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The Effect of Unheated Sections on Moisture Transport in the Emplacement Drift

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General Objectives

- Prepare Thermal Hydrological Near-Field/In-Drift Model
  - Develop a multi-scale, coupled seepage model that accounts for natural convection processes in the emplacement drifts
  - Use TOUGH2 code for rock mass and MULTIFLUX code for in-drift processes
  - Apply an efficient NTCF methodology for coupling in-rock and in-drift model elements
  - Study two application scales:
    - Mountain-scale/drift-scale model to provide temperature and relative humidity evolutions along representative drifts
    - Small-scale, high-resolution seepage model to evaluate evaporation impact on seepage predictions
- Study the Impact of Natural Convection on Seepage with

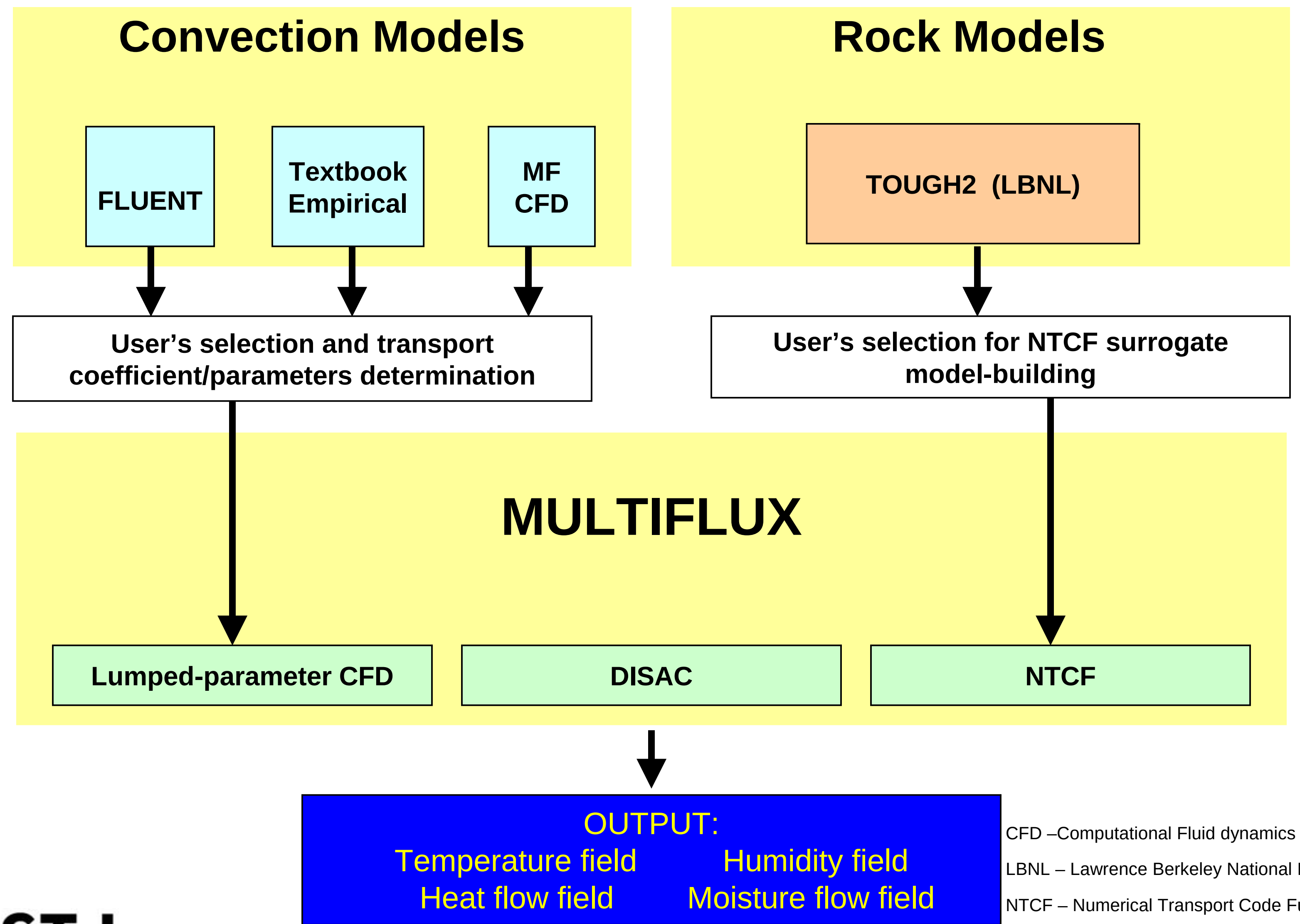
→ Less conservatism in seepage predictions

→ More realistic performance estimate of natural barrier

Goals of Current Study

- **Configure a thermal-hydrological – natural-ventilation model for simulating temperature, humidity, and condensate distributions in the coupled domains of in-drift airspace and near-field rockmass. Rokmass model: TOUGH2, in-drift model: MULTIFLUX (MF)**
- **Obtain meaningful results from the model for a practical application in which the beneficial effects of unheated drift sections are analyzed.**
- **Study the sensitivity to the axial dispersion coefficient with the model.**

Coupled Modeling with MULTIFLUX and TOUGH2

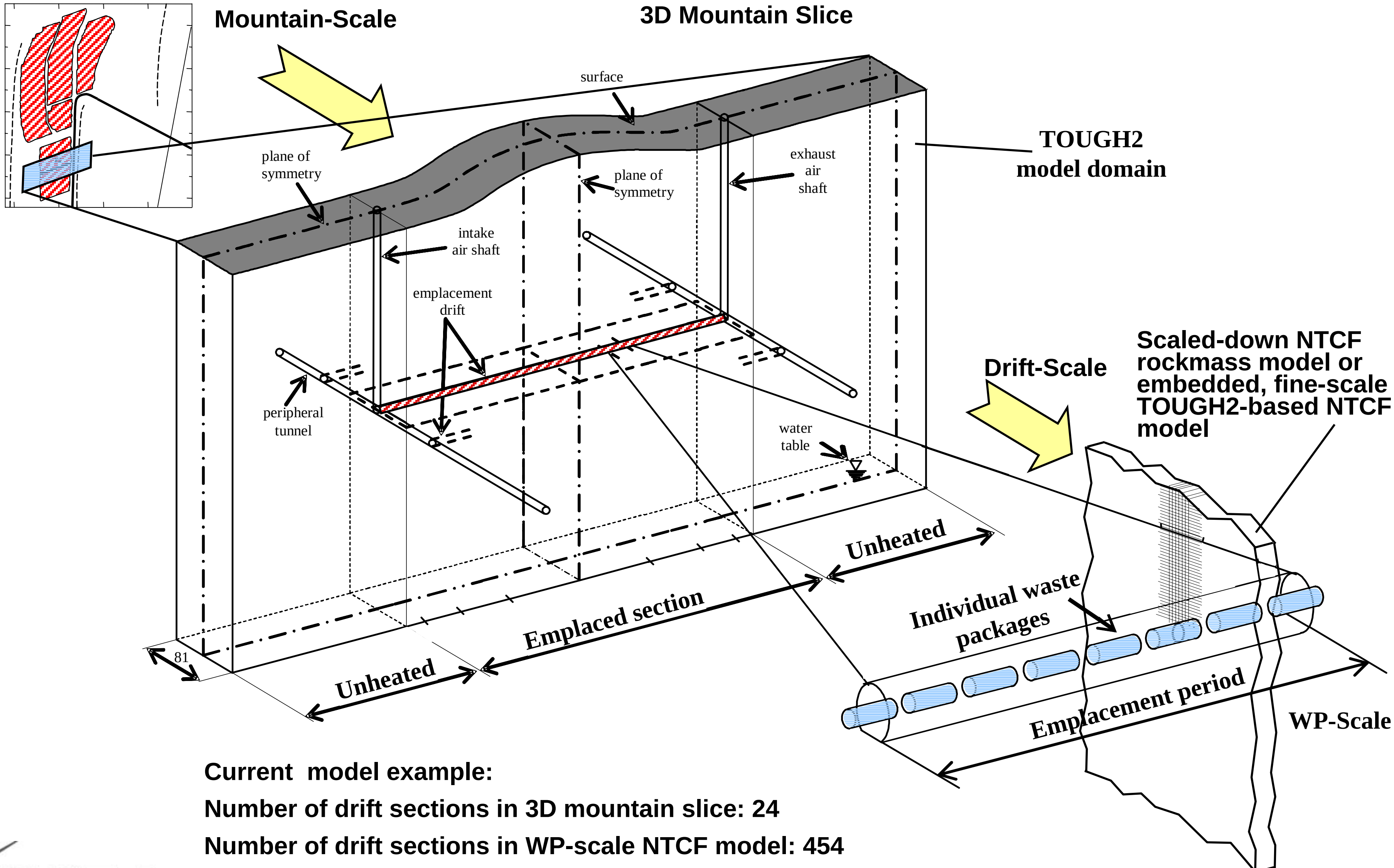


CFD –Computational Fluid dynamics

LBNL – Lawrence Berkeley National Laboratory

NTCF – Numerical Transport Code Functionalization

Mountain-Scale-to-Drift-Scale Model



Current model example:

Number of drift sections in 3D mountain slice: 24

Number of drift sections in WP-scale NTCF model: 454

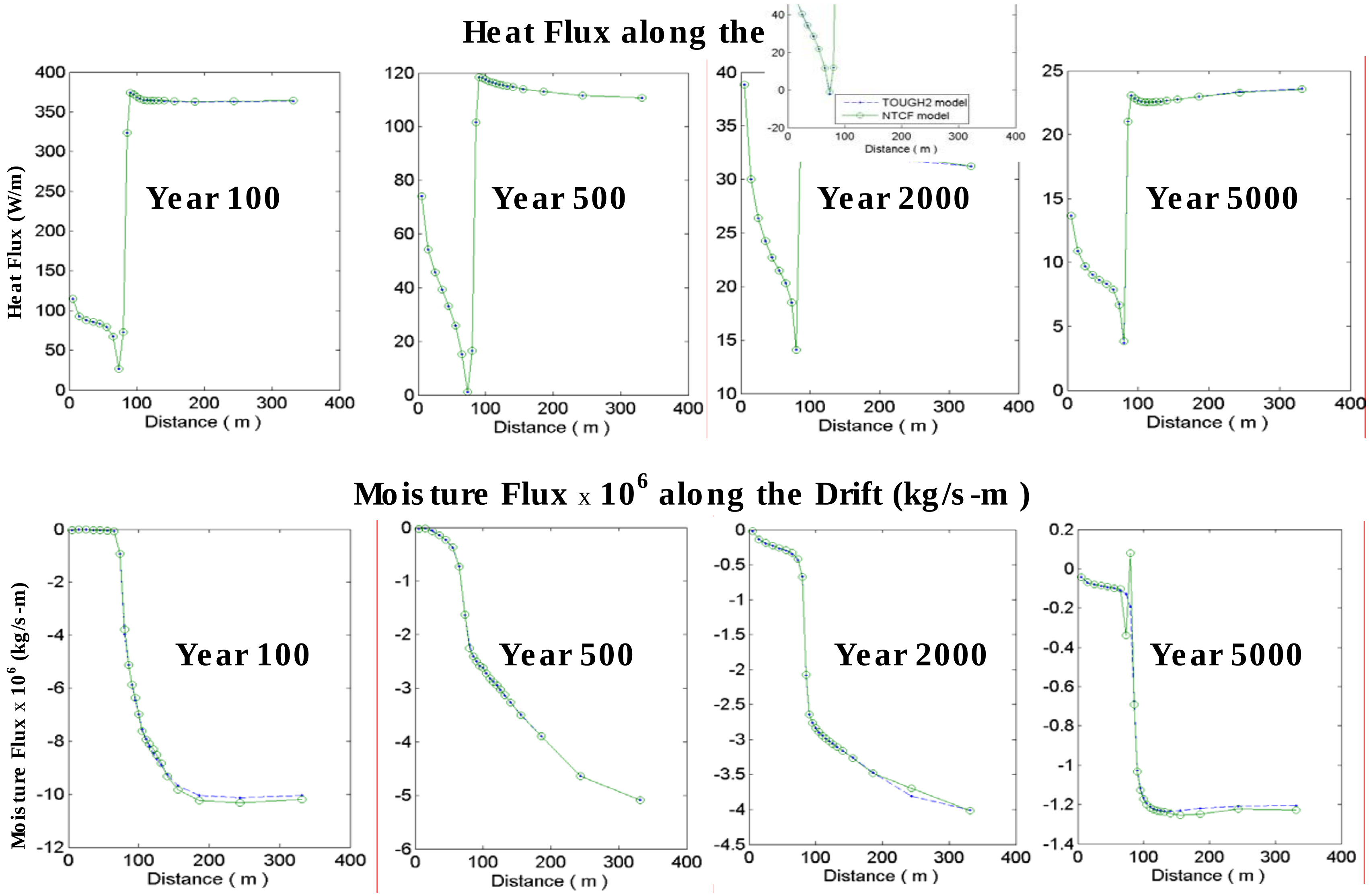
Mountain-Scale NTCF matrix model

$$qh = qh^c + hh \cdot \left(T - T^c\right) + \langle T \rangle \cdot hm \cdot \left(P - P^c\right)$$

$$qm = qm^c + mh \cdot \left(T - T^c\right) + \langle T \rangle \cdot mm \cdot \left(P - P^c\right)$$

- T , P : wall temperature and partial vapor pressure vectors
- qh, qm : heat and moisture fluxes from TOUGH2
- T^c , P^c : central input boundary conditions
- qh^c, qm^c : central output fluxes from TOUGH2, for $T=T^c$ and $P=P^c$
- hh , hm : dynamic admittance matrices for heat flow
- mh , mm : dynamic admittance matrices for moisture flow

NTCF Model Fit Against Input TOUGH2 Data



Energy Balance Equation in the CFD Model of MF

The energy balance equation in the CFD model of MF for “x” directional flow in “dy” by “dz” cross-section is:

$$\rho c \frac{\partial T}{\partial t} + \rho c v_i \frac{\partial T}{\partial x} = \rho c a \frac{\partial^2 T}{\partial x^2} + \rho c a \frac{\partial^2 T}{\partial y^2} + \rho c a \frac{\partial^2 T}{\partial z^2} + \dot{q}_h$$

where,

v_i - *velocity*

ρ - *density of moist air*

c - *specific heat of moist air*

$\dot{q}_h$ - *latent heat source or sink for condensation or evaporation*

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Moisture Transport Convection-Diffusion Equation in the CFD Model of MF

The simplified moisture transport convection-diffusion equation in the CFD model of MF for “x” directional flow in “dy” by “dz” cross-section is**:**

$$\frac{\partial \rho_v}{\partial t} + v_i \frac{\partial \rho_v}{\partial x} = D\frac{\partial^2 \rho_v}{\partial x^2} + D\frac{\partial^2 \rho_v}{\partial y^2} + D\frac{\partial^2 \rho_v}{\partial z^2} + \dot{q}_{cm} + \dot{q}_{sm}$$

where,

v_i - *velocity*

D - *molecular or eddy diffusivity for vapor*

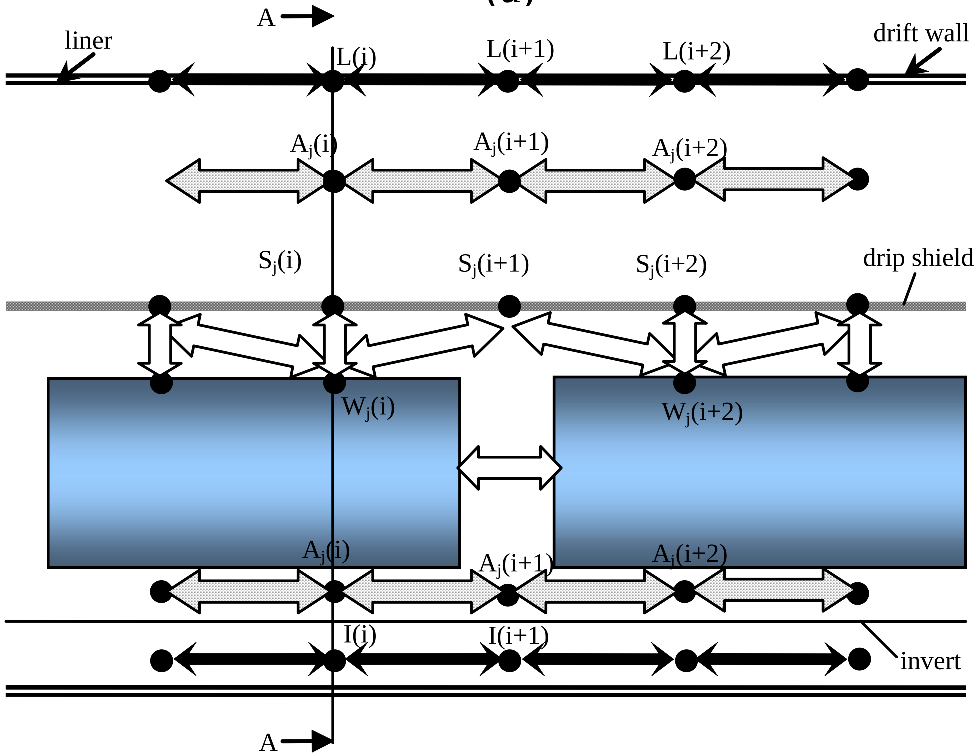
$\dot{q}_{sm}$ - *moisture source or sink due to condensation or evaporation*

$\dot{q}_{cm}$ - *vapor flux in superheated steam form*

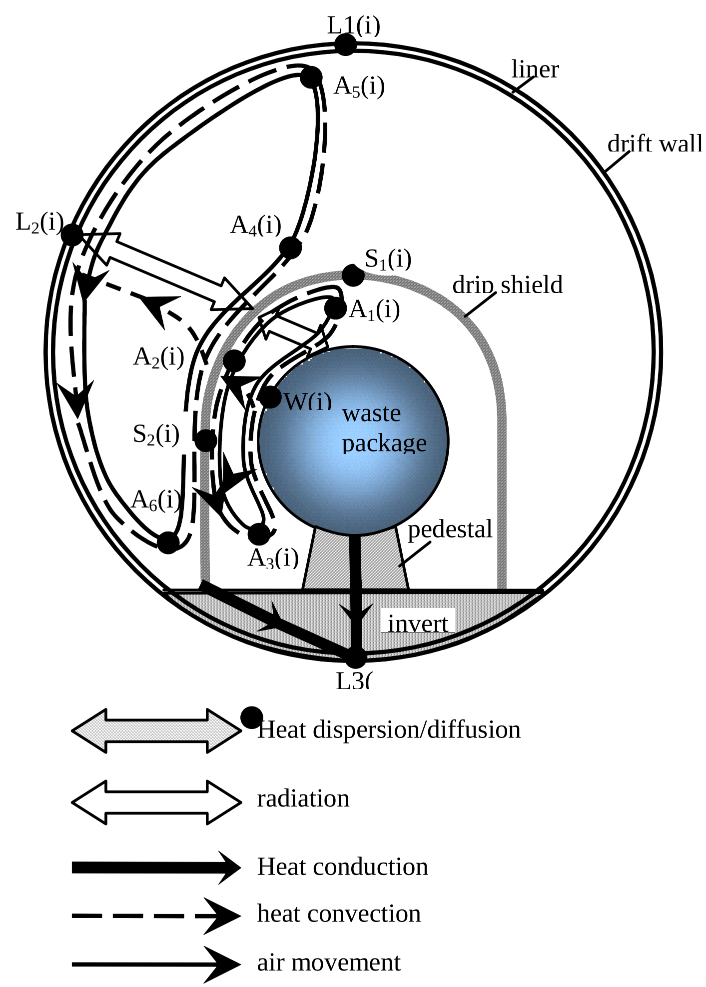
In-Drift Lumped-Parameter CFD Model Concept

In-Drift Heat Flow Processes (Simplified Diagram)

(a)

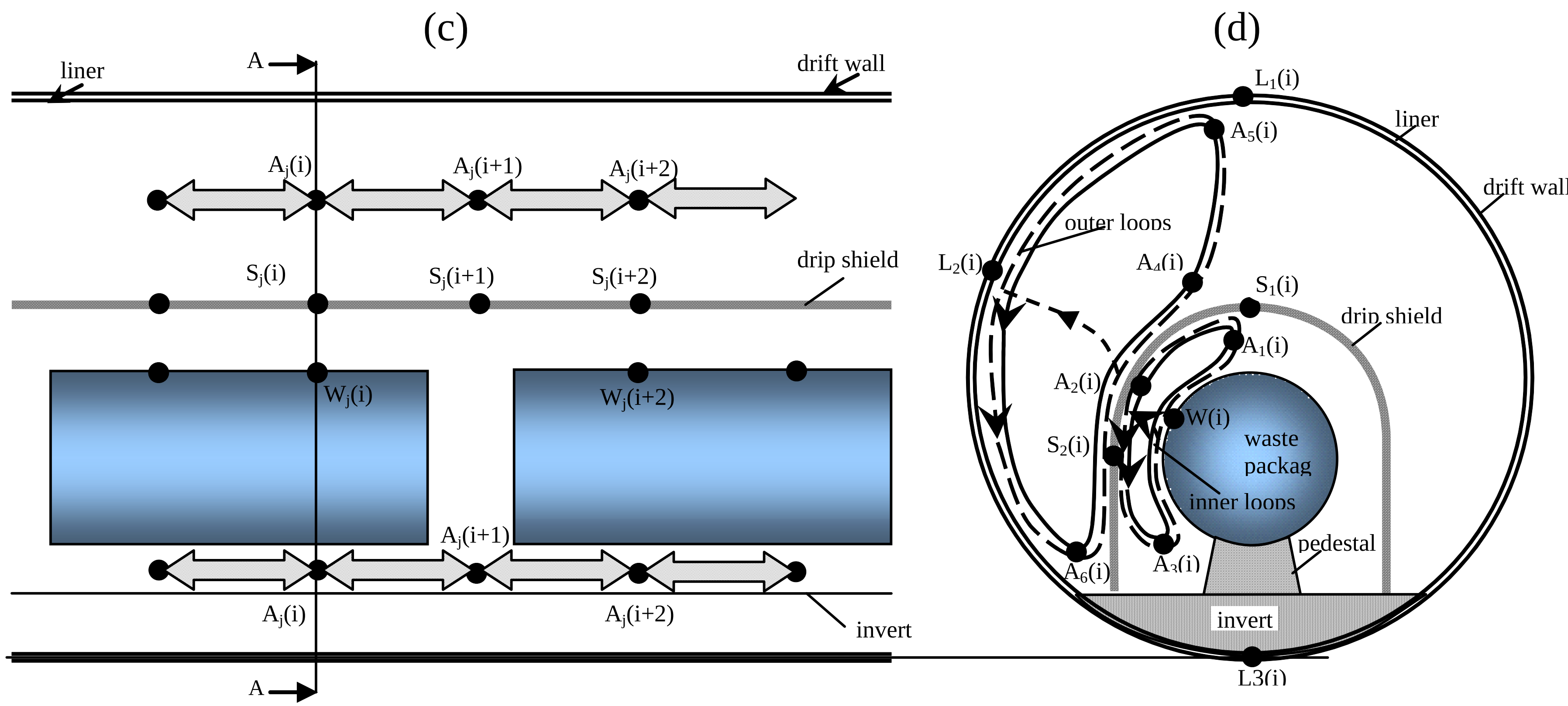


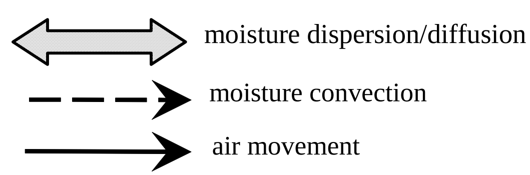
(b)



a_j : air nodes j=1,2, … 6
W : waste package nodes
L : liner nodes
I : invert nodes
S : drip shield nodes

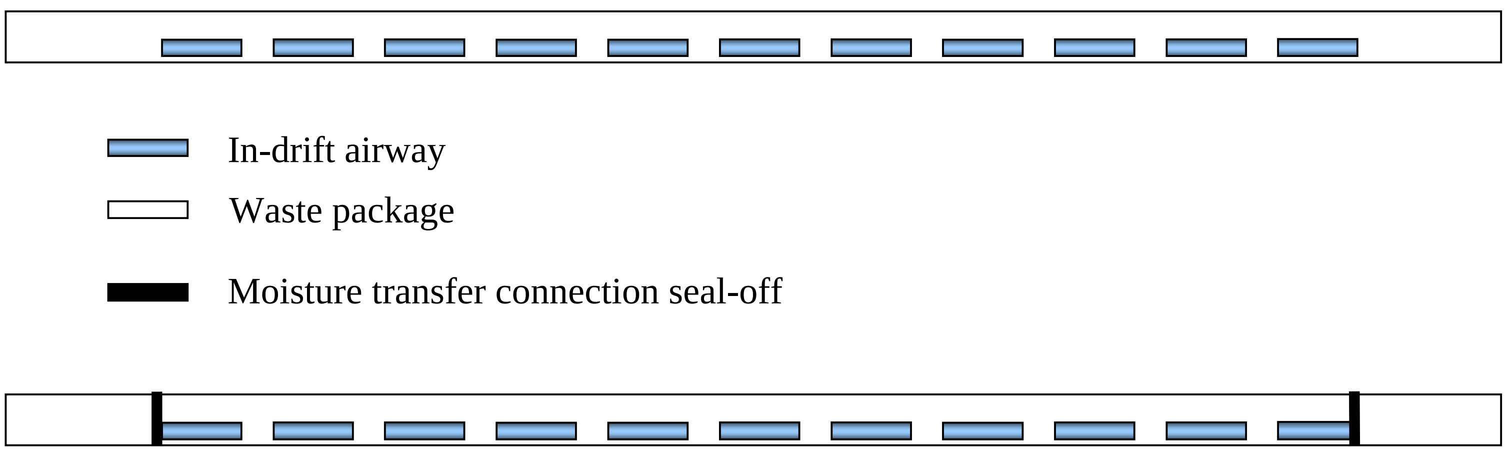
In-Drift Moisture Flow Processes (Simplified Diagram)



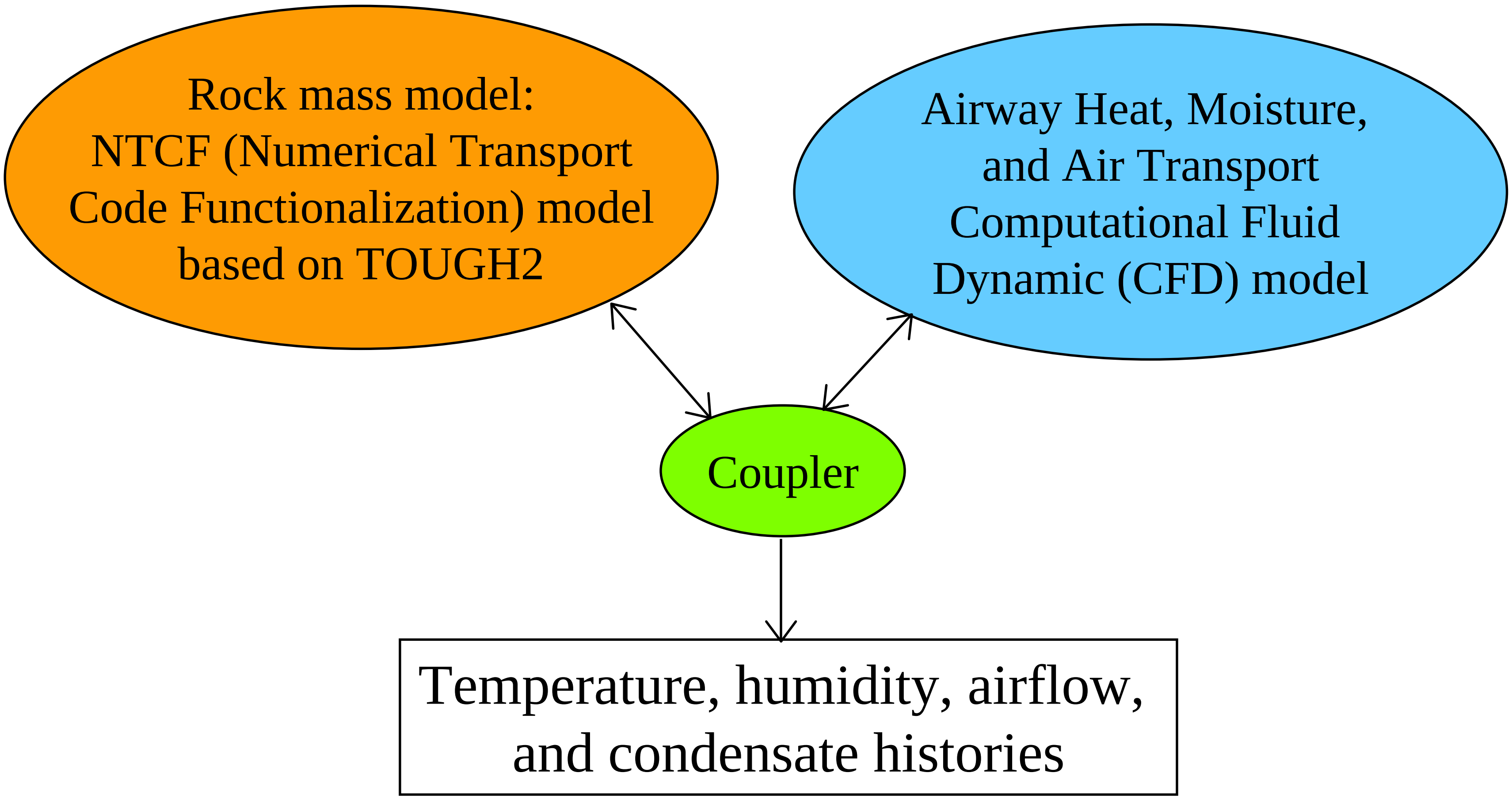


A_j : air nodes j=1,2, … 6
W : waste package nodes
S : drip shield nodes

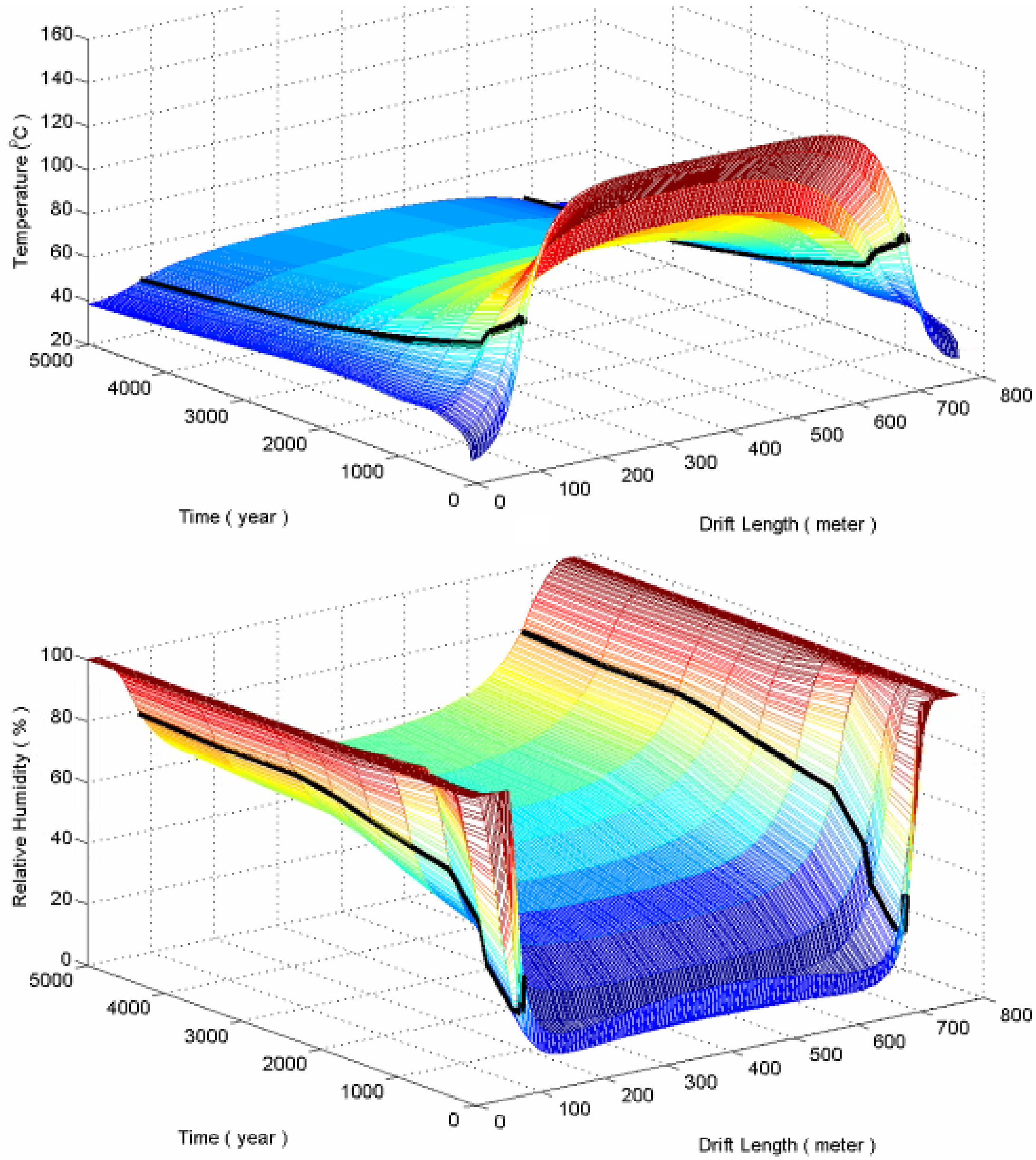
Sectional view of the emplacement drift with un-sealed and sealed-off unheated sections



Simplified Logic Flow Chart of Coupling In-Drift CFD and In-Rock NTCF Model Elements



Results: Temperature and Relative Humidity on the Drift Wall, Un-Sealed Unheated Drift Sections



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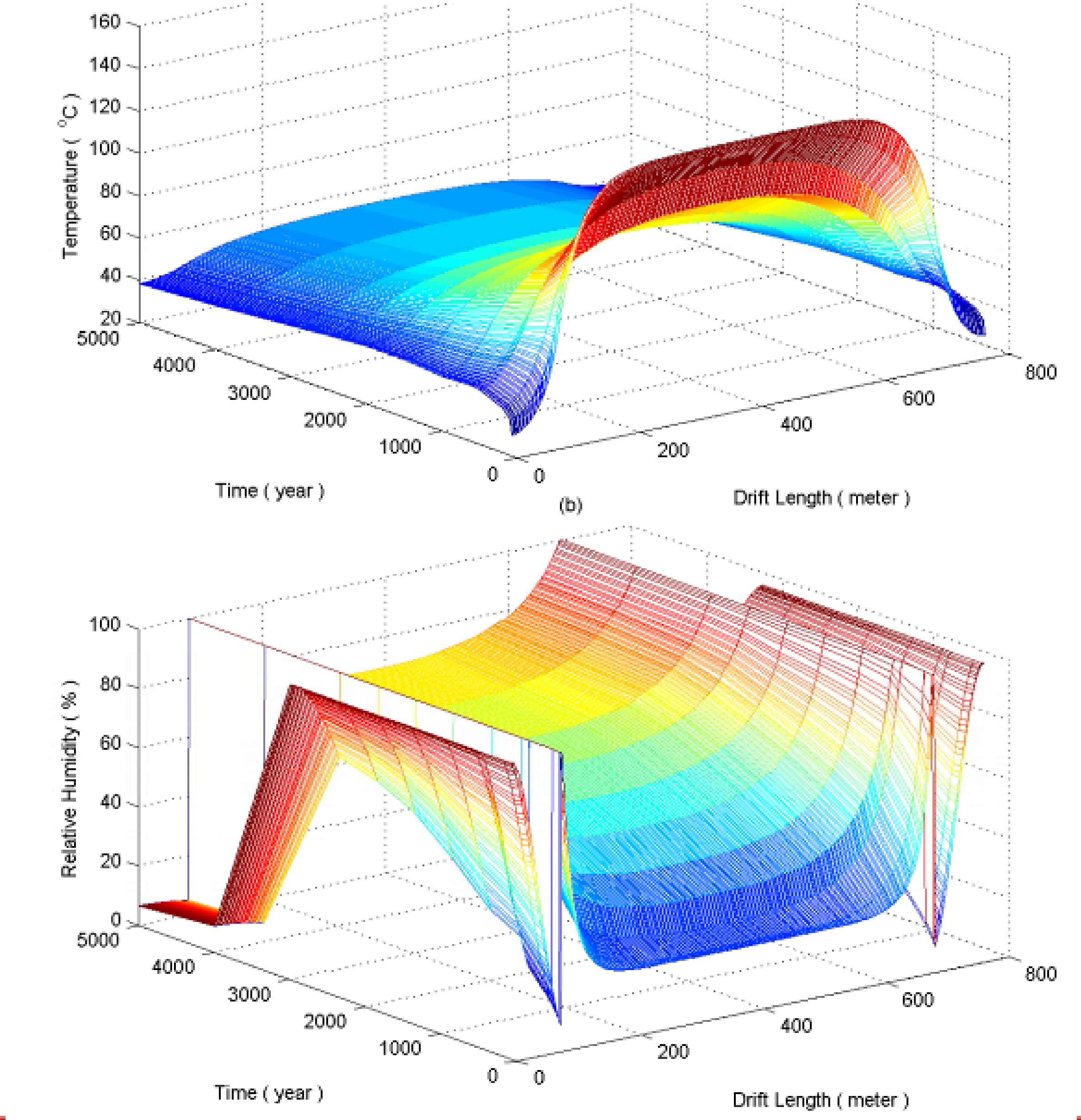
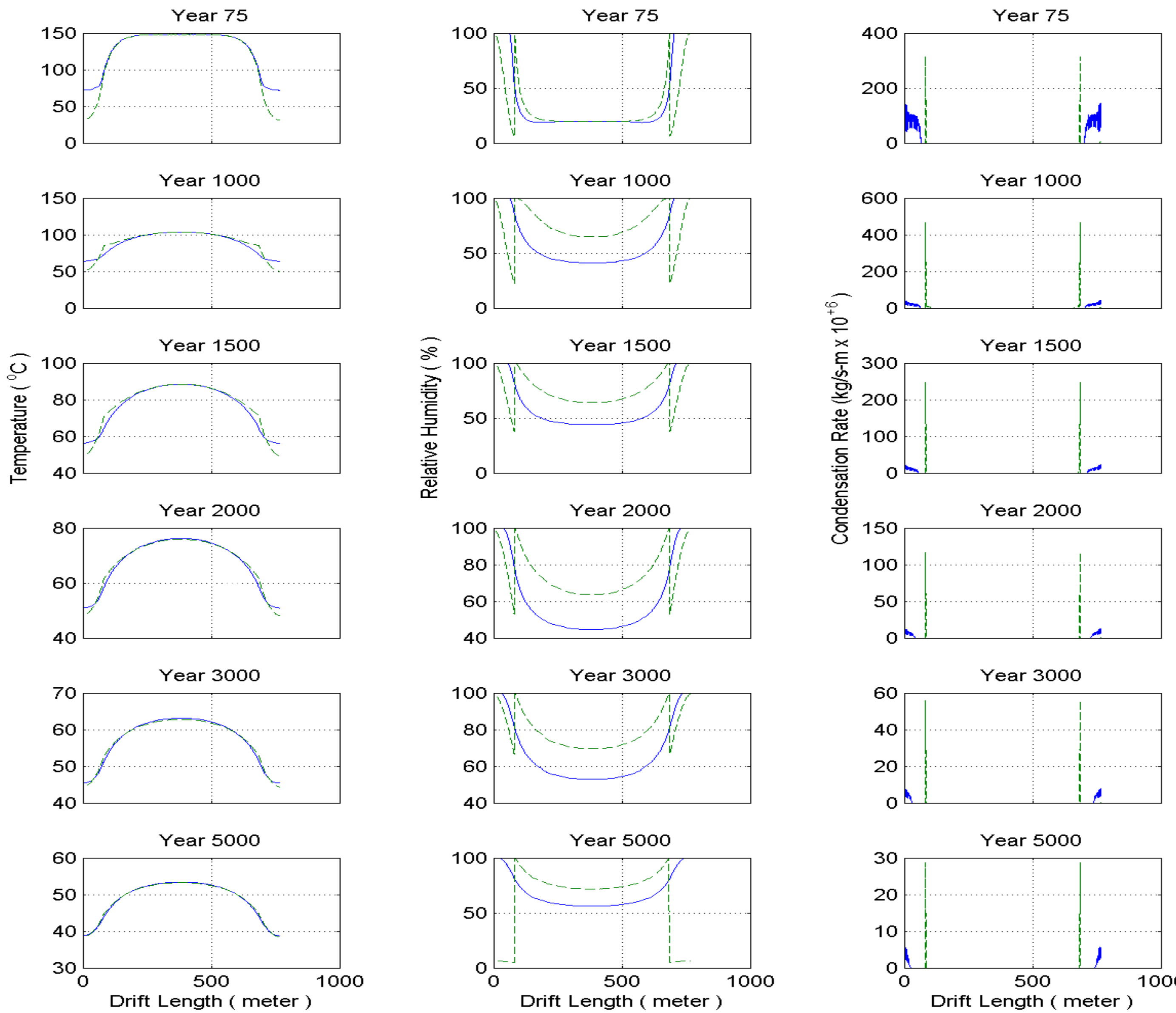
Results: Temperature and Relative Humidity on the Drift Wall with Sealed-off Unheated Sections



Axial distribution of (a) drift wall temperature, (b) relative humidity, and (c) condensation rate using an axial moisture dispersion coefficient of 0.1 m^2/s

solid line: unheated sections not sealed

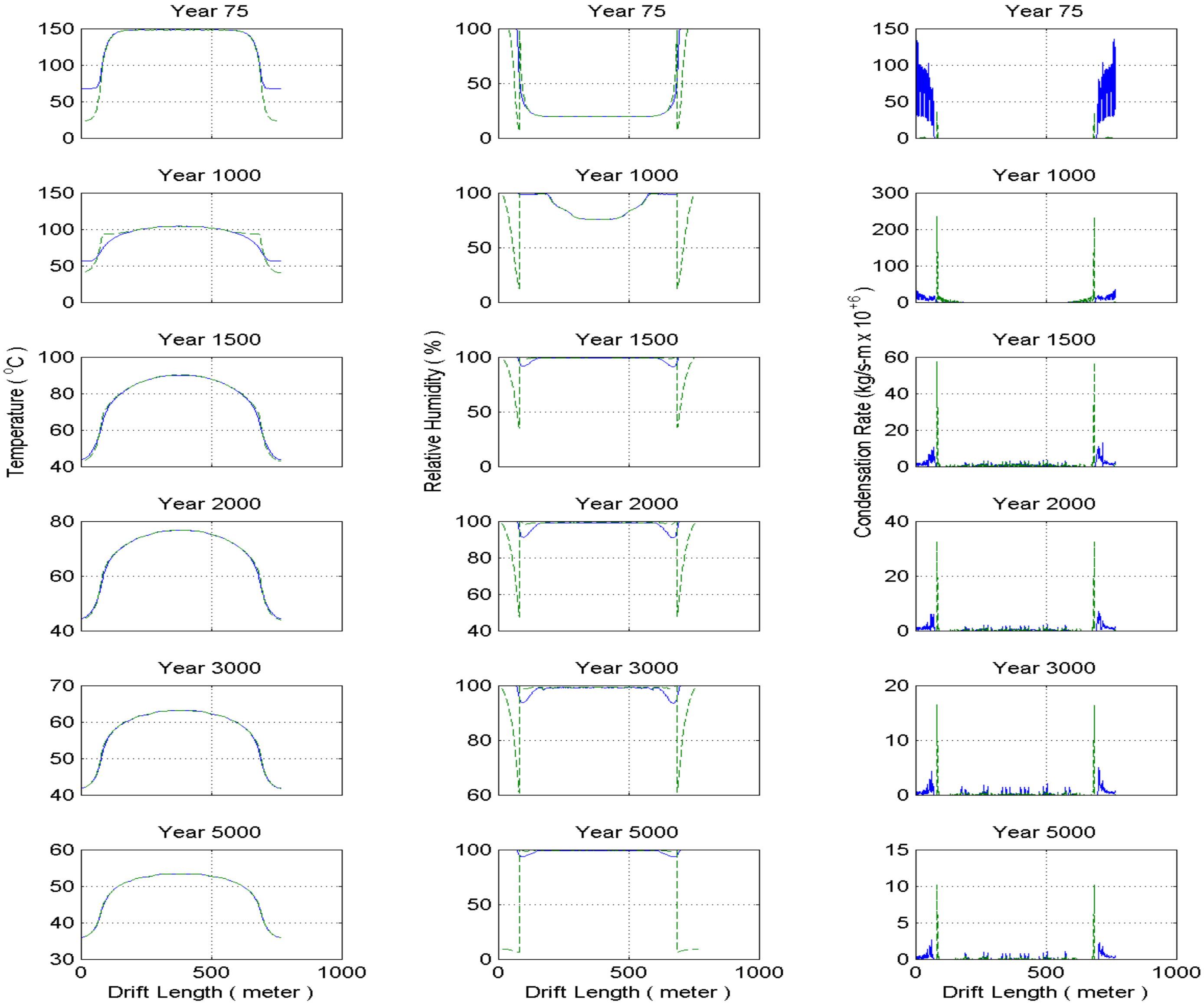
dashed line: unheated sections sealed off



Axial distribution of (a) drift wall temperature, (b) relative humidity, and (c) condensation rate using an axial moisture dispersion coefficient of 0.004 m^2/s

solid line: unheated sections not sealed

dashed line: unheated sections sealed off



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Future Model: Proposed, Variable Dispersion Coefficient in the CFD Model Element

$$D = D_0 \left\{ 1 + 76 Ra_{L_C,\Delta T_r}^{0.05} \left[1 + 0.05 \left(\frac{L_C}{L} \right) Ra_{L_C,\Delta T_L}^{0.5} \right] \right\}$$

L_c - *gap-width characteristic length*

$Ra_{Lc,\Delta Tr}$ - *calculated with the gap-width characteristic length, L_c, and temperature difference in radial direction*

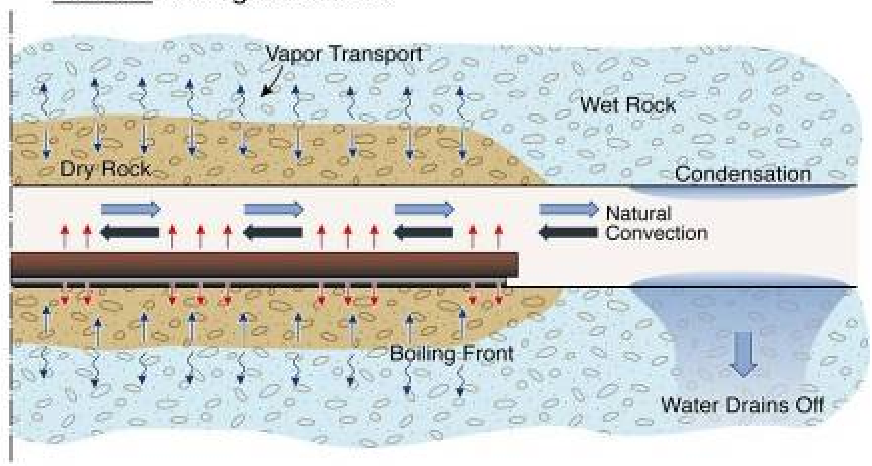
L - *axially connected length*

$Ra_{Lc,\Delta Tr}$ - *calculated with the same characteristic length but with a temperature difference over the axially connected distance, L*

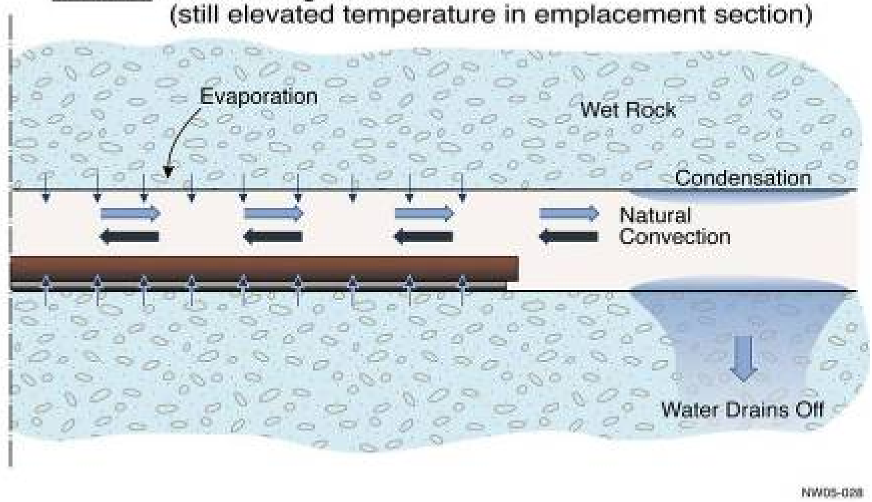
Fit of Dispersion Coefficient Values (m^2/s) between Proposed and Published Results by Webb and Itamura

		Without Temperature Tilt		With Temperature Tilt	
		1000 Yrs	3000 Yrs	1000 Yrs	3000 Yrs
Under Drip Shield	Published results	0.006	0.007	0.007	0.009
	proposed	0.004	0.004	0.009	0.008
Outside Drip Shield	published results	0.004	0.004	0.1	0.1
	proposed	0.004	0.004	0.1	0.081

Observed Natural Convection Effects



More drying of rock mass and later rewetting (delay of seepage)



Smaller potential for seepage and less seepage magnitude

Conclusions

- A fully-coupled, in-drift and near-field, in-rock model is configured and applied for the solution of a complex thermo-hydrologic-airflow problem at YM.
- As a coupled thermal-hydrologic model exercise, the beneficial effect of elongated, unheated emplacement drift sections at both ends was studied and comparatively evaluated.
- No condensation was found around the WPs, and an improvement to the results for a drift arrangement without the long unheated sections was achieved in the high axial dispersion coefficient case.
- Lower condensation rates and fewer condensation locations in the emplacement drift are predicted with the present model than those obtained using an approximate, and basically uncoupled condensation model.

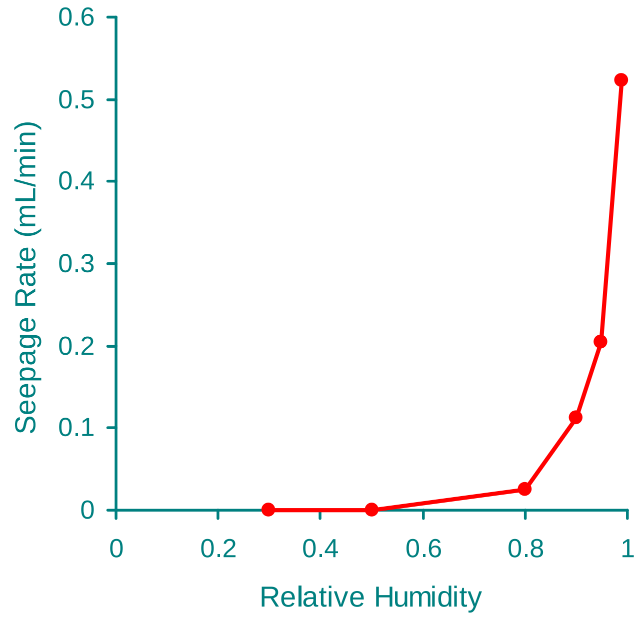
Conclusions (Continued)

- The current result illustrates the benefit of maintaining unheated, low-temperature sections in the drift airspace in order to lower the relative humidity in the active emplacement drift section.
- Significant sensitivity to the axial dispersion coefficient in the emplacement drift is found. This fact underlines the importance of a fast-running, efficient modeling method, since input data variations will likely be needed in future studies and design exercises.
- The range of the values for axial dispersion coefficient arches over three orders of magnitude from molecular diffusion to turbulent dispersion in an emplacement drift.
- In order to reduce uncertainties, it will be important to use location-specific, temperature-field dependent coefficients in the lumped-parameter CFD model instead of overall constants for the entire drift in future studies using a dispersion coefficient model example proposed in the current paper.

Support Material

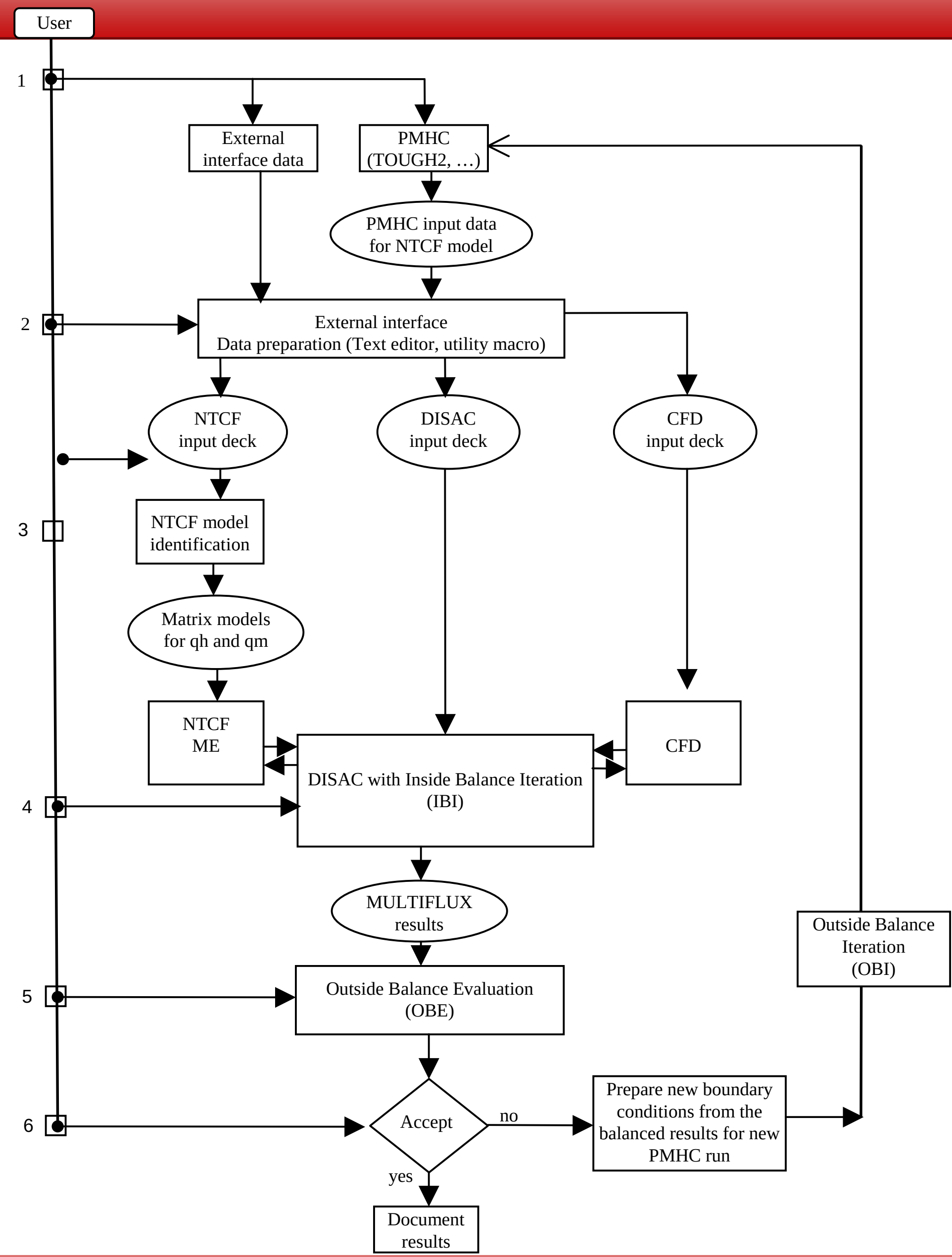
Background

- **Seepage of water into emplacement drifts is important for performance assessment (PA)**
- **Seepage predictions in PA are currently conducted using a conservative assumption of 100% relative humidity (RH) in emplacement drifts (no evaporation)**
- **Natural convection processes in emplacement drifts will create evaporative potential over long drift sections**



Significant reduction in seepage rates possible

Logic Flow Chart of the Coupled Simulation



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Embedded High-Resolution Seepage Model