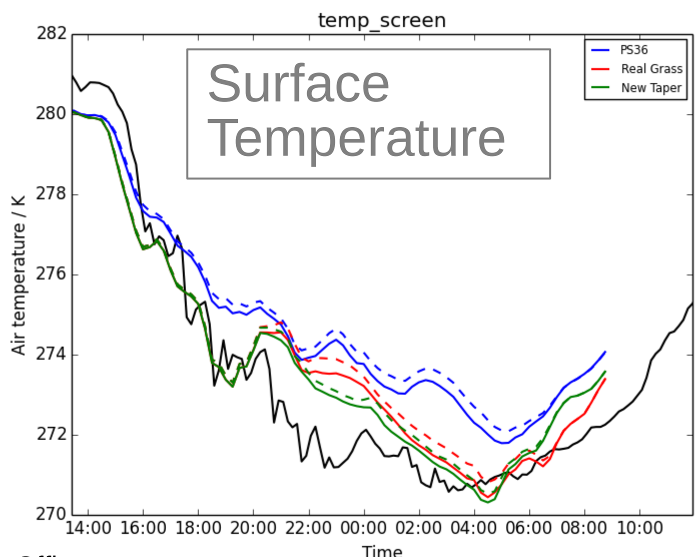


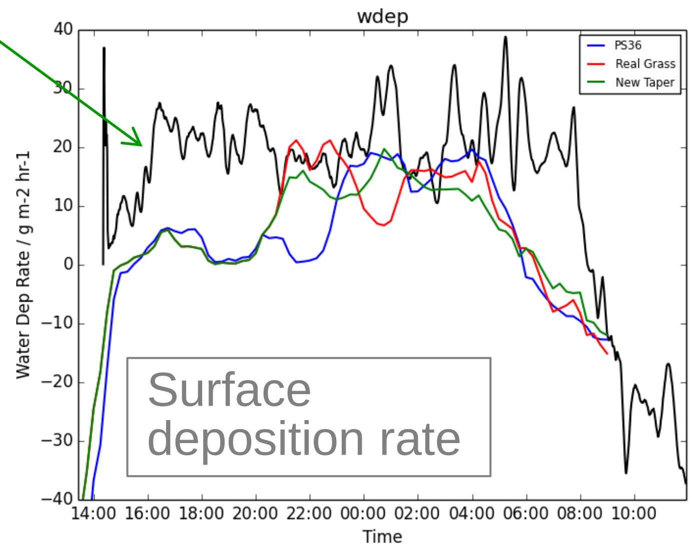
The role of aerosol and cloud microphysics

Slowing the transition to optically thick fog

- Weak cooling rates in fog imply limited droplet activation
  - Hence already “taper” to small N at surface
- Impose N=50cm^{-3} below 50m
  - Reduces fog optical thickness giving cooler surface
  - Surface fog deposition rate still realistic
- Still lacking dew deposition in the early evening despite reasonable surface T

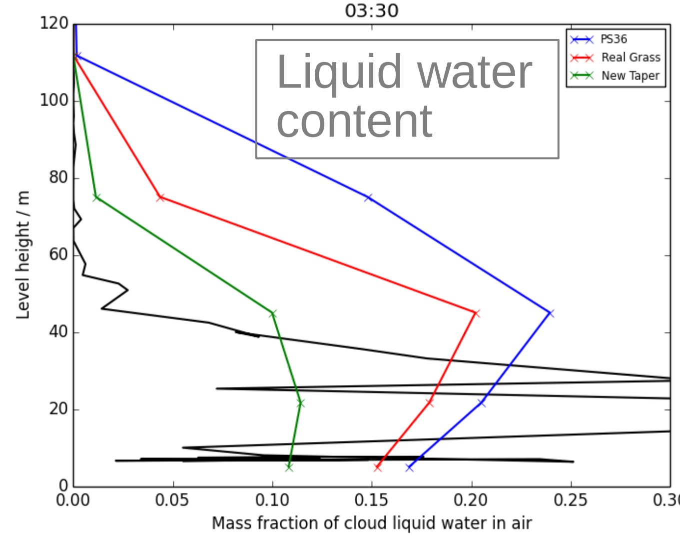


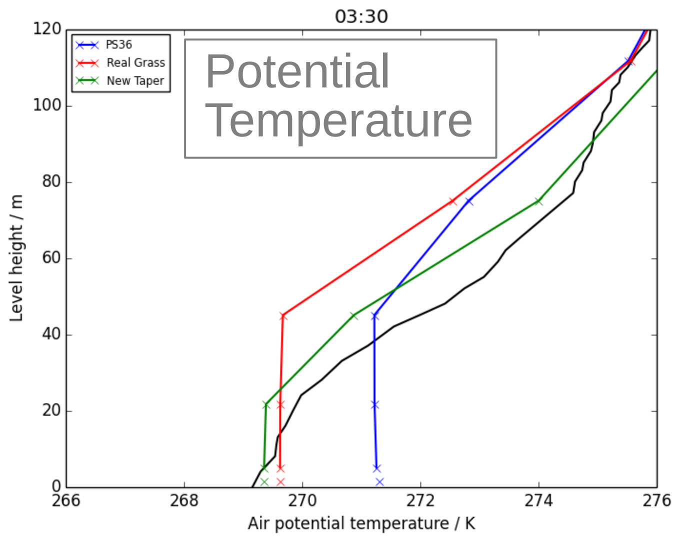


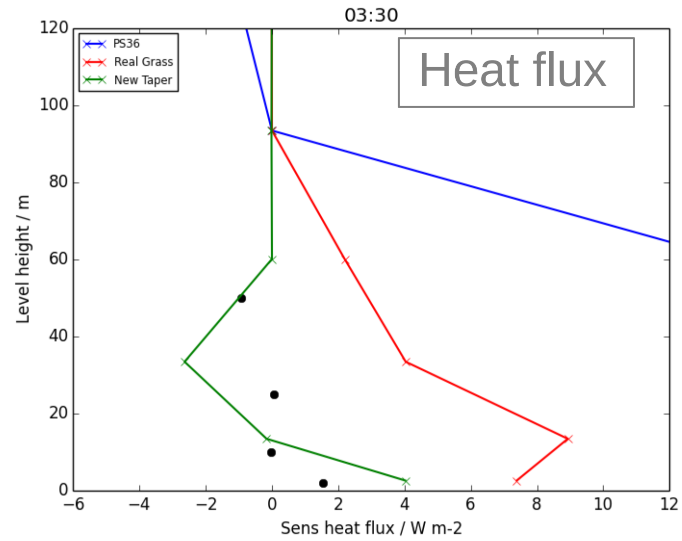


Slowing the transition to optically thick fog

- Optically thinner fog also improves temperature profile and heat fluxes







Summary (1)

- Fog is hard!
- Large-scale meteorology is a key uncertainty
  - Use of ensembles
- Highlights weaknesses in parametrizations
  - Result of feedbacks and imbalances between many small scale processes

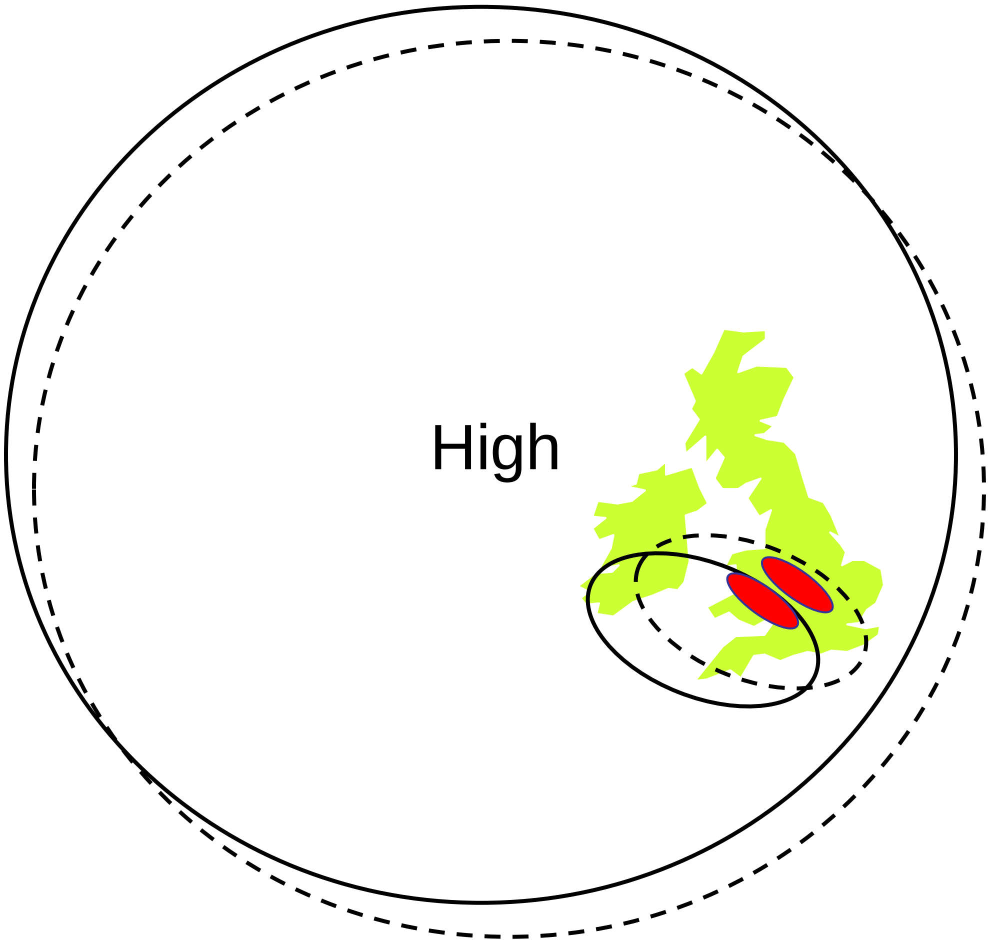
Summary (2)

- Met Office fog research is focussed around LANFEX
- On-going work is investigating:
  - Cloud scheme: needs to be more adaptive
    - PC2, parametrize RH_{crit}?
  - Turbulent mixing in stable BL: still too strong?
    - May also need to represent effect of small hills properly (how?)
  - Surface characteristics: critical for accurate diurnal T
    - Need much better ancillary information (vegetation coverage, canopy height, LAI, etc)
  - Aerosol ↔ droplets: important for accurate microphysical properties (for radiation and settling) and thence fog evolution
    - How complex?
      - Tweak taper profile; prognostic cloud drop number; full chemistry?

Thank You

Questions?

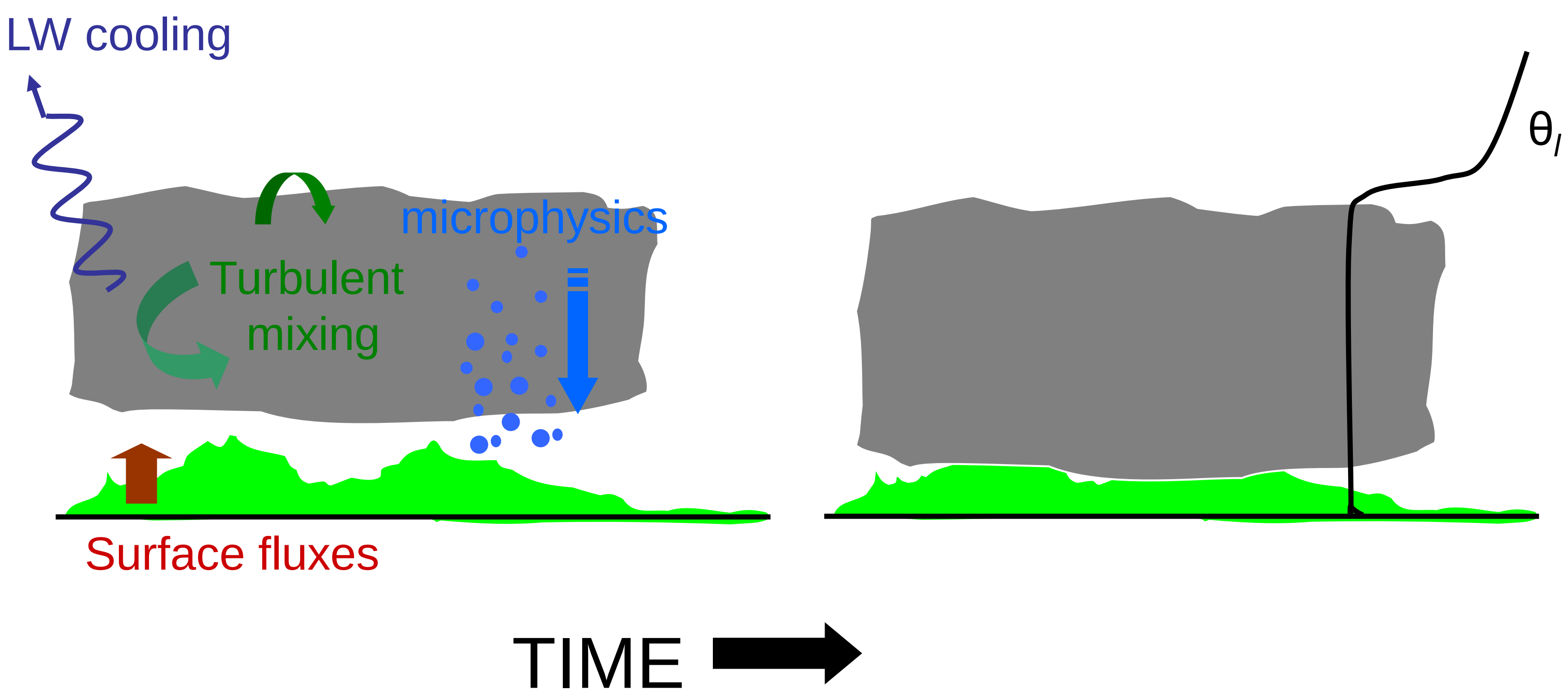
Small uncertainty at large scales
→ large uncertainty at small scales



5% error at 1000 km = 100% error at 50 km

Stratus lowering to fog

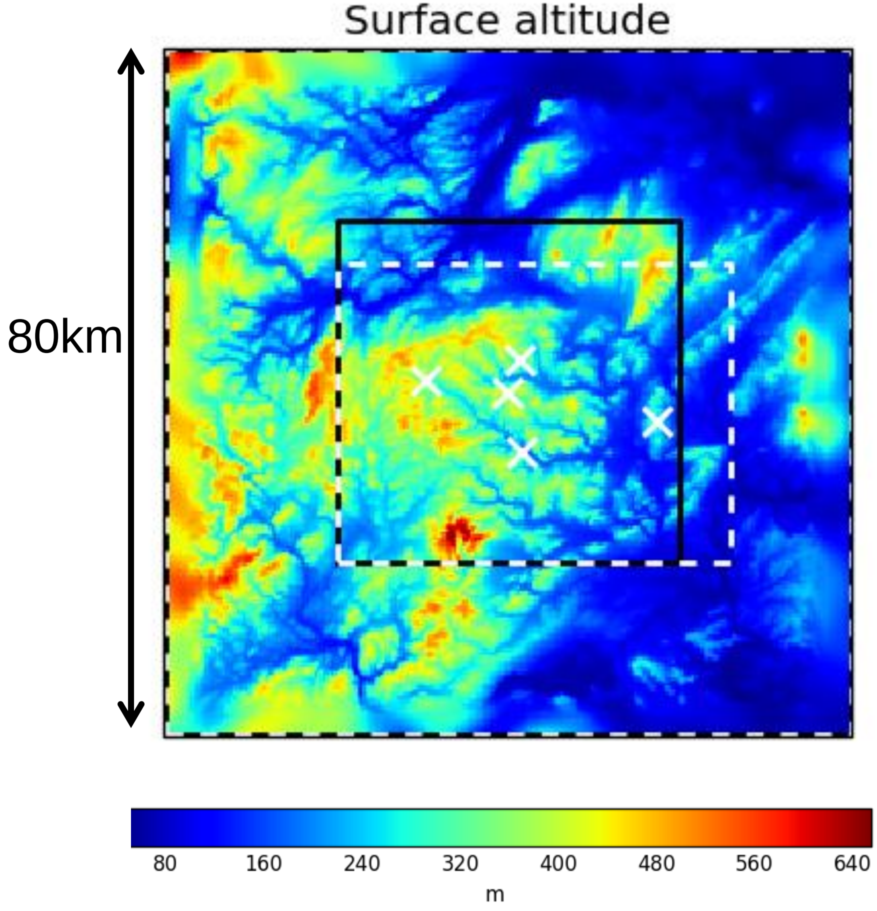
- Simpler system, well-mixed boundary layer, thicker cloud (better resolved)
- But cloud base height very sensitive to the boundary layer moisture and temperature budgets
  - Lifting base: warming from surface, entrainment drying, precip to surface
  - Lowering base: LW cooling, cooling/moistening from surface, evaporation of precip



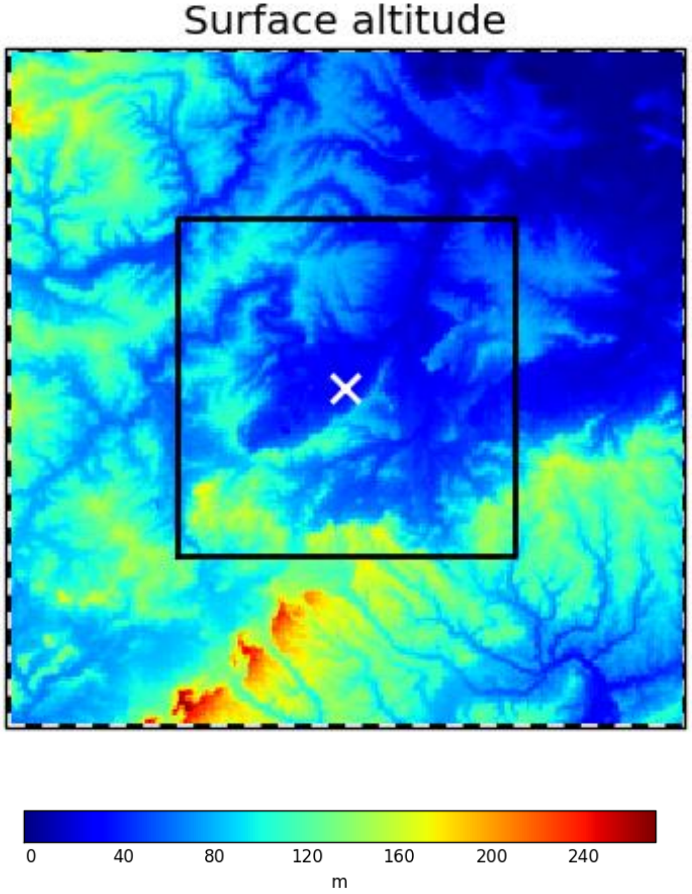
LANFEX modelling domains

- Comparing grids from 1.5km down to 100m (or less)

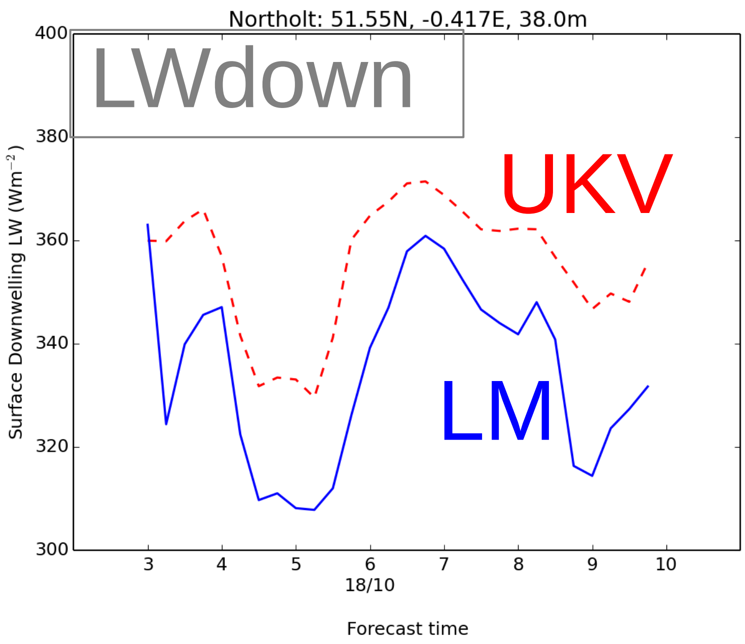
Shropshire

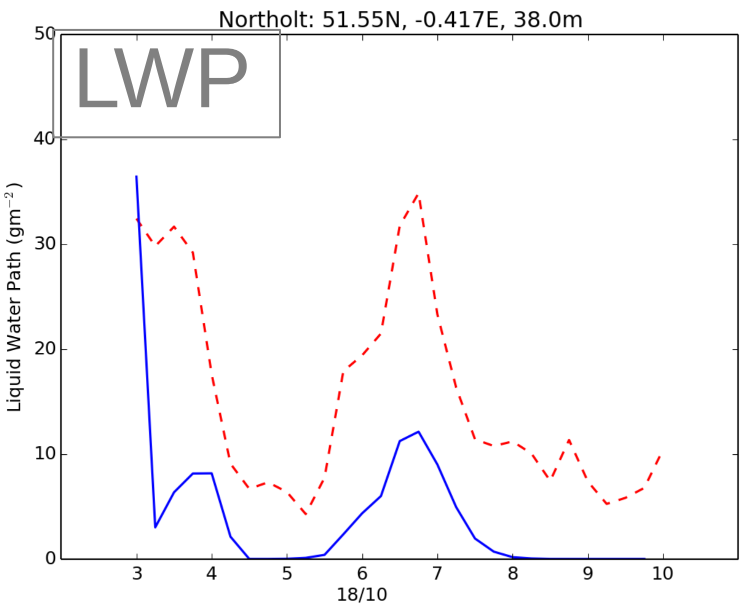


Cardington

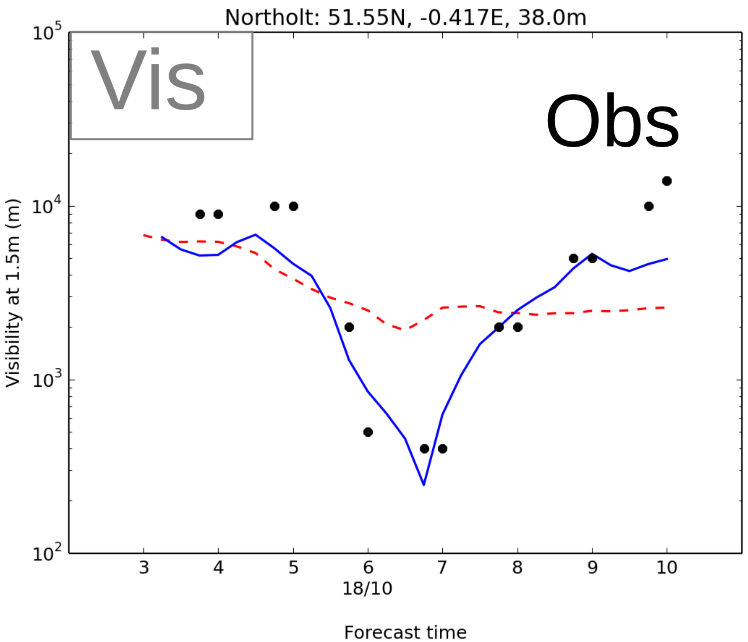


Excessive cloud in UKV





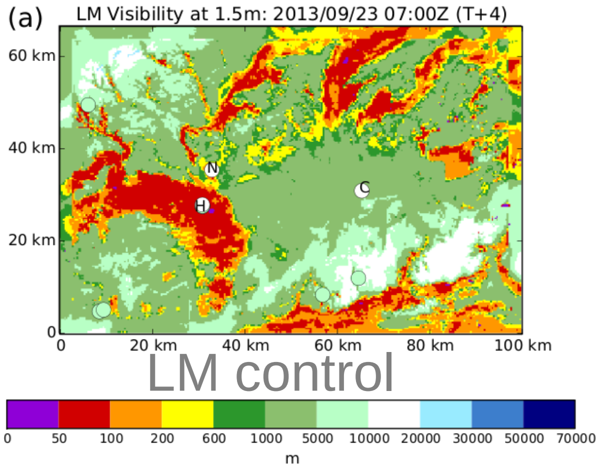
- LM breaks cloud from 4.30-5.30
  - Allows surface temperature to cool, and fog to form
- UKV maintains thin cloud
  - Extra downwelling LW keeps surface warm and prevents fog forming



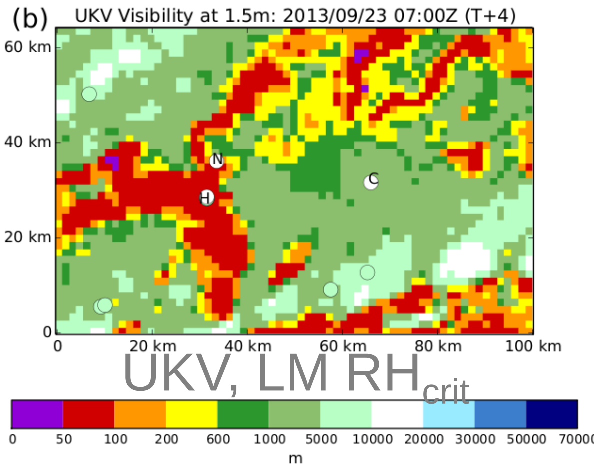
What works for 1 case...

23rd Sept 2013, more low cloud, less fog

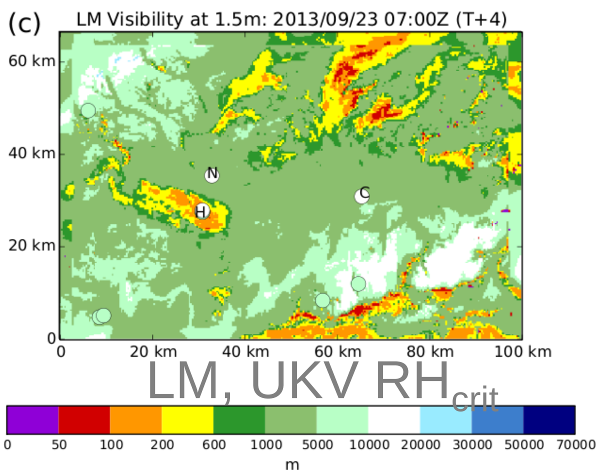
- Cloud scheme dominates impact
- Here, the UKV RH_{crit} value works better – LM was too foggy due to lack of cloud
- Hence can't simply tune RH_{crit}, need adaptivity
    - PC2? Parametrize RH_{crit}?



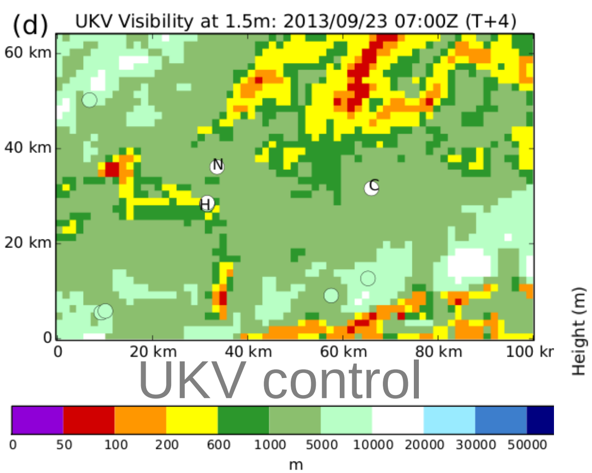
LM control



UKV, LM RH_{crit}

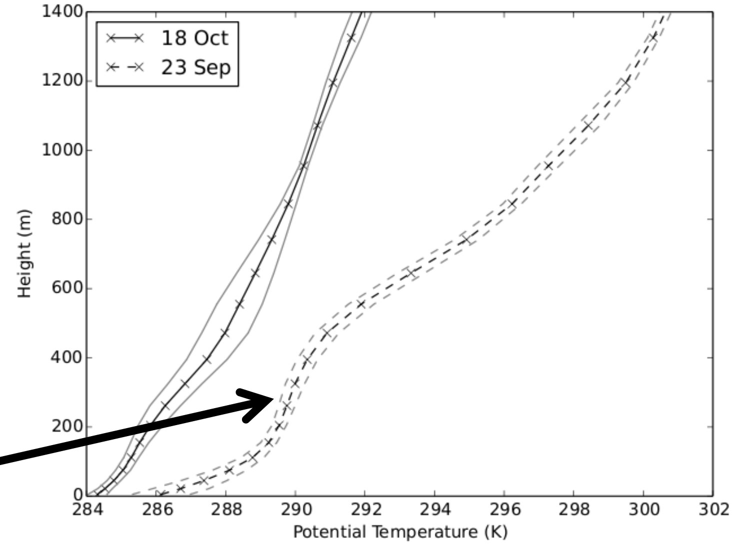


LM, UKV RH_{crit}



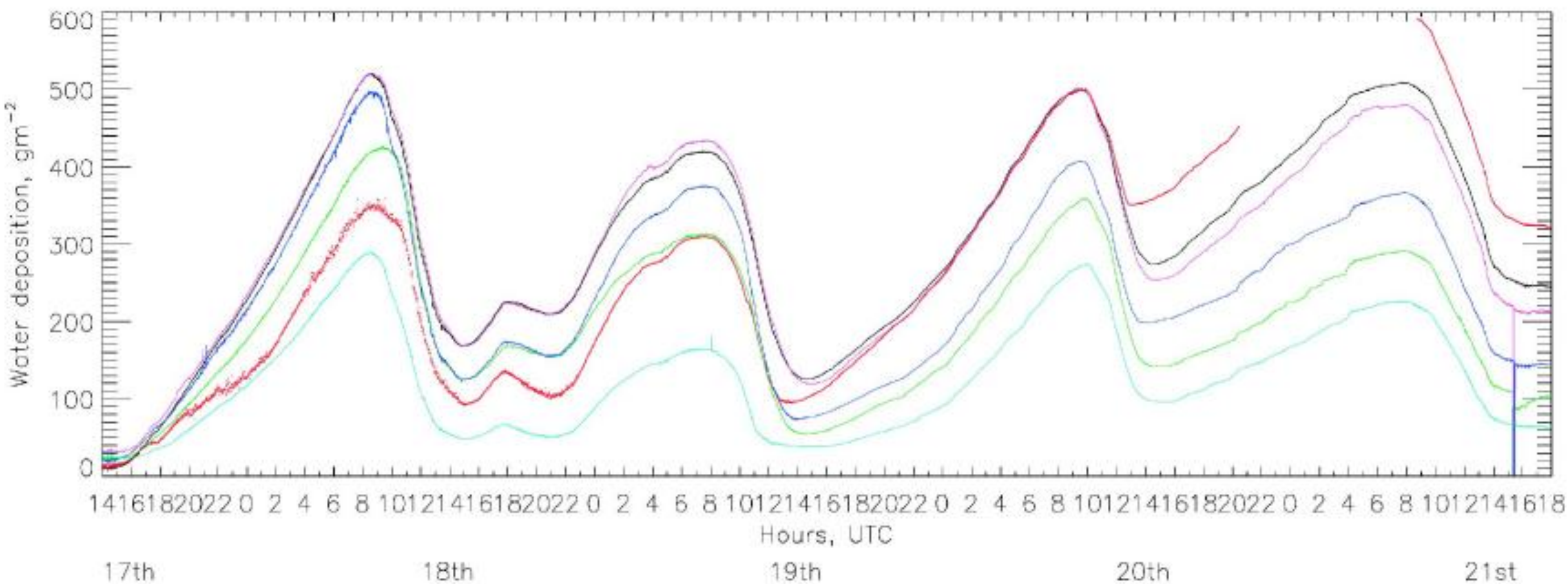
UKV control

Atmosphere is more stable in this case



Dew deposition

- There is enormous variability in dew deposition at Cardington (Met Office Research Unit)
  - By location around the site (see below)
  - By surface characteristics (eg. long/short/dead grass)

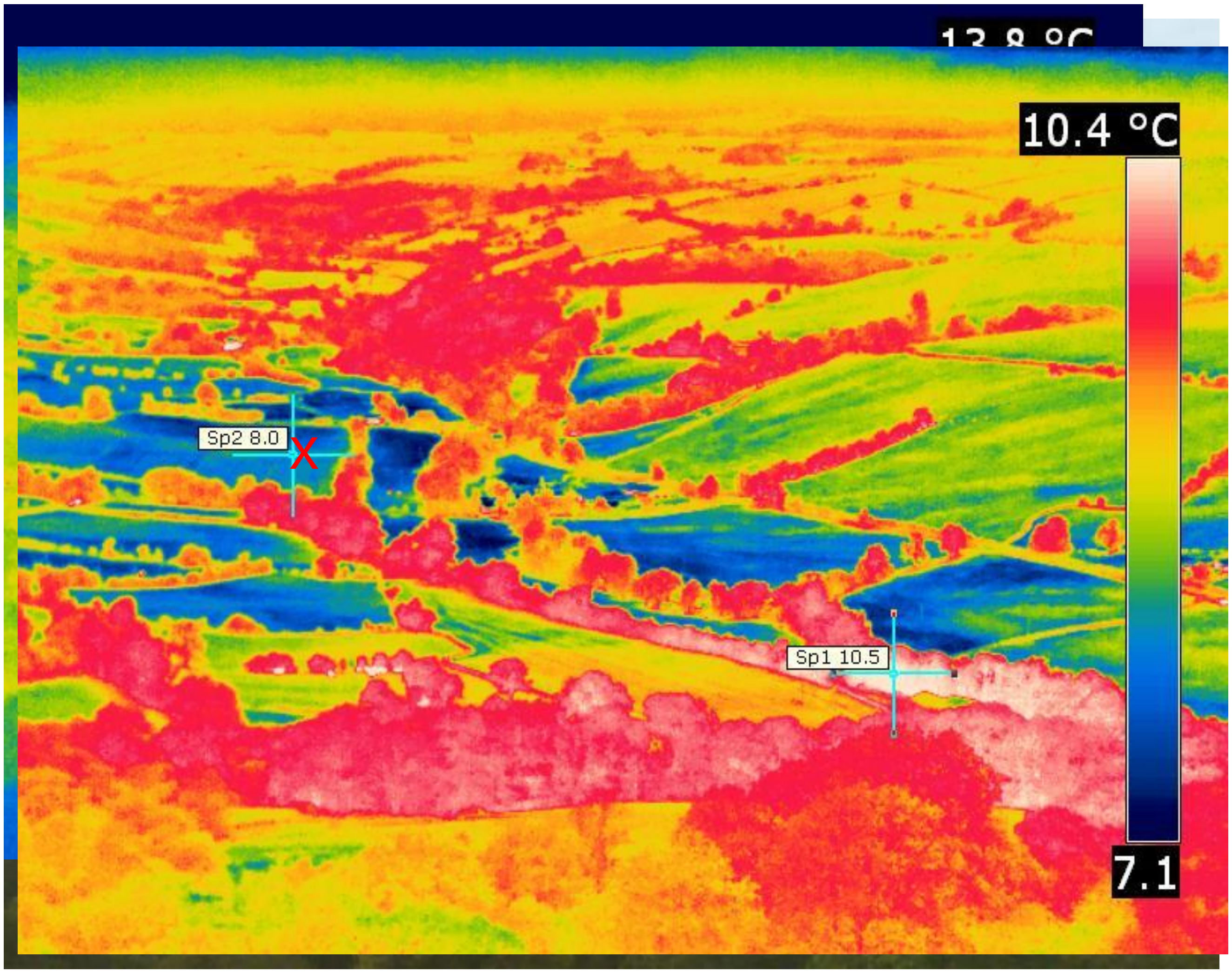


November 2011

Surface heterogeneity: evening (2130)

Surface heterogeneity: daytime (1700)

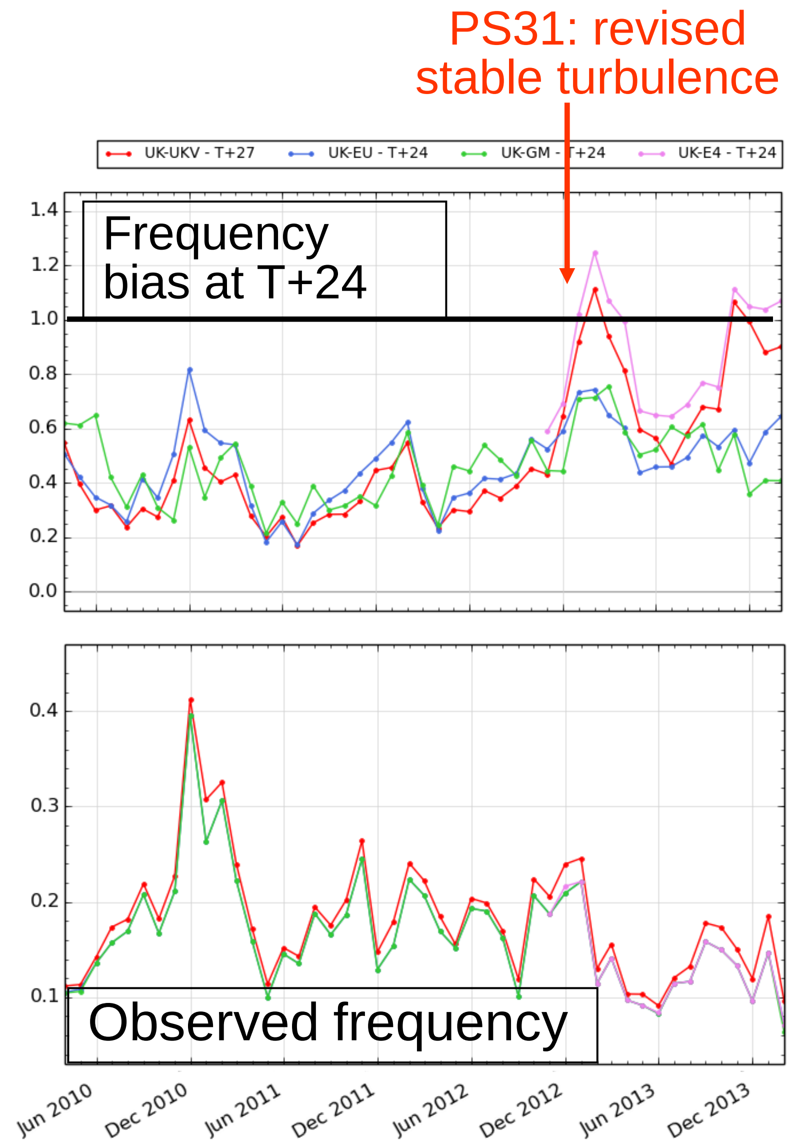
- Trees/hedges 2-3K warmer than fields so gridbox mean T will be biased warm compared to grass obs



Met Office

Verification of RH > 96%

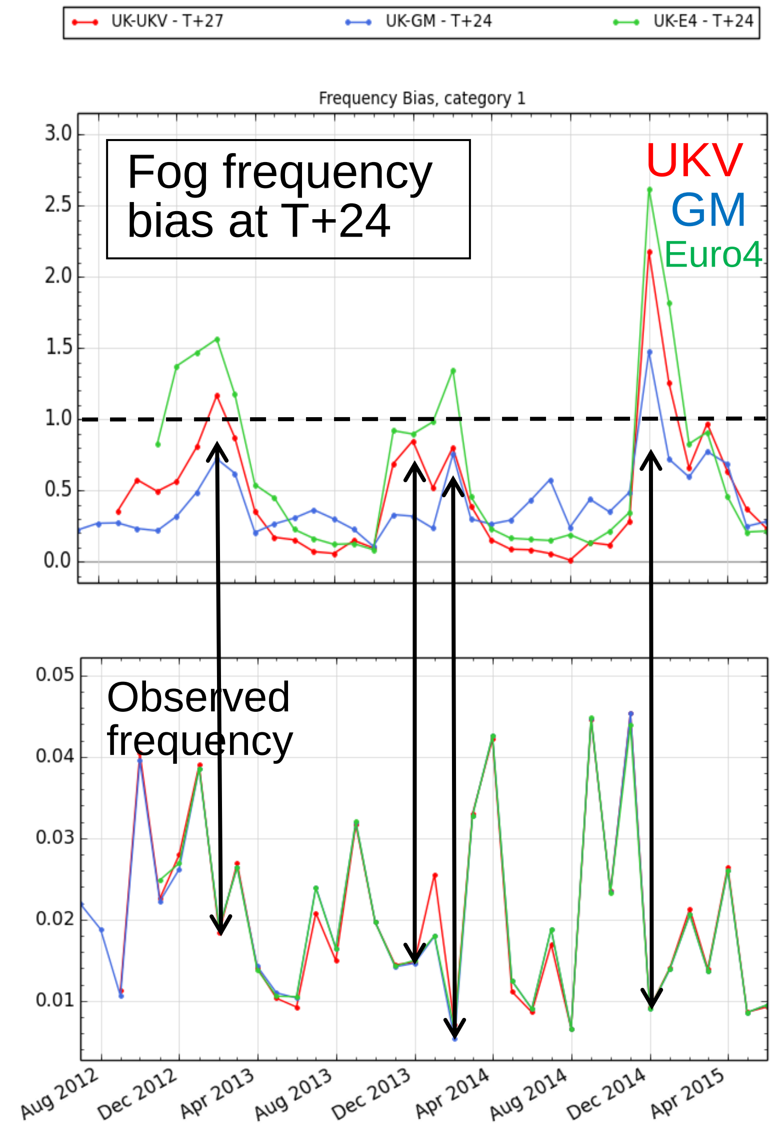
- Getting near-surface air close to saturation has got to be a prerequisite for good fog forecasts
- UKV got a lot better at predicting RH close to saturation (at least in winter) from 2013 (PS31)
    - deliberate anticipated impact of changes to stable boundary layer mixing
- But what about actual fog forecasts?



Verification of fog (vis<1km)

Met Office

- UKV fog frequency bias is almost always very low
  - Even higher frequency biases are in winter and when there is relatively little fog
    - So statistical significance isn't high
    - But also partly due to missing low cloud
- Why is fog frequency bias much worse (lower) than that for high RH?
  - Often get high RH without fog
    - E.g., competition between dew deposition and fog



Fog is also patchy

- ETS for fog (vis<1km) is poor (UKV~0.1)
- But getting a hit at a site for an infrequent and patchy quantity like fog is hard
- Starting to use neighbourhoods to give a local fog probability
  - UKV scores show some skill even at 4km scale (3x3 points)
  - MOGREPS-UK ensemble gives significantly better skill than UKV