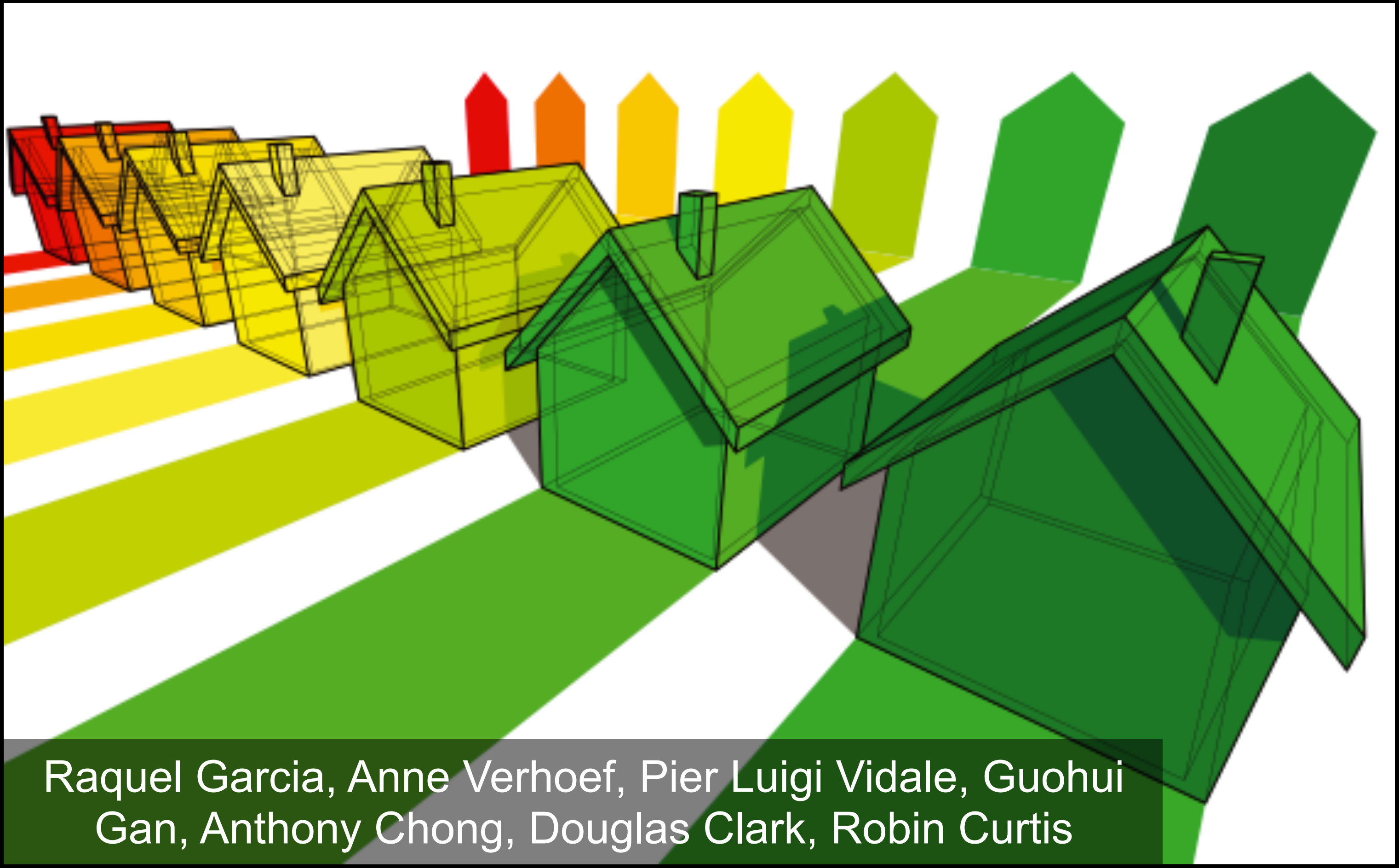
Application of JULES for the assessment of the CO_2 mitigation potential of horizontal GCHP



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JULES meeting, 12th -13th January 2012

Outline

- Renewable heating in the UK
- What is a Horizontal Ground Coupled Heat Pump (GCHP)?
- GROMIT project tools
  - JULES Land Surface model] JULES-HP
  - Heat extraction model]
- Field experiments – Drayton St Leonard
- JULES-HP (1D) – Sensitivity runs
- CO_2 Mitigation Potential
  - CHESS JULES-HP – UK distributed runs
- Conclusions/Recommendations

Aim: To investigate and optimise the CO_2 mitigation potential of horizontal GCHPs under current and future UK environmental conditions

Impacts of climate change

- Imbalance between population numbers and vital sustaining resources:
    - Food supply, crops
    - Water availability
    - Ecosystems

Impacts of climate change

- Imbalance between population numbers and vital sustaining resources:

  - Food supply, crops
  - Water availability
  - Ecosystems
  - ENERGY SUPPLY

- Increase opposition/distrust to Nuclear Technology development
- Interest turns now to the development of Renewable source of energy

Renewable heating in the UK

By 2020, UK needs to generate 15% of its consumed energy from renewables, up from 6.7% in 2009, to meet our contribution to the EU renewable energy target

Heating and cooling systems of buildings account for 30%-50% of the global energy consumption [Kharseh et al., 2010]

Low-carbon technologies such as horizontal GCHPs can contribute to reduce UK's energy bills and reduce the CO_2 emissions

Semi-detached and detached dwellings account for approximately 40% of the total housing stocks in the UK [Singh, 2010]

Increased interest of Government and Industry in the UK, but also at the European Community level and International agencies to develop further this technology:

- Financial support schemes - Renewable Heat Incentive (RHI)
- Independent advice for customers - Energy Saving Trust (EST)

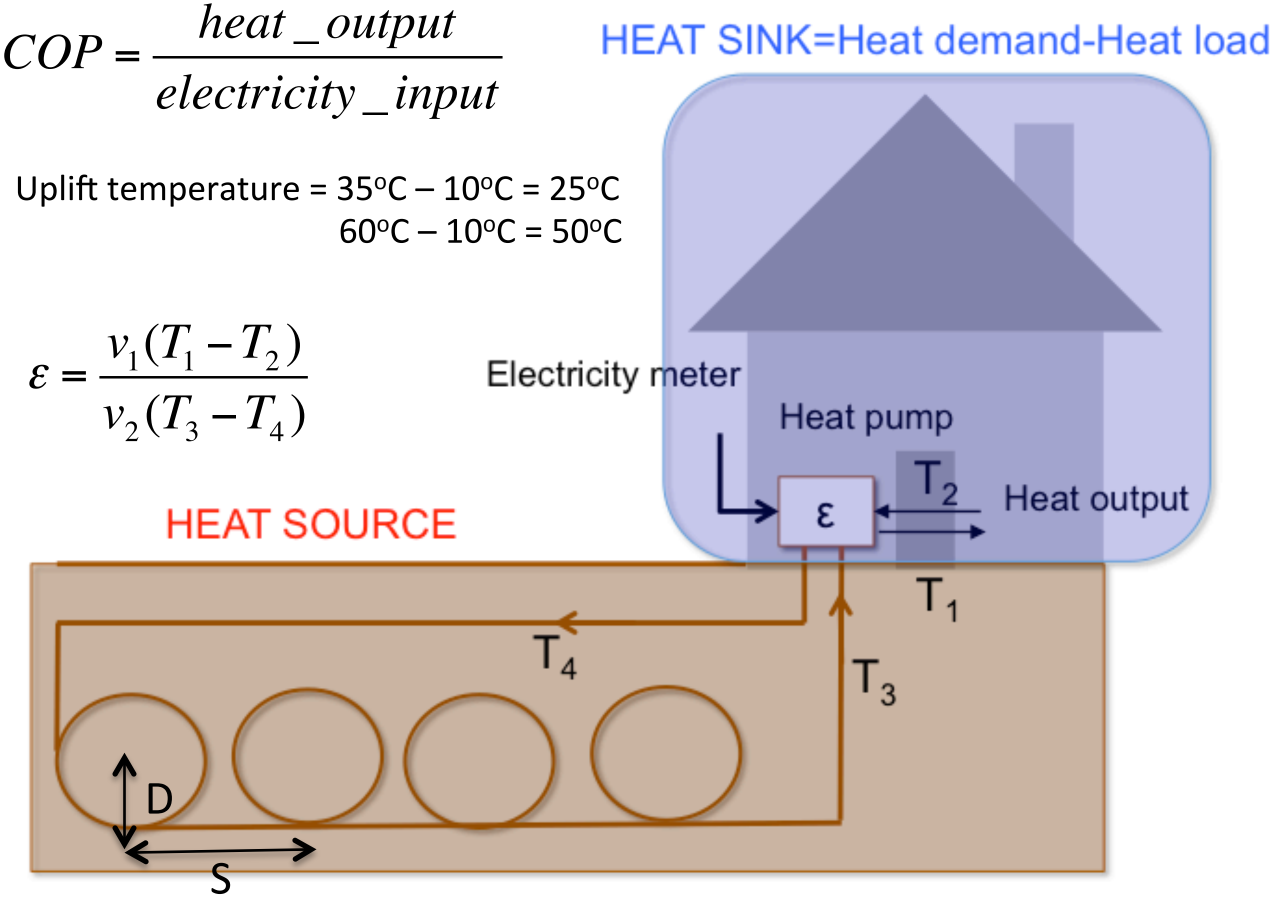
What is a horizontal Ground Source Heat Pump (GCHP)?

COP: Coefficient of Performance

$$COP = \frac{heat\_output}{electricity\_input}$$

Uplift temperature = 35ºC – 10ºC = 25ºC
60ºC – 10ºC = 50ºC

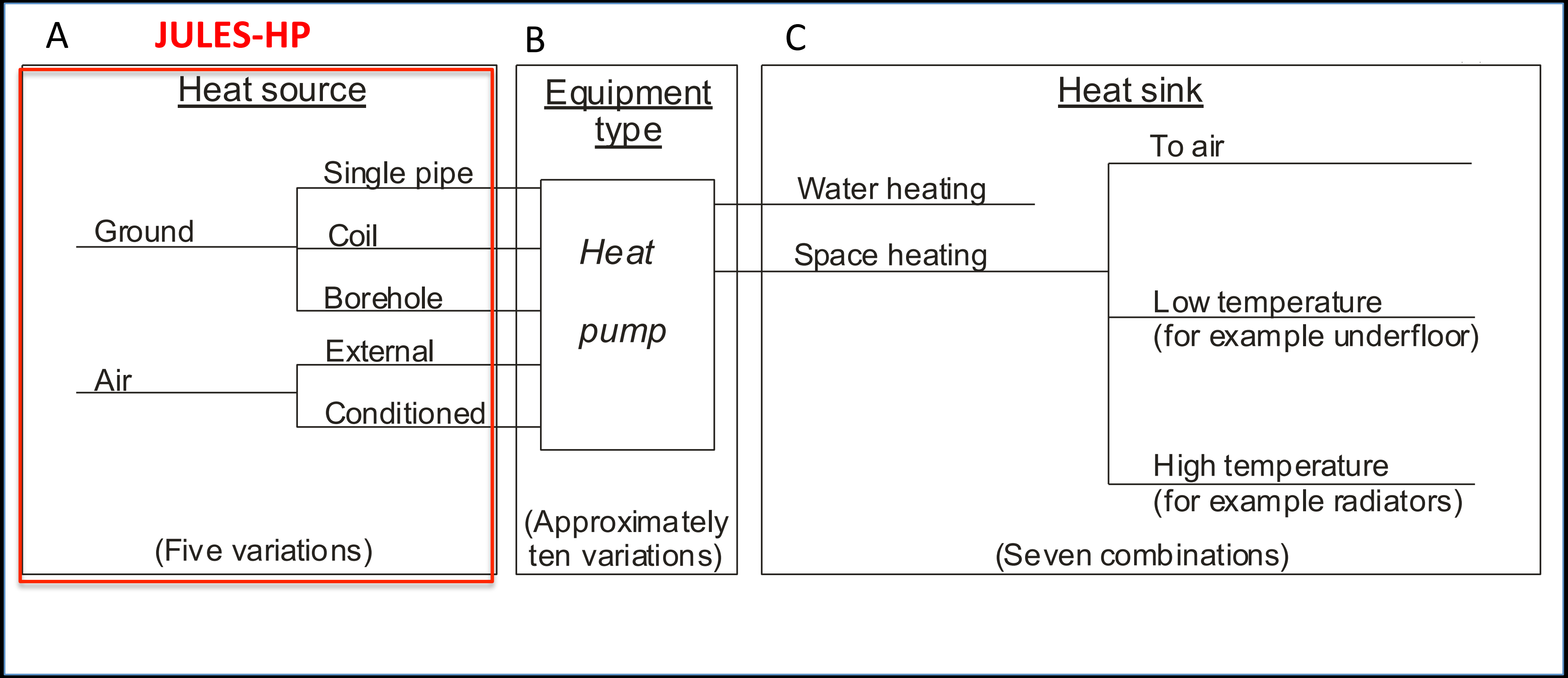
$$\varepsilon = \frac{v_1(T_1 - T_2)}{v_2(T_3 - T_4)}$$



Range of GCHP systems

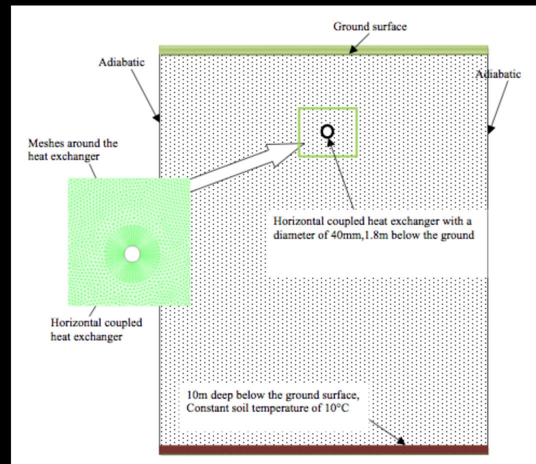
Source: Energy Saving Trust, Heat Pump Technical Monitoring Specification, 2008

COP = f(A, B,C)

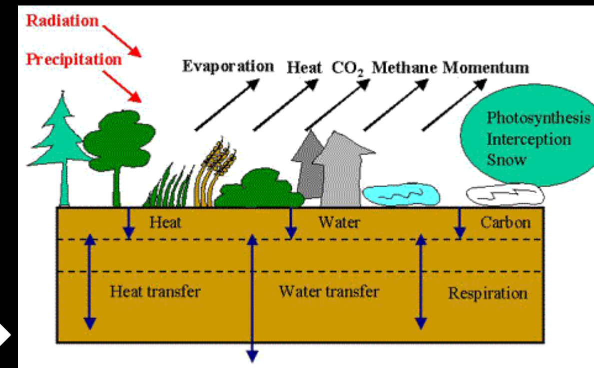


GROMIT project tools

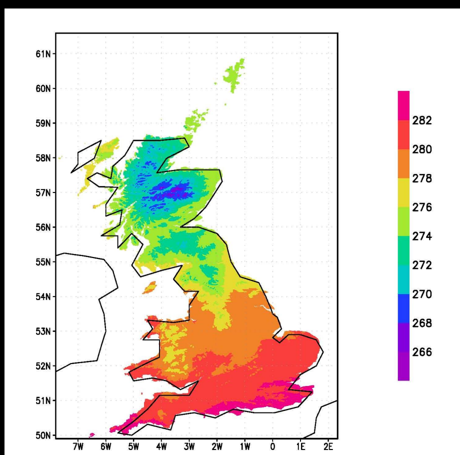
GCHP model



Land surface model

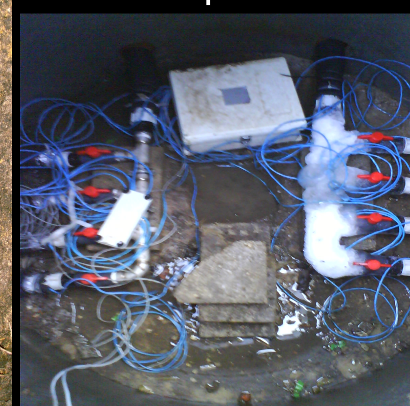


UK Driving data, e.g.
Air Temperature (K)
1 January 2003



Model development

Field experiments

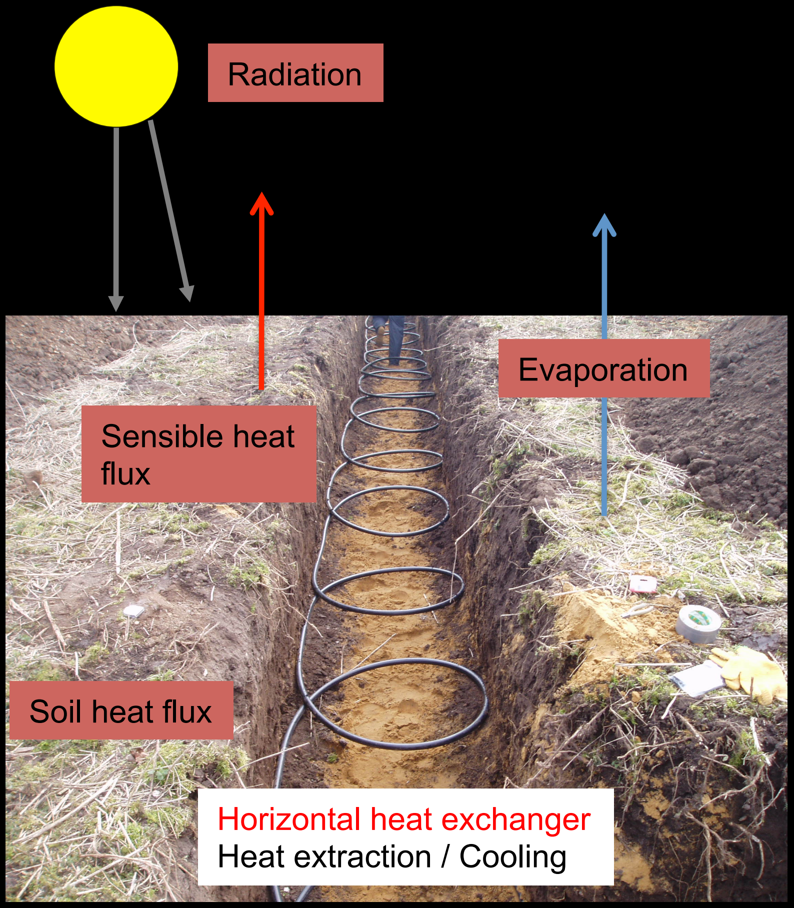


Impact studies

UK Soil texture data, to calculate soil physical properties

This methodology could help to:

- Expand the use of this technology/ optimize the design and installation
- Predict the COP and thus the CO_2 mitigation potential for different combinations of soil type/GCHP system
- Make recommendations to relevant government bodies concerning the optimal configuration of future installations of GCHPs at UK domestic, institutional, commercial and agricultural developments



JULES-heat extraction model (JULES-HP)

Dynamic interaction between the soil environment and the heat pump

$$C_A \Delta z_i \frac{\partial T_i}{\partial t} = \frac{\partial}{\partial z}\left[\lambda_i \frac{\partial T_i}{\partial z}\right] - c_w W_{l,i} \Delta z_i \frac{\partial T_i}{\partial z}$$

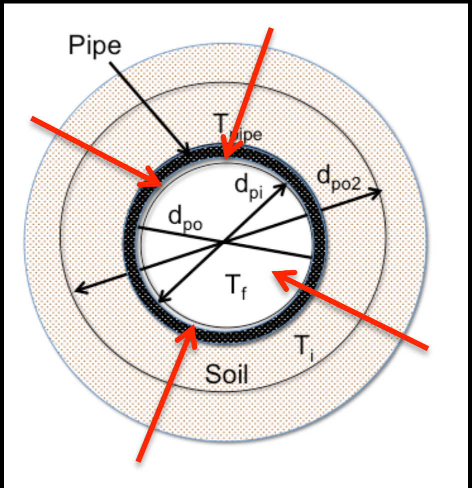
Heat transfer in JULES

$$C_{h,i} \frac{\partial \psi_i}{\partial t} = \frac{\partial}{\partial z}\left[k_i \frac{\partial \psi_i}{\partial z} + K_i\right] - E_i$$

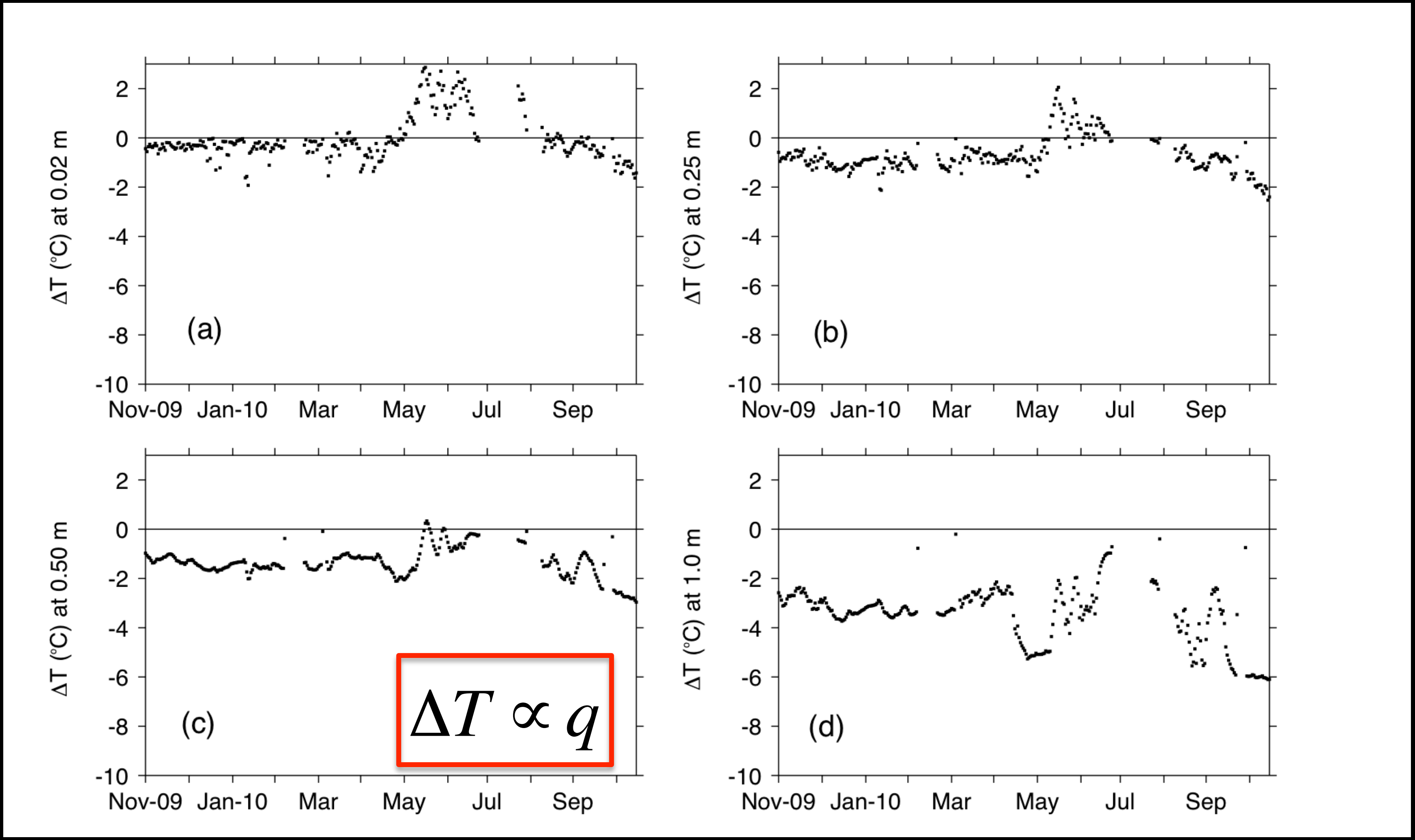
Flow of water in JULES

$$q = 2\pi\lambda_i L \frac{T_{pipe} - T_i}{\ln \frac{d_{po2}}{d_{po}}} = AU_{pipe}\left(T_f - T_{pipe}\right)$$

Heat flux from a layer of soil outside the pipe equals the heat transfer from outer surface to inner surface of pipe

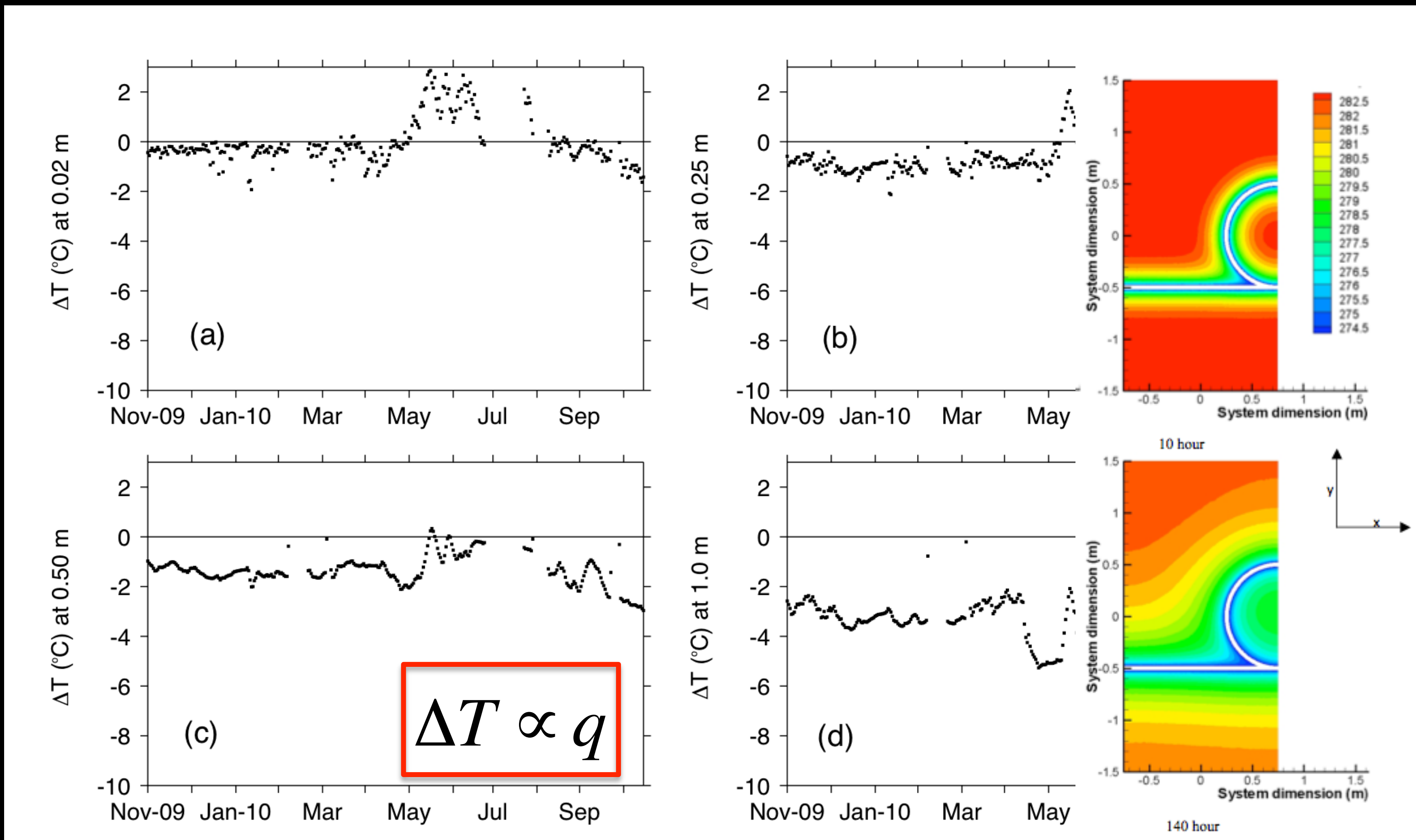


Preliminary studies, Drayton St Leonard, near Oxford



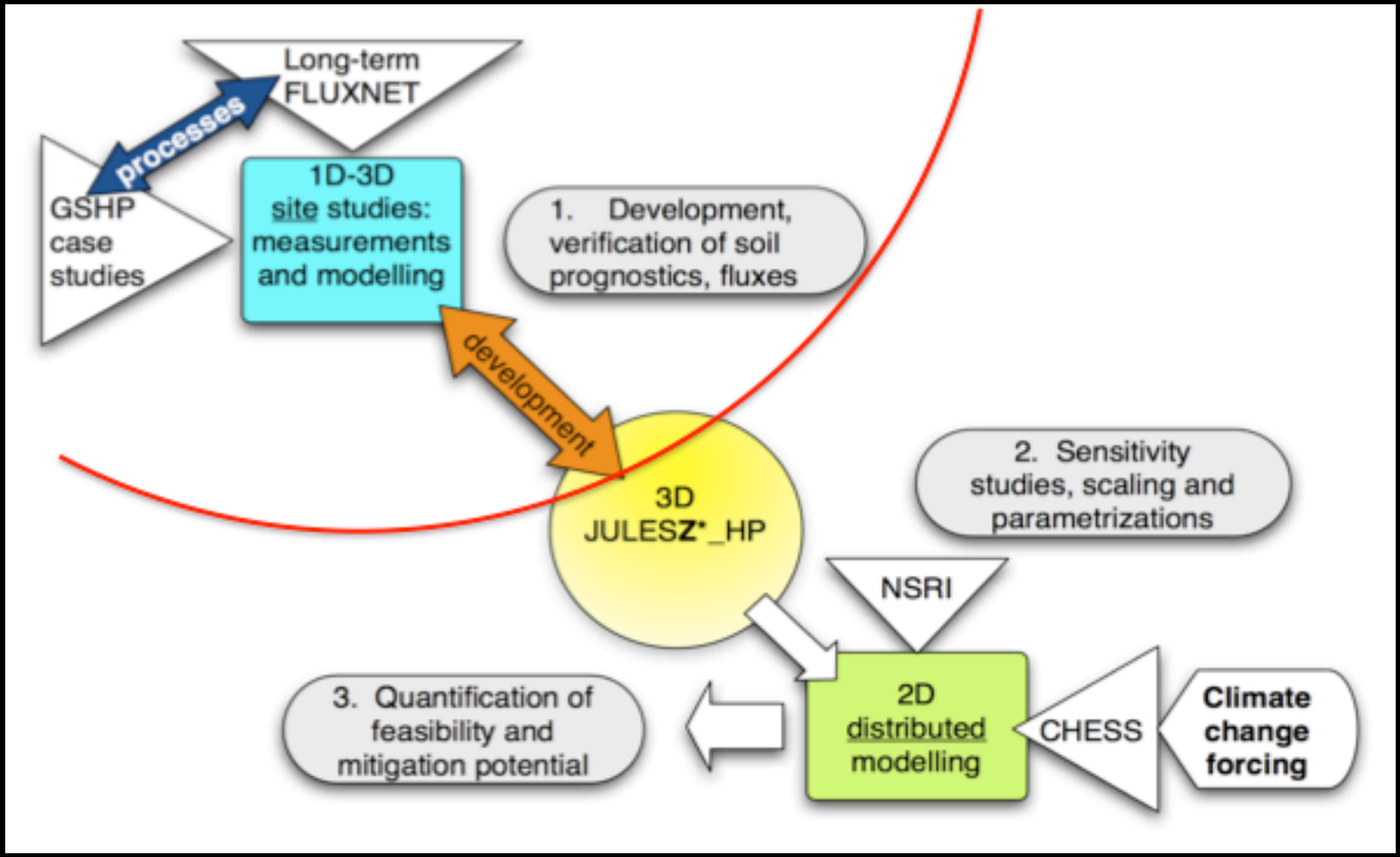
Average soil temp differences between the slinky and the reference profile for Drayton St Leonard

Preliminary studies, Drayton St Leonard, near Oxford



Average soil temp differences between the slinky and the reference profile for Drayton St Leonard

GROMIT rationale



Model simulation

- Verification (1D simulations)
- Sensitivity runs

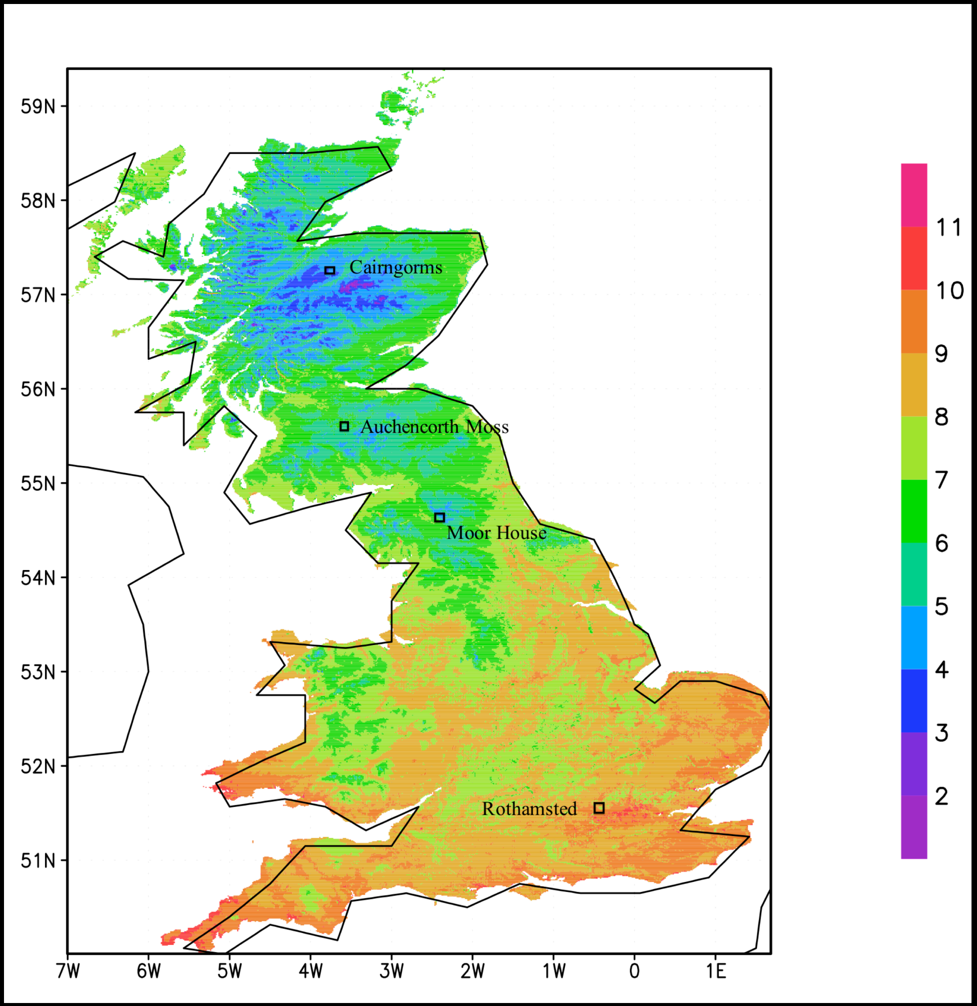
JULES-HP 1D sensitivity runs

1. Installation depth (1.0m, 1.5m and 2.0m)

2. Pipe configuration and loop spacing

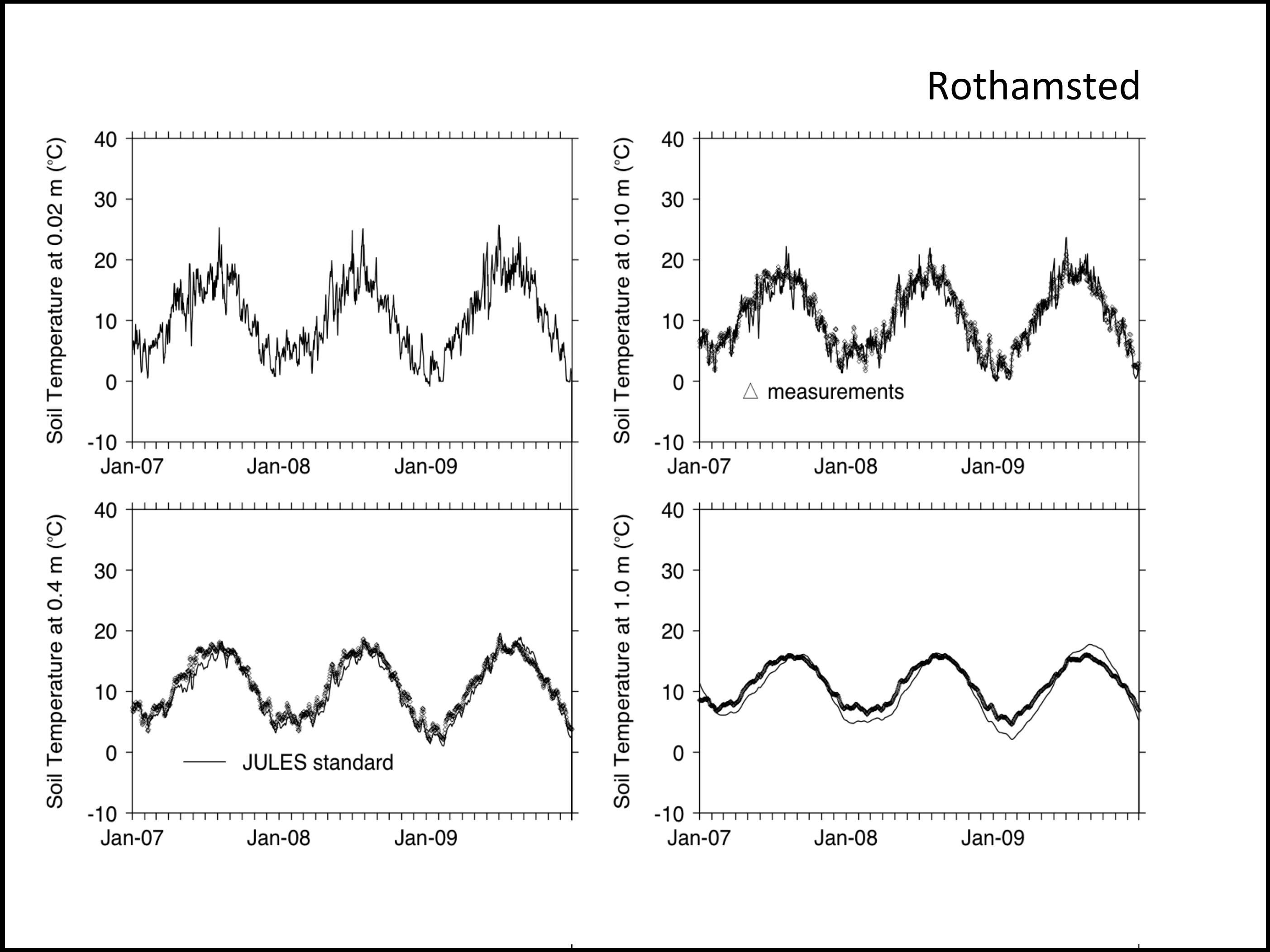
3. Fluid temperature T_f = 273 - 275 K

4. Soil texture

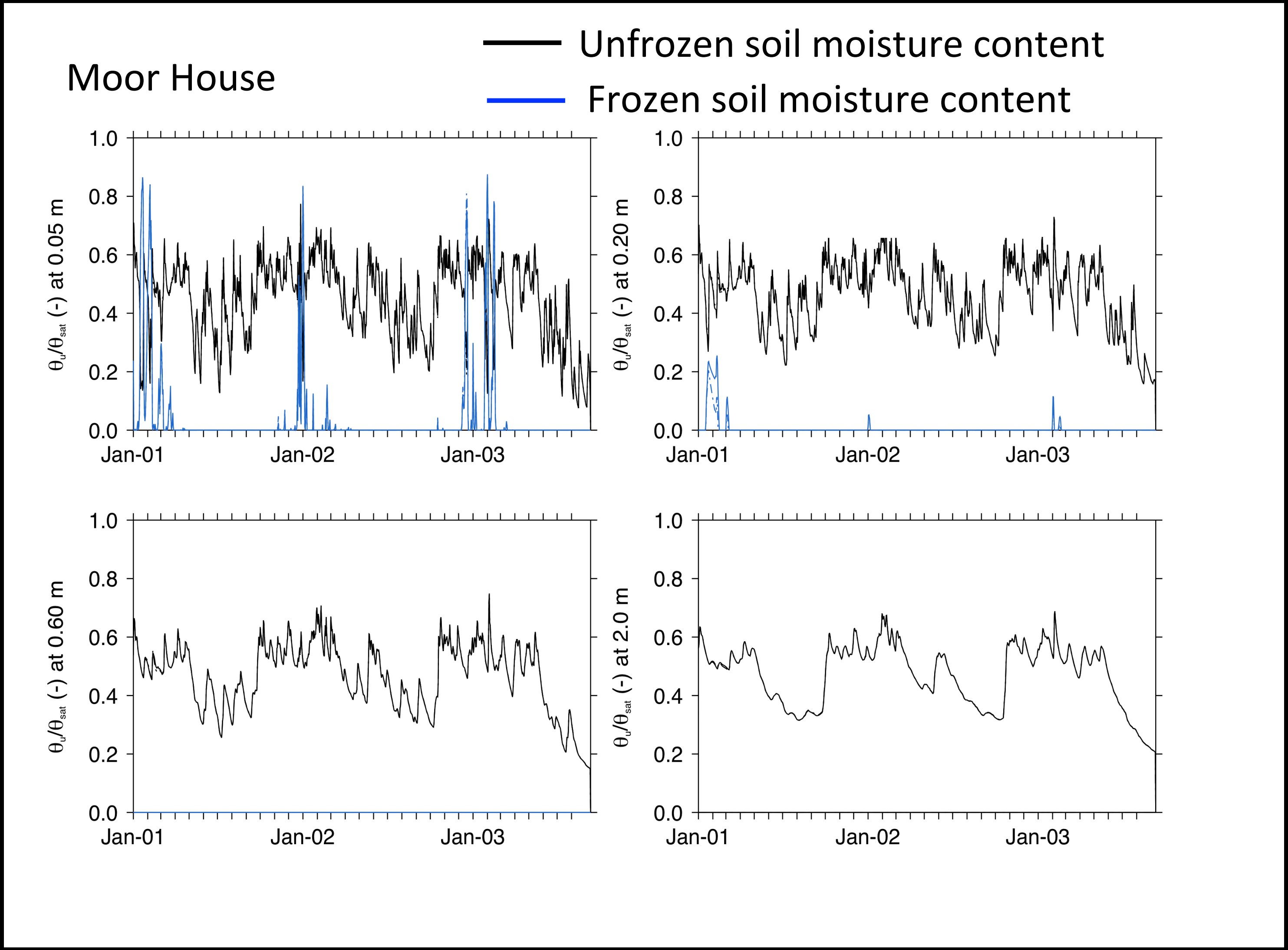


Courtesy of D. Clark, Soil temperature (average over 3m), December

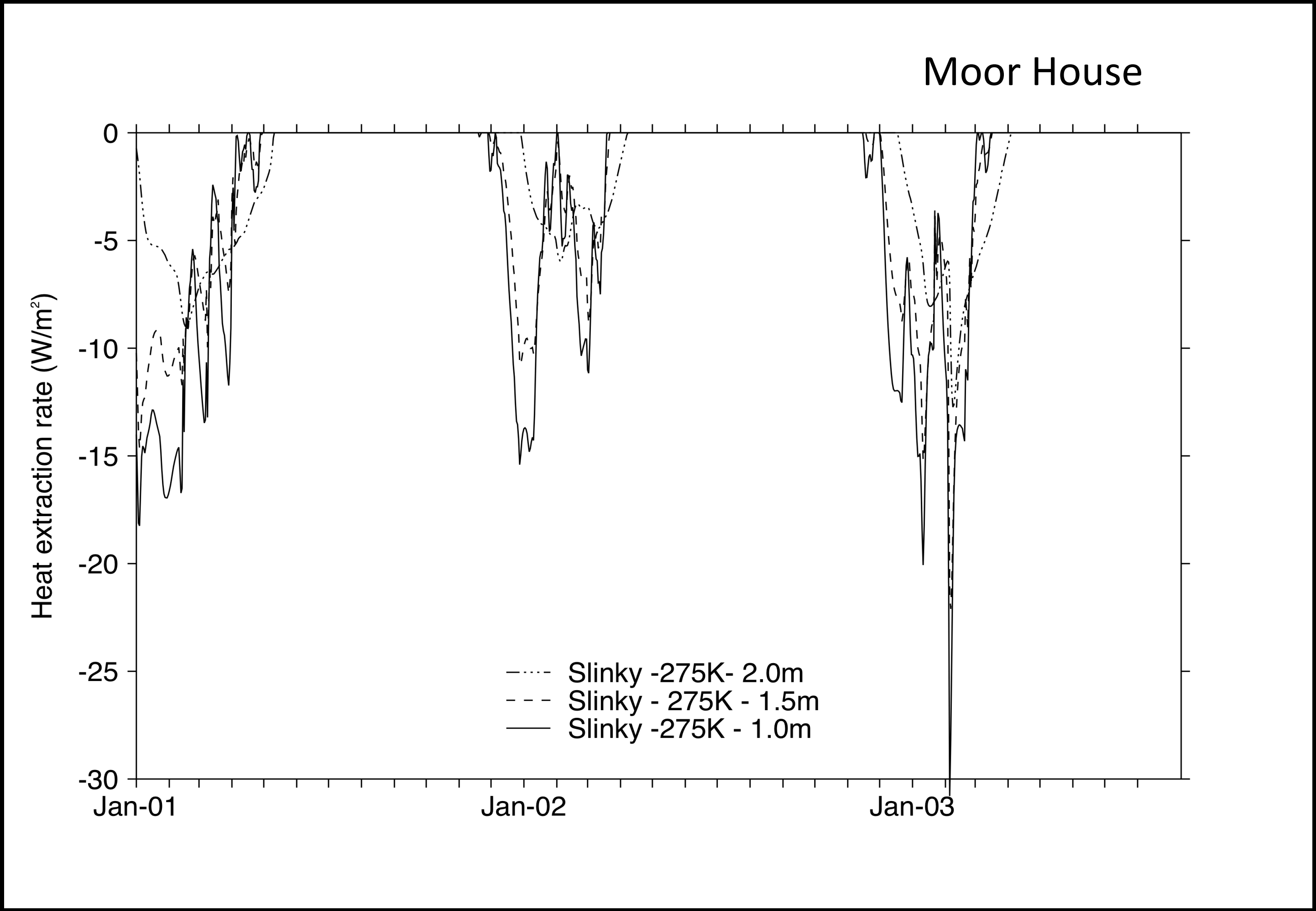
JULES-HP 1D sensitivity runs



JULES-HP 1D sensitivity runs

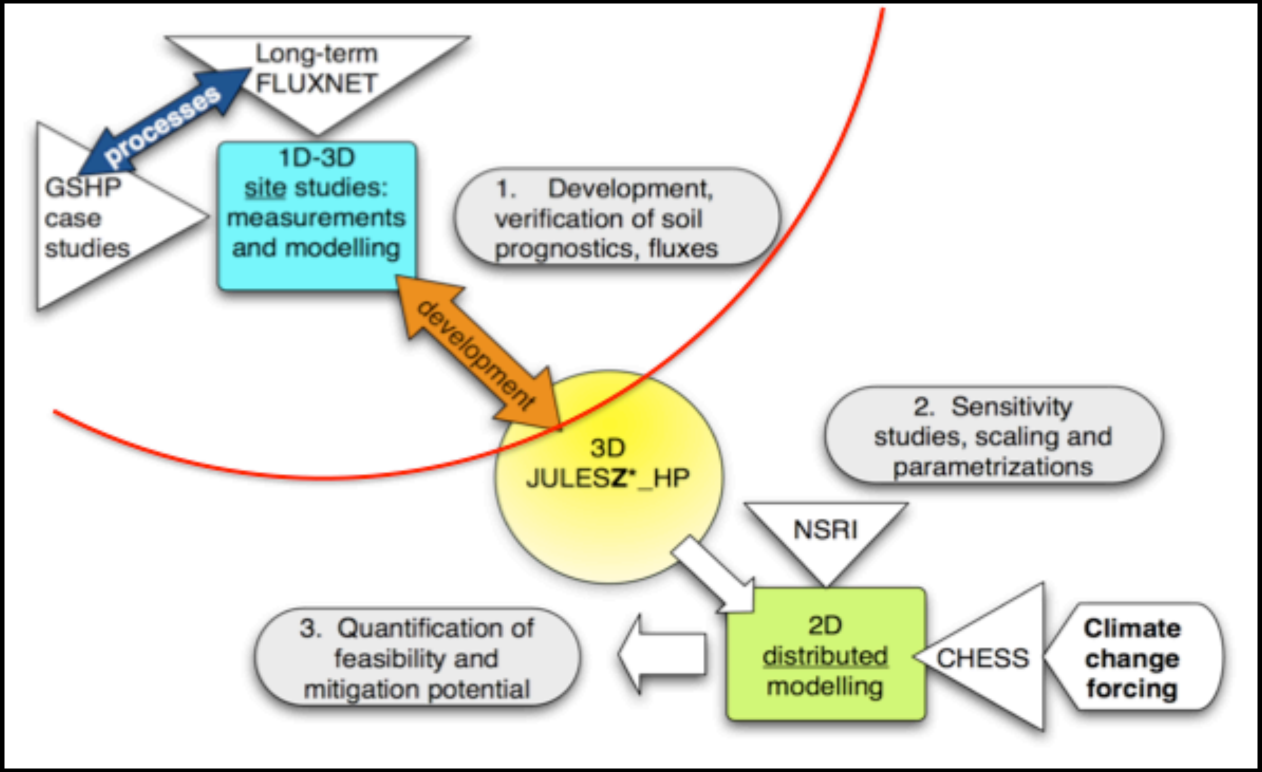


JULES-HP 1D sensitivity runs



Slinky coil diameters (D) = 1m
Spacing between coils (S) =1.5 m

JULES-HP CHESS runs



Model simulation

- Climate change impact
- Climate change scenarios (UKCIP)
- COP under future environmental conditions

CO_2 savings – Mitigation potential

Geothermal CO_2 emission (GCE, g/year)

$$GCE\left[\frac{g}{year}\right] = ED[KW]\cdot hours\left[\frac{hours}{year}\right]\cdot EM\left[\frac{gCO_2}{KWh}\right]$$

Conventional CO_2 emission (CCE, g/year)

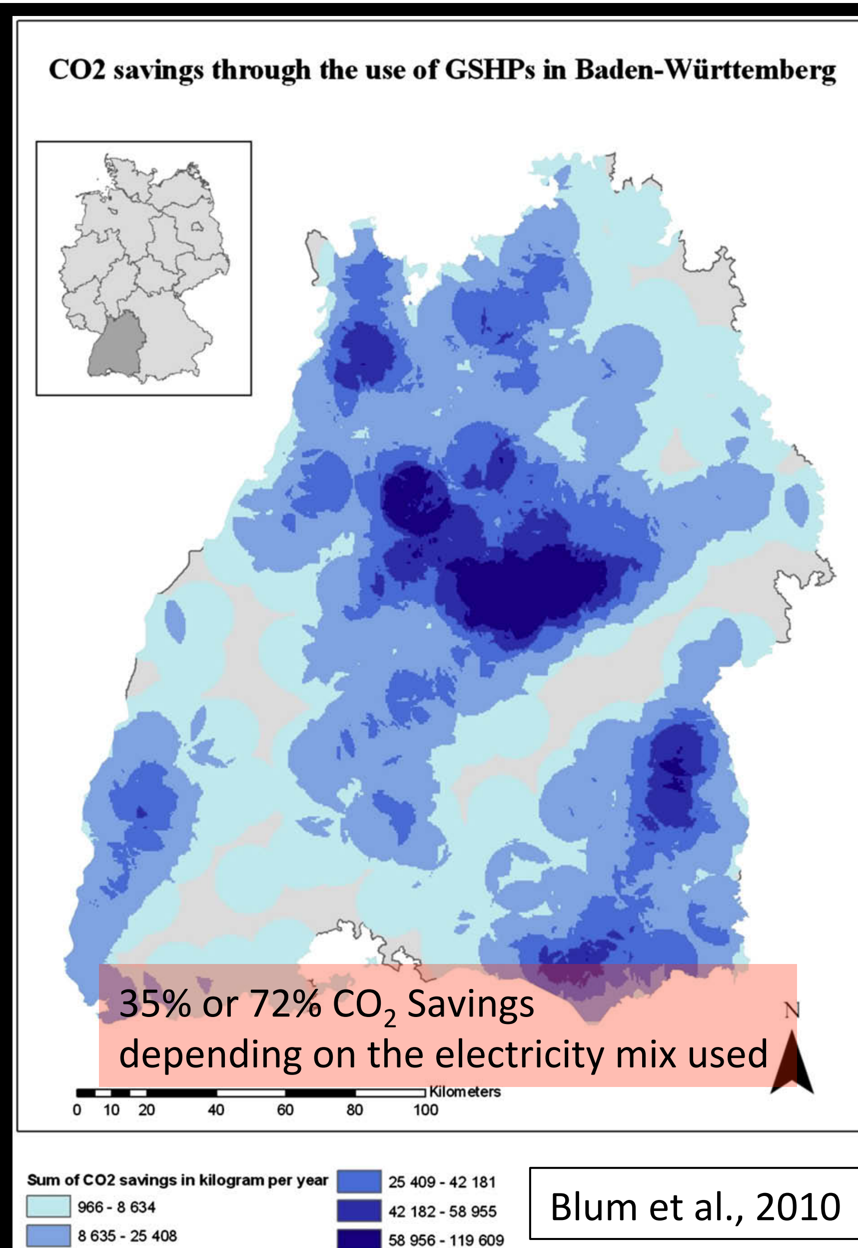
$$CCE\left[\frac{g}{year}\right] = HD[KW]\cdot hours\left[\frac{hours}{year}\right]\cdot EM\left[\frac{gCO_2}{KWh}\right]$$

CO_2 savings (CS, g/year)

$$CS\left[\frac{g}{year}\right] = GCE\left[\frac{g}{year}\right] - CCE\left[\frac{g}{year}\right]$$

i.e. A heat pump of ~10KW_{th} installed in Reading is able to produce approximately 21000KWh heat annually >>

CO_2 savings ~ 2500 Kg/year



35% or 72% CO_2 Savings depending on the electricity mix used

Blum et al., 2010

Conclusions – Recommendations

- Installation depths at 1.0m give us higher heat extractions rates, however it would be preferable to install the pipes slightly deeper to avoid the influence by variable meteorological conditions

- A value of 1.5m for the spacing between coils is recommended to avoid disturbances between the neighbours coils

- For larger values for the spacing between the coils (S=2m, S=3), a slightly smaller slinky coil diameter would be better (0.8m)

- The fluid temperature of the pipe will have a direct effect on the heat extraction rates of the system

- The coefficient of performance of a heat pump will not remain constant and will depend on the operating conditions and outdoor temperatures


THANKS!