Physics Presentation

For 32nd EWGLAM and 17th SRNWP Annual Meeting 2010

4th – 7th October 2010 Exeter, U.K

Presented by Mike Bush (but the work of many people in the Met Office!)

Contents

Diagnosis of screen temperatures during the evening transition

- Screen-level temperatures are calculated in the UM by interpolation between the surface potential temperature and that on the lowest model level using surface similarity theory
- There has long been evidence that this is not always appropriate in very stable conditions
- It has not been clear what should be done…
- Following recent comparisons between the UM and field data, a new screen temperature diagnostic has been developed
- This has now been implemented operationally

Diagnosis of screen temperatures during the evening transition

- Field data from Cardington (Bedfordshire) include continuous measurements of both screen-level and surface temperatures

- Model comparisons with this data show that on calm, clear winter evenings the forecast surface temperature may be quite reasonable

- However the forecast screen temperature is too cold

- The screen temperature is tied too closely to the surface

Model comparison with Cardington data and M-O theory

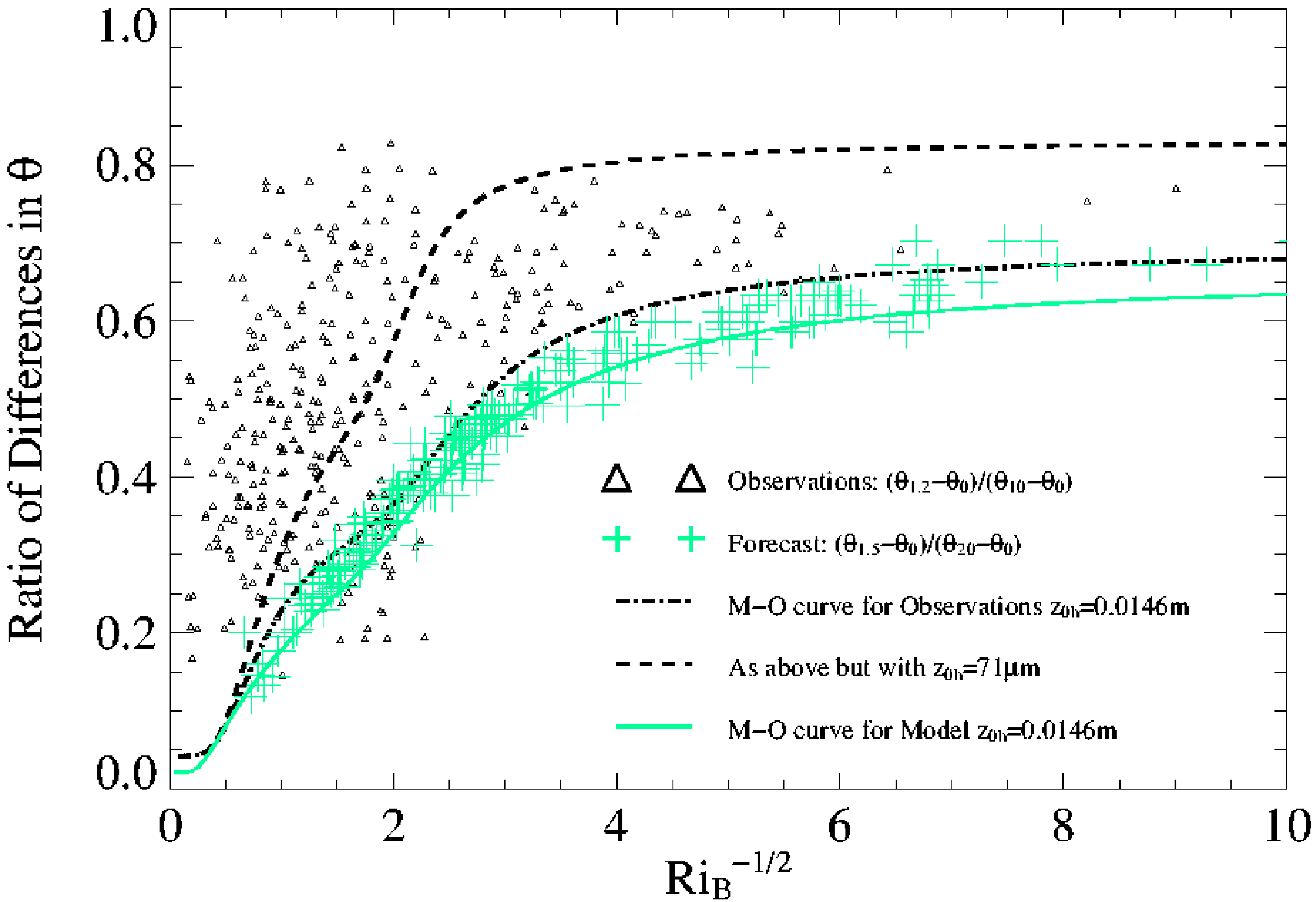
Observed

Tscreen – Tsurface

greater than model

Tscreen – Tsurface

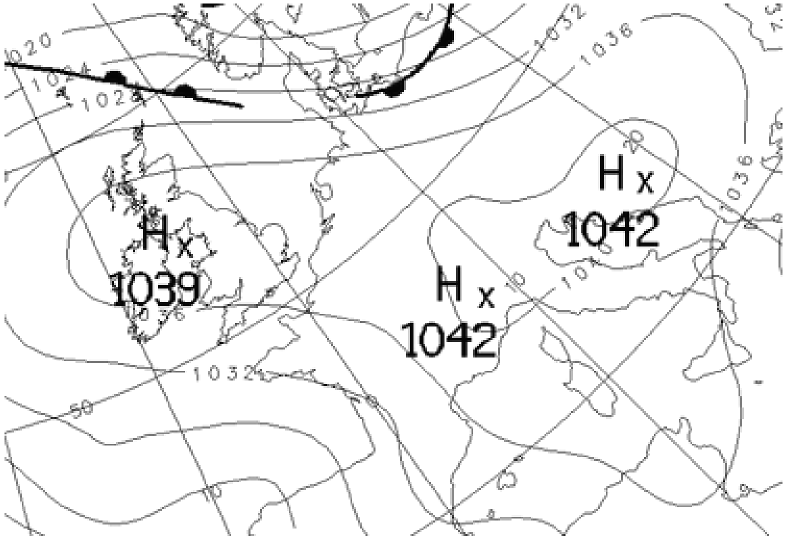
in stable conditions

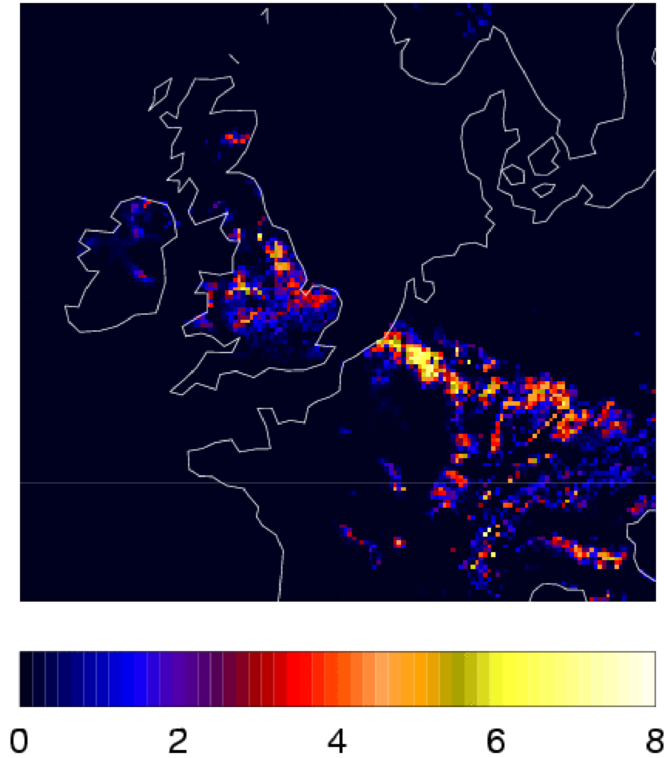


The revised diagnostic

- Standard diagnostic works well in stronger winds
- Radiative cooling at screen-level is dominant in very light winds
- Treat screen temperature as a prognostic with radiative cooling, interpolating back towards the standard diagnostic depending on the wind speed and surface cooling rate
- Decoupling currently suppressed from a few hours after transition, pending a better understanding of the nocturnal conditions

17/02/2008 18Z

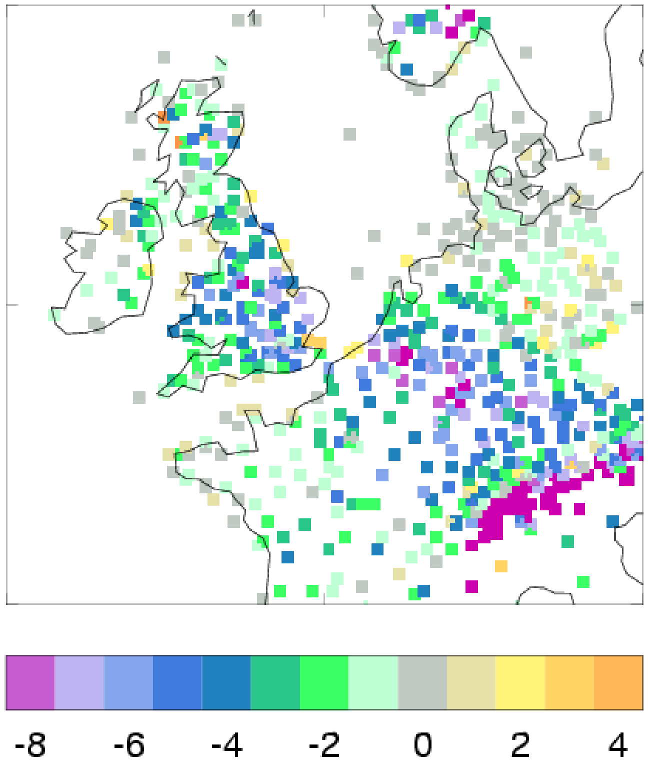


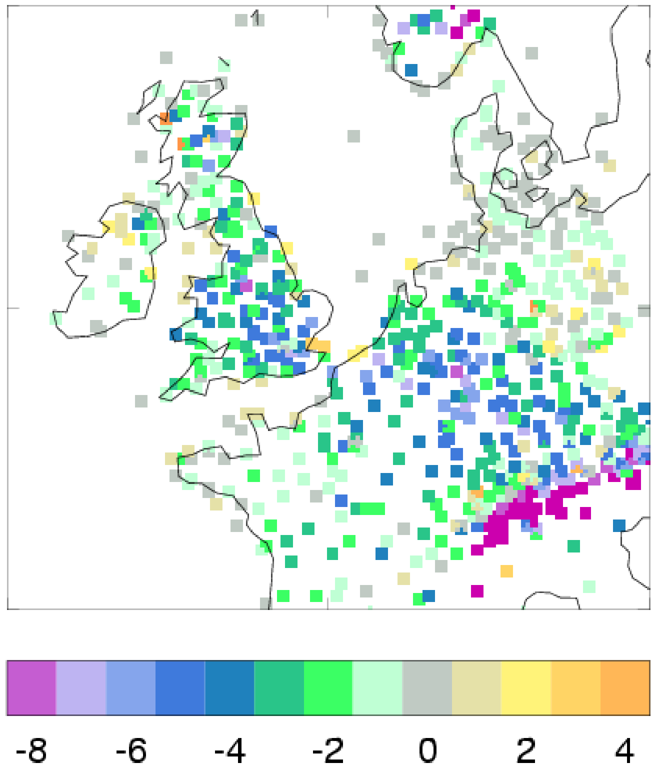


Impact of revised diagnostic (top right)

Bias in screen temperature:

Control (left) and revised diagnostic (right)



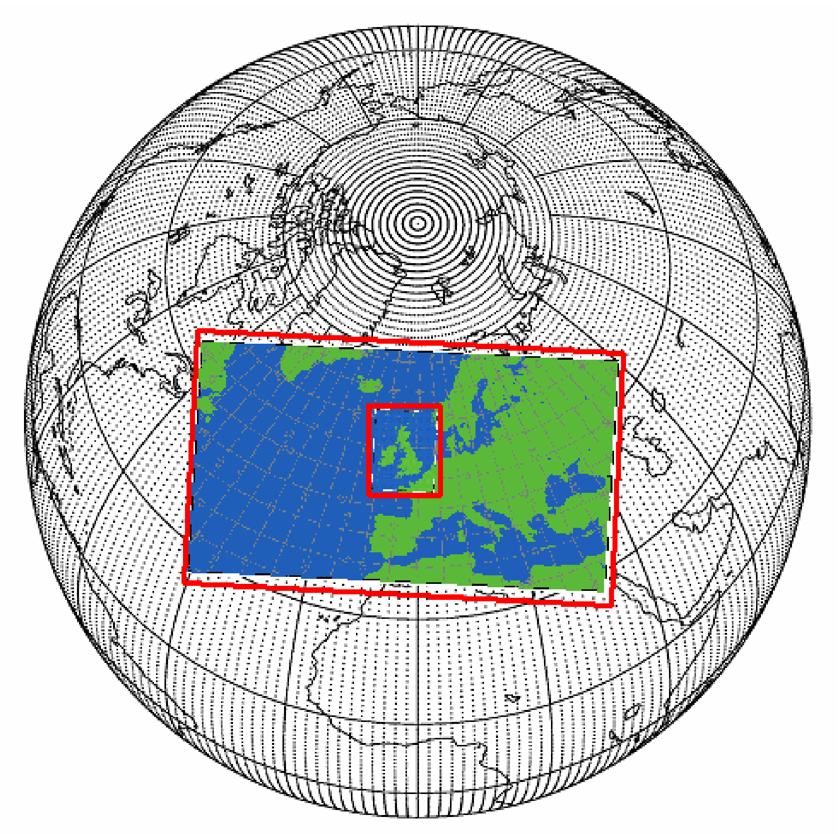


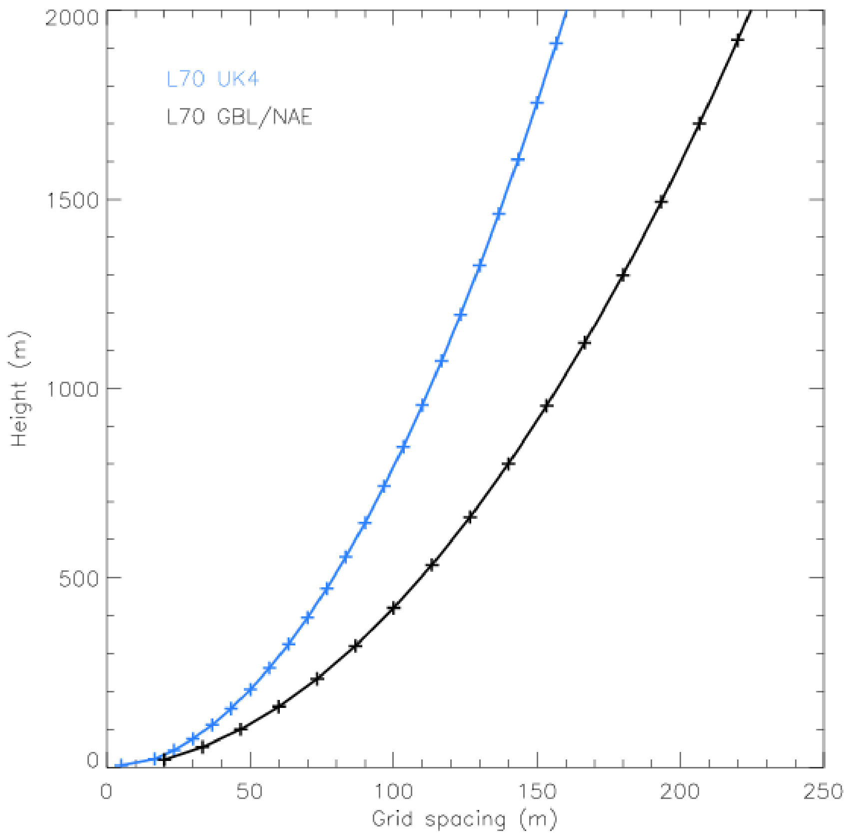
The operational forecast models

NWP (horizontal grid lengths, lid):

- Global: 25 km , 80km
- N.Atlantic/Europe: 12 km , 80km
- UK: 1.5 km , 40km

Vertical grids (lowest 2km):





Operational UKV set-up

- 744 (622 1.5 km) x 928 (810 1.5 km) points.
- 1.5 km over UK
  - Variable resolution stretching to 4 km away from UK
- 70 Levels: lowest at 5m for scalars (2.5m for winds), 16 levels below 1km
- 50s timestep
- 4 runs/day to T+36, since Autumn 2009
- Initial state from 3DVAR (4DVAR under development)

Operational UKV set-up

Physical parametrizations

- Same as global model, except:
  - Convection parametization: none, but closure option to give “shallow” in low CAPE environments is used at 4km
  - Horizontal diffusion: “Smagorinsky-Lilly”
  - Microphysics: Prognostic rain

    (also has prognostic ice but already in global model)
  - Drag: no orographic drag (either GWD or form drag via z_0)
  - Cloud: diagnostic (global now has prognostic cloud, “PC2”)
- So note PBL mixing in the vertical is the same
  - Lock et al (2000): K-profile+entrainment unstable, local Ri stable BLs

as the PBL turbulence is still unresolved

Horizontal diffusion

Met Office

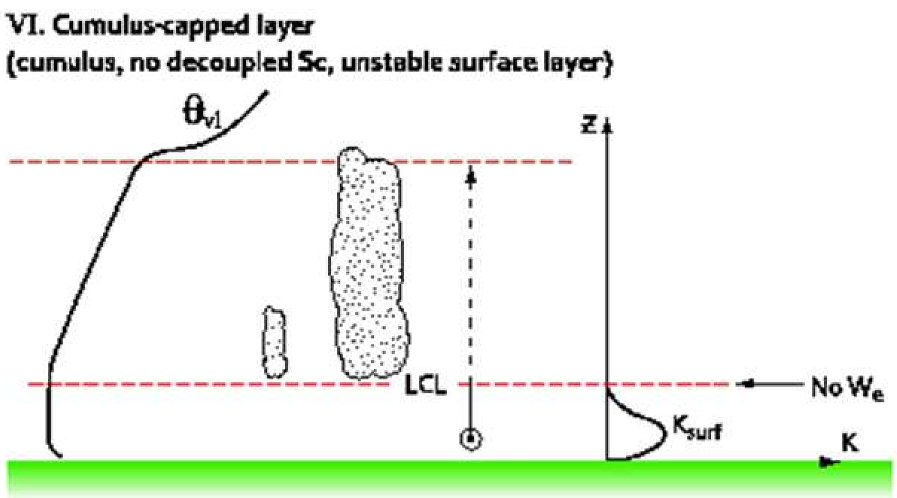
- “Smagorinsky-Lilly”
- C_S = mixing-length ratio

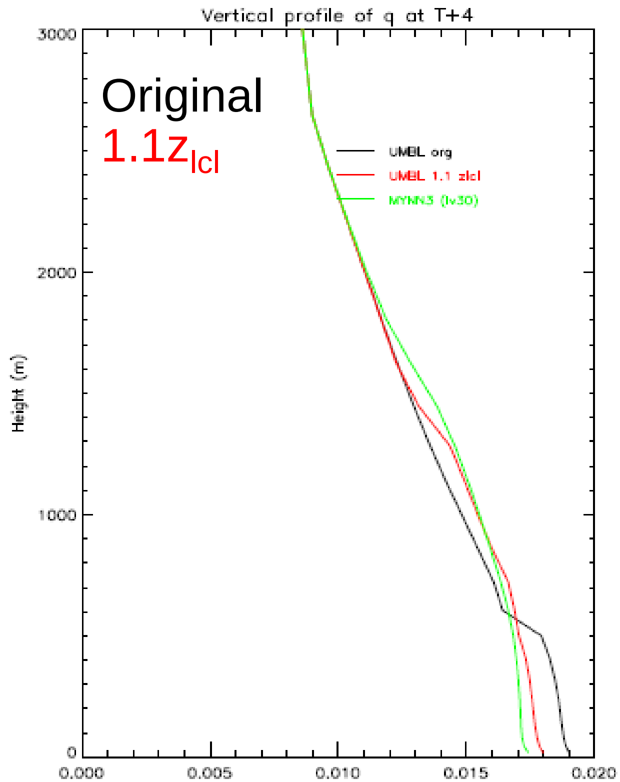
$$\boxed{\begin{array}{l} K = \lambda^2 Sf\left(Ri\right) \\ \lambda = c_s \Delta,\ c_s = 0.1 \end{array}}$$

- K (sub-grid diffusion coefficient) is a function of mixing length, shear (S) and a Richardson Number (Ri) dependent stability function (tails)
- With increasing horizontal resolution, the grid length (delta) decreases as does the mixing length (lambda)
- K therefore decreases with increasing resolution giving less parametrized mixing. More resolved mixing.

Recent developments

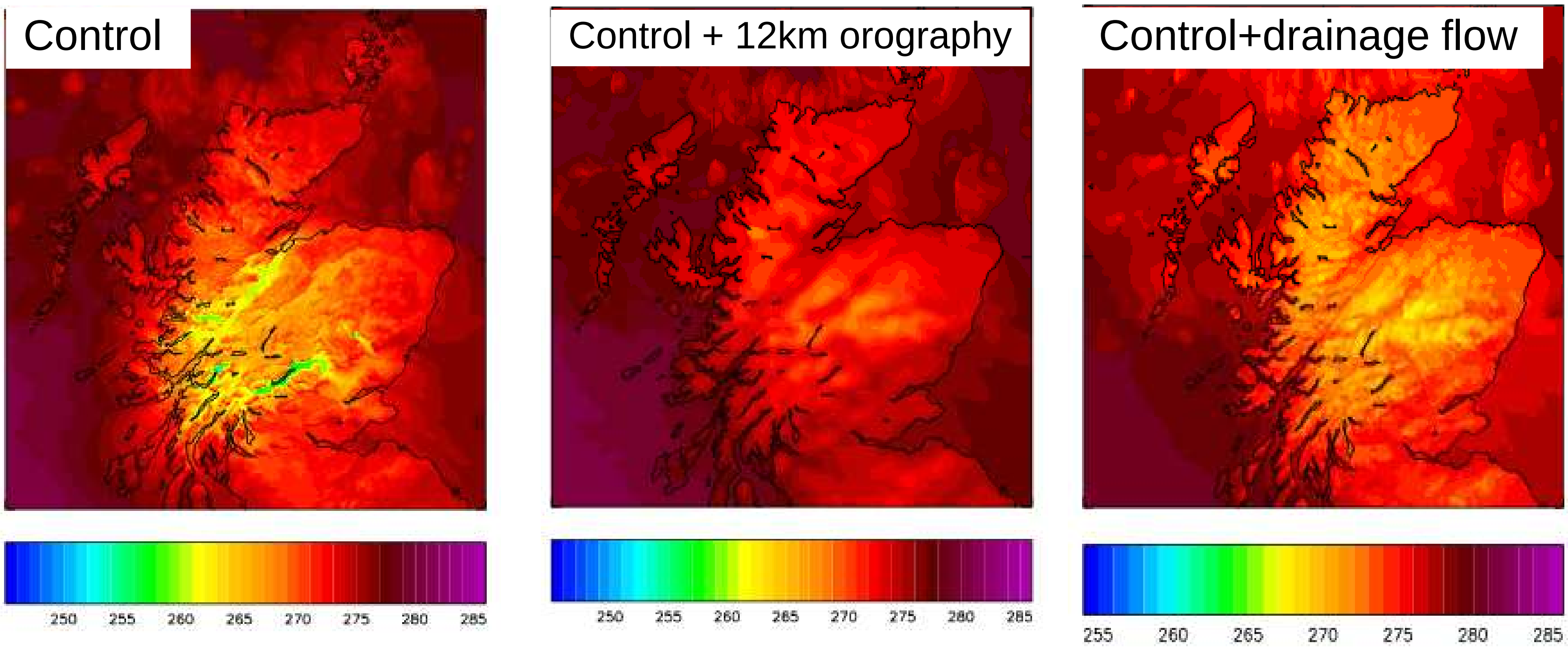
- PBL mixing in cumulus layers is capped at the LCL and no PBL mixing occurs across the LCL
  - In the GCM the convection parametrization is triggered to continue parametrized transport across and above the LCL
- Without the convection parametrization, a jump forms at the LCL
- Simple solution, to allow the PBL to mix to the top of LCL transition zone (Grant and Lock, 2004) = $1.1z_{lcl}$





Recent developments

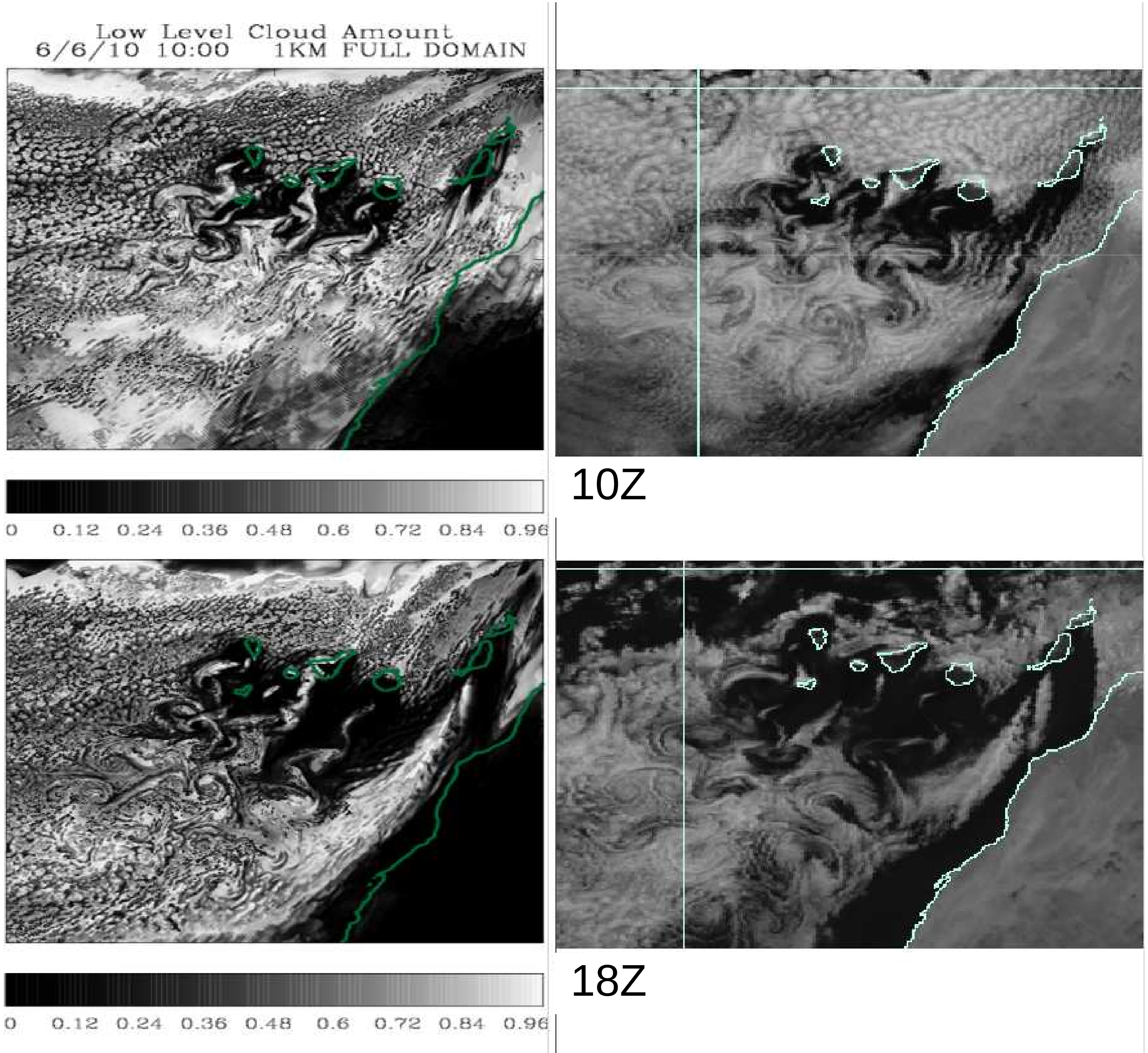
- Winter 2010 valley cooling problem
  - See poster presented by Jorge Bornemann



$T_{1.5m}$ at 12Z 2/2/10

Stratocumulus break-up over the Canary Islands

- 1km resolution UM runs
- Model low level cloud amount (left)
- Satellite imagery (right)
- Spin-up problems at northern boundary



First COLPEX results

COLPEX (Met Office / NCAS)

- COLPEX: Cold pool Experiment
- COLPEX is a field campaign aimed at studying the behaviour of the boundary layer over complex terrain.
- Of specific interest is the formation of cold-pools in valleys which form under stable night-time conditions.
- Large variations in temperature and visibility often occur over short distances in regions of only moderate topography.
- These are of great practical significance and yet pose major forecasting challenges, due to both a lack of detailed understanding of the processes involved and because crucial topographic variations are often not resolved in current forecast models.
- Collaborative project with NCAS (NERC centre for Atmospheric Science)

Location and instrumentation

- The observational campaign was run for 15 months in Shropshire, UK, in a region of small hills and valleys
- Typical ridge-valley heights are 75-150m and valley widths 1-3km.
- The instrumentation consisted of three sites with instrumented flux towers, a Doppler lidar and a network of 30 simpler meteorological stations.
- Further instrumentation were deployed during 17 intensive observation periods including radiosonde launches from two sites, a cloud droplet probe, aerosol monitoring equipment and an instrumented car.

Clun (Shropshire)

Photos courtesy of Jeremy Price and Dave Bamber, MRU Cardington

Upper Duffryn

Photos courtesy of Jeremy Price and Dave Bamber, MRU Cardington

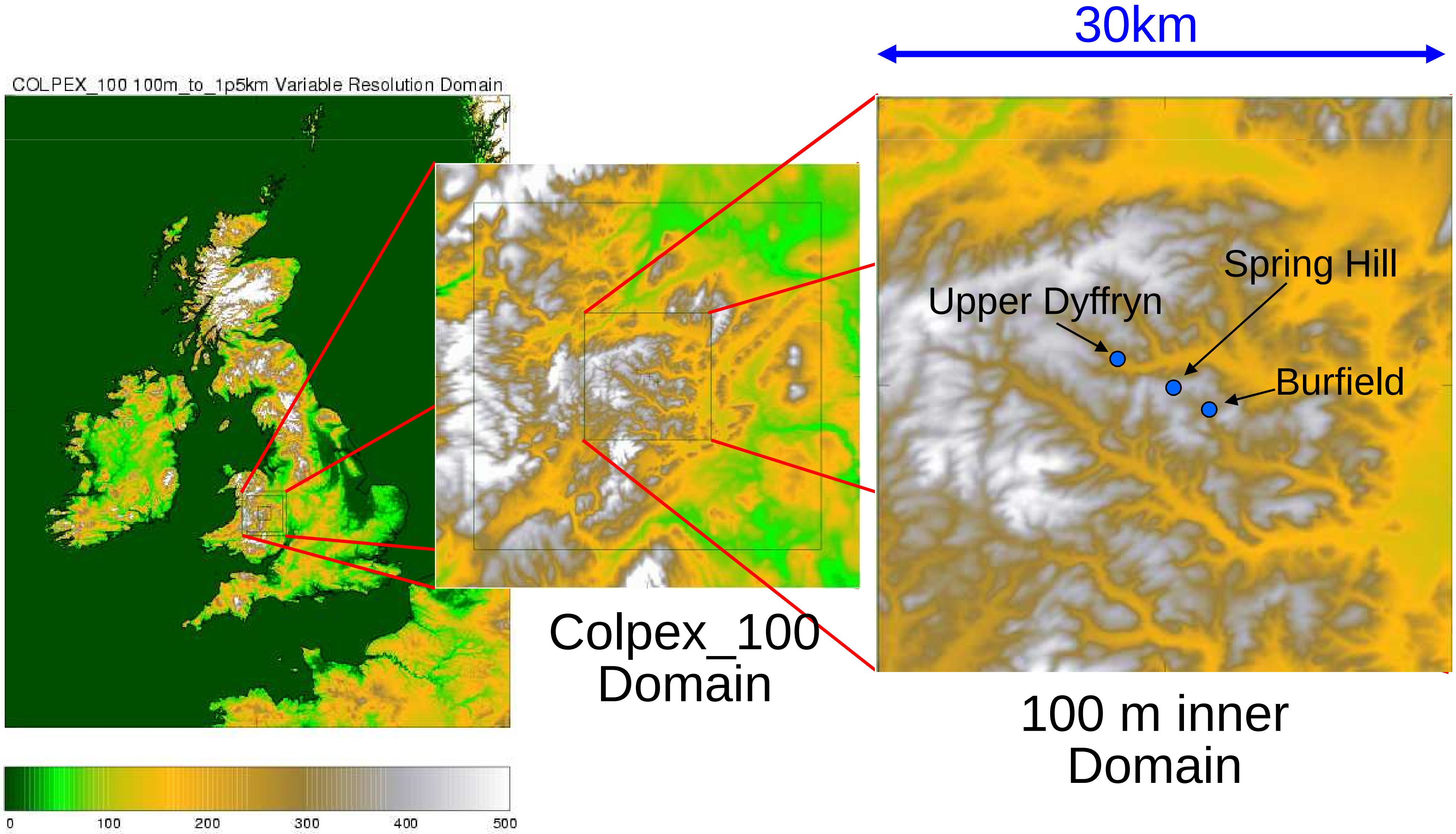
100m UM simulations

- Nested suite: UK4, HRTM (1.5km) and 100 m model
- UK4 initialised every 3 hours with T+1h operational dump
- 1.5km and 100m models “free running”
- Very high resolution (100m) UM simulations
  - Provide a database which will aid interpretation of the observations
  - Area average to inform parametrization at coarser resolution
  - Inform choices about the next generation of operational forecast models

Initial MetUM setup: COLPEX_100

- 100m horizontal resolution over 30 km square.
- Variable resolution outside stretching to 1.5 km. (412x412 domain covering ~100 km square).
- 70 levels, 5 s timestep (both might need improvement).
- RHcrit=0.99 below 500m then gradual decrease to 0.9 above 3km.
- 3D Smagorinsky, LEM stability functions, c_s=0.15. Dry static adjustment above 3km.

COLPEX_100 Orography



Colpex_100 Domain

100 m inner Domain

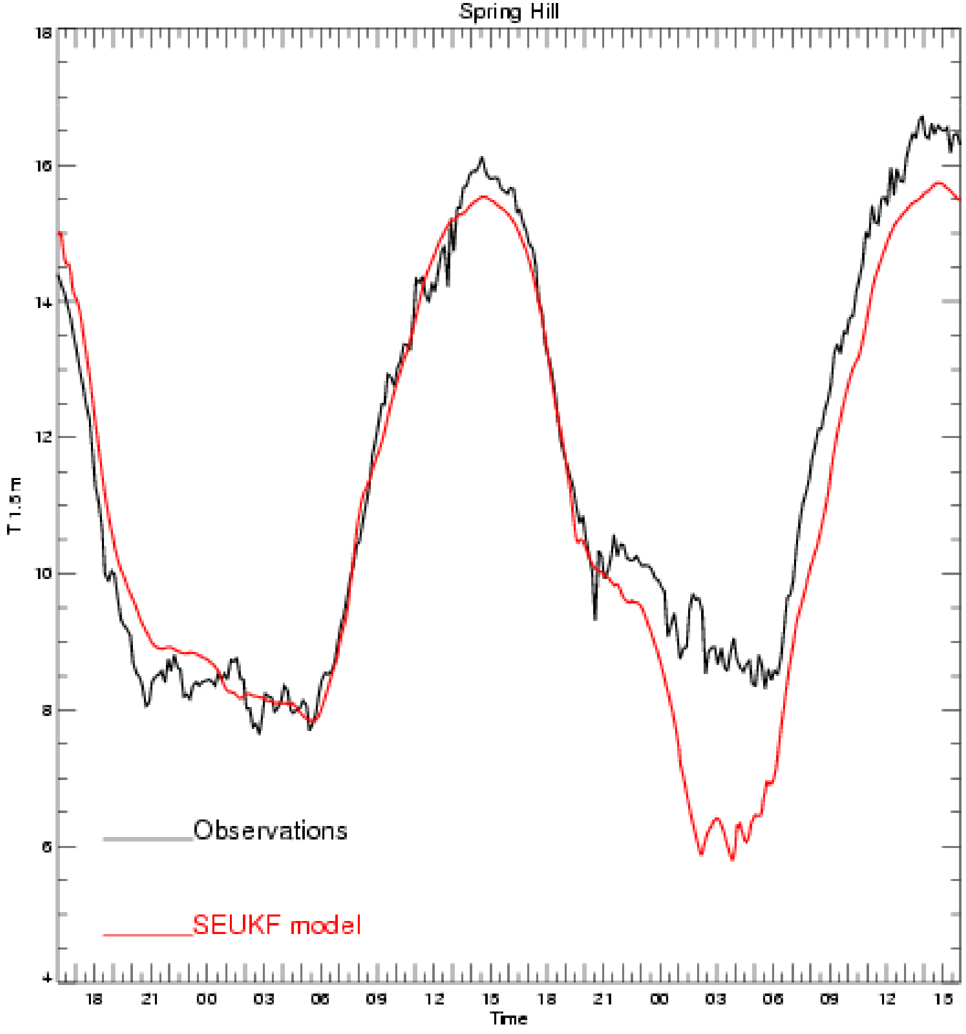
Simulations

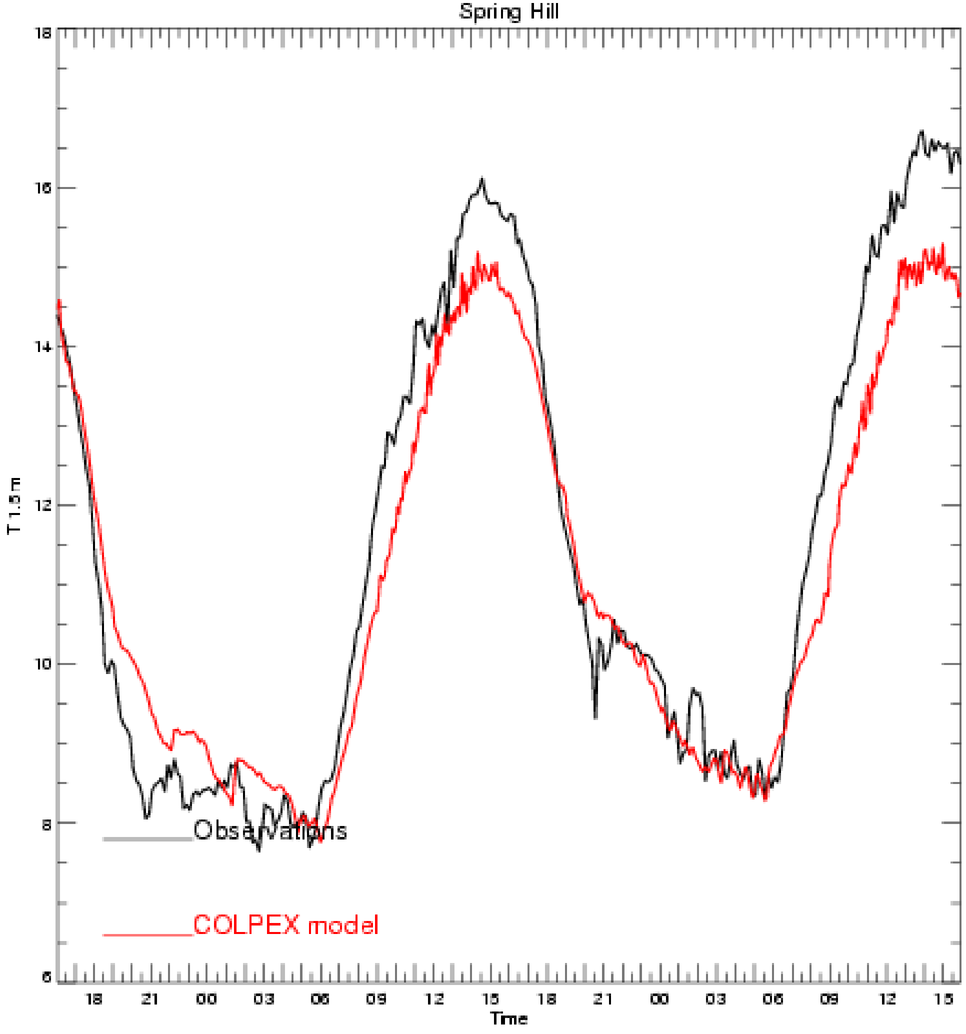
- 48-hour simulation covering IOP nights of 09/10 and 10/11 September
- 1600 UTC 09 September to 1600 UTC 11 September
- Model results compared to observations
  - Limited so far, to Met Office mast data and Hobo temperatures
- Sensitivity tests
- COLPEX suite working on MONSooN
- University of Leeds are also starting to run the model

Impact of resolution: Screen T time series: Springhill

1.5 km

100 m

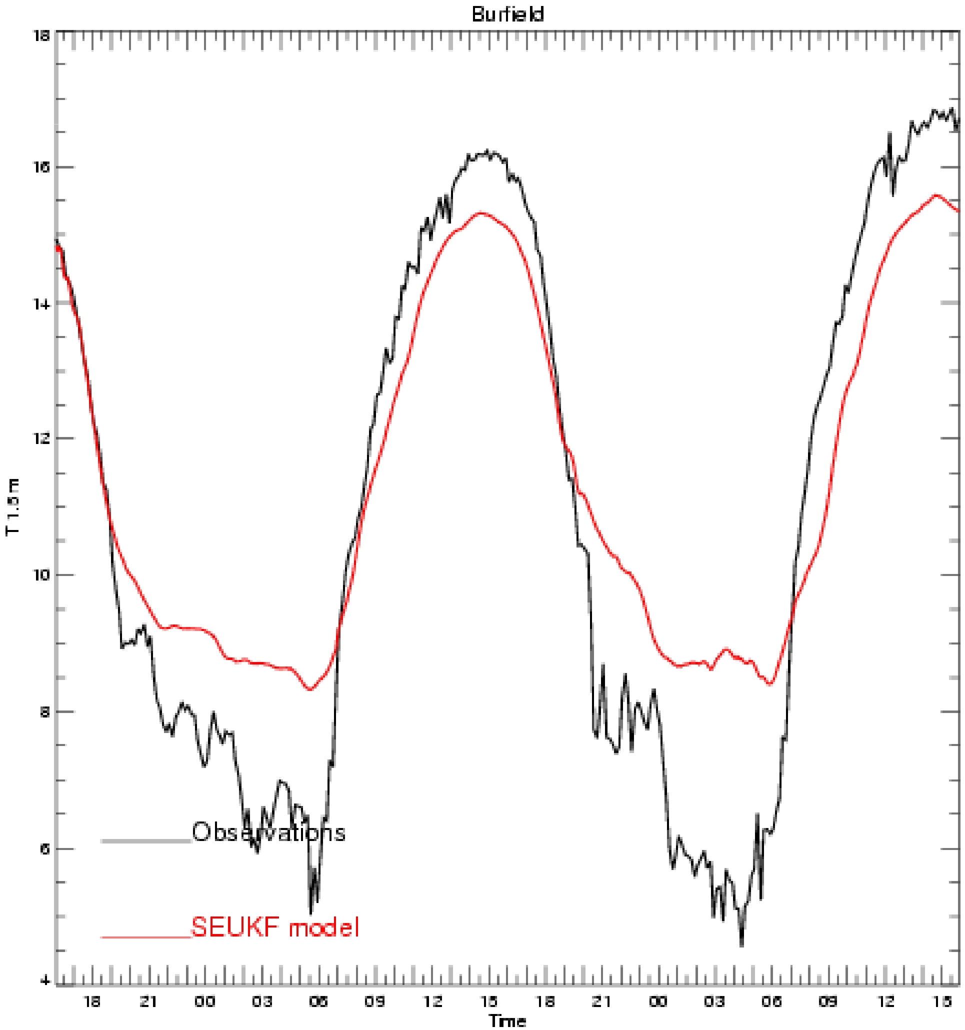




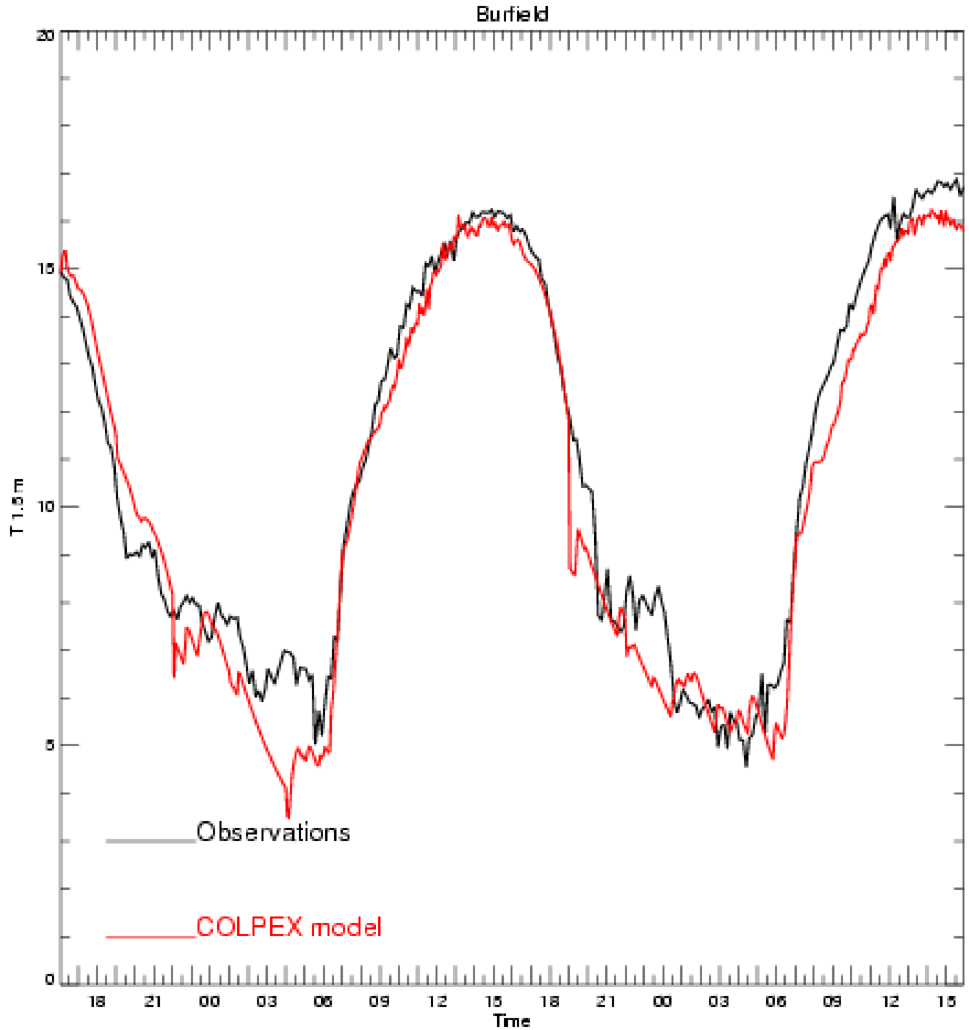
Impact of resolution: Screen T time series: Burfield

Met Office

1.5 km

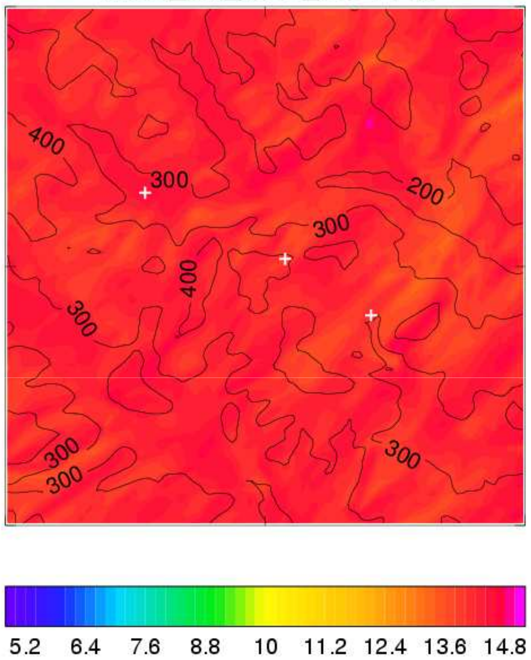


100 m

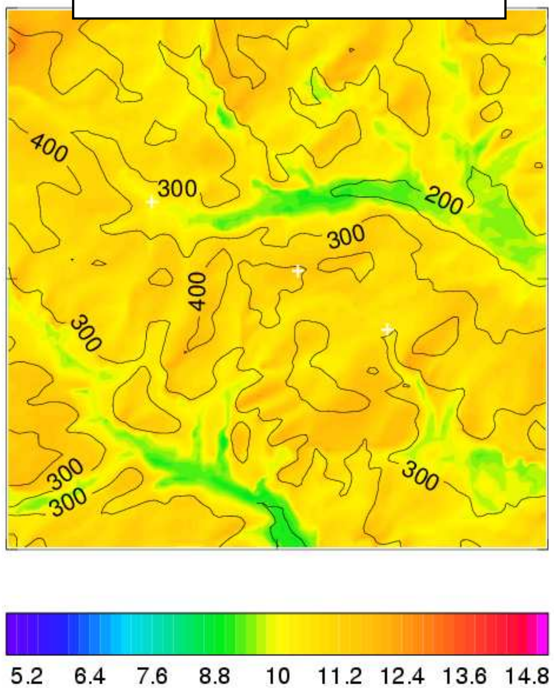


100m runs
Potential temperature at 5 m

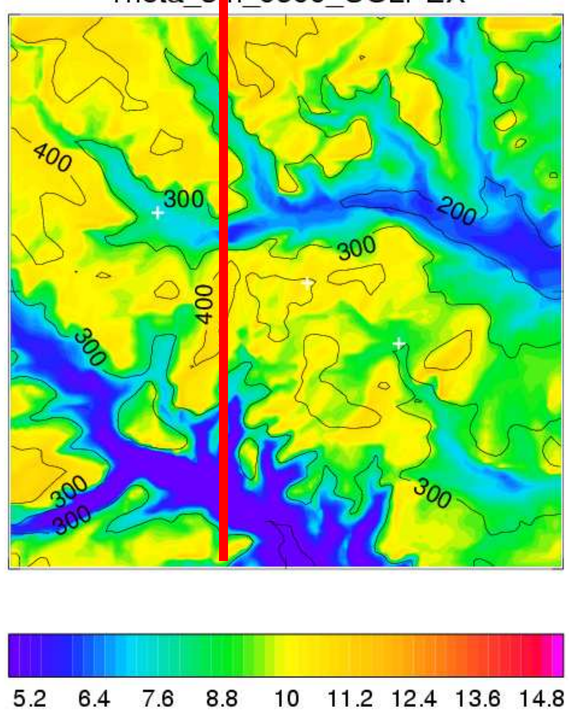
1800 UTC 10/09



2300 UTC 10/09



0600 UTC 11/09

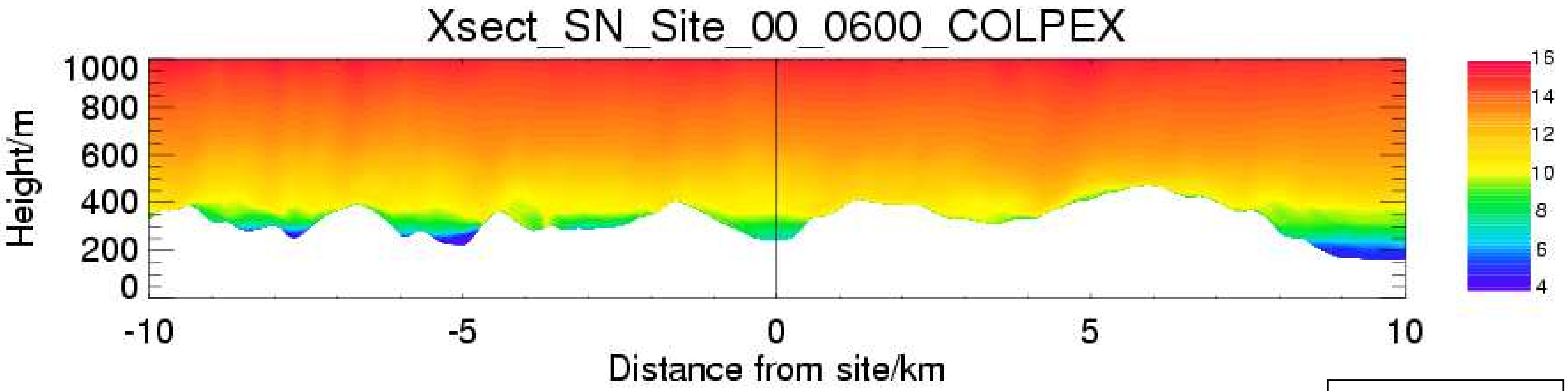


North-South section through Upper Dyffryn, Clun Valley

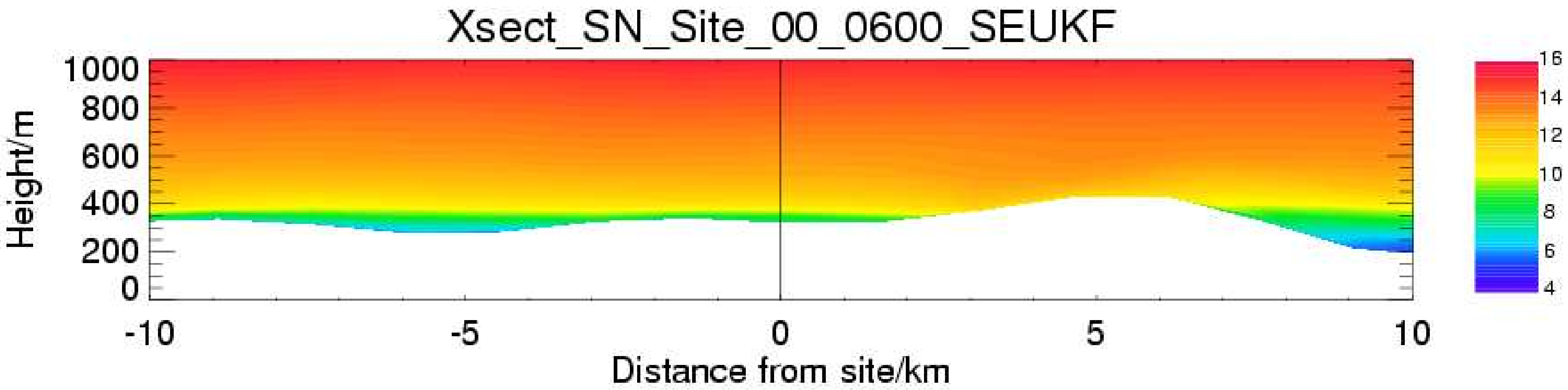
0600 11 September 2009

θ (°C)

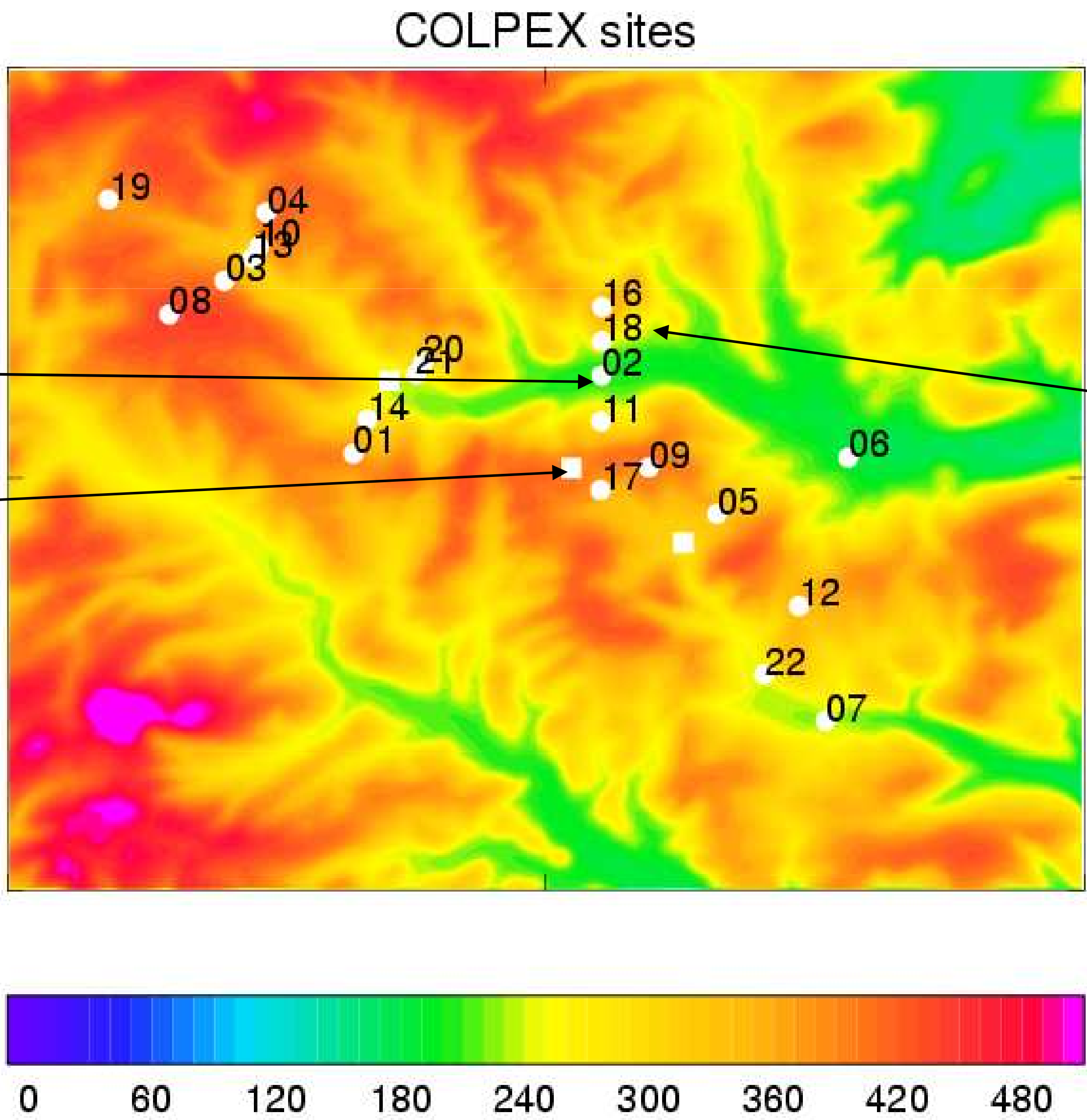
Δx=100 m



Δx=1.5 km



Observation locations and orography



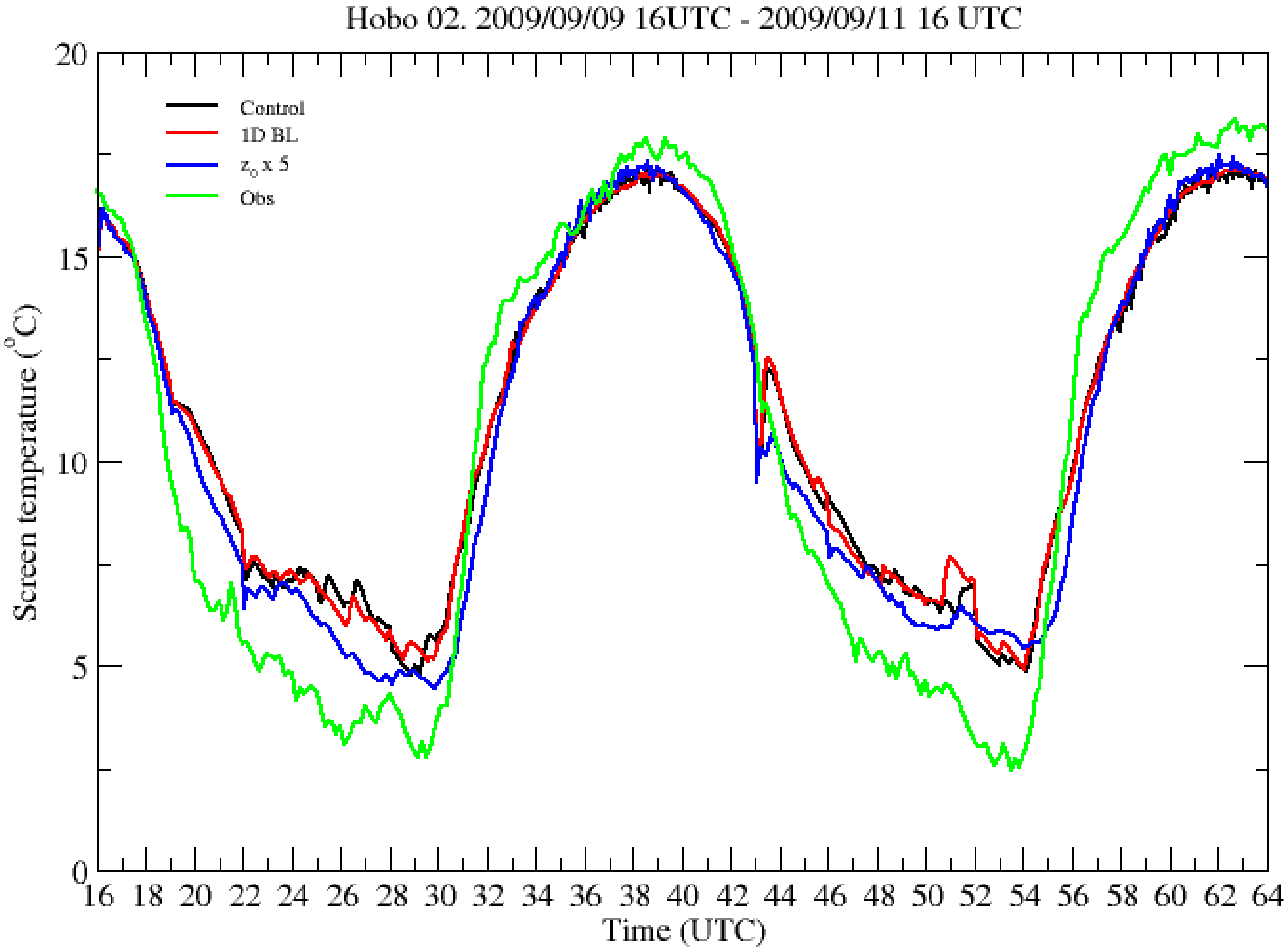
Hobo2

Springhill

Hobo 18

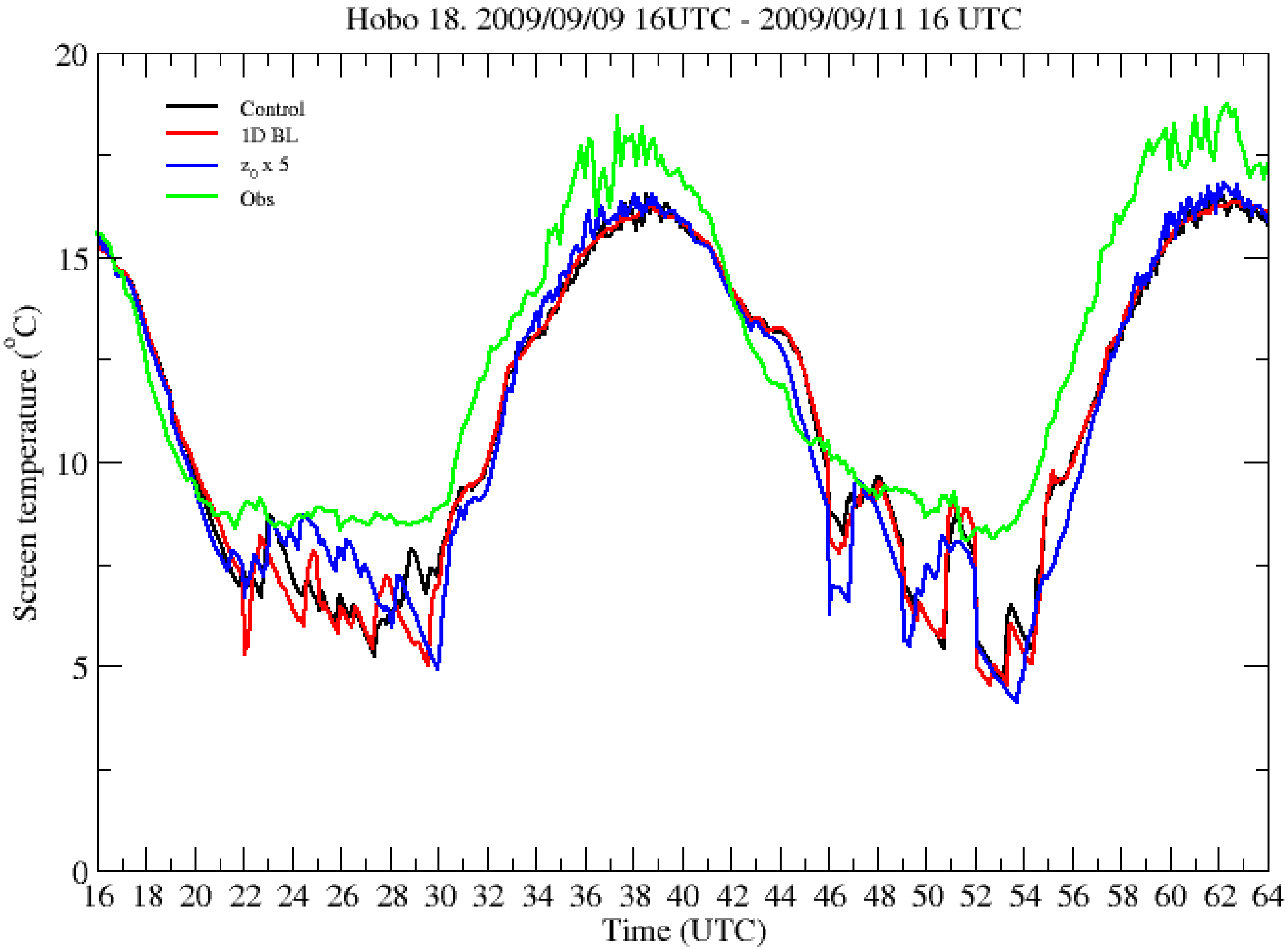
Screen T time series: Hobo 02

- Valley floor
- Model too warm at night



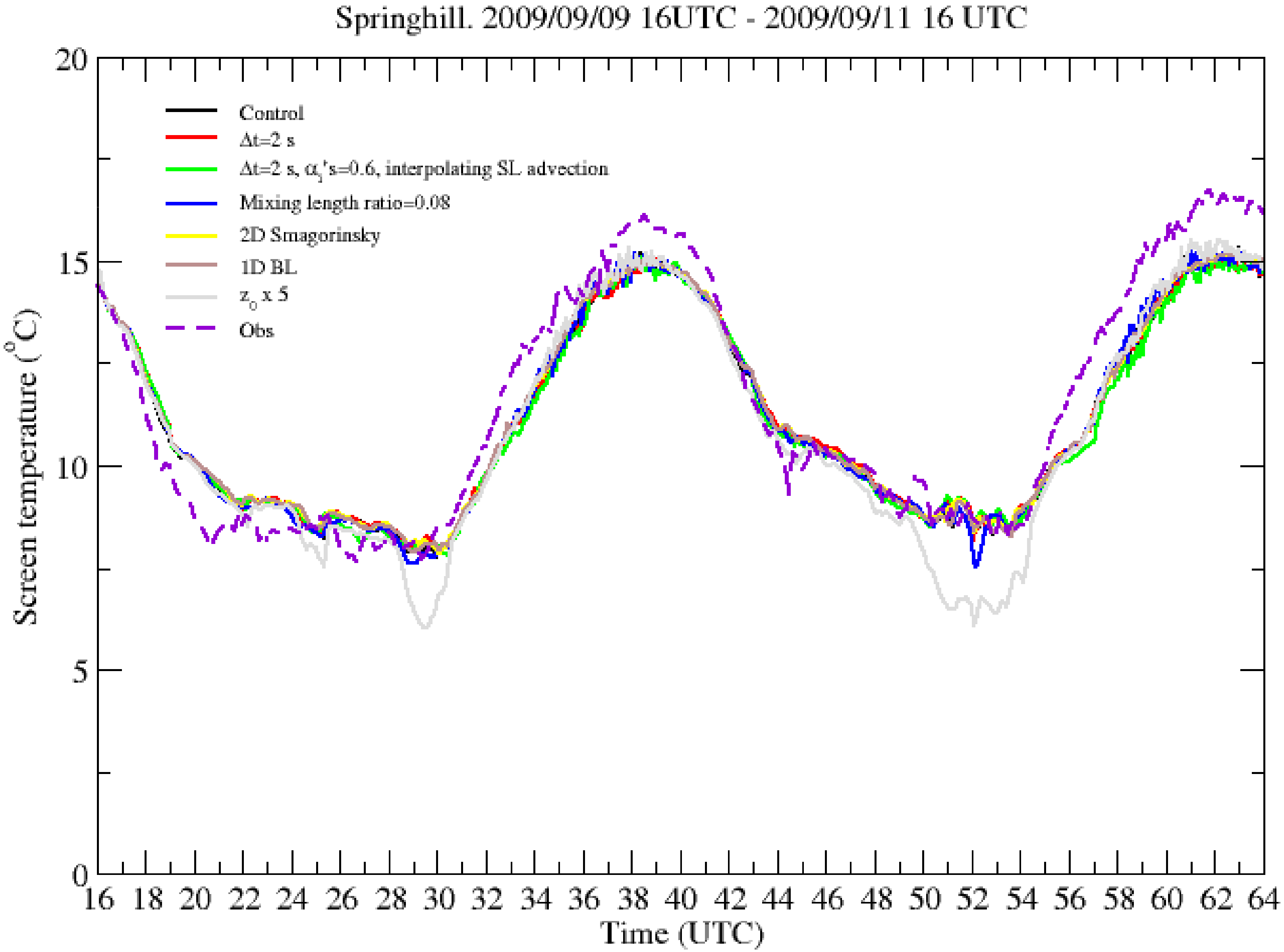
Screen T time series: Hobo 18

- Valley side
- Model too cold



Screen T time series: Springhill

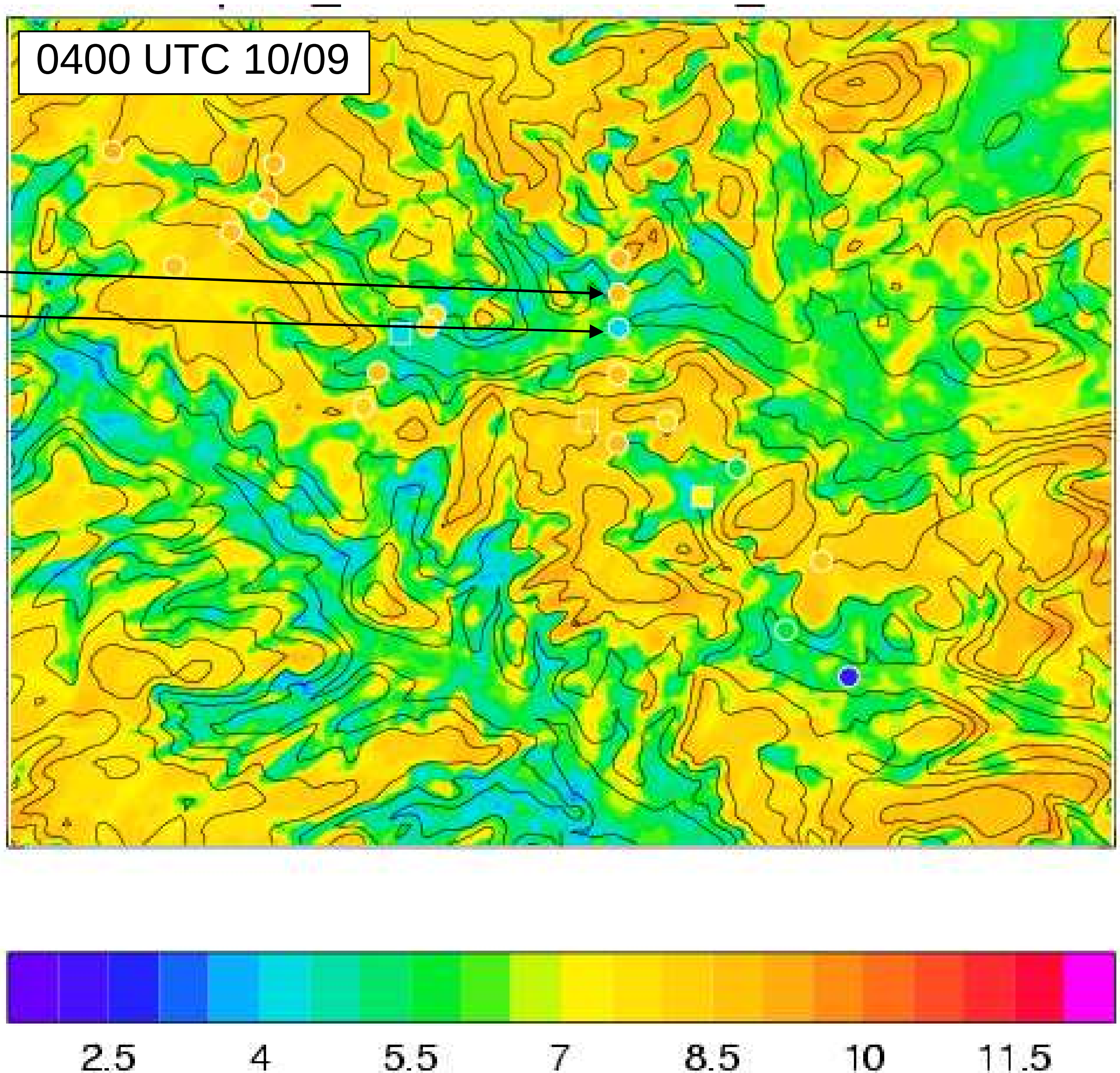
- Hill top
- Model too cold during day



Model screen temperature comparison with HOBO and MRU mast data

Model valley sides too cold
bottom too warm

Real cold pool is colder and less extensive than in model?

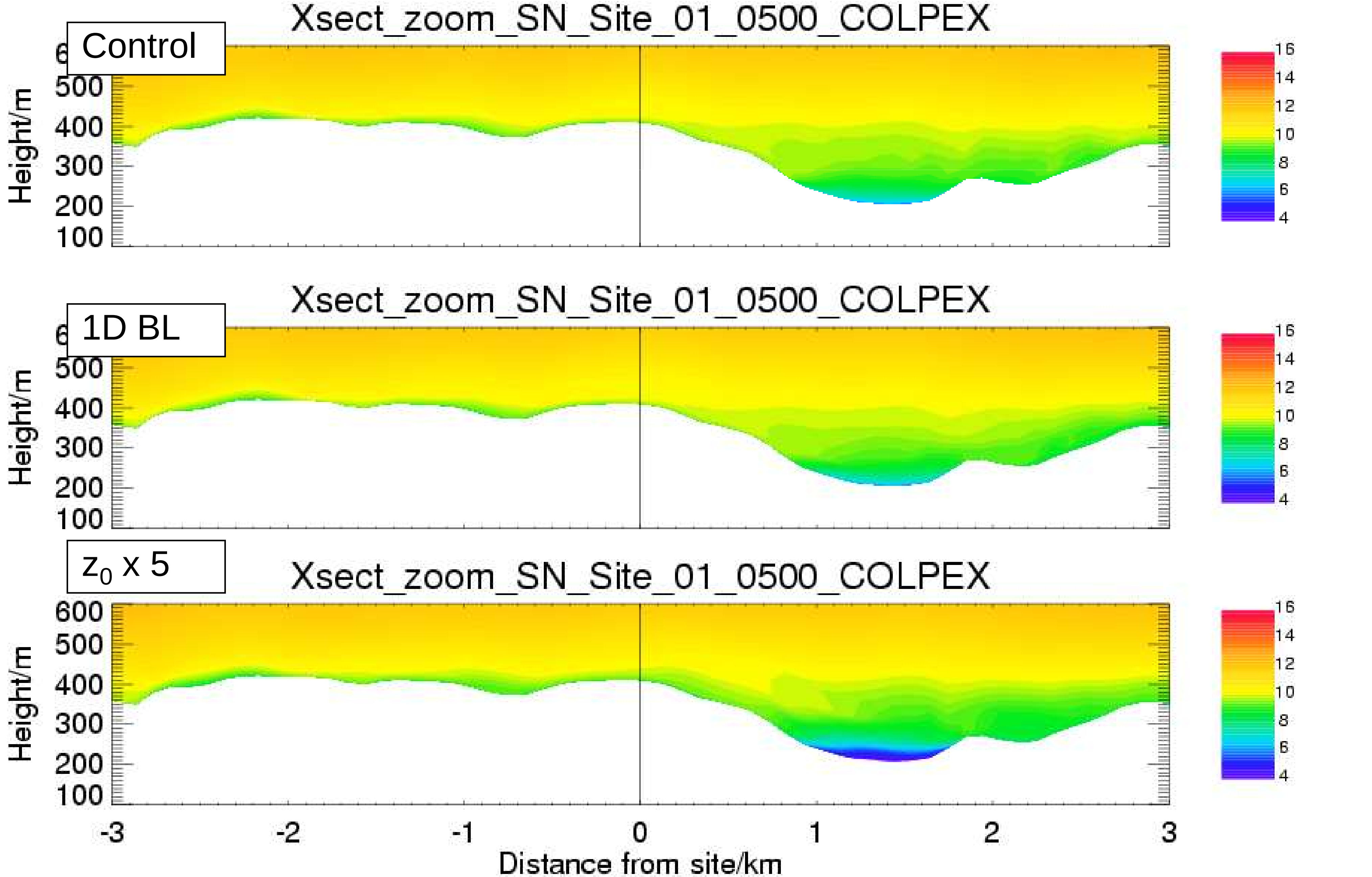


Sensitivity tests

- Time step (reduce from 5 s to 2 s)
- “Accurate dynamics”, particularly for gravity waves
  - Δt=2s, time off-centring weights all set to 0.6, fully-interpolating θ advection
- Reduce mixing-length ratio, c_s, from 0.15 to 0.08
- 2-D Smagorinsky + 1D PBL scheme (=standard UKV)
- 1-D boundary-layer (no Smagorinsky horizontal diffusion)
- Increased surface drag (z_0 x 5)

Cold pool depth

0500 UTC 10/09

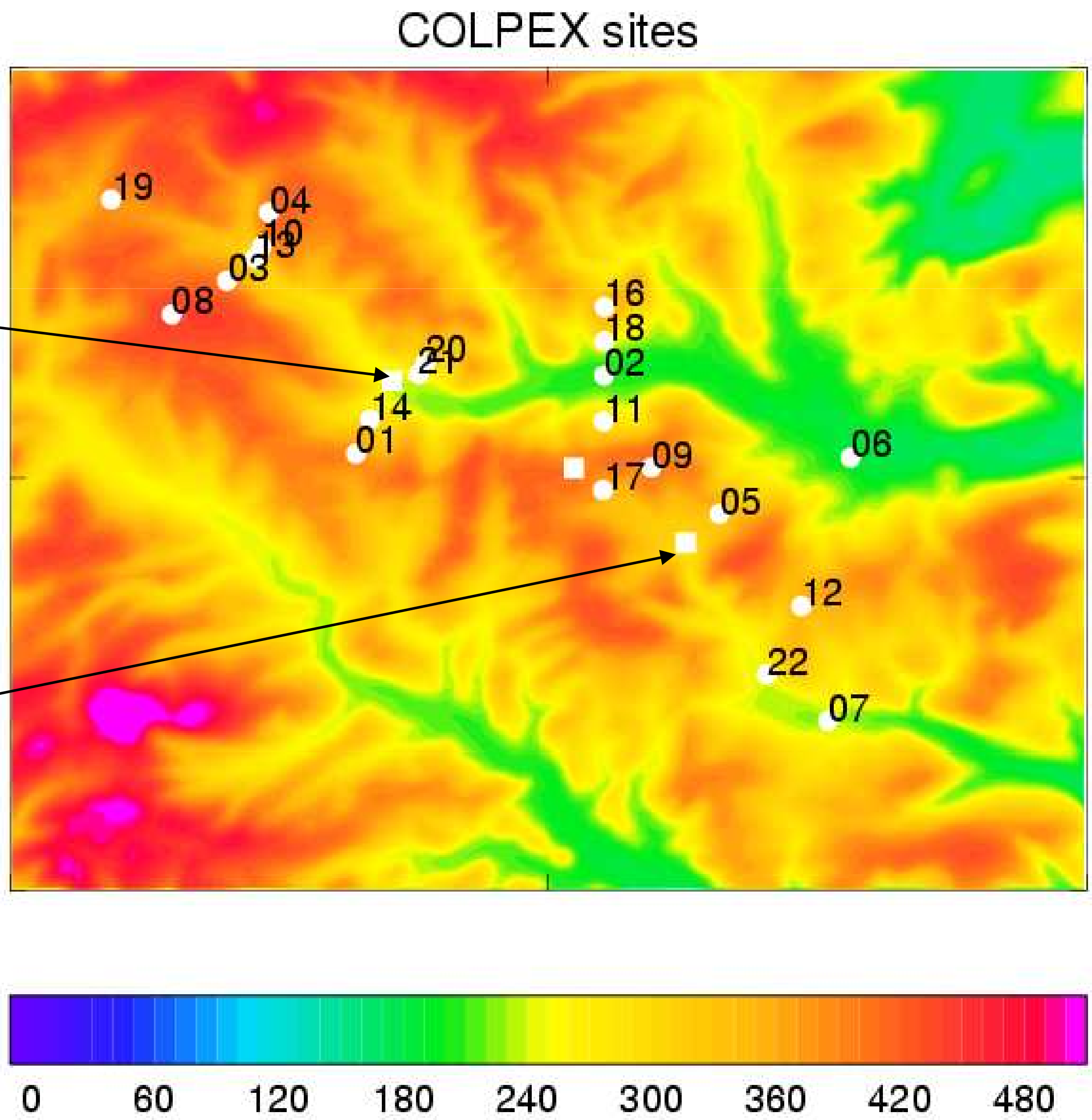


Met Office

Dyffryn and Burfield locations

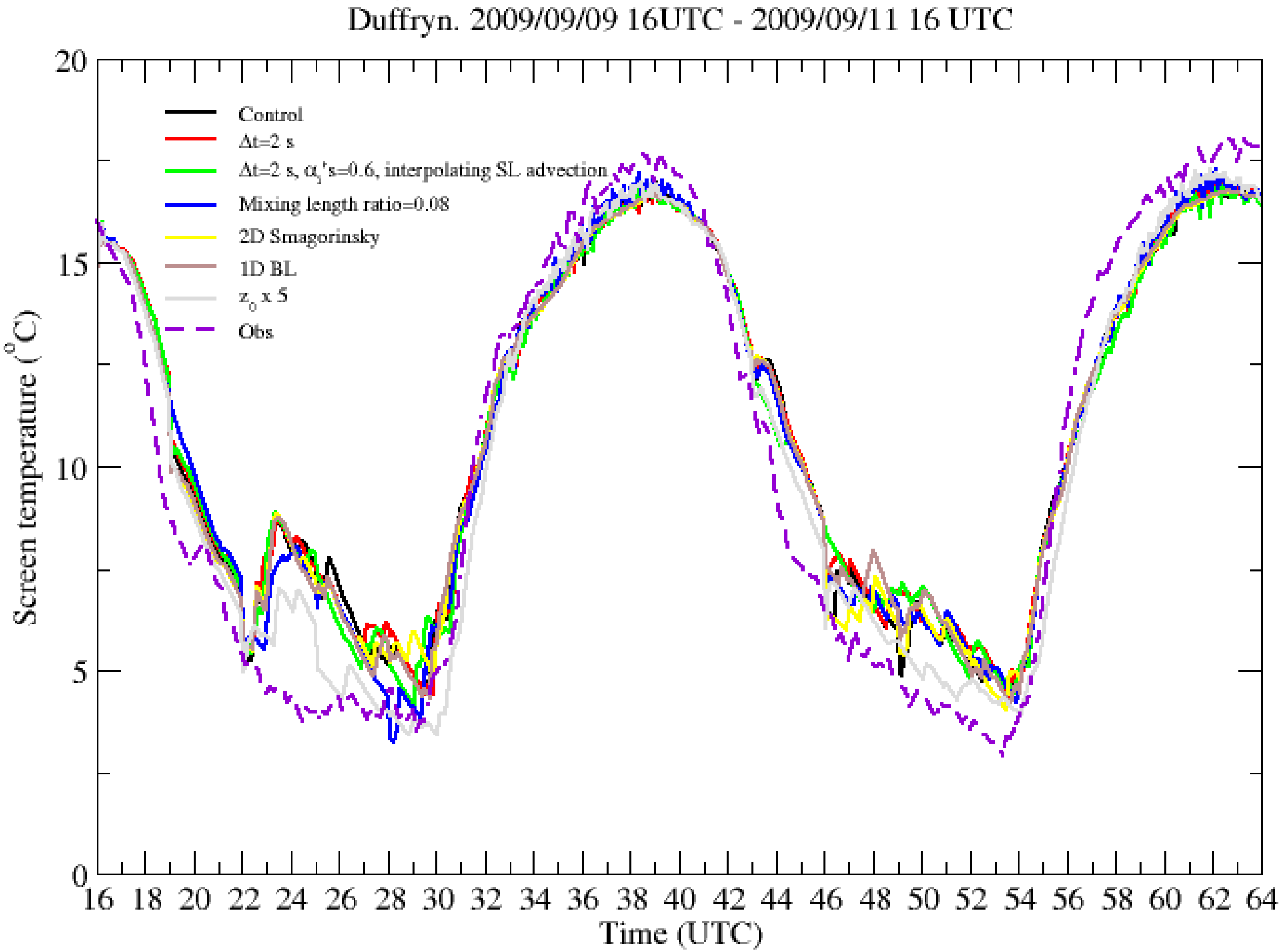
Dyffryn

Burfield

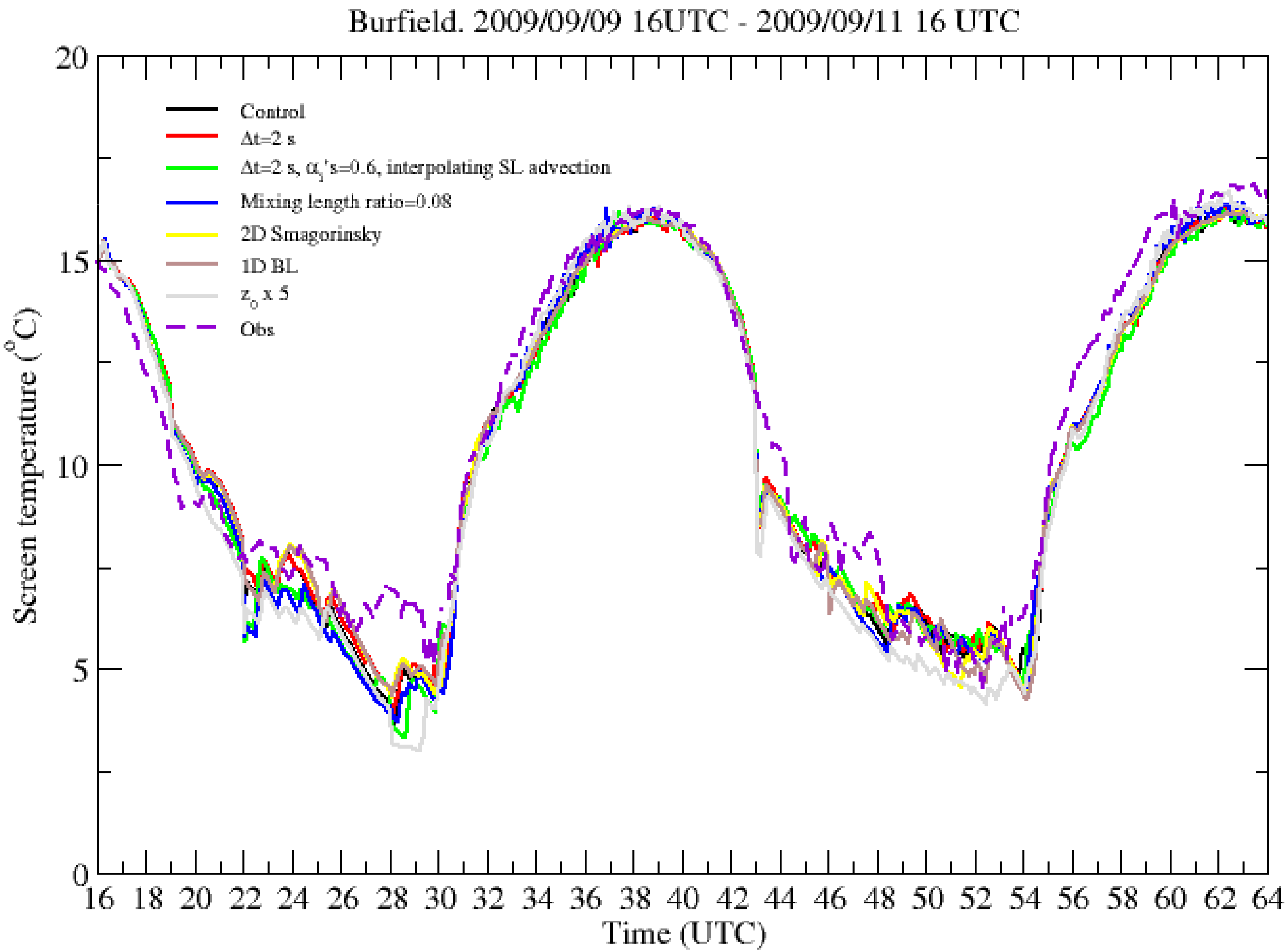


Screen T time series: Dyffryn

- Valley floor
- Model too warm at night



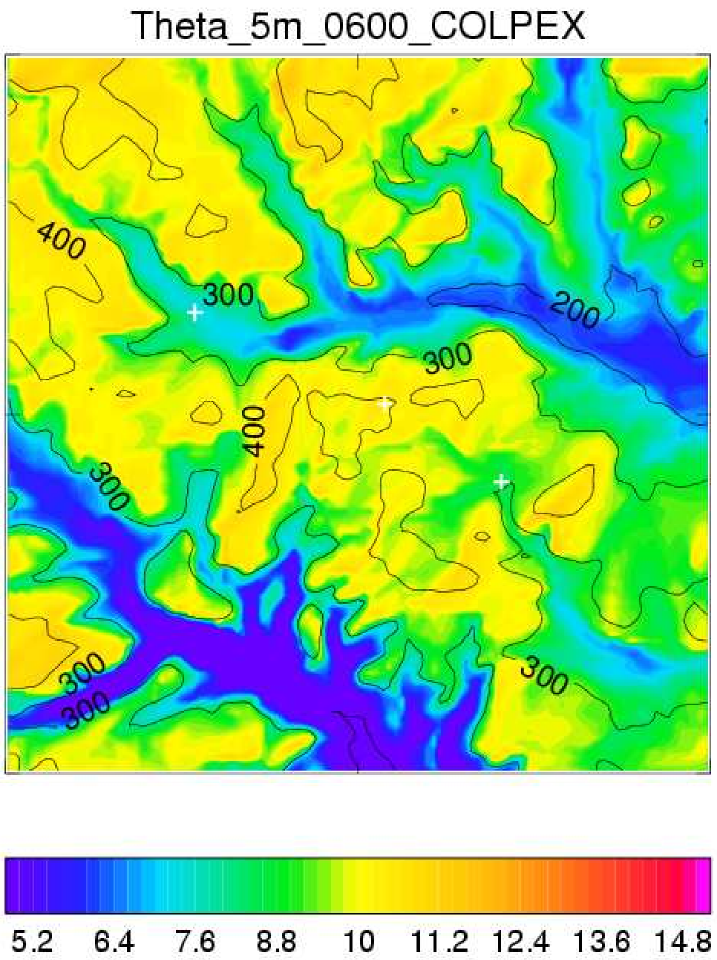
Screen T time series: Burfield



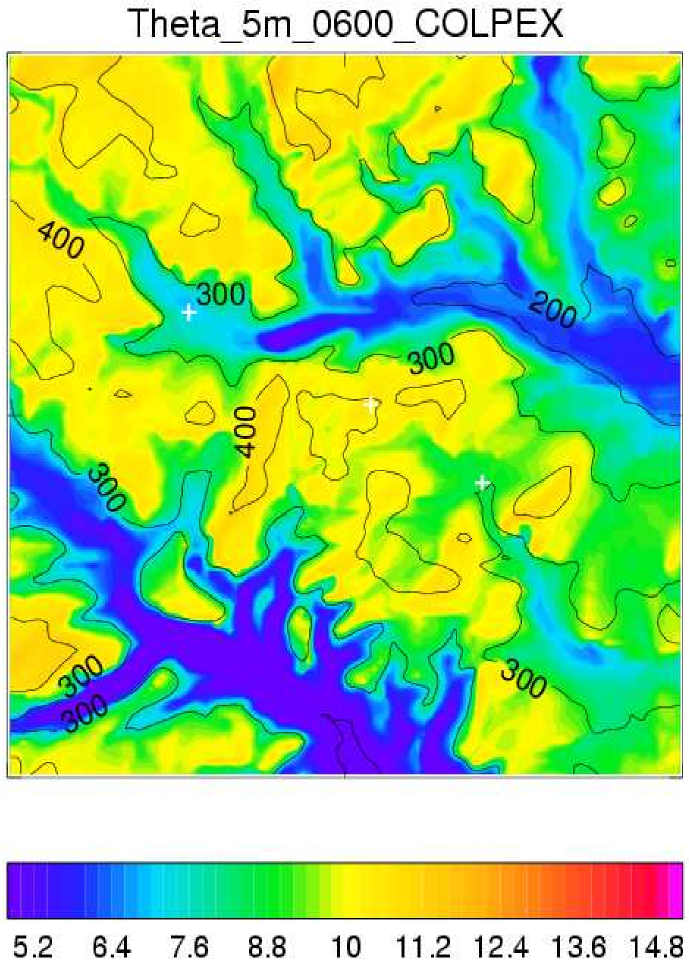
Mixing length ratio 0.08 vs control

- Slightly deeper (worse), colder (better) pools
- Note little impact at 3 main sites

Control (ratio=0.15)



Ratio=0.08



Summary of 9-11 September case

- Based on LIMITED comparisons with data:
  - Valley bottom too warm at night
  - On hill tops model is generally too cold during day
  - Model is too cold on valley sides
- Possibly pointing to a general cold bias in model, and insufficient resolution to properly capture cold pools?
- Clear benefit of very high resolution (100 m) over 1.5 km

Summary of sensitivity tests

- Tests so far show some small sensitivity to:
  - Mixing length
  - Time step, off-centring and advection scheme
- Greater sensitivity to:
  - 1D BL vs Smagorinsky (1D BL gives less noisy daytime timeseries)
  - Increased surface drag (colder cold pools)
- The sensitivity mostly appears down valley from Dyffryn.

Summary of issues for parametrizations in high resolution UM

Issues for turbulent mixing

Met Office

- Current system (standard 1D BL scheme, horizontal Smagorinsky) performs quite well
- Now the model is operational, we are starting to look in more detail at performance (e.g. stability functions, mixing lengths, resolution of drainage flows). COLPEX will form a crucial part
- Shallow convection: UKV *looks* remarkably good without it! Still problems with transition to deep convection
- Stochastic energy backscatter will be implemented experimentally
- We are experimenting with forms of blending between the vertical 1D BL scheme and Smagorinsky (eg. a dependence on how well resolved the PBL is)
- Reviewing (lack of) form drag from unresolved hills

Issues for surface

- Current surface scheme is generally very good. We do not know enough about its limitations (COLPEX important).
- Heterogeneity and horizontal transport of soil moisture may be important at ~1.5 km or less.
- Land-use accuracy – esp. deciduous trees.
- Canopy impacts on drainage flows.
- Developing improved urban representation
- We do know that we miss diurnal SST variation. Impact small but not insignificant.
- We do not know the importance of wave coupling for surface drag at high resolution, or the importance of ocean currents etc.

Issues for cloud and microphysics

- Still running with single ice, prognostic rain, though dual ice/snow +graupel prognostics available. No evidence of need for added complexity.
- Main driver is probably assimilation of reflectivity
- Warm rain autoconversion is an issue (actually in all UM configurations). Needs review of formulation and (probably) coupling to aerosol
- Choice of critical RH in cloud scheme needs review, but experience suggests impact is small.

Questions

Thank you