Very high resolution model simulations of cold-air pooling in complex terrain during COLPEX

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Motivation and Outline

- Small-scale valleys are poorly resolved by even the finest resolution NWP models currently in use (e.g. ~1km resolution), yet the temperature and wind variations on small scales can be significant.

- How well can an operational NWP model simulate the flows within small-scale valleys?
  - What is the potential of future high-resolution local forecast systems?

- Simulations have been conducted for flows observed during the field phase of COLPEX.

- The model results will be used to identify the key physical processes involved in cold pool formation and to develop relationships between the cold pool properties and the synoptic conditions.
Key Questions

• How well can an operational forecast model simulate cold-air pooling on sub-kilometre scales?

• Which physical processes (in the model) dominate the formation and evolution of cold air pools?
  • Advection
  • Sheltering (suppression of turbulent mixing aloft)
  • Radiative cooling
• Met Office Unified Model:
  • Non-hydrostatic deep atmosphere fully compressible dynamical core
  • Semi-implicit semi-Lagrangian dynamical (SISL) core

• Nested suite:
  • Operational 4km model (UK4)
  • 1.5 km southern UK model
  • 100 m variable resolution

• UK4 initialised every 3 hours with T+1h operational analysis

• Provides boundary data for the 1.5km and 100m models, keeping them close to the “truth”

• 1.5km and 100m models “free running” i.e not reinitialised every 3 hours
100 m resolution orography dataset
50 m resolution land-use dataset

Stretching zone

Δ=1.5km

Δ=100m

Clun valley

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Vertical grid and timestep

• Operational grid: 70 levels up to 40 km
  • Stretched, with 5 levels below 112 m
• Enhanced resolution: 140 levels up to 40 km
  • Stretched, with 12 levels below 112 m
• 100m model uses a 5 second timestep
  • For 20 ms\(^{-1}\) winds aloft, this implies a horizontal Courant number of 1.
• Made possible via SISL formulation of model
9th September 2009 IOP

• Initial focus on the clear-sky COLPEX IOP

• Simulation from 15UTC 09 to 15 UTC 13 September 2009
Potential temperature at 2m

2009/09/09 1800 UTC

2009/09/09 1900 UTC

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Potential temperature at 2m
Potential temperature at 2m

2009/09/09 2200 UTC

2009/09/09 2300 UTC
North-South section through Upper Dyffryn, Clun Valley

Xsect SN Site 00 20090909 2200_COLPEX

Xsect SN Site 00 20090910 0000_COLPEX

Xsect SN Site 00 20090910 0200_COLPEX

θ (°C)
North-South section through Upper Dyffryn, Clun Valley

Clearly 1.5km resolution is inadequate!
Model screen temperature: $\Delta=100\text{m} \text{ L140 vs } \Delta=1.5\text{km} \text{ L70}$

- Temperature minima well represented
- Daytime temperatures too cold
- Clear benefit of 100m resolution over 1.5km
140-level 100 m model results

Duffryn (Clun valley)  Springhill (hill-top)  Burfield (valley)

\( T(\,^\circ C) \)

\(-\text{model}-\)
\(-\text{obs}-\)

Wind speed (ms\(^{-1}\))
Cold pool strength

- Repeatable nighttime $\Delta T$ of approx. -4 K
- 100m L140 model gives good prediction of $\Delta T$ amplitude
- Coarser vertical resolution (L70) results in weaker cold pools

Temperature differences 09-13 Sept 2009

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Heat budget

Q: What are the dominant sources of cooling?

Can use the model $\theta$ budget to identify which are the important processes at different times during the night.
Cooling in valley is relatively rapid around sunset. Later on, hill-top and valley cooling rates are similar. Model heat budget suggests early rapid cooling in valley is largely due to greater turbulent heat flux divergence (relative to advection).
Conclusions

• The model provides a credible simulation of clear-sky cold-pool cases observed during COLPEX
  
  • Some room for improvement still.
  
  • Foggy cases are more challenging!

• The results show clear benefit of using enhanced vertical resolution. 100m horizontal resolution appears to be sufficient, but further refinement might be beneficial.
Conclusions (contd)

• Analysis of the model near-surface $\theta$ evolution in and outside the valley suggests that:

• In agreement with the observations, relatively rapid cooling occurs in the valley around sunset. Following this, the hill-top and valley cooling rates are similar.

• This rapid valley cooling rate is largely due to large turbulent heat flux divergence. This is presumably due to:
  
  • Strong surface cooling and reduced downward turbulent heat flux aloft, due to sheltering in the valley.
Future work

• Look at more cases
  • How well does the model perform?
  • How general is the heat budget behaviour, and is it consistent with the observations?

• Run for long time periods e.g. 1-2 months
  • What is the impact of realistic soil properties?
  • Use the model to deduce relationships for NWP post-processing
Thankyou for listening!