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Horizontal systems - Theory, tools and Design

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Introduction

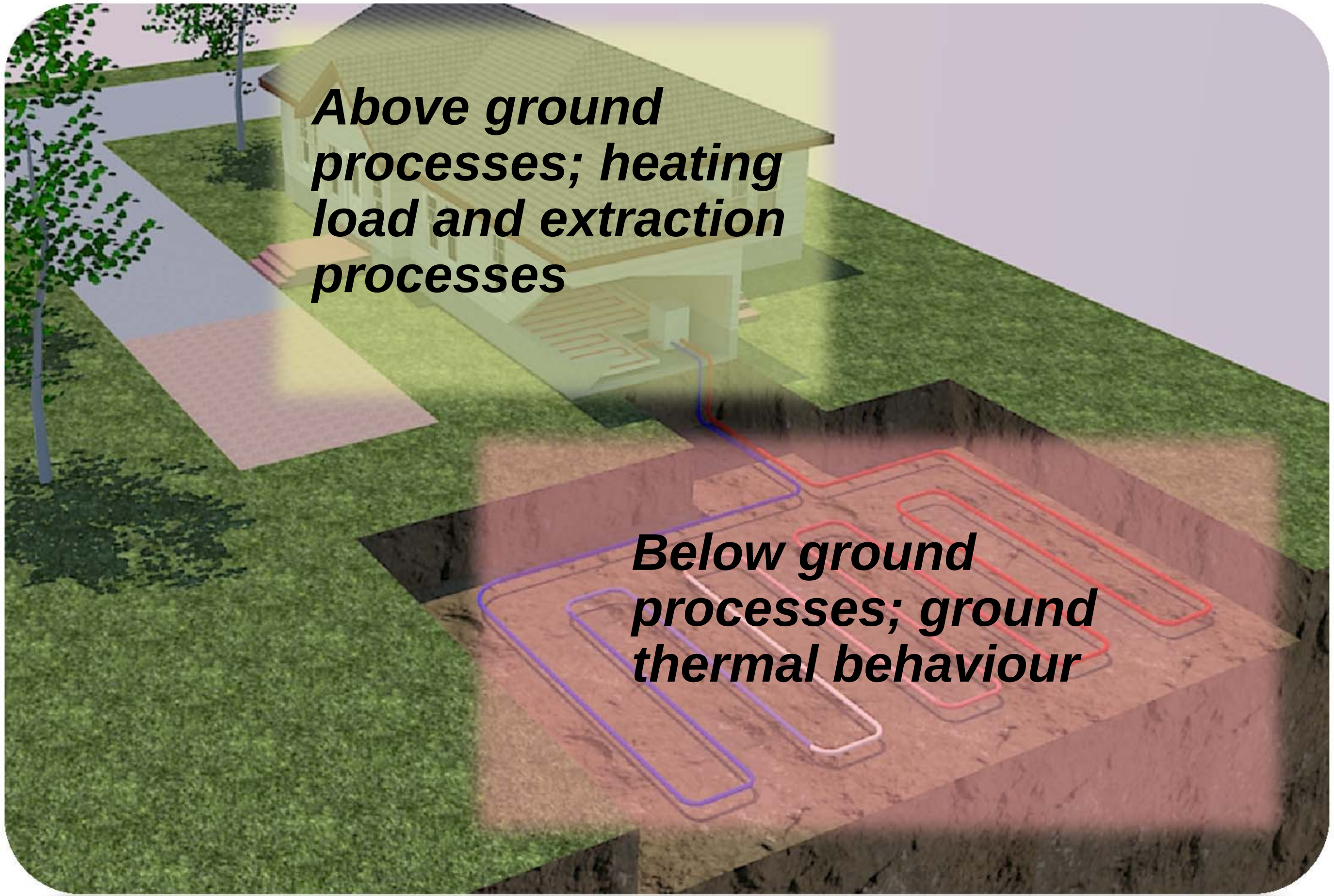
Research AIM : *Improve knowledge related to the ground thermal behaviour due to heat extraction from GSH systems*

Work can be sub-divided into two categories, namely:

i)	Experimental investigation –	*Knowledge obtained from a horizontal ground loop site located in Powys, Mid-Wales*
ii)	Numerical investigation –	*Numerical simulations investigating the behaviour and subsequent sensitivity analysis*

Introduction

Our focus is mainly on the ground behaviour, not the above ground processes

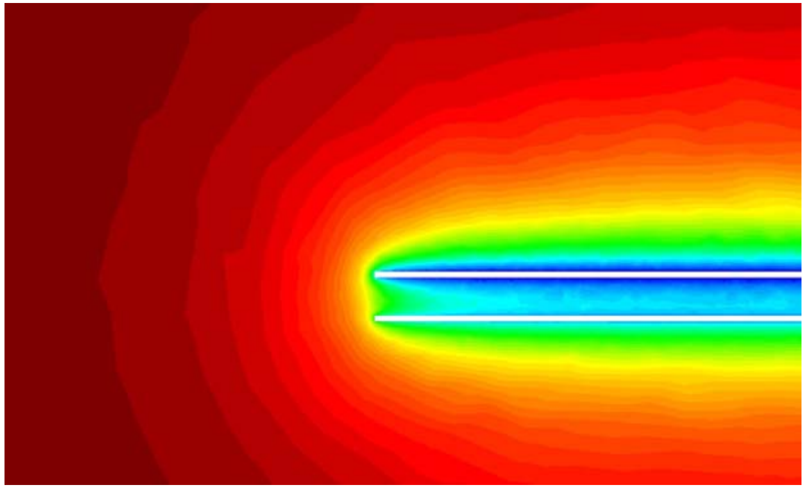


Model Development

- Development of the numerical model COMPASS
  - Couple heat, moisture, mechanical and chemical behaviour
  - Previously developed to investigate the heat, moisture, mechanical and chemical behaviour in unsaturated soils
  - Applied to a range of geoenvironmental problems
  - Based on finite element and finite difference approach

- Development of boundary conditions related to ground source heat
  - The ground loop boundary
  - The surface boundary

- Verification and Validation with experimental data
  - Verification against various alternative solutions
  - Using experimental data from monitored site



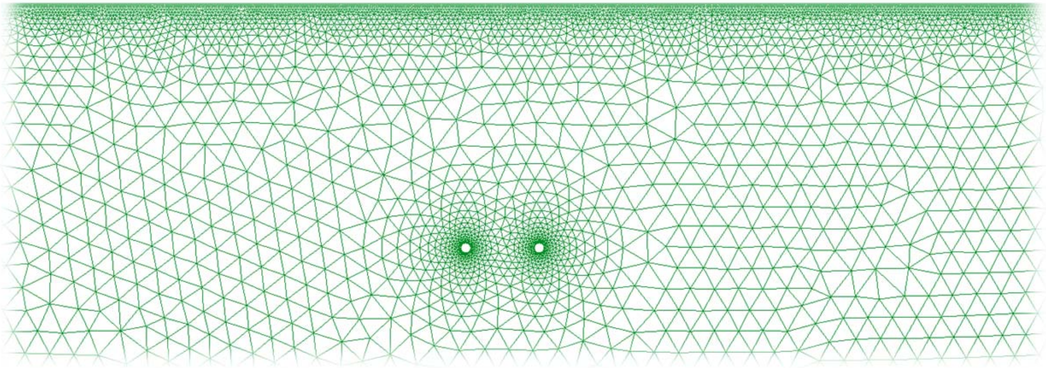
Example simulation results showing the temperature distribution around a horizontal system

Factors to be considered when modelling

- Boundary conditions to prescribe
  - Ground loop boundary
  - Surface boundary

- Analysis type and model domain
  - Type, i.e. 2D or 3D
  - Size of the domain
  - Mesh density

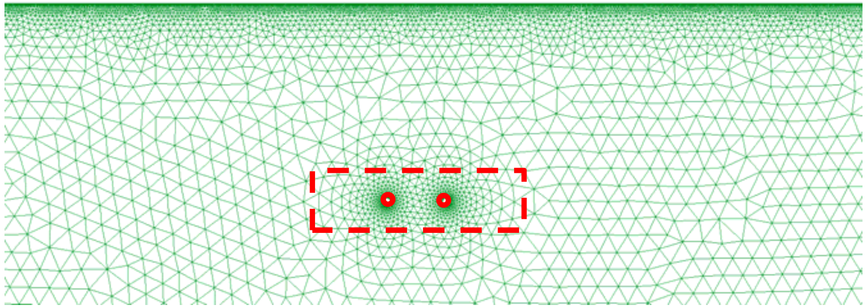
- Material properties
  - Thermal conductivity, $Wm^{-1}K^{-1}$
  - Specific heat capacity, $Jkg^{-1}K^{-1}$



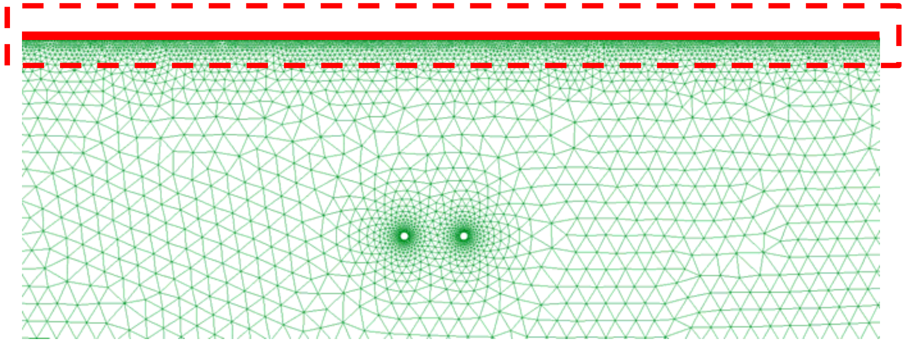
Section of a two dimensional mesh used to model the ground response from a horizontal GSH system

Boundary considerations – Horizontal ground loops

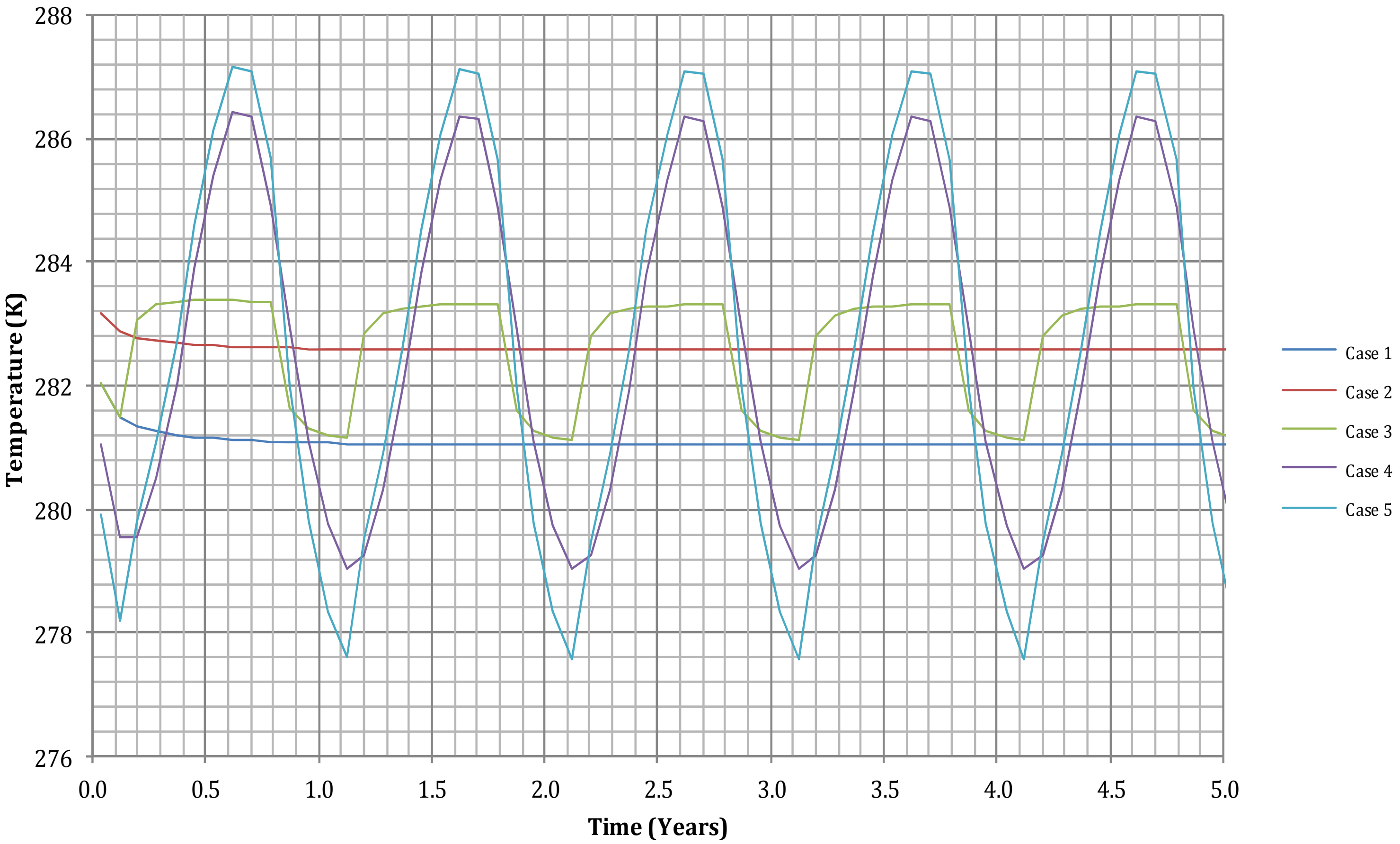
- Ground loop can be represented in a number of ways, with varying complexity:
  - Uniform steady or transient heat flux, Wm^{-2}
  - Non-uniform steady or transient heat flux, Wm^{-2}



- Ground surface boundary
  - Fixed temperature only
  - Radiation heat only
  - Coupled radiation and mass transfer



Boundary considerations – Ground loop surface



Surface Boundary Development – A coupled heat and mass

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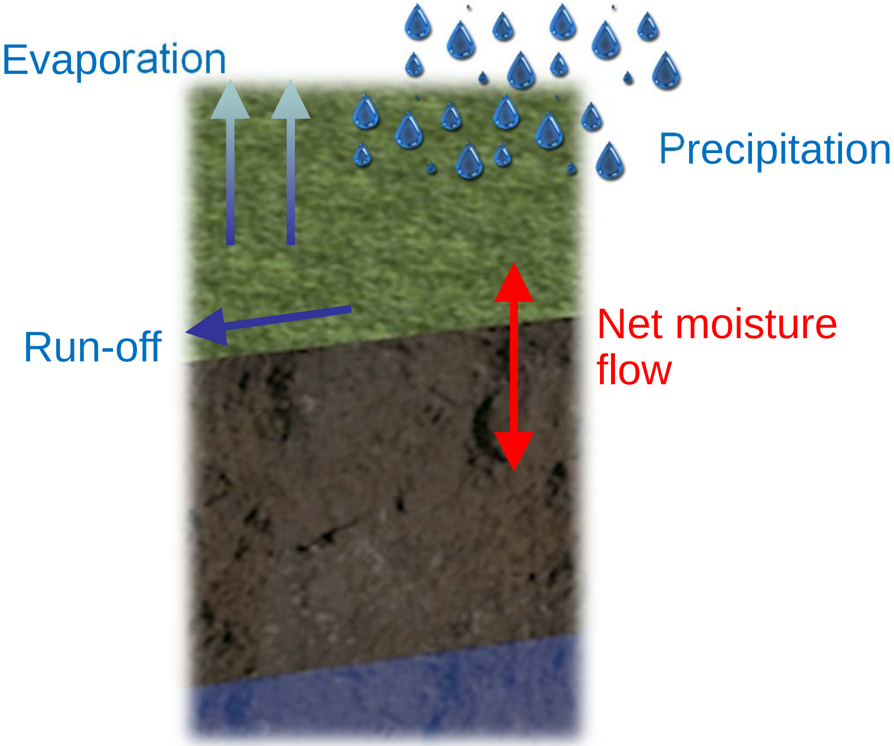
Why develop and apply a heat and mass surface boundary?

1. Latent heat flux component associated with evaporation
2. <u>Water transfer in the ground</u>



Coupled Heat and Mass Surface boundary: Energy Balance Equation

$$S_{Flux} = H_{SW} + H_{Net\ LW} + H_{SO} + H_{LE}$$

where:

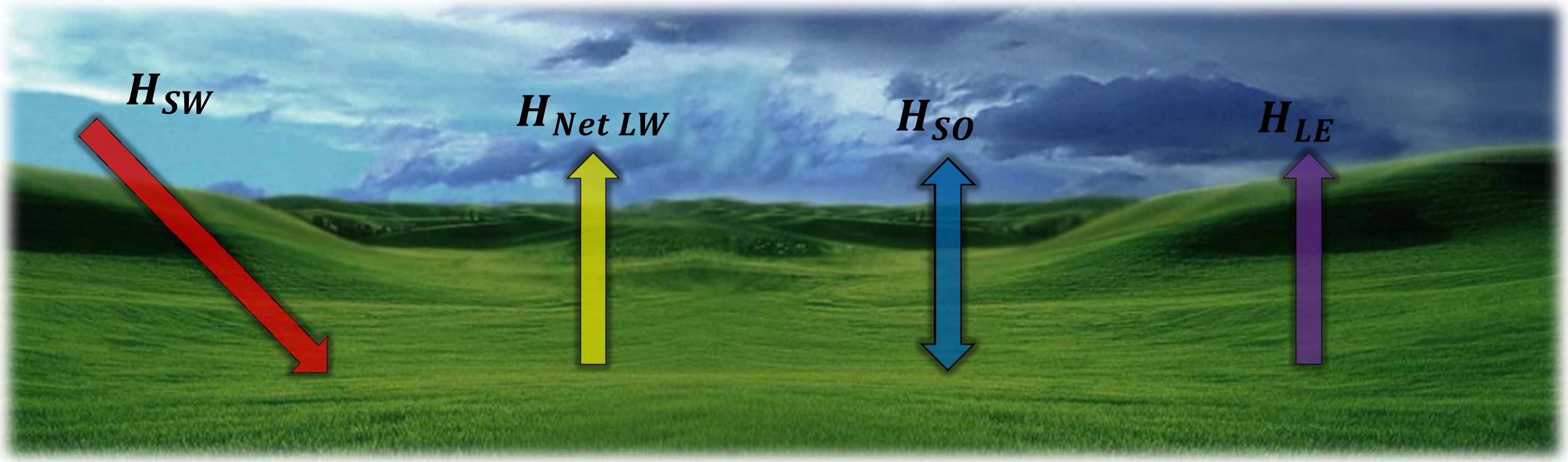
S_{Flux} = *Overall surface heat flux, W m^{-2}*

H_{SW} = *Shortwave solar radiation, W m^{-2}*

$H_{Net\ LW}$ = *Net longwave radiation, W m^{-2}*

H_{SO} = *Sensible heat transfer, W m^{-2}*

H_{LE} = *Latent heat transfer, W m^{-2}*



Coupled Heat and Mass Surface boundary: Latent Heat Calculation

$$H_{LE} = L.E$$

where:

L = *Latent heat of vaporization, J kg^{-1}*

E = *Water vapor flux, kg m^{-2}S^{-1}*

**Latent heat of vaporization for water is 2260 KJ kg^{-1} at sea level*

$$E = \rho_a\, f(u)\,(q_a - q_s)$$

where:

ρ_a = *Air density, kg m^{-3}*

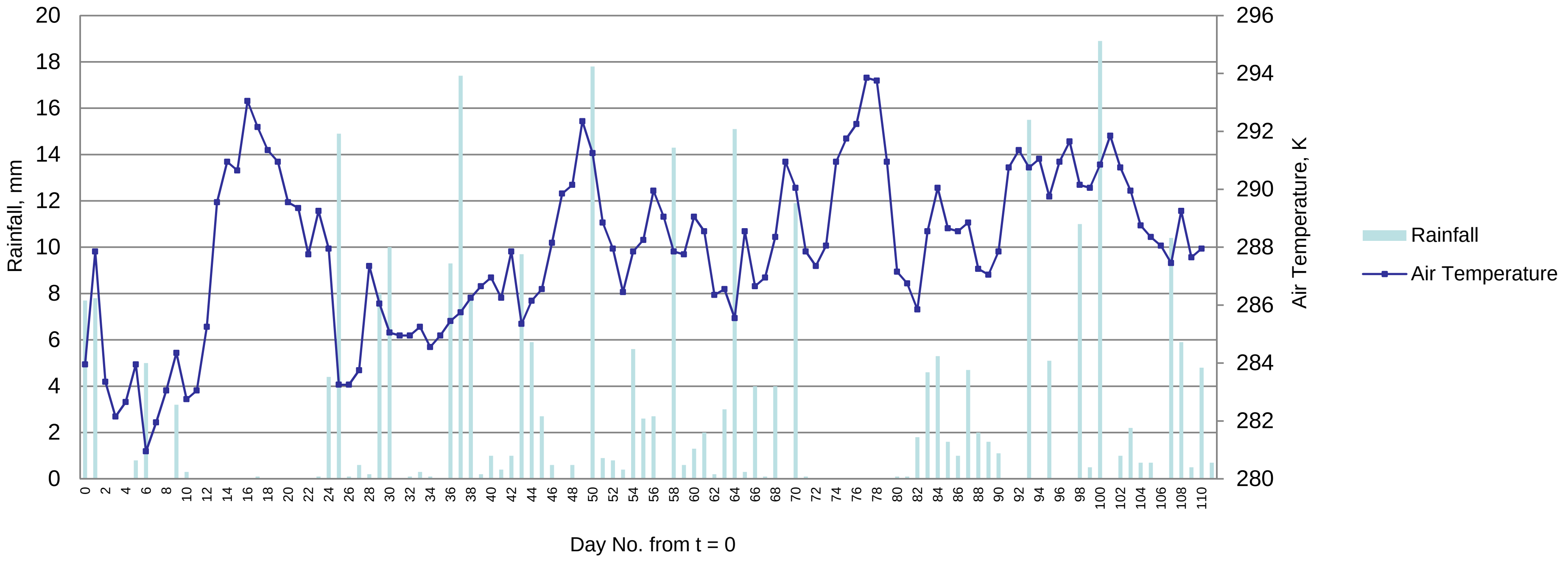
$f(u)$ = *Transition function, non-dimensional*

q_a = *Air specific humidity, kg kg^{-1}*

q_s = *Soil surface specific humidity, kg kg^{-1}*

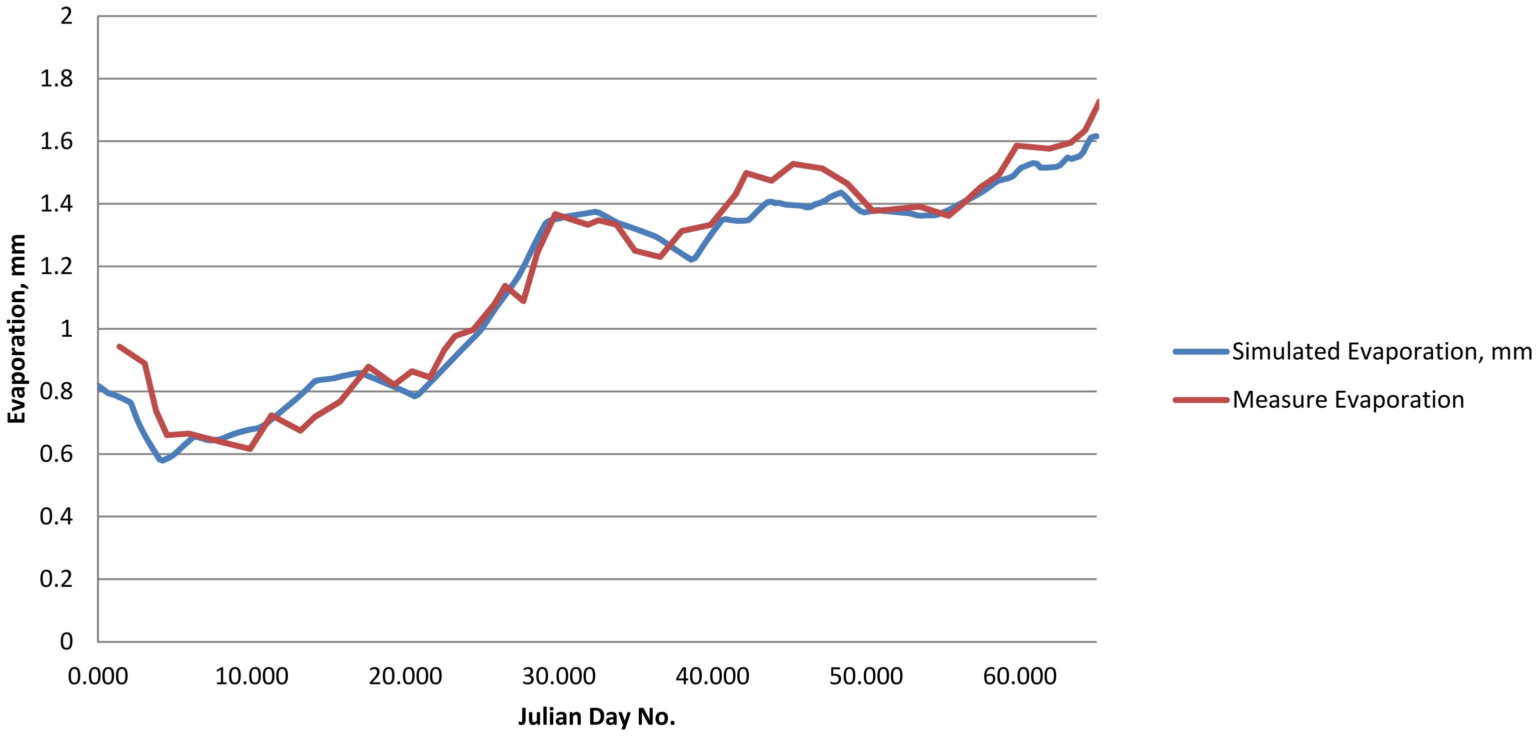
Coupled Heat and Mass Surface boundary: Model Application

Inclusion of the surface boundary theory in COMPASS



Coupled Heat and Mass Surface boundary: Model Validation

Initial validation of the mass component of the developed boundary



Further developments – High Performance Computing

- Coupled heat and mass simulations will have *double* the number of freedoms than a heat only simulation
- Results in larger a system matrix and therefore more computational effort is required
- The domain size and simulation duration can become a problem

- Methods to reduce computational times…
  - *Reducing mesh size*
  - *Serial code optimisation*
  - *Application of iterative solvers*
  - *High performance computing (HPC)*
    - *Parallel computational method*

Intel quad core processor Q9300

SEREN: Where next?

Experimental project progress…

Experimental site development & installation

Data retrieval

Numerical project progress…

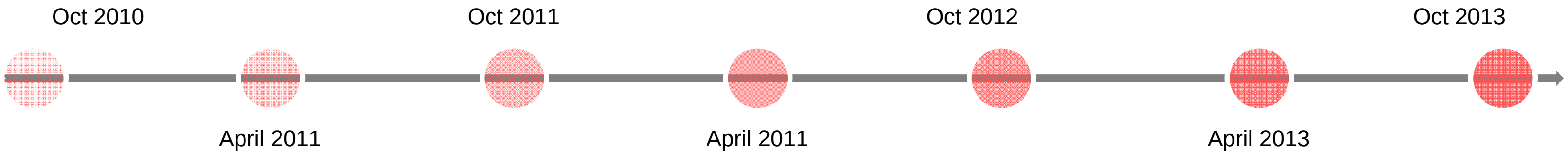
Boundary development

Parallel computing development

Validation

Long term analysis and simulations

Sensitivity analysis



Oct 2010

April 2011

Oct 2011

April 2011

Oct 2012

April 2013

Oct 2013

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Many Thanks

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