ASSESSMENT OF OPEN THERMODYNAMIC SYSTEM CONCEPTS FOR FLUVIOKARST TEMPERATURE CALCULATIONS – AN EXAMPLE, THE CENT-FONTS RESURGENCE (HÉRAULT, FRANCE)

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Answers to the anonymous review 1

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Dear colleague,

First we want to thank you for your work and comments about our paper. You will find below our detailed answers to your comments we recalled in italic and smaller font.

General comments
In this manuscript, the authors aim to quantify the error made when no heat exchange between the conduit system and the porous fraction matrix of a karstic system is taking into account. Apparently, this heat exchange is often ignored in fluviokarst studies (I am not an expert on this) and therefore this study may be worth publishing. However, I have the feeling that the state of the art in, for example, stream temperature modelling is much further and therefore the authors should better explain the novelty of this study.

Indeed, since years, numerous works have tried to describe the thermal and hydrologic behavior in the karstic structures by recording and modeling external data as recession curves and/or temperature. This approach does not deny the internal heat propagation processes but renounce to assess their local consequences. From a fluid mechanic point of view, the mass and energy conservative principles that drive the physical exchanges involved in the heart of these black boxes are well known. The existence of such internal processes prevent from using temperature as a conservative tracer, at least without caution.

In this work, we aim to quantify the first order of the error done considering temperature as a conservative tracer. The benefit that could be obtained of such an assessment and the deciphering of conditions for which it could be applied is obvious because of the low cost and easiness of such measurements. However, conversely to the feeling of the reviewer (who did not mention any reference to support this point), we do not know any precise article that treats this objective and that could have been added to the reference list as a precursor.

We will explain below that our approach aims for preserving as far as possible the generality of the problem against the hydrological and geometrical local particularities. If we had such purpose, and with the knowledge of detailed internal boundary conditions we would have developed numerical models including particular boundary conditions and local hydrologic values; and solved the equations on the basis of existing scientific works and methods. Doing this we would have definitively lost the generality which is aimed in the present work. Conversely, we have chosen to describe à more sophisticated fluid mechanics physic in the simplest geometry adapted to describe the problem. This allows cautious extrapolation of the work results to most of the karstic configurations.

A second important point is that there are several shortcomings in this manuscript (including several formulas) that should be fixed (see below). This makes me advice at least major revisions (and close to rejection). I think all the 'shortcomings' could be fixed, but the authors have to explain clearly the novelty of this work…

Major issues:

1) *The English is of poor quality. Often articles are missing, but also strange sentences occur that are difficult to understand. Since there are so many, I won't list them here. I advice to let the manuscript be corrected by a native speaker.*

We apologize for the poor quality of the language. The new version of the paper will be corrected by a specialized scientific translator in order to reach the HESS quality standard.

2) *The manuscript is written in an unnecessary complicated manner:*
   a. *It sometimes reads as a mathematical paper. This is not by definition wrong, but makes it more difficult to read. For example, Eq (1) can also be replaced by a phrase like "we assumed water to be an uncompressible fluid".*

It is indeed a presentation choice that has been done for the whole paper and that is coherent with the aims of the work. Indeed we do not wish wander from mathematical and physical conservative principles that drive fluid mechanics. As an example, within this context we prefer using a classical equation describing the effect of water uncompressibility instead of a sentence, especially as its mathematical expression (Eq. 1) determines further equations through the mathematical development (Eqs. 4, 6, 7 and 11).
We will emphasize these points in the new version of the article, which is writen more in a fluid mechanics modelisation spirit than local hydrological study.

   b. *The introduction of the 'wall' between the CS and PFM is unnecessary. Instead of explaining that in one case the wall is only permeable to water and in the other case also to heat exchange, it is enough to explain that in one case diffusive heat exchange is not taken into account and in the other it is.*

The word « wall » and the concept of wall are commonly used by the community that works on modeling of kart conduit systems behavior (see e.g. Luehman et al, 2011 ; Covington et al, 2011, 2009, 2012 ; Saar et al, 2011 whose detailed references are given in the paper). However, beyond this semantic aspect, the physical difference between the AW and CW cases goes beyond the existence of the wall. Indeed as a consequence of the CW, heat propagates from the CS deep in the PFM (not only at the wall). We worry that a shorter description, without employing the word « wall » may hide the complexity of the physics that is taken into account in the CW model with the computation of the convective and conductives terms in the whole volume of the PFM (not only at the wall). However, considering that this important point was not enough described, we will improve the discussion of these aspects in the new version of the paper.

   c. *The model of the CS is explained as a "sequence of open thermodynamic systems segments". Also this is not by definition wrong, but it boils down to numerical grid cells for which water flow and heat exchange is calculated. In this respect, the title was also a bit misleading to me, since the study boils down to the effect of heat diffusion with the PFM.*

We agree with the comment above that it is not wrong to speak of open thermodynamic systems but that may be not enough to give a suitable idea of the actual work. We propose to modify the title of the paper as :
« Assessment of Conservative Tracer Approximation for Temperature in Open Thermodynamic Context for Fluviokarst – an Example, the Cent-Fonts Resurgence (Hérault, France) »

d. *The same is true when referring to the Ostrogradsky theorem (conservation law) and the first law of thermodynamics (conservation of energy)*

This remark is in accordance with the point a above and appeals, for us, the same answer related to the global spirit of the paper. The concepts of mass and energy conservations, Ostrogradsky theorem and resulting basic fluid mechanics equations seems sufficiently well known among the scientific community to build a didactic footing to describe after the more sophisticated developments necessary to the actual work and physical assumptions done in the paper.

e. *Is it really necessary to rewrite the formulas in terms of dimensionless numbers? The study is a sensitivity study, where (if I understand it correctly) only the radius of the CS, the thermal diffusivity and the total length of the system are changed. Since some of these parameters occur in more than one dimensionless parameter, another parameter should be changed as well in order to only change one dimensionless parameter. This makes the results fuzzier than when only the sensitivity to one physical parameter is shown.*

We are here on a very important point. As we mentioned above, we put as an unavoidable condition to preserve the generality of the study, avoiding considering particular cases (even if it could be interesting from a local point of view). Since the beginning, theoretical fluid mecanics progresses have been built on universal mass and energy conservation principles. Thanks to the rescaling of the problems with dimensionless equations, scientists have overtaken the problems inherent to the diverse unit systems and allowed accurate comparison of empirical and, more recently, numerical results. Furthermore, dimensionless expression of the equation opens the possibility of analogous treatment of the huge variability of geophysical systems and boundary conditions. Indeed we must keep in mind that if a physical effect often depends on a particular physical parameter, its final relative importance in a natural system depends mostly of its combination with other physical effects, which also depend on various other physical parameters. These combinations appear clearly in the classical fluid mechanic dimensionless numbers as the Peclet, Reynold or Prandtl numbers. The dimensionless approach is therefore unavoidable to keep the generality of the approach.

3) *There are simplifications and errors in several formulas:*

a. *Eq. 3: No storage of heat is taken into account.*

The heat capacity Cp appears (with density) in both sides of Eq. 3. As we have considered these physical parameters do not depend on temperature, they can be removed that leads to the present expression of Eq. 3. However this is not said in the text of the paper. This will be added in the new version.

b. *Eq. 4: RH is not hydraulic radius, but a pipe radius. Hydraulic radius is the ration of crosssectional area and wetted perimeter, which is for a completely filled circular pipe given by: pipe radius divided by 2. Make clear that the radius flux is pointed outwards (explaining the negative sign). It is assumed here that with increasing flow, only the flow velocity increases, while I expect also the pipe radius to increase. This is indirectly also mentioned on P177, L3 and 4, but not taken into account in this formula*

You comment is right : Rh is the pipe radius and not the hydraulic radius. This will be corrected in the new version of the paper. However, the equations and results will be absolutely not changed by this semantic (and necessary) correction. The radius flux is actually pointing outward that explains the negative sign. The effects related to pipe radius value and to the flow velocity conditions determine the Peclet and Reynolds numbers through the scaling of the equations (see Table 1).

Working on this answer we saw that the viscosity does not appear in Table 1 in the expression of the Reynolds number (as it should do). This seems to be due to a font problem (since the viscosity symbol also disappeared a few lines above) and has not been corrected during the proof reading. This will be done in the next version of the paper.

c. Eq. 9: Units don't match: An area should be added on the right-hand side.

The units of Eq. match. Both RHS and LHS are (K/s) (Kelvin divided by second). Confusion may have been induced by the laplacian sign in the RHS of Eq. 9. It will be replaced by its full development in term of partial derivatives in the new version of the paper.

d. Eq. 10: Units don't match.

e. Eq. 11: Unit don't match.

f. Eq. 12: Units don't match.

g. Eq. 13: Units don't match: $T\infty/\Delta T$ has the wrong unit. I also suggest not normalizing the error: it becomes less intuitively and it matters if temperature is given in Kelvin or Celsius.

Eqs. 10, 11, 12 and 13 have not unit that explains the presence of dimensionless numbers as Pe, Red and thermal diffusivity ratio. The error must be rescaled simultaneously with the other equations to keep its homogeneity with the others parameters of the study. The scaling scheme given in Table 1 allows converting easily the dimensionless values from/into physical values for lengths, velocities, temperatures and errors. This has been done in the paper to show the error level reached in the example case.

4) A couple of more specific comments:

a. At which distance is $T\infty$ taken? And how is the temperature in PFM calculated (how many grid cells, which grid size, numerical scheme)? These aspects may influence the temperature for the CW case significantly.

In the model $T\infty$ is taken at the dimensionless radial distance 0.2, which means that the computation box for the CW model has an aspect ratio of 5 (ratio of the axial to the radial lengths). The computation grid use 100 points in the radial direction and 500 points in the axial dimension. We used an Alternate Direction Implicit method with second order accurate finite differences in the x and r directions (Douglas and Rachford, 1956 – full reference given in the paper). It is clear from Fig. 2, that the influence of heat conduction through the CS/PFM is more important near the beginning of the CS (low values of x) and decreases very rapidly to become negligible when the radial distance to the axis increases. However we agree that it is necessary to give more information about the numerical method. This will be done in the new version of the paper.

b. P180, L10-11: This is the diffusivity for stagnant water: In moving water, heat exchange also occurs by dispersion, which is highly dependent on the turbulence of the water and is often treated as a calibration parameter.

The convective heat transport is taken into account thanks to the advection terms in the LHS of Eqs. 8 and 9. It is clear that in karstic conduit systems the fluid motions may be turbulent (according to the value of the Reynolds number). In that case, the cooling will be more efficient by a better dissipation of heat near the wall of the CS. A better assessment of this effect will be studied in a further work. However, we must keep in mind that, in the PFM, the velocity of water motion is several orders of magnitude lower than in the CS that prevent from using a calibration parameter for turbulence in this part of the model.

c. The figures are of poor quality and therefore difficult to read.

d. Figure 2: What is on the z-axis? Also the x and y-axes are difficult to read.

e. Figure 4: The error on the y-axes has a different formulation than Eq 13.

We agree that the Figures were of poor quality. This is why we have redrawn the figures 1, 2 and 4 in order to increase their readability. The new versions of the figures are included in this comment answer. Furthermore, the label of error on the Fig. error axis was effectively wrong. This has been corrected in the new version of the figure. These new figures will be included in the new version of the paper.

We want to thank you again for your comments that greatly improve the form and the quality of this work.

Philippe Machetel and David Yuen

Table 1

Acronyms

AW	Adiabatic Wall conduit system
CS	Conduit System (assumed cylindrical for the study)
CW	Conductive Wall conduit system
CV	Control volume of the open thermodynamic system
PFM	Porous Fractured Matrix

Notations, units, description

D_m	(m^2/s)	Thermal diffusivity of porous matrix
D_w	(m^2/s)	Thermal diffusivity of water
υ	(m^2/s)	Kinematic viscosity
N		number of AW in the sequence
Q_m	(m^3/s)	total discharge of matrix-conduit flow in the CS
Q_i	(m^3/s)	total discharge of intrusion in the CS at swallow zone
Q_o	(m^3/s)	total discharge of spring output of the CS
$Q_{i,n}$	(m^3/s)	Intrusive flow in the nth AW of the sequence
$Q_{m,n}$	(m^3/s)	Discharge of matrix-conduit flow in the n^{th} AW
$Q_{o,n}$	(m^3/s)	Output flow in the nth AW of the sequence
r	(m)	radial coordinate from CS cylindrical axis (positively oriented outward)
R_H	(m)	Hydraulic radius of the CS
t	(s or -)	time
$T(x,r)$	(°K or°C or -)	Temperature (function of x and r)
T_∞	(°K or°C)	Far field temperature in the fluviokarst
T_i	(°K or°C)	Temperature of the intrusive flow at the swallow zone
$\vec{v}$	(m/s or -)	Fluid velocity vector
$v_r(x,r)$	(m/s or -)	Radial component of velocity (function of x and r)
$v_x(x,r)$	(m/s or -)	x component of velocity (function of x and r)
x	(m or -)	x coordinate along the axis of the cylindrical CS

Scales

L	(m)	Scaling for lengths
V	(m/s)	Scaling for velocity ($V = (Q_s - Q_i)/(\pi R_H^2)$)
ΔT	(°K)	Scaling for temperature ($\Delta T = T_i - T_\infty$); ($T = \Delta T T' + T_\infty$)

Dimensionless numbers

Pe	(-)	Peclet number in the conduit ($Pe = LV/D_w$)
Pr	(-)	Prandtl number ($Pr = \upsilon / D_W$)
Re_d	(-)	CS Reynolds number ($Re_d = 2VR_H/\upsilon$)

Figure 1

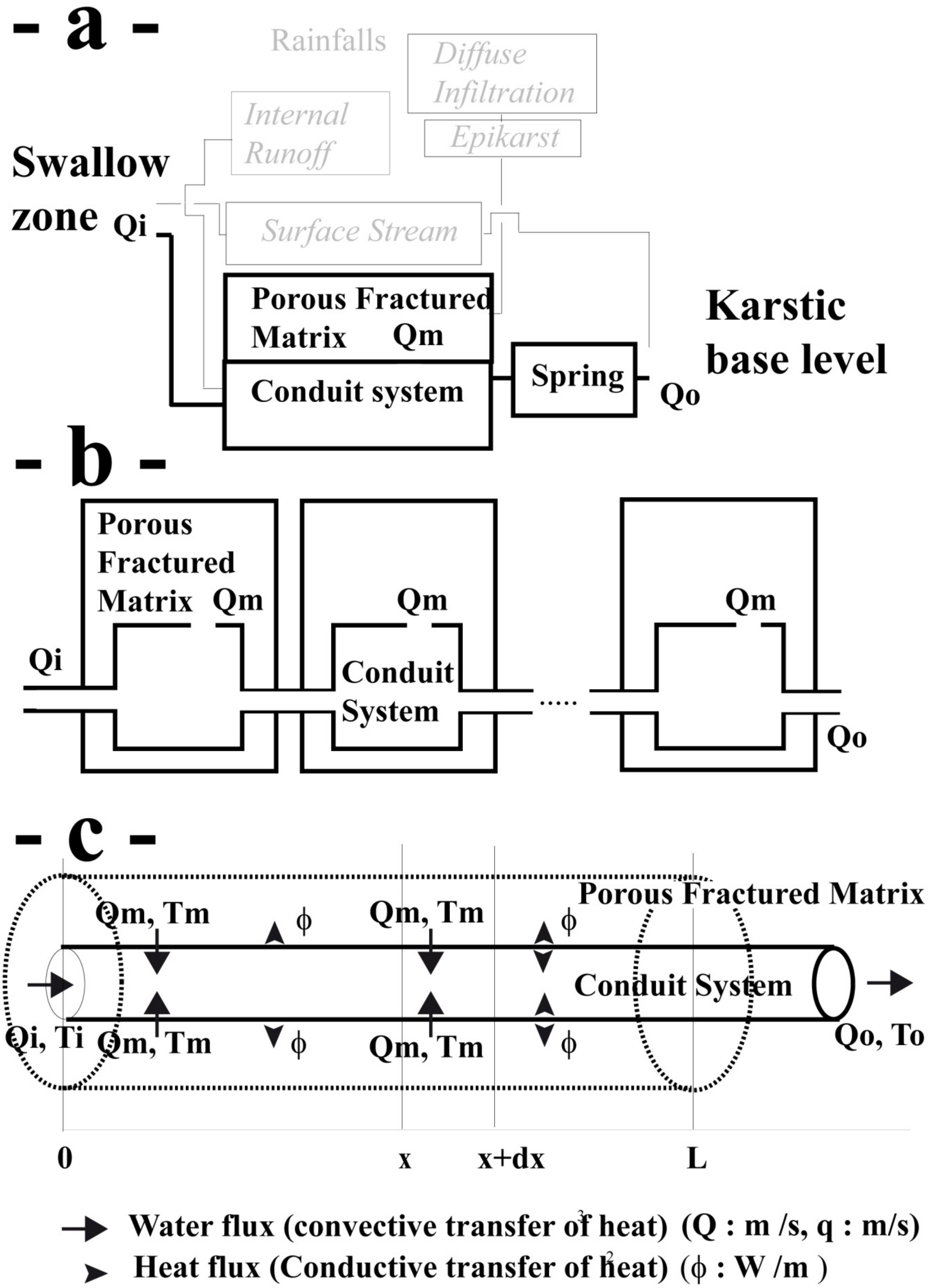

- a -
Rainfalls
Diffuse Infiltration
Epikarst
Internal Runoff
Swallow zone
Qi
Surface Stream
Porous Fractured Matrix Qm
Conduit system
Spring
Qo
Karstic base level
- b -
Porous Fractured Matrix Qm
Qi
Qm
Conduit System
Qm
.....
Qo
- c -
Porous Fractured Matrix
Qm, Tm
ϕ
Qm, Tm
ϕ
Conduit System
Qi, Ti
Qm, Tm
ϕ
Qm, Tm
ϕ
Qo, To
0
x
x+dx
L
x
Water flux (convective transfer of heat) (Q : m3/s, q : m/s)
Heat flux (Conductive transfer of heat) (ϕ : W/m2)

Figure 2

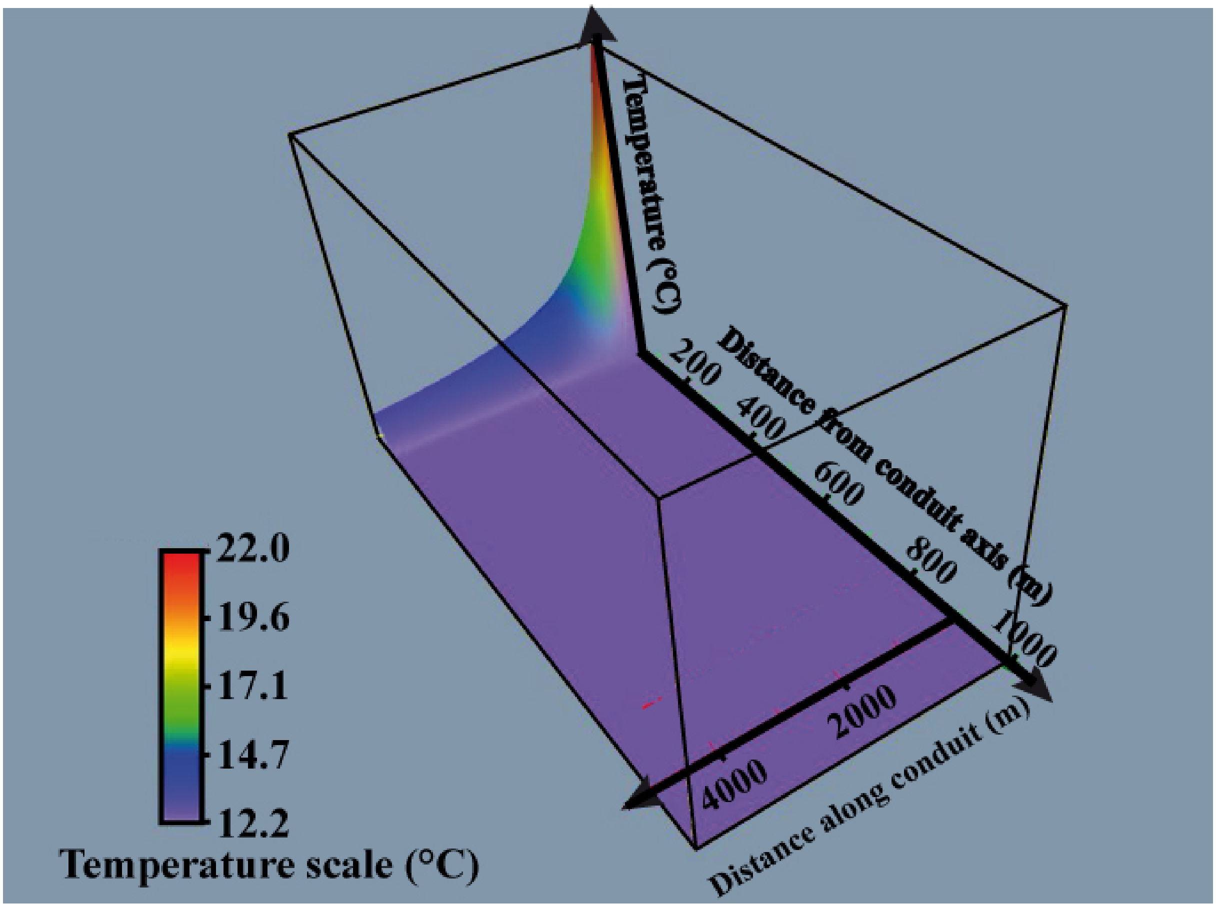
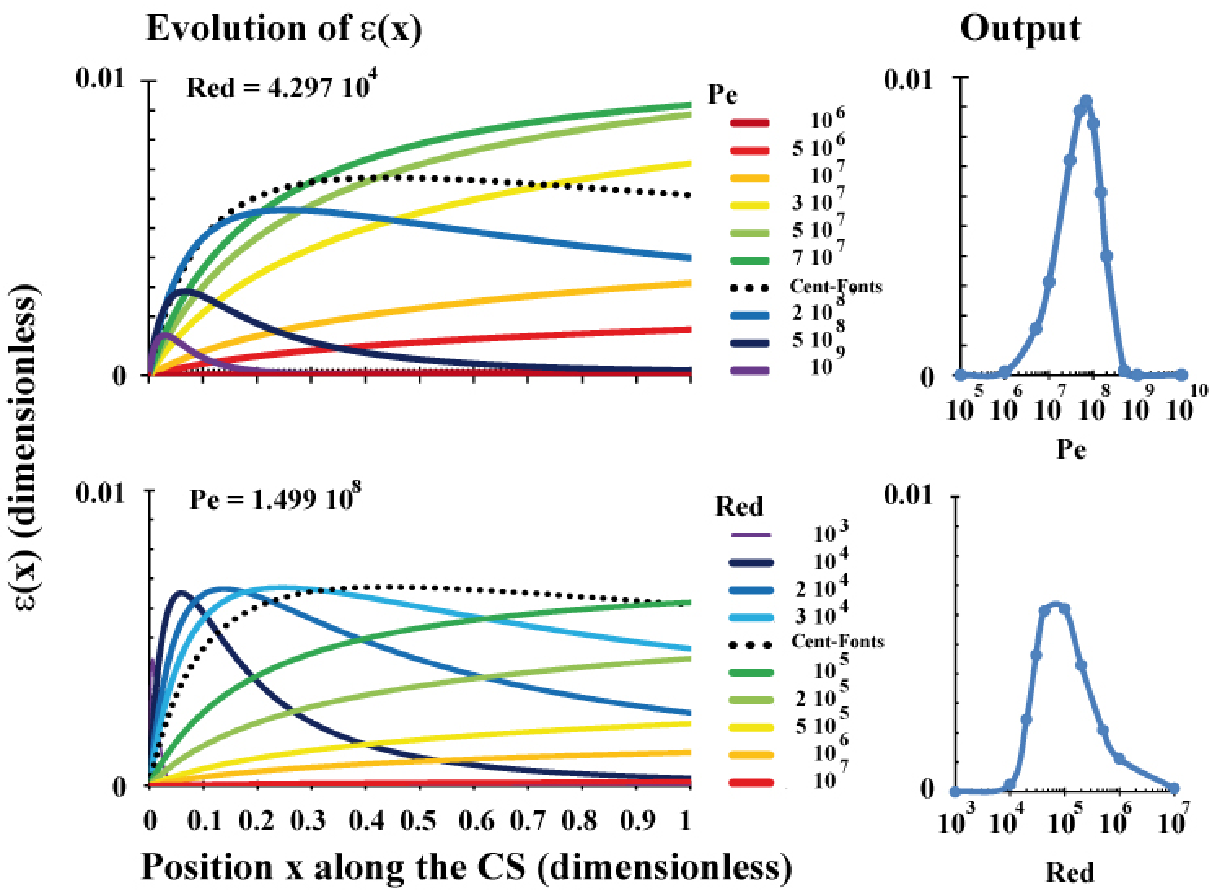

Temperature (°C)
Distance from conduit axis (m)
200
400
600
800
1000
2000
4000
Distance along conduit (m)
22.0
19.6
17.1
14.7
12.2
Temperature scale (°C)

Figure 4



Evolution of ε(x)
Output
Red = 4.297 10^4
Pe
10^6
5 10^6
10^7
3 10^7
5 10^7
7 10^7
Cent-Fonts
2 10^8
5 10^8
10^9
Pe = 1.499 10^8
Red
10^3
10^4
2 10^4
3 10^4
Cent-Fonts
10^5
2 10^5
5 10^5
10^6
10^7
ε(x) (dimensionless)
0.01
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Position x along the CS (dimensionless)
10^5 10^6 10^7 10^8 10^9 10^10
Pe
10^3 10^4 10^5 10^6 10^7
Red