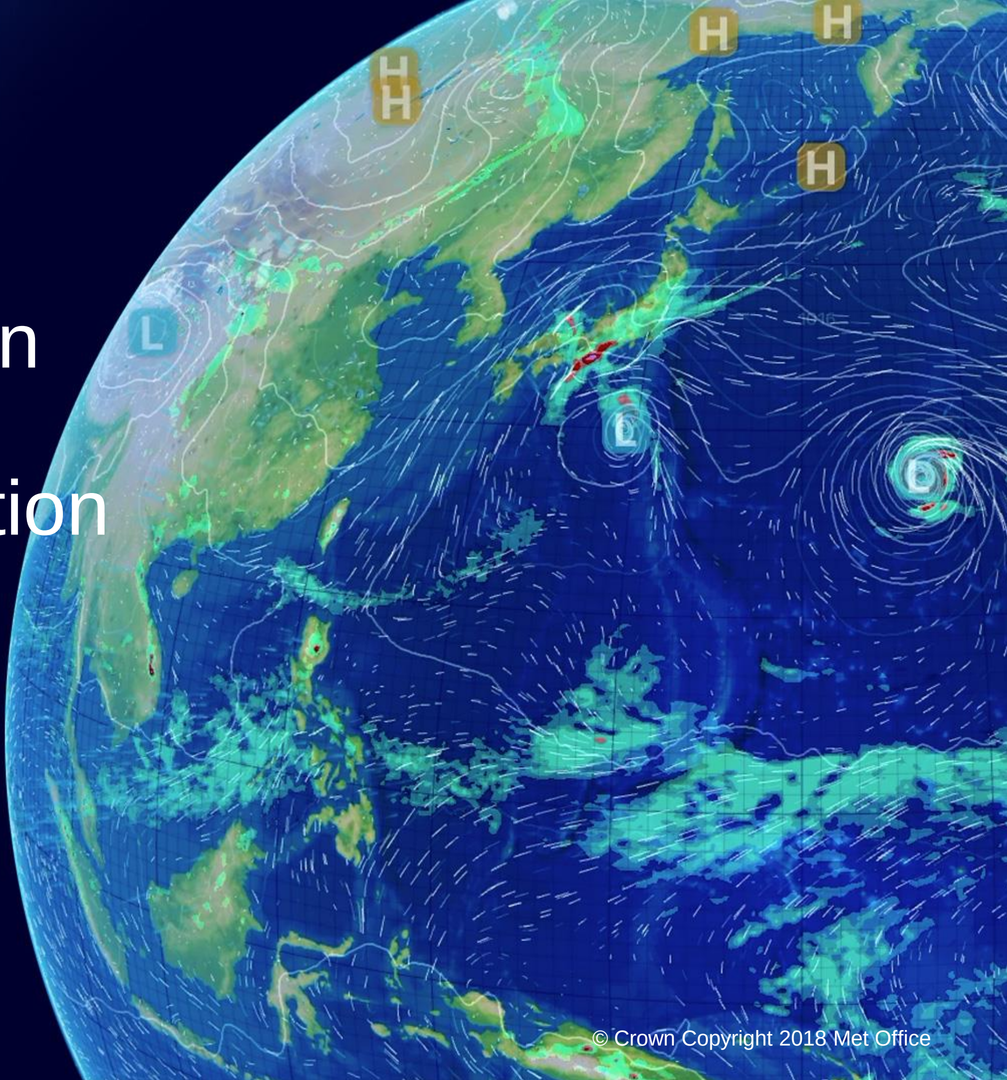
Large-eddy simulations in GABLS4: The role of the Land-surface and Radiation



GABLS4 Workshop, Toulouse, Sept. 2018

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Motivation

- To investigate the interaction of turbulence with full physics including the surface and radiation
- To examine the impact of surface heterogeneity

Technical Background

The Met Office Large-Eddy Model

- Basic model is now almost 30 years old!
  - **Boussinesq** or anelastic options
  - Smagorinsky subgrid diffusion scheme
    - Reduction of mixing length near the wall
    - Stability dependence of mixing length included
  - Advection: **Piacsek-Williams** or TVD
  - Stochastic back-scatter can be included
  - Simple surface boundary conditions: prescribed surface temperature or flux
- Recently main application has been as a cloud-resolving model
  - Microphysics and radiation schemes introduced
- Was used in GABLS3

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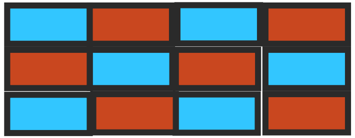
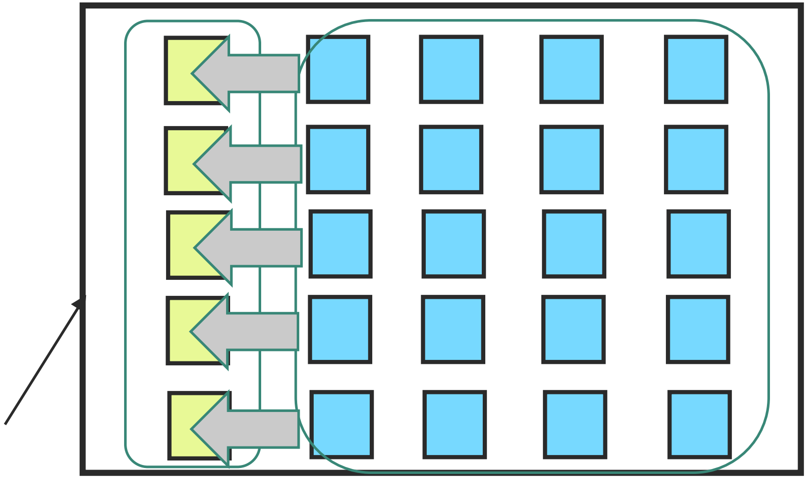
MONC

- Coding of the original model restricts options for MPP to assigning one vertical slice to a PE – increasingly inefficient as computing power grows
- Decided to recode large-eddy model with the same science in collaboration with academic partners, funded by NERC
  - Work mainly carried out at Edinburgh Parallel Computing Centre in 2014 & 2015
  - Highly scalable (aimed principally at cloud & aerosol modelling at 10s of m)
  - Modern programming style
  - Flexible architecture based on components with callbacks
  - Diagnostic output from an IO-server
- Original project did not cover full functionality of LES
  - Microphysics and radiation only recently added
  - Diagnostics originally very limited – still being worked on
  - Back scatter is not available

MPP aspects



- MONC supports 2D domain decomposition in the horizontal
- One PE as an IO server for a group of computing nodes (around 10)
- Asynchronous IO
- NetCDF output controlled by .xml files



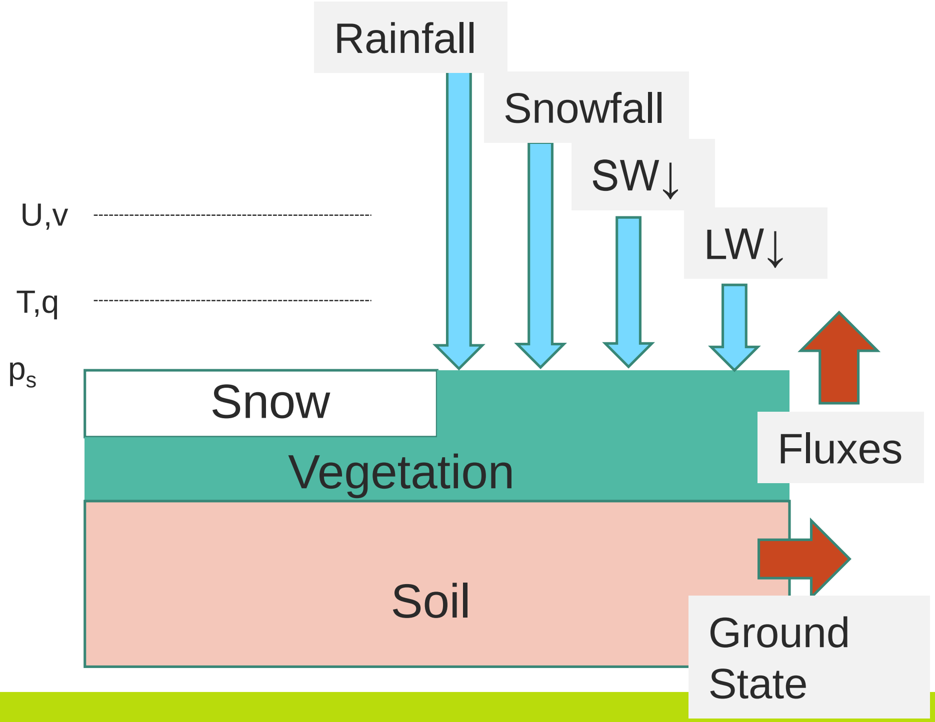
Boundary Conditions and the Land Surface

Boundary Conditions

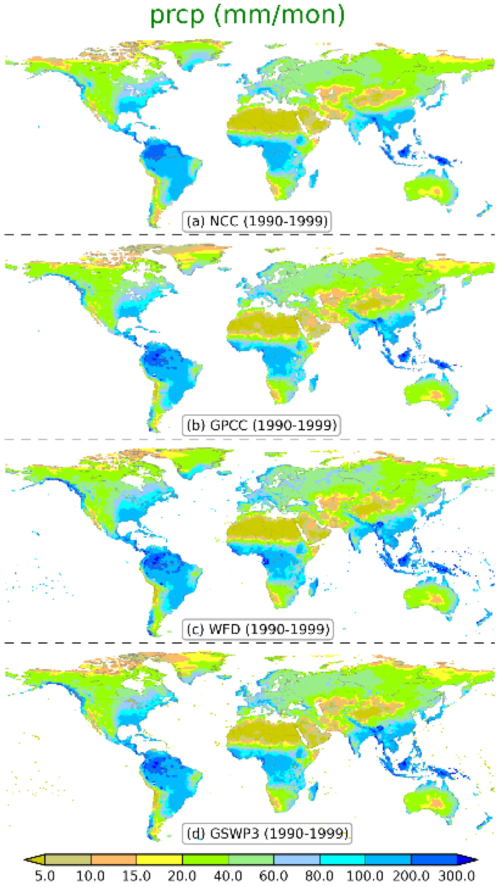
- Most LES have been done with prescribed temperature or fluxes
- Land Surface Models (LSMs) are increasingly complicated, but surface interactions can be important
- Options:
    - Implement bespoke land-surface component in LES
        - Possible, but it is another code to maintain
    - Exchange fields through a coupler
        - Processes are too fast for this to work well
    - Use an existing land-surface scheme
        - “Deep coupling:” All IO through LES: a significant amount of technical work
        - “Shallow coupling:” Use as much of LSM as possible including IO and control

Standalone Land Surface Models

- Land-surface models represent
  - Vegetative canopy
  - Lying snow
  - Underlying soil or ice
- Still largely column-based, though increasing interest in lateral flows for hydrology
- Standalone runs for process studies



- Long history of studies at single points eg. FLUXNET sites
- Increasing use of standalone runs at the global scale within CMIP eg. GSWP3
- …So LSMs may already have sophisticated capabilities for setting options, netCDF and even MPP
  - **Making use of this functionality may be easier than coupling everything through the large-eddy model**



Example of forcing from GSWP3

Coupling MONC to JULES

- JULES = Joint UK Land Environment Simulator -- used in UM
- Main task is just to replace top-level program
- Inherit MPP decomposition from MONC: redefine MPI_COMM_WORLD for JULES as just computing group
- Call JULES initialization during MONC initialization on each PE
- Use JULES diagnostic system for JULES output
- Replicate calling to JULES routines within MONC

```
…
CALL MPI_INIT
 CALL init(nml_dir)
 DO ! Timesteps
    CALL update_forcing
    CALL control(timestep)
    CALL output_data()
    CALL next_time(timestep)
    IF ( end_of_run) EXIT
 END DO
```

- JULES is forced using u, v, T and q on level 1 and radiative fluxes (either from interactive radiation or from prescribed data in netCDF files)
- Need to write a component in MONC – a set of callbacks
- Controlling options can come from operational namelists
- Making netCDF input is relatively easy in python
- A few irritations like subroutines with the same name in MONC and JULES!

GABLS4: Stage 2

- Main LES cases in GABLS4 are in Stages 3 and 4, but are quite idealized
  - Would like interactive water vapour for radiation & surface
- Base simulations on Stage 2
  - Standard: Prescribed surface temperature, interactive q + Radiation
  - NoRad: As Std, but without radiative heating in the atmosphere
  - JULES: Fully coupled JULES (effectively Stage 1b)
  - TJL: As Std but with prescribed (uniform) surface temperature taken as grid-box mean from JULES

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Land Surface Coupling

Configuration of JULES -- Snow

- JULES:
  - Scientifically as for NWP/Climate model, except
    - Grain size fixed at 69 μm to give average albedo of 0.81
    - 19 layers from Stage 2 configuration, not just 3: top layer 1.2 cm thick
    - Timestep: 60 s
    - $z_0 = 0.001$ m, $z_{0h} = 0.0001$ m

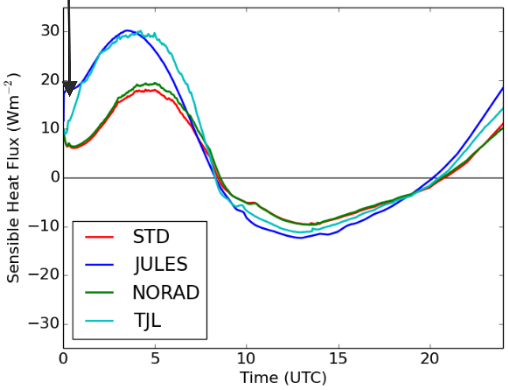
- MONC:
  - Scientifically as for Stage 3
  - 200 x 200 x 500 points, 5 x 5 x 2 m
  - Timestep: 0.1 s

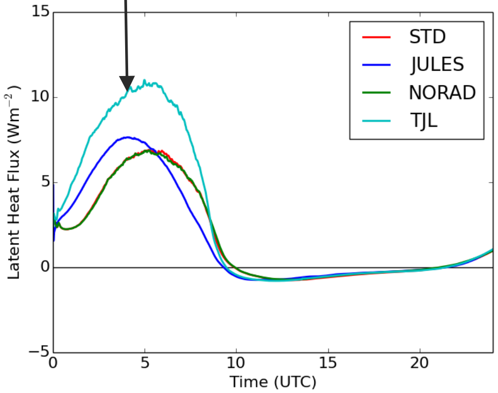
- Radiation:
  - SOCRATES code, as in UM and SCM GABLS4
  - Timestep 60 s

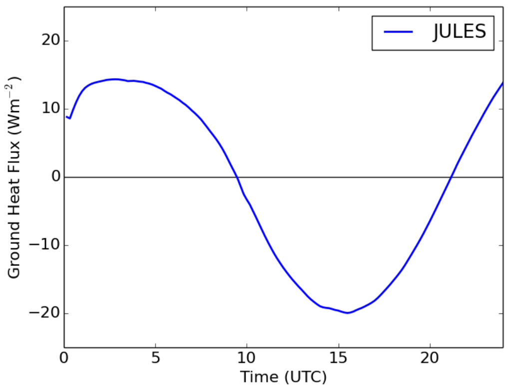
Surface Flux Budget

Spinup, Rapid adjustment of T_{srf}

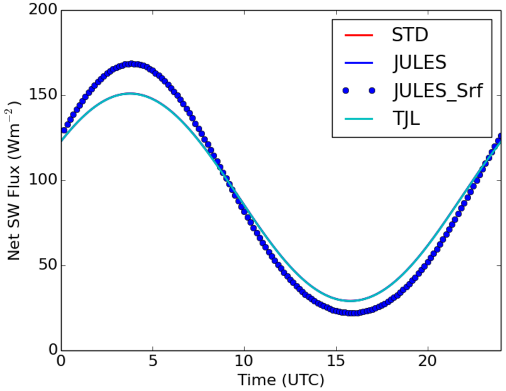
Why is LH so high?

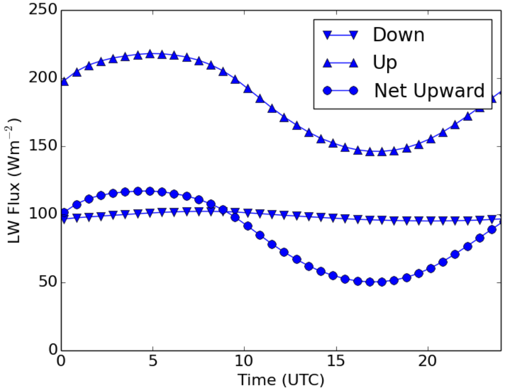


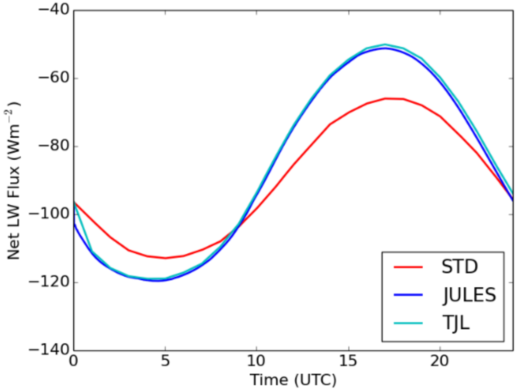




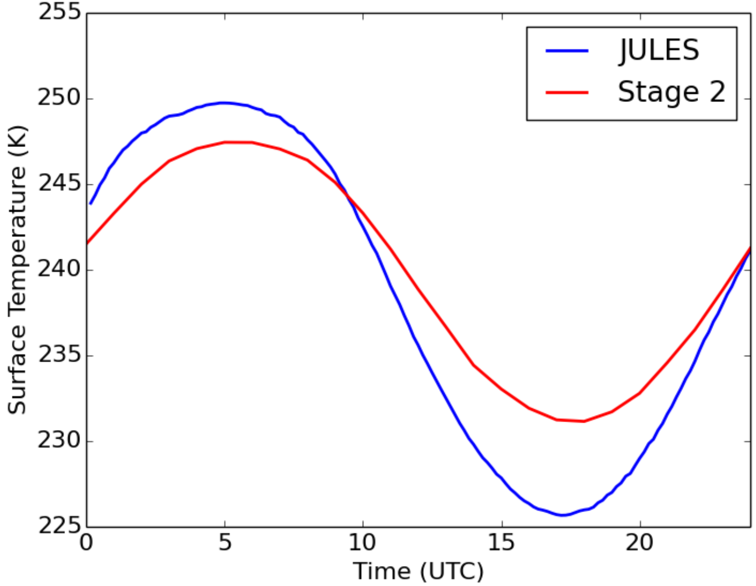
Surface radiative fluxes

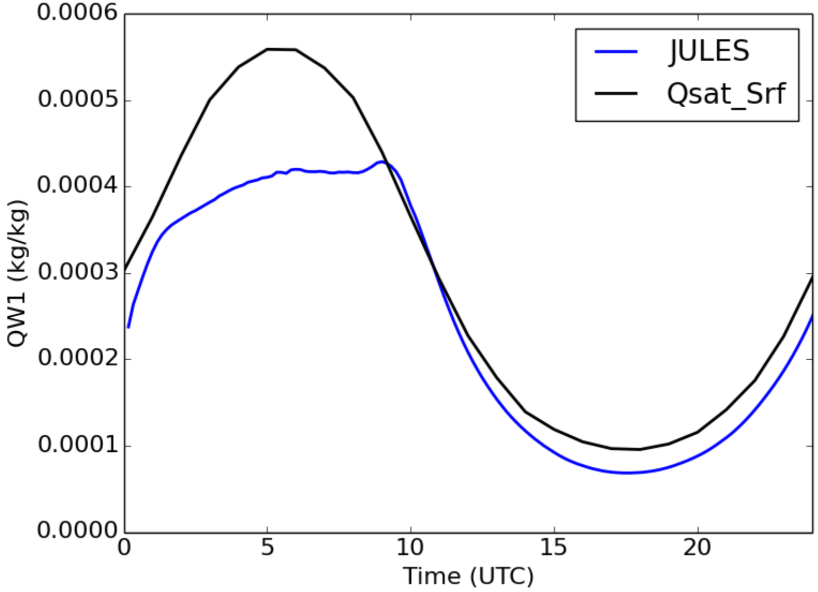




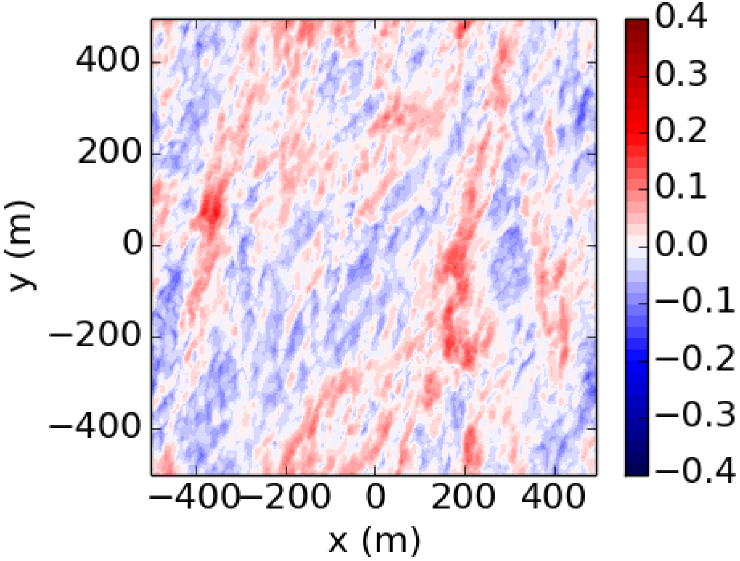


Surface Temperature & Humidity

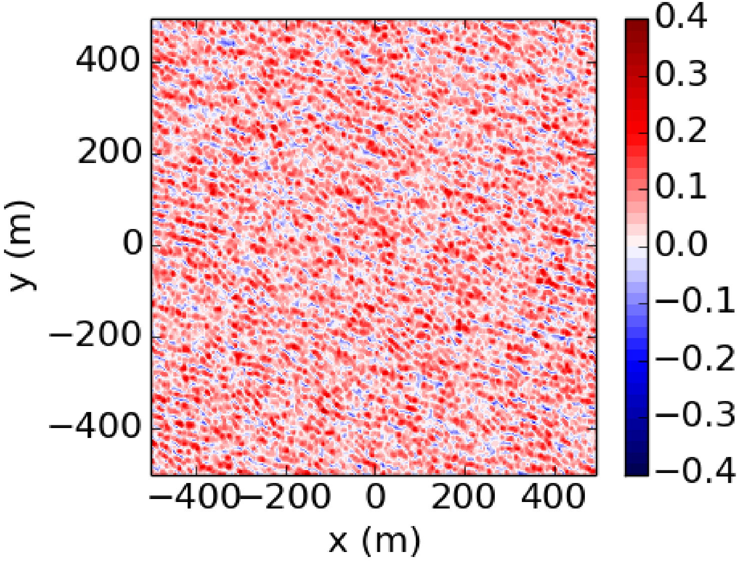




Heterogeneity in surface temperature



At T_{max}: STD=0.04 K



At T_{min}: STD=0.08 K

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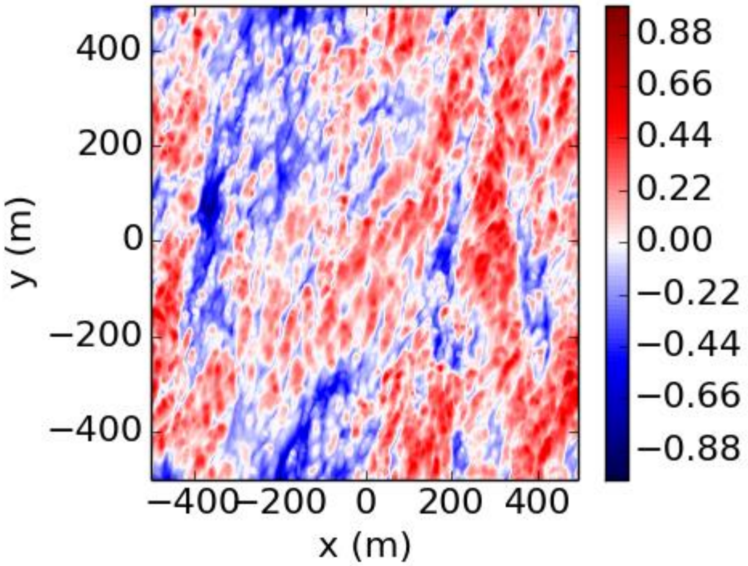
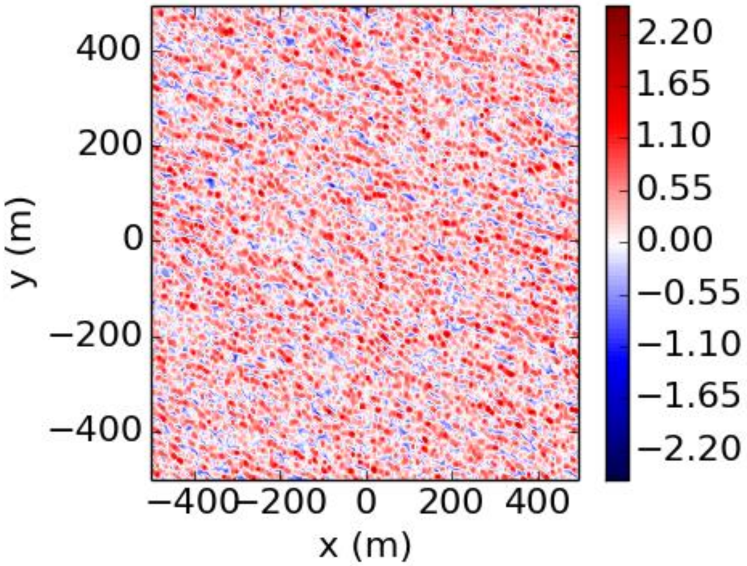
Heterogeneity in Sensible Heat Flux

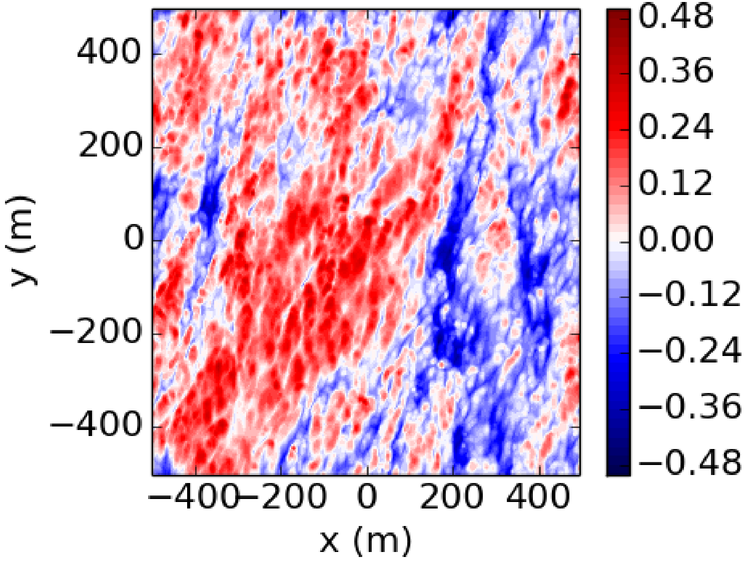


At T_{max}: STD=0.21 Wm^{-2}

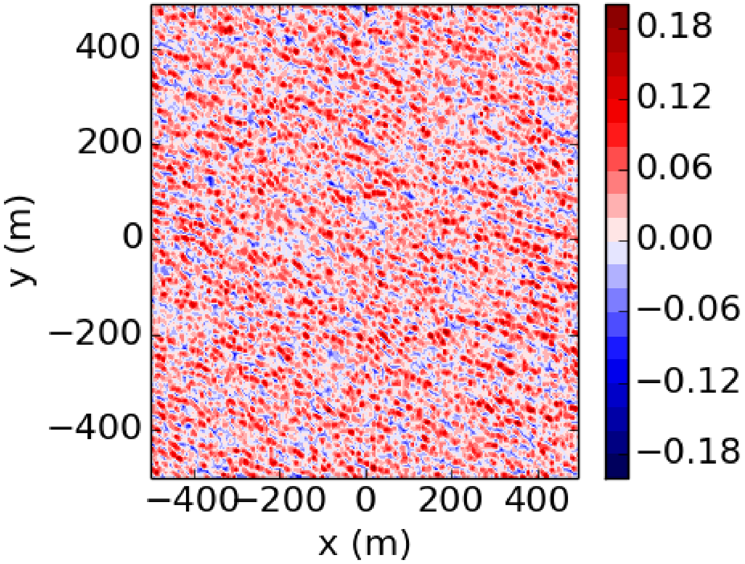


At T_{min}: STD=0.49 Wm^{-2}

Heterogeneity in Latent Heat Flux



At T_{max}: STD=0.13 Wm^{-2}



At T_{min}: STD=0.05 Wm^{-2}

Profiles and Radiation

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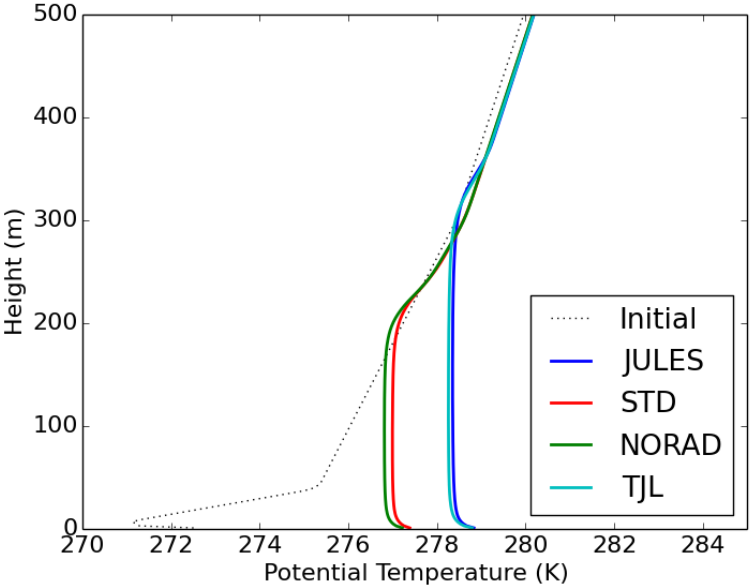
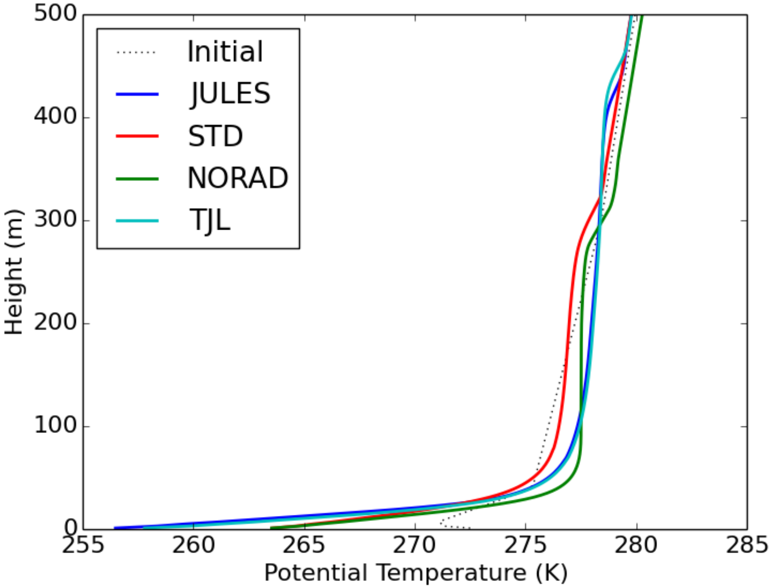
Potential Temperature



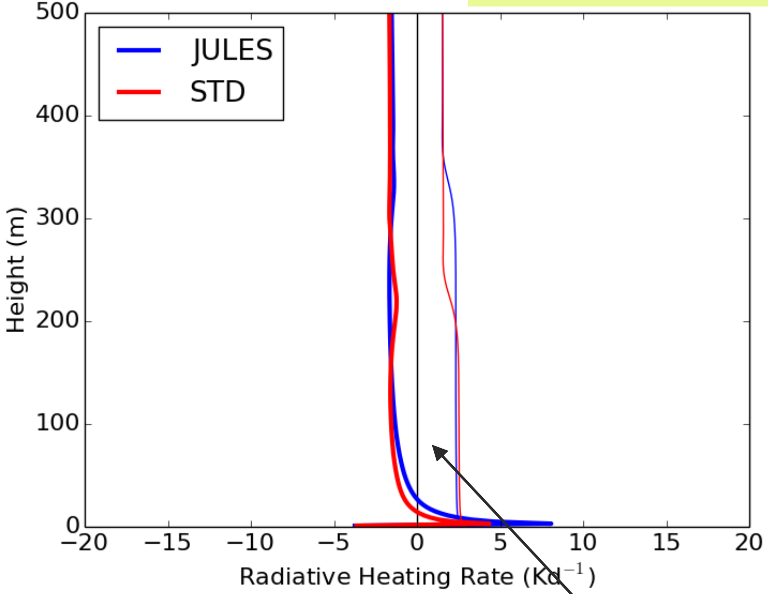
At T_{max}



At T_{min}

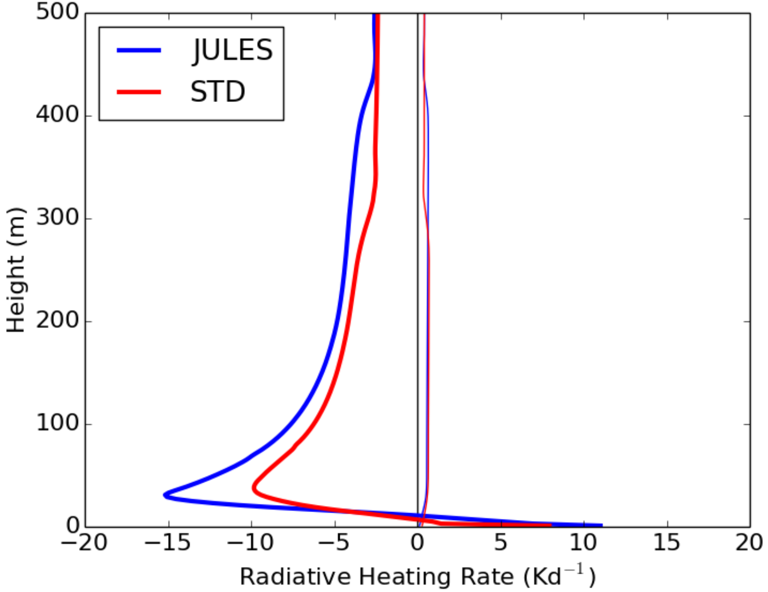
Radiative Heating Rates

Thick lines LW
Thin lines SW



At T_{max}

SW dominant

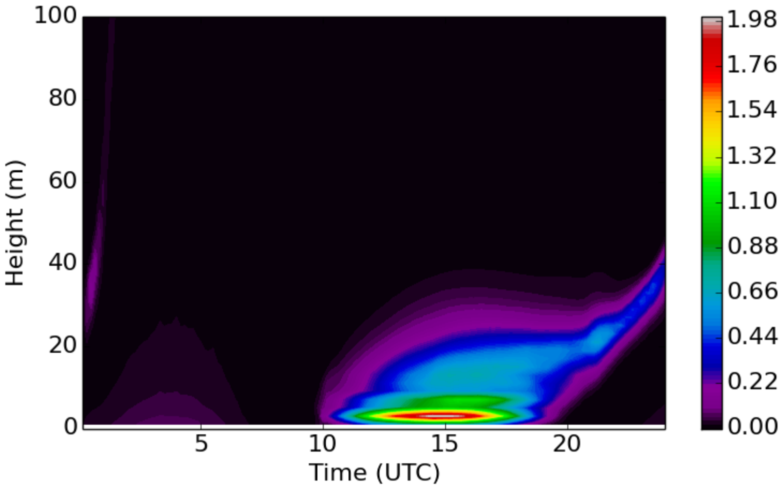


At T_{min}

Turbulence

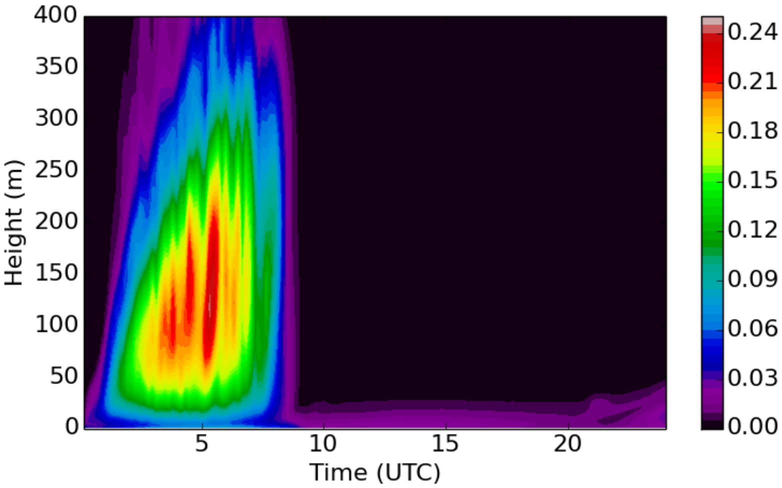
Variances from run with JULES

Variance of θ



Variance on lowest level (mainly subgrid) consistent with Tsrf. Spike on next level (resolved) needs investigation.

Variance of w



Weak turbulence persists, even with cols surface.

Conclusions

- Although full land surface schemes are complicated, “shallow coupling” to LES may not be too hard
  - In this case it was technically easier than coupling radiation
- The main impact of the land surface is on the mean state through the surface energy budget
  - This can be very sensitive to surface properties
- Radiative heating in the atmosphere alters temperature profile by a couple of K: cooler at top of surface inversion