A 3D high resolution model for local fog prediction

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Outline

Introduction – Radiation Fog

Why and Why is it so Difficult to Forecast?

Local Stand-Alone Model Concept

Unified Model at Very High Resolution

Model Physics

Radiation Temperature Profile

Stable Boundary Layer

Single Profile Forcing

Conclusions

Introduction

- Fog and low visibility conditions can have a high impact on both aviation and ground transport.

CNN

Luxair crash 06.11.2002 – 18 dead

BBC

Accident on M4
near Cardiff
10.12.2003

Radiation Fog - FORMATION

After the evening transition, the energy balance in the lower atmosphere is no longer dominated by incoming solar radiation.

Following evening transition:

- Turbulent diffusion of moisture and possible dew deposition

- Radiative cooling
  - of surface

    AND

  - of air (mostly to surface)

Radiation Fog - FORMATION

"The development of radiation fog is primarily controlled by a balance between radiative cooling, which encourages fog, and turbulence, which inhibits it."
Roach et al 1976, Brown and Roach 1976, Turton and Brown 1987

- Radiative cooling (of surface and air) in lower atmosphere.
- Increasing stability near to surface.
- Damping of turbulent diffusion, dew deposition inhibited.
- If the air is sufficiently moist, cooling leads to saturation and condensation of water droplets forming fog!
- Wind lulls coincide with maximum cooling and significant fog development.

Radiation Fog – DEVELOPMENT and DISSIPATION

DEVELOPMENT

- Fog droplets also cool radiatively and grow.
- Once the fog is developed, the surface inversion moves to the top of the fog layer.
- Radiation, cooling and condensation now take place mainly at the fog top.

DISSIPATION

- Fog droplets settle due to gravity.
- Cold thermals occur in the fog and entrain warm air. The fog becomes unstable, behaving like Strato-Cumulus.
- At sunrise the fog may burn off if optically thin or near its edges.

Numerical Fog Forecasting - 1

Numerical fog forecasting is difficult!

- Fog evolution depends sensitively on several physical processes.
- These processes occur on a sub-grid scale. Hence they must be parametrised.

  Radiation

  Stable Boundary Layer – turbulence

  Surface Exchange

  Soil

  Microphysics

Numerical Fog Forecasting - 2

Numerical fog forecasting is difficult!

- Orography is also important – it can cause pooling of cold air. A 3D model is needed to represent this and the winds.
- LW radiative cooling is sensitive to [synoptic] cloud cover.
- Vertical resolution is important, e.g. to capture radiative fluxes near the surface. Fog may be very shallow, only 2-5m deep, in the initial stages!

Local Stand-Alone Model

- Centrally run NWP at ~1 km scale over areas the size of UK will be feasible by end of the decade.
- Communication of large volumes of output data to the field is likely to remain a major problem.
- Develop a model (based on UM) to run at high resolution over a small domain, forced by a single profile (model or sonde) – to be run on a local PC in the field.

Met Office Supercomputer

GLOBAL/
MES

Communications

Local 'PC'

Local Stand-alone Model - Components

Unified Model at Very High Resolution

1 km horizontal grid, 76 vertical levels

Model Physics

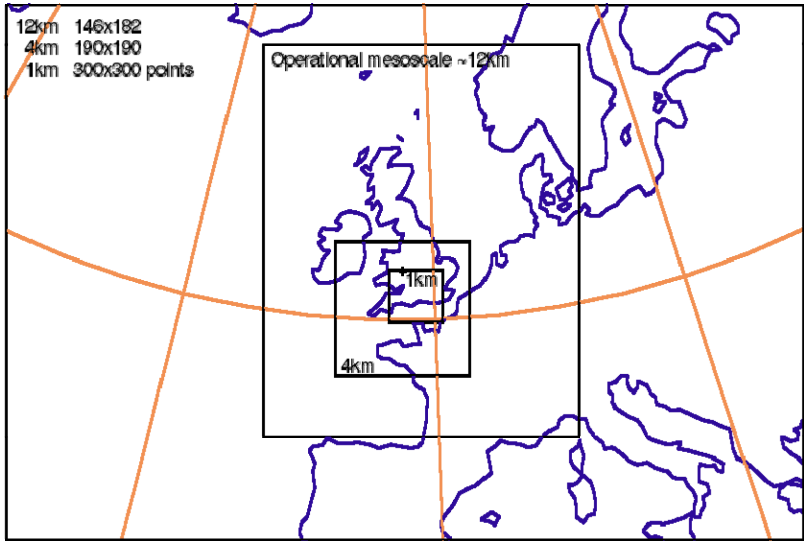
Optimise for fog forecasting at very high resolution

Single Profile Forcing

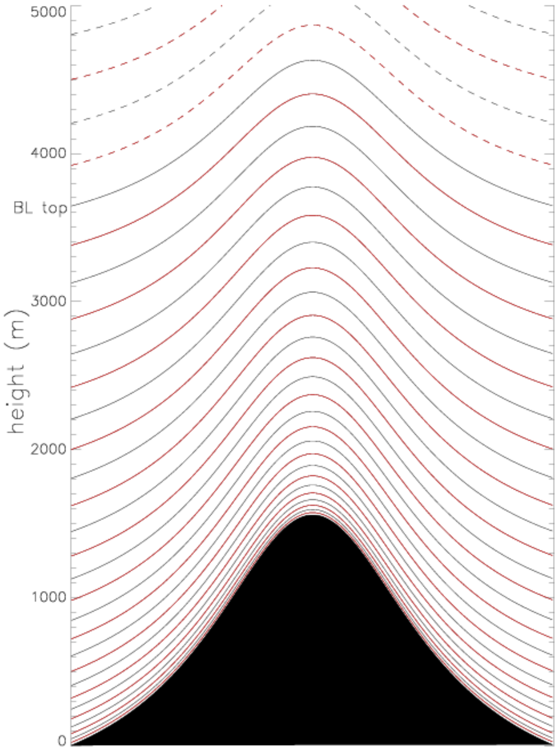
Very High Resolution Modelling

1-Way Nested Limited Area Configuration

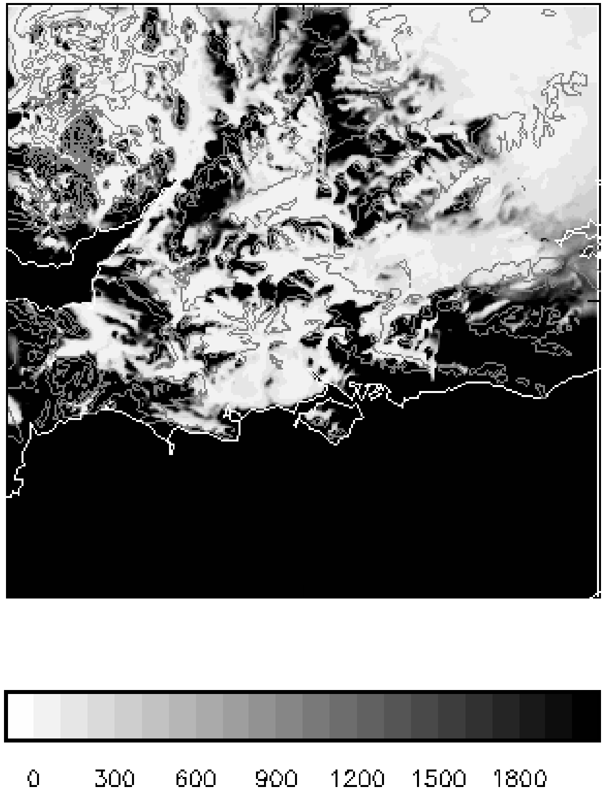
HORIZONTAL



VERTICAL (BL)



18 UTC 09/12/2003 1km L76 Forecast



Visibility

100m orography contours

Physics

Model Physics

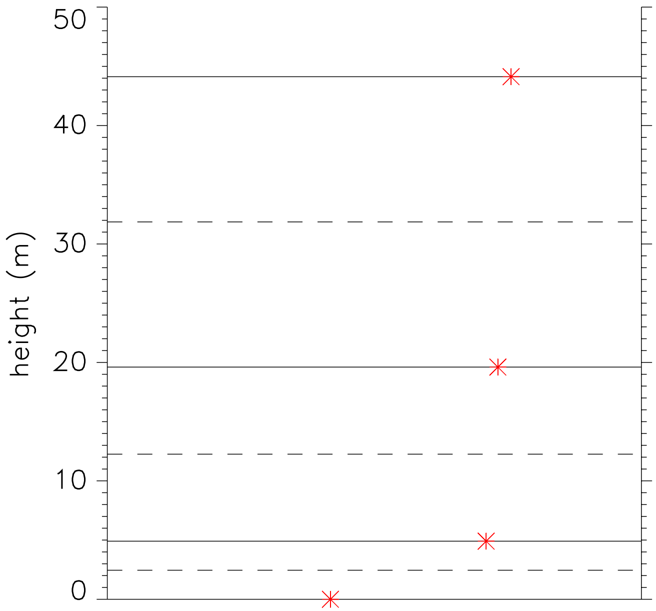
Physics parametrisations in the Unified Model are designed for a wide range of grid scales, from Mesoscale (12 km) to Climate (~300 km).

Physics formulation needs optimising for high resolution fog forecasting.

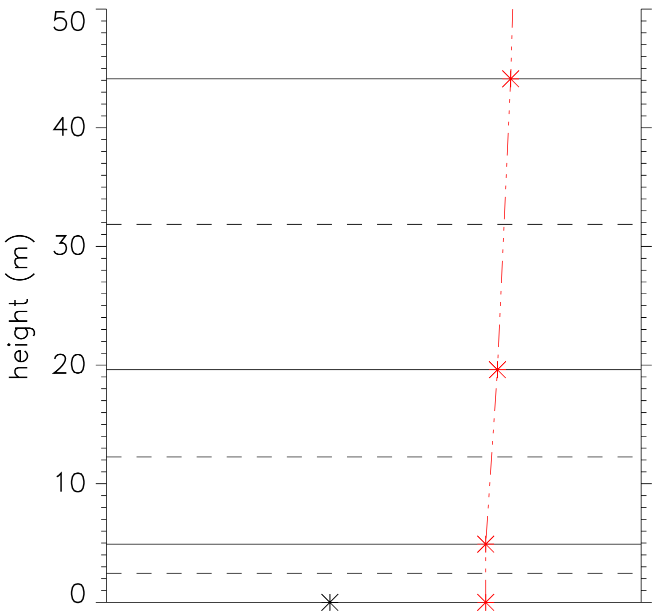
- Radiation
  - Temperature profile near surface
- Boundary Layer Scheme
  - Stability functions

Radiation – Potential improvements

VERTICAL GRID
T on model levels



RADIATION SCHEME
T profile



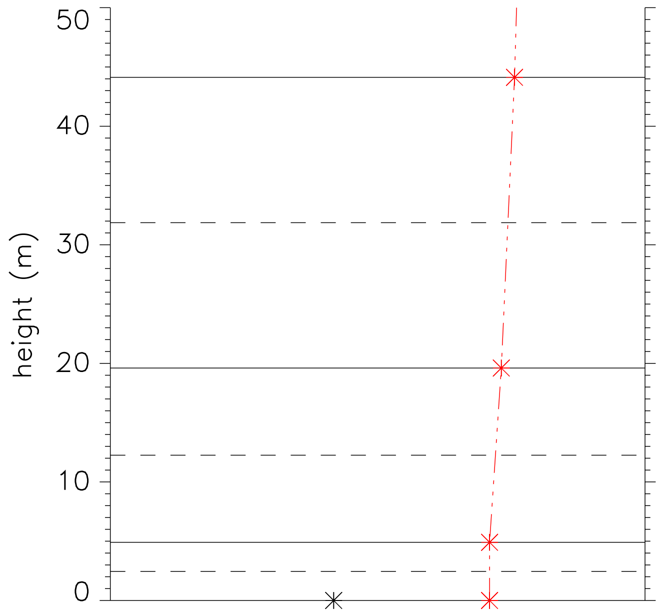
TEMPERATURE PROFILE near surface

- Radiation scheme sets T at bottom of atmosphere, i.e. at surface, to T on first model theta-level.

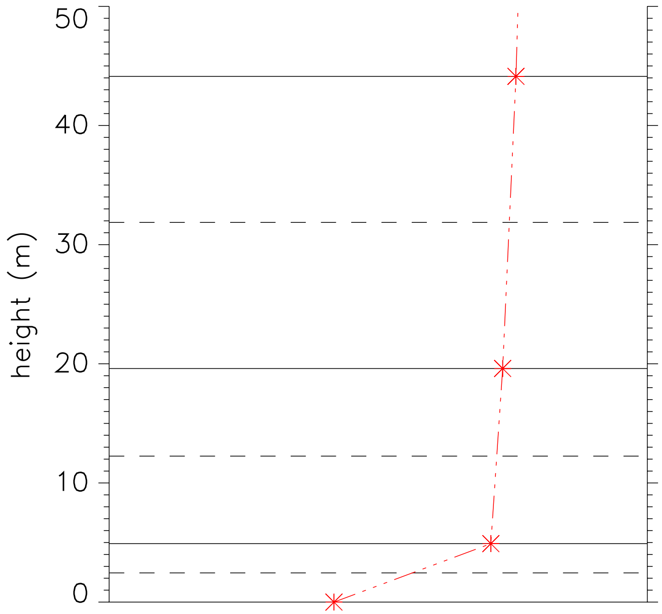
Radiation – Potential improvements

RADIATION SCHEME

T profile



T profile using T_*

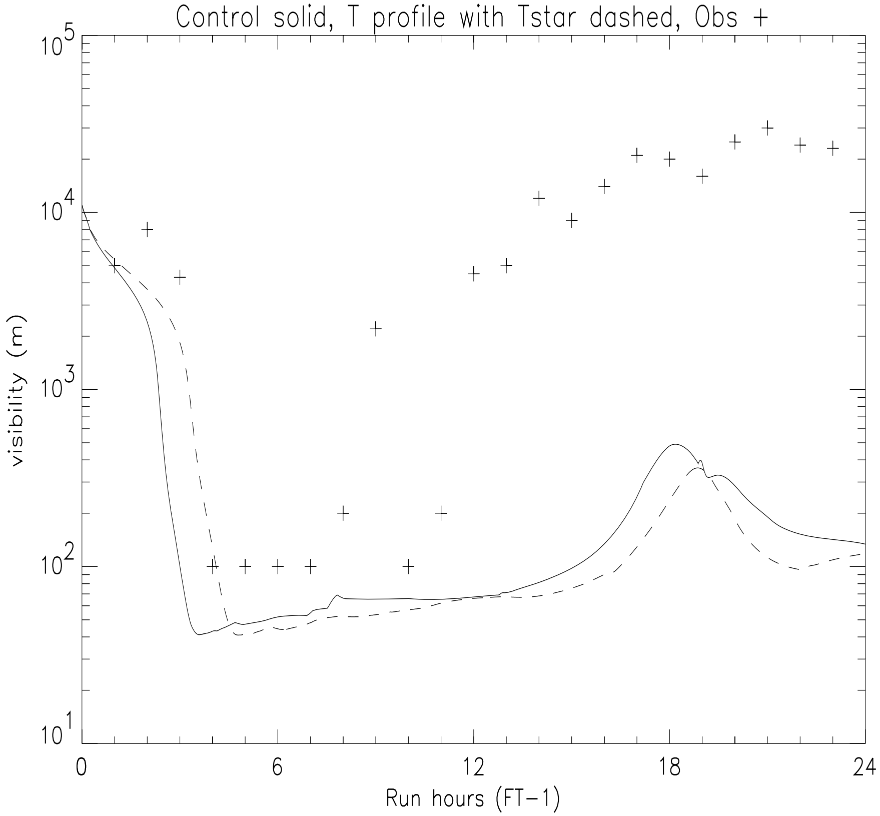


TEMPERATURE PROFILE near surface

- Radiation scheme sets T at bottom of atmosphere, i.e. at surface, to T on first model theta-level.
- T_* could be a better choice over land.

Radiation – Temperature profile

Visibility at 1.5m



Using T_* in radiation code profile gives
- Less cooling
- Sharper inversion
- Later fog formation

Why?

Single Column UM 6.0, 76 levels,
Initial profile from 3D model

Stable Boundary Layer

First order SBL scheme in UM:

$$\overline{\chi w} = -K_{\chi} \frac{\partial \chi}{\partial z}; \quad \chi = U, V, \theta$$

$$K_{\chi} = \lambda^2 \left| \frac{\partial \mathbf{u}}{\partial z} \right| f_{\chi}(Ri)$$

λ Mixing length

$f_{\chi}(Ri)$ Stability function

$$\frac{1}{\lambda} = \frac{1}{\kappa(z+z_0)} + \frac{1}{\lambda_0}; \lambda_0 = MAX(40, 0.15h)$$

$$Ri = \frac{\frac{g}{\theta_0}\frac{\partial \theta}{\partial z}}{\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2}$$

Gradient Richardson number
Ri < 0.25 turbulence ‘turns on’
(empirically, not in model)

NWP stability functions

LONG

$$f_\chi(Ri) = \frac{1}{1+10Ri}$$

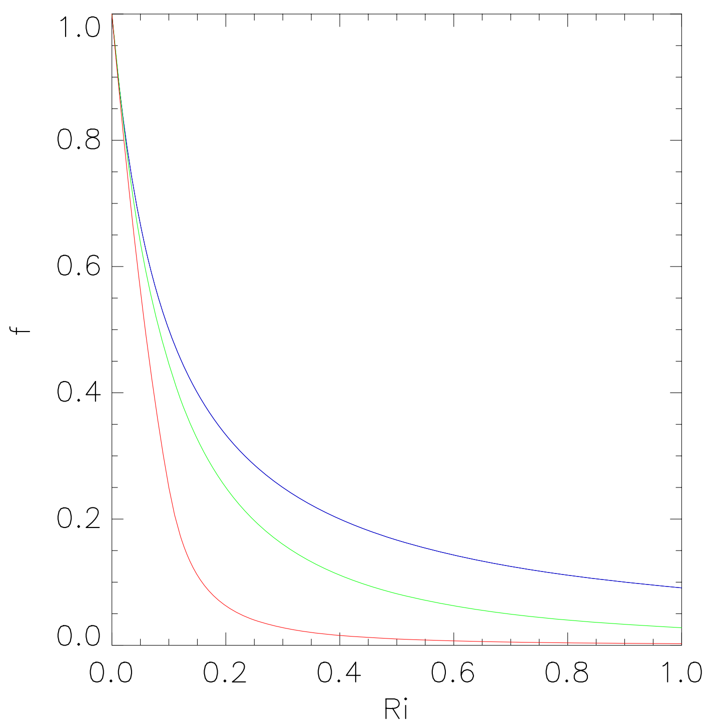
LOUIS

$$f_\chi(Ri) = \frac{1}{(1+5Ri)^2}$$

SHARPEST

$$f_\chi(Ri) = (1-5Ri)^2 \quad 0 < Ri < 0.1$$

$$f_\chi(Ri) = \frac{1}{(20Ri)^2} \quad Ri > 0.1$$



SHARPEST has least mixing

NWP stability functions

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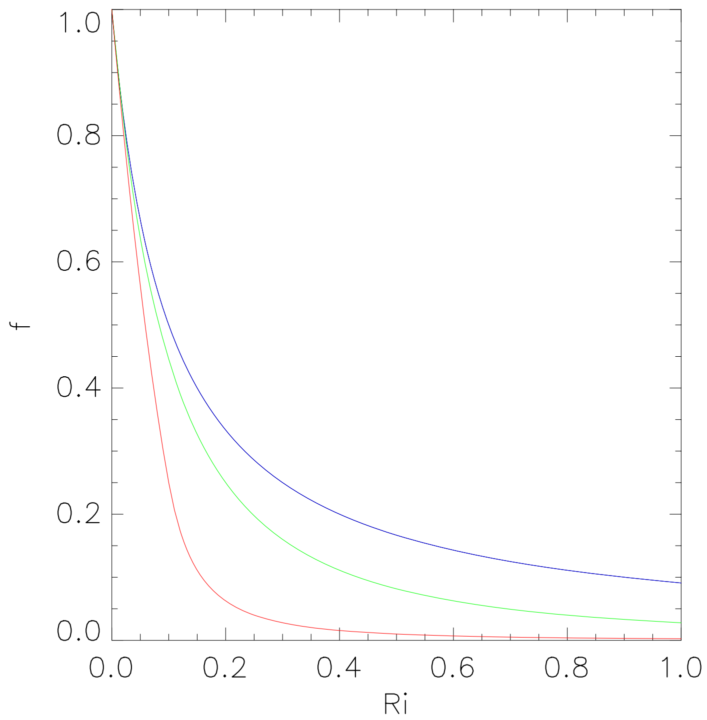


SHARPEST has least mixing

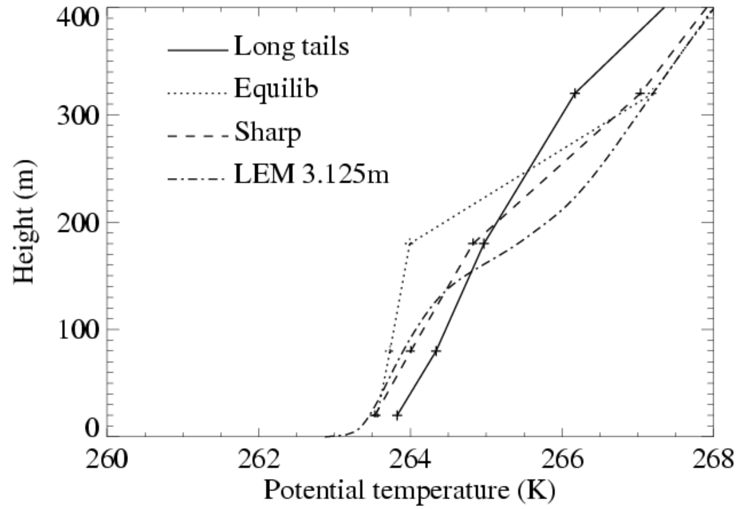
- UM is tuned!

SHARPEST above 200m, scales to Louis with z below 200m.

NWP stability functions

- Stability functions with more mixing compensate for sub-grid heterogeneity of surface.
- But SHARPEST is in fashion – best agreement with LES in GABLS. www.gabls.org
- Sub-grid surface more homogeneous at very high resolution.
- Rerun 3D case studies with SHARPEST.

Single Column Model vs LEM



Anne McCabe
Bob Beare

SHARPEST Results

In 3 case studies, model forecasts using SHARPEST stability functions consistently show

- Screen temperature 0.5-1.0 K cooler
- Relative humidity 1-3% higher
- 10m winds 0.2-0.4 ms^{-1} less
- Lower visibility

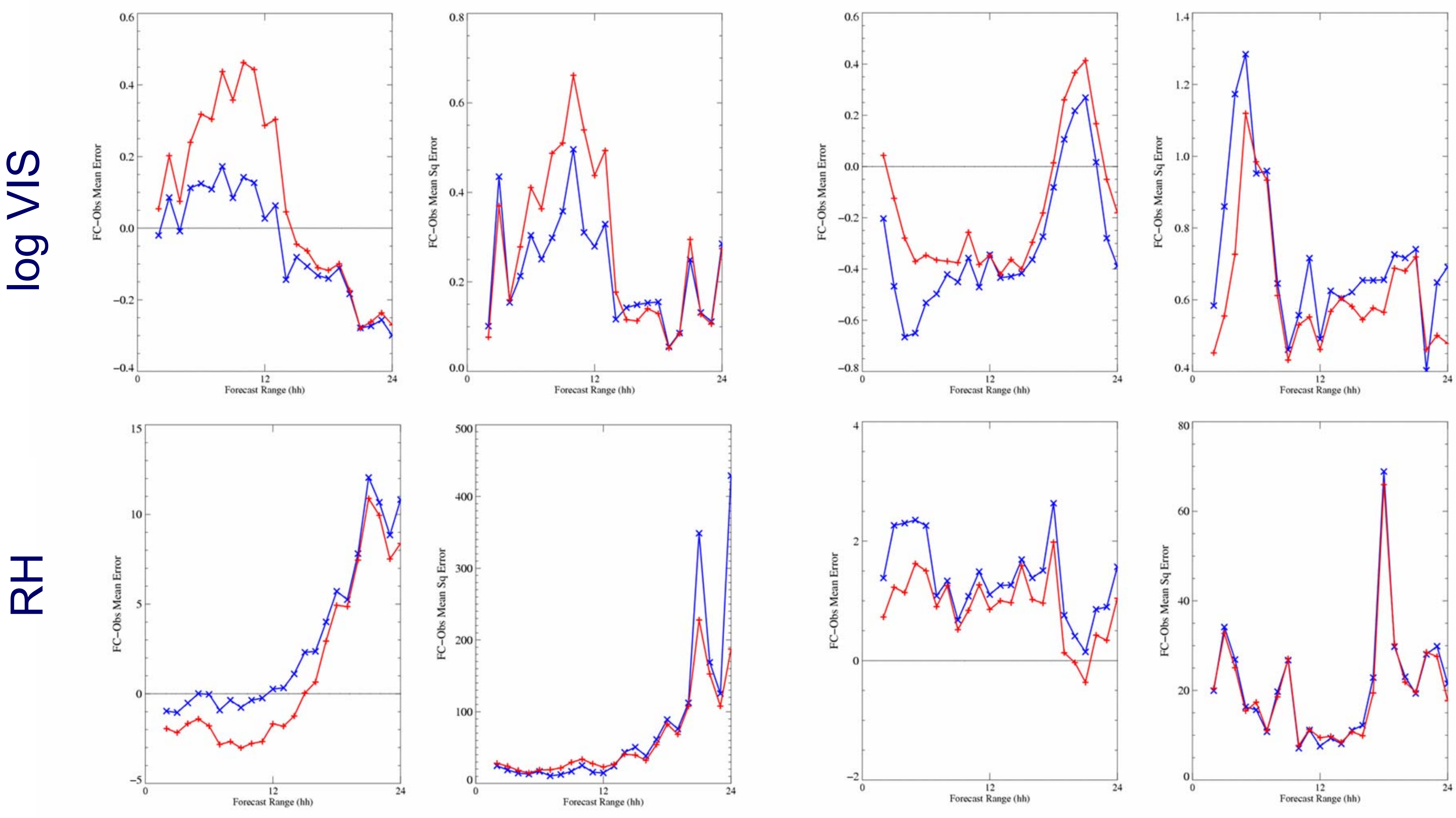
SHARPEST stability functions produce less mixing and hence quicker fog formation, thicker fog and slower fog dissipation.

Impact on forecast varies – best verification is for more patchy fog, e.g. 06-07.11.2003.

Verification

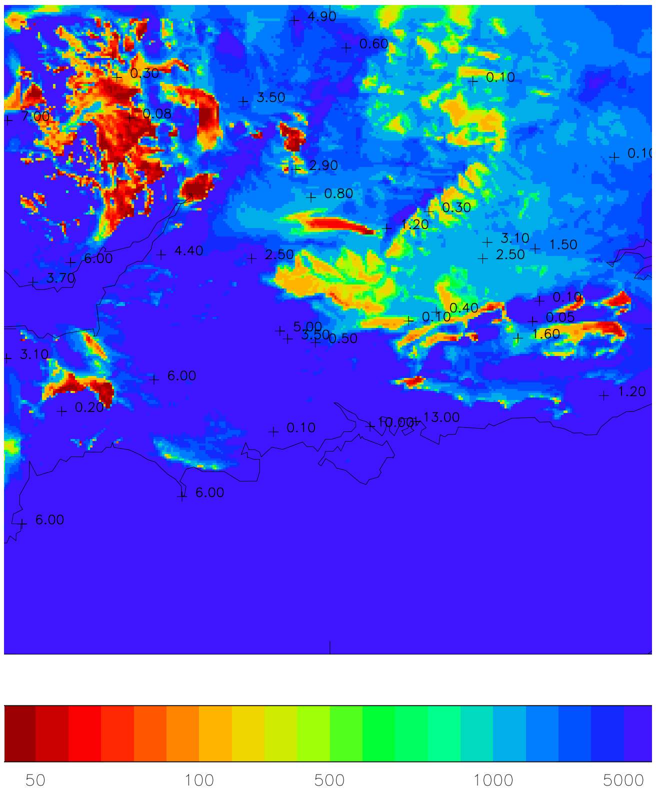
1kL76 (red) vs. SHARPEST (blue)

From 18 UTC 06/11/2003 From 18 UTC 09/12/2003

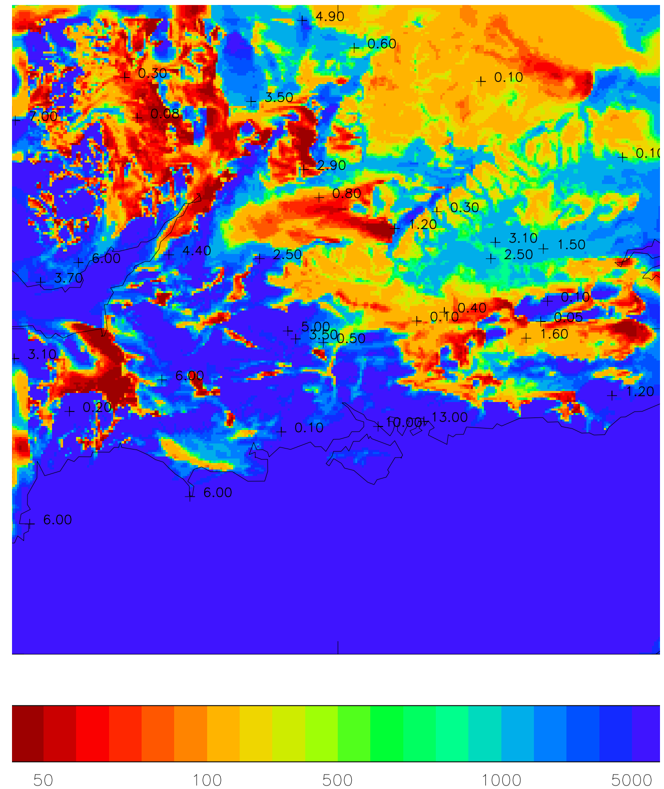


At 04 UTC 07/11/2003 from 18 UTC 06/11/2003 T+10 Forecast

1km L76



SHARPEST stability fns



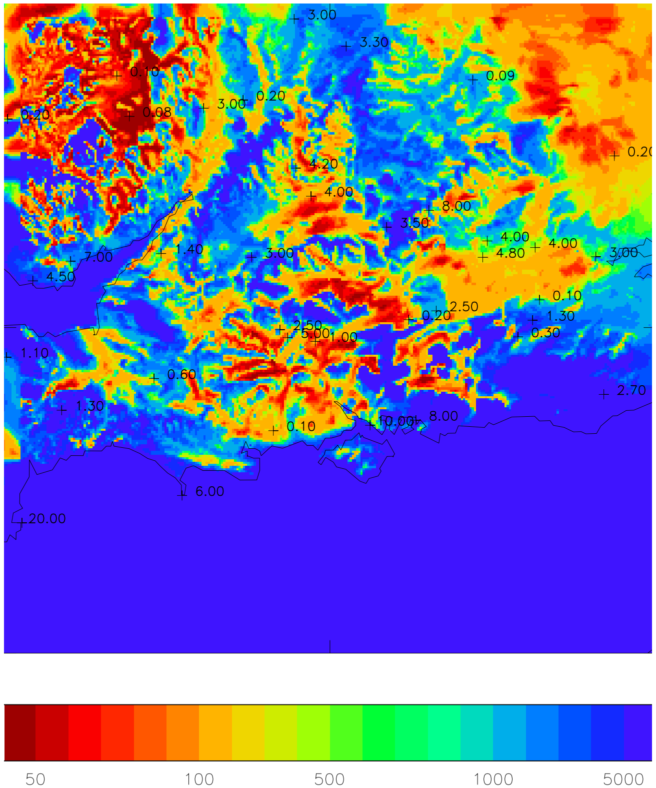
Visibility (m) at station height, synoptic observations (km)

Summary (physics)

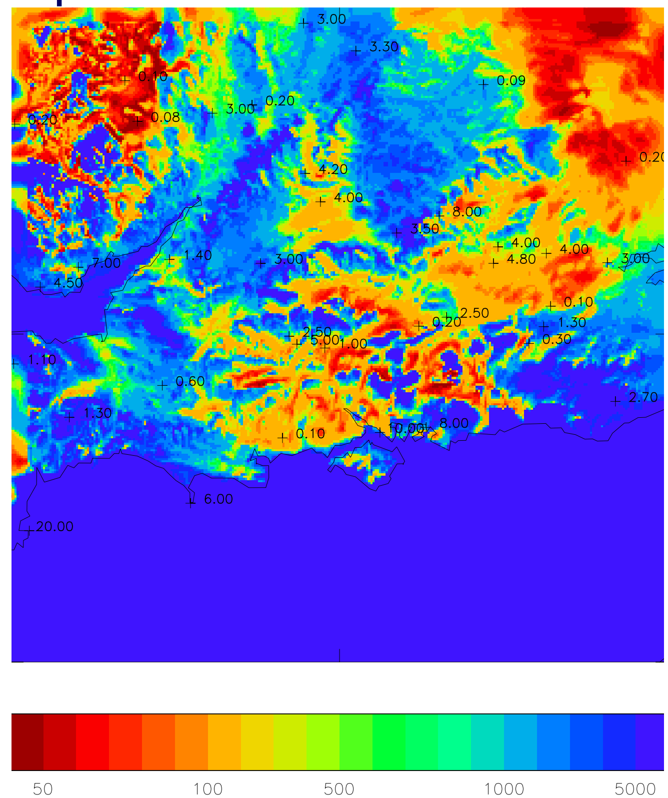
- Radiation scheme – Profile using T_* forms fog later.
- SHARPEST stability functions produce less mixing and hence quicker fog formation, thicker fog and slower fog dissipation. They verify best in patchy fog cases.
- More physics could be investigated, e.g. partial radiation time-stepping, droplet settling.
- Particular attention needed to timing of fog formation and dissipation.
- Use SHARPEST stability functions and Radiation T profile with T_*.

At 21 UTC 09/12/2003 from 18 UTC 09/12/2003 T+3 Forecast

1km L76



SHARPEST stability fns and T profile with T_*



Visibility (m) at station height, synoptic observations (km)

Local Stand-Alone Model

Local Stand-alone Model - Components

- Unified Model at Very High Resolution
  - 1km horizontal grid, 76 vertical levels, small (e.g. 50x50km) domain
- Model Physics
  - Optimised for fog forecasting at very high resolution
  - SHARPEST stability functions
  - T profile including T_* in radiation code

- Single Profile Forcing
  - Choice of forcing data – model or sonde
- Run on local PC – using Ported Unified Model

Single Profile Forcing

Initialize 3D model over high resolution domain with

- Profile of θ, q, u and v
- pmsl

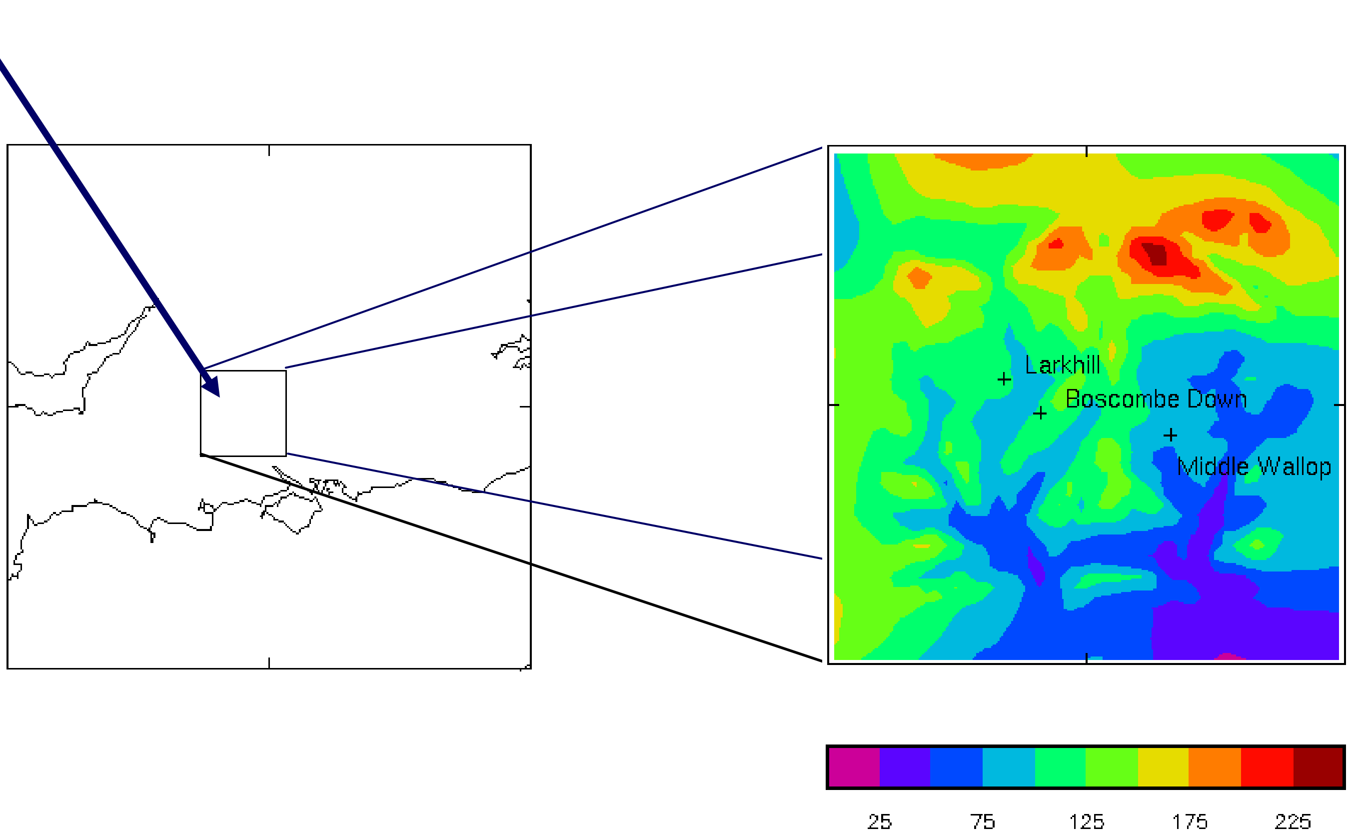
Forced hourly with profile through LBCs – option for time-varying profile with model data

Data can be taken from

- [Crisis Area] Mesoscale or Global Model
    - Average
    - Lowest Grid Point
- Local Radiosonde

Boscombe Down Domain

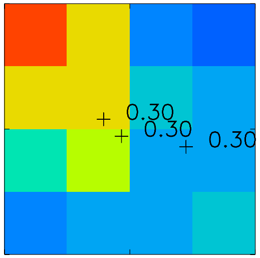
50 x 50 km domain inset on 300 x 300 km domain



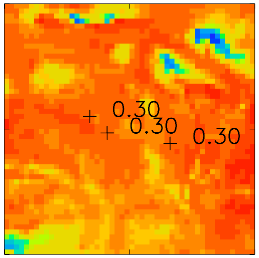
Model orography (m)

At 07 UTC 03/12/2004 from 18 UTC 02/12/2004
T+13 Forecast - Visibility

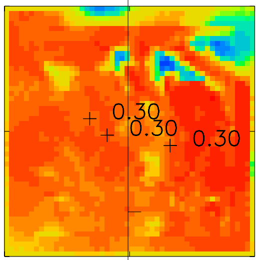
MES



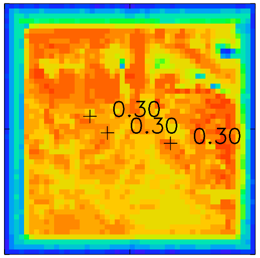
300 x 300 LBC



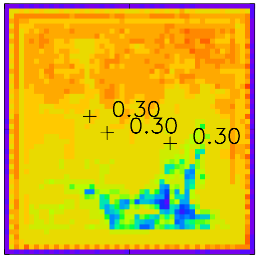
50 x 50 LBC



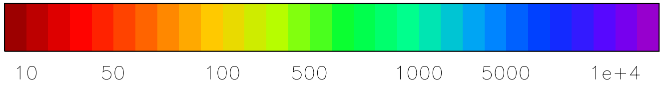
SPF AVE hourly



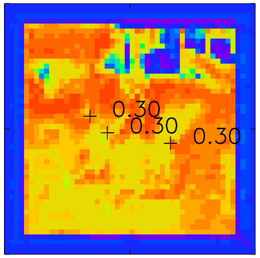
SPF LGP hourly



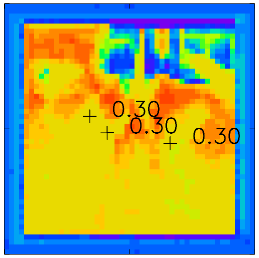
Visibility (m)



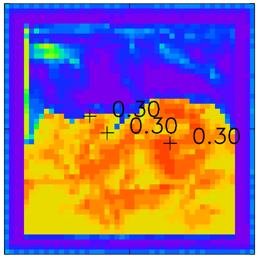
SPF AVE INIT



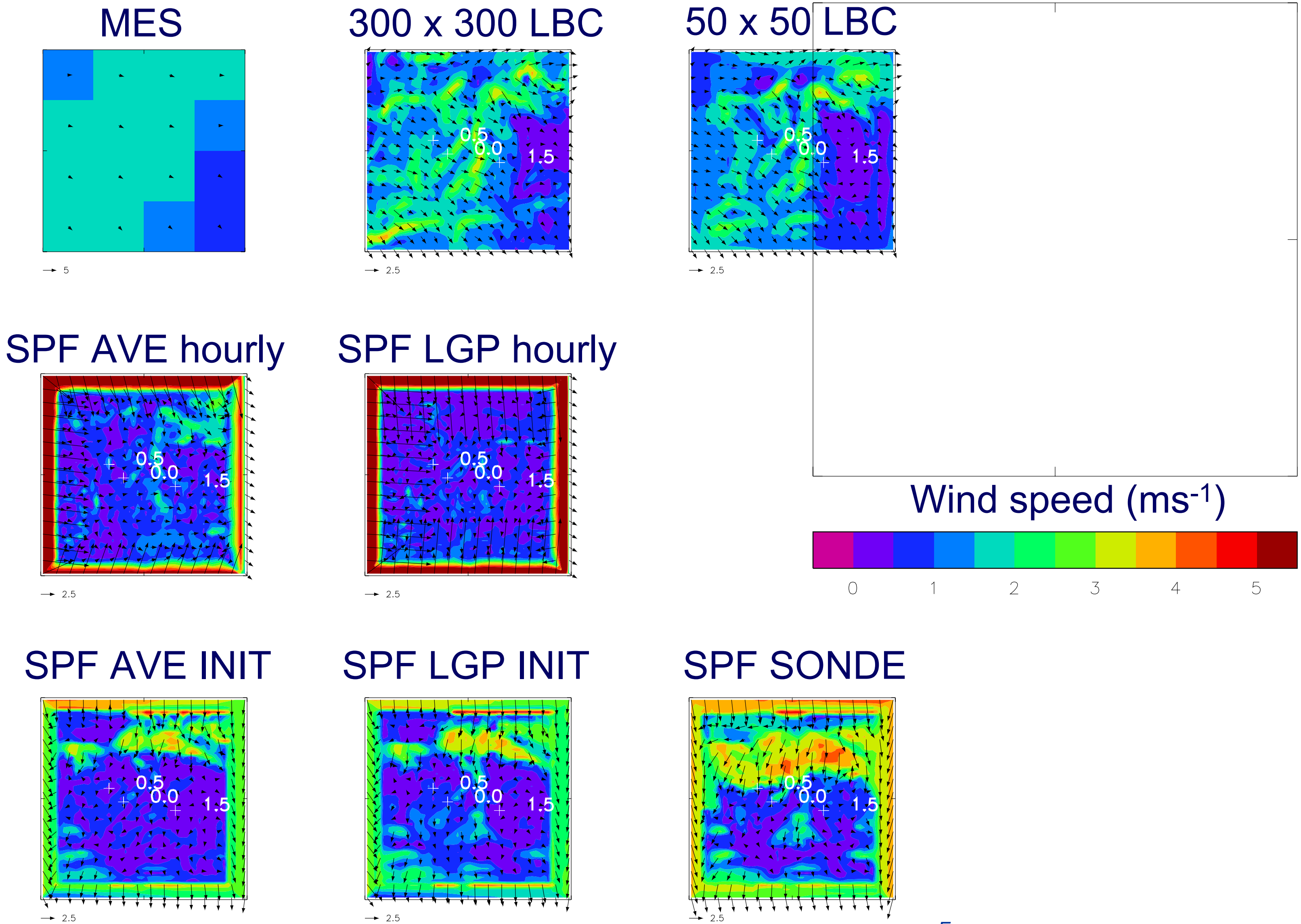
SPF LGP INIT



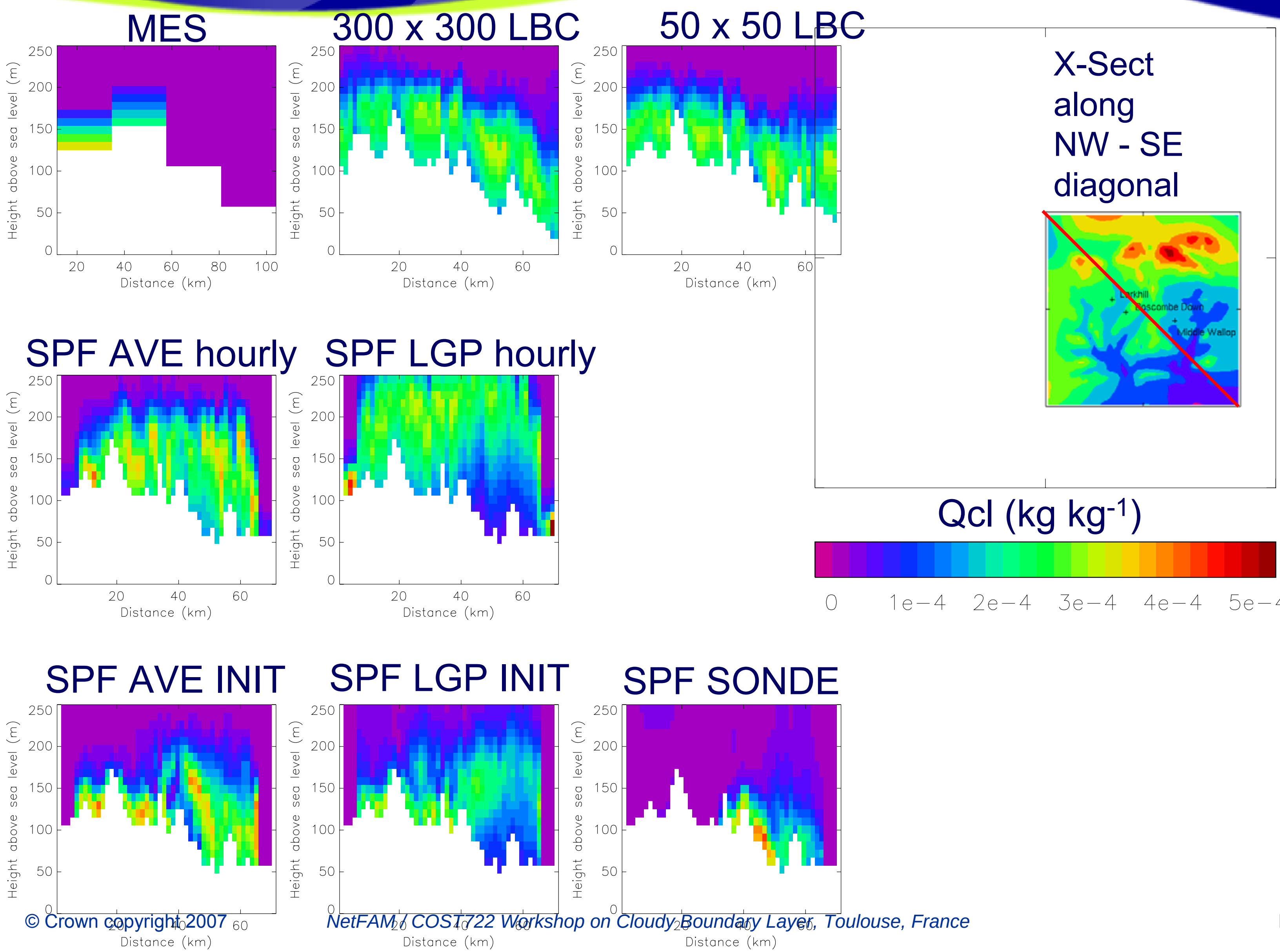
SPF SONDE



At 07 UTC 03/12/2004 from 18 UTC 02/12/2004 T+13 Forecast – 10m Winds



At 07 UTC 03/12/2004 from 18 UTC 02/12/2004 T+13 Forecast – Cloud Liquid Water X-Sect



Single Profile Forcing at Very High Resolution

- Works remarkably well for radiation fog situations
- Forecast very sensitive to forcing – ensemble approach could be useful
- SONDE as good as any other technique – may allow more recent observational data than model, which will take up to 3 hrs to run and transmit to field

Questions

References

- *Turton and Brown 1987,* QJRMS **113**, pp. 37-54
- *Roach et al 1976,* QJRMS **102**, pp. 313-333
- *Brown and Roach 1976,* QJRMS **102**, pp. 335-354
- *Capon 2004,* NWP Technical Report FR444

  http://www.metoffice.gov.uk/research/nwp/publications/papers/technical_reports/