**Davies and Pommier Snow Model Manual**

Preliminaries

The code models the long-term (~4.5 Gyr) evolution of an equilibrium snow zone in a terrestrial planetary core that grows downwards from the core-mantle boundary (CMB). The equations and approximations are described in detail in Davies and Pommier (2018, <https://www.sciencedirect.com/science/article/pii/S0012821X17305940>).

Some points about the modelling approach:

* Core properties vary in radius and time; lateral variations are assumed to average out.
* Regions without snow are assumed to be hydrostatic, adiabatic and isentropic.
* Solid phase is assumed to be dispersed such that physics associated with a solid matrix can be ignored.
* The snow zone is on the liquidus and the liquidus and core temperature are equal. Cooling leads to freezing and retention of light elements in the liquid, creating a stable chemical stratification across the snow zone.
* Upon cooling the light element concentration at any radius is that which depresses the liquidus to the new core temperature.

The main assumptions are:

1. All light element remains in the liquid phase on freezing;
2. Fast melting, i.e. instantaneous relaxation to phase equilibrium;
3. Fast remelting of sinking solid, i.e. rapid sinking and remelting of solid iron.
4. An adiabatic temperature profile exists throughout the core.

The Code

The code comprises the following files:

|  |  |
| --- | --- |
| parameters.f90 | Universal constants |
| parameters\_core.f90 | Parameters relevant to the terrestrial body under consideration: CMB radius, diffusion coefficients, heat of reaction.  **May need modification** |
| thermal\_history.f90 | Driver program – performs initialisation and call the main routine in core\_evolution.f90. This would be the place to plug in evolution models for a solid mantle, magma ocean, etc. |
| core\_evolution.f90: | Calls routines in core\_model.f90 that setup core interior structure, calculate energy and entropy balances. |
| core\_model.f90 | See above. |
| drspln.f, splat.f | Supplementary routines for integration. |
| Makefile | Builds the code. |

To build the code from scratch with default settings, type

make

at the command prompt.

The Makefile is basic. Its default settings are

COMPILER = gfortran

COMPFLAGS = -c

EXECUTABLE = thermal\_history

And hence the executable will be called “thermal\_historu” unless changed by the user. To remove all compiled code type “make clean”.

Input file

The default name for the input file is “run.in”, though any name can be used. It looks like this:

\* File stem

OUT

\* Use polynomial (=1) or Labrosse (=2) representation; QPne0 (=1); Qhne0 (=1)

1 2 2

\* rho, P, at earth's centre; cp

7211e0 21e9 780

\* density params for OC (1st 4) and IC

7211e0 0.0 0.0 0.0 0.0 0.0

\* Entropy of melting

1.99731 -0.0082006 0.d0 0.d0 0.d0

\* Melting params, Tm0, Tm1, Tm2, Tm3, Tm4, depression of melt pt

1990.48621274289 -0.00218881211768781 3.77133942042793e-07 0 0.0 0.106

\* Temperature params

2000.0 -2.4208444515784e-12 -8.09246626536291e-08 0.0

\* conductivity params k0, k1, k2

40 0.0 0.0

\* Concentrations for O, S, Si

0.0000 0.172 0.0000

\* Tcmb, ri, rs, h

2400.d0 0.0 1627e3 0.d0

\* delta t, total t

5d6 1d9

\* What are you specifying: 1=Qcmb; 2=EJ; 3=Qcmb post IC formation; EJ otherwise

\* Also give the value of the thing you're inputting

1 1e12

\* file to read CMB hf

/nfs/a88/earcd/THERMAL\_HISTORY/DAVIES\_NIMMO/MARS/DATA/Q/rcmb=1627e3/WN04-Qcmb

All lines that begin with an \* are comments and will be ignored by the code – these are handy for adding in notes. Below is a description of this file.

|  |  |
| --- | --- |
| \* File stem | All files output by the code with begin with this stem. Helps for running multiple runs in the same directory. |
| \* Use polynomial (=1) or Labrosse (=2) representation; QPne0 (=1); Qhne0 (=1) | This line requires 3 numbers.  Param 1: should the radial dependence of all quantities be represented using polynomials (value = 1) or as exponentials following Labrosse (2001) (value = 2). Polynomials are more accurate so default = 1.  Param 2: Calculate pressure heating, QP? 1 = yes, otherwise no.  Param 3: Calculate heat of reaction, Qh? 1 = yes, otherwise no. |
| \* rho, P, at earth's centre; cp | 3 params, in order:  Density at Earth’s centre (not used with polynomial representation).  Pressure at CMB.  Specific heat (assumed constant). |
| \* density params for OC (1st 4) and IC | in OC  in OC  Note that determines gravity, , and pressure, . |
| \* Entropy of melting |  |
| \* Melting params, Tm0, Tm1, Tm2, Tm3, Tm4, melt\_pt\_dep | Melting temperature of pure iron is the first term. The (constant) melting point depression can be set by the user through the variable melt\_pt\_dep; setting this to zero will calculate the melting point depression as in Davies (2015) |
| \* Temperature params | where is the temperature at Earth’s centre. |
| \* conductivity params k0, k1, k2 |  |
| \* Concentrations for O, S, Si | Initial uniform molar concentrations of oxygen, sulphur and silicon. Set to zero to ignore. |
| \* Tcmb, ri, rs, h | The initial CMB temperature (overrides set above)  = ICB radius (used if integrating backwards in time)  = initial radius of a snow zone (usually zero).  = value in W/kg of radiogenic heating. |
| \* delta t, total t | Timestep and total integration time |
| \* What are you specifying: 1=Qcmb; 2=EJ; 3=Qcmb post IC formation; EJ otherwise  \* Also give the value of the thing you're inputting | There are 4 modes in which the code can be run:   1. Set a value of CMB heat flow for all time 2. Set a value for the dynamo entropy for all time 3. Set during inner core growth and before inner core growth 4. Read from a file (filename given on line below). |
| \* file to read CMB hf |  |

Running the code

To run the code with “run.in” as the input file do

[PATH\_TO\_thermal\_history]/thermal\_history < run.in > OUT &

The code writes out information as it goes, which is here redirected to the new file OUT.

Outputs

The code outputs the following files:

[File stem]\_diagnostics:

|  |  |  |
| --- | --- | --- |
| Quantity | Units | Explanation |
| Time | Millions of years | Time. Initial time = 0. |
| Tc | K | CMB temperature |
| dTcdt | K/Gyr | CMB cooling rate |
| Ri | Km | Inner core boundary radius |
| Rs | Km | Snow zone radius |
| Dridt | Km/Myr | Rate of inner core growth |
| M\_c | Kg | Mass of whole core |
| M\_oc | Kg | Mass of convecting core |
| M\_snow | kg | Mass of snow zone |

[File stem]\_energy:

|  |  |  |
| --- | --- | --- |
| Quantity | Units | Explanation |
| Time | Myrs | Time. Initial time = 0. |
| Qs | TW | Secular cooling of whole core |
| Qg | TW | Gravitational energy from inner core growth |
| Ql | TW | Latent heat release from inner core growth |
| Qr | TW | Radiogenic heating |
| Qcmb | TW | CMB heat flow |
| Qa | TW | Total adiabatic heat flow out of the core |
| QL\_rs | TW | Latent heat absorbed in shell of remelting material at base of snow zone |
| QL\_snow | TW | Latent heat released by freezing throughout snow zone |
| QL\_melt | TW | Latent heat absorbed on remelting at base of snow zone |
| Qg\_snow | TW | Gravitational energy released by falling snow inside the snow zone |
| Qg\_melt | TW | Gravitational energy released by mixing of remelted material throughout the bulk core. |

[File stem]\_entropy:

|  |  |  |
| --- | --- | --- |
| Quantity | Units | Explanation |
| Time | Myrs | Time. Initial time = 0. |
| Es | MW/K | Entropy from secular cooling of whole core |
| Eg | MW/K | Entropy due to Qg |
| El | MW/K | Entropy due to Ql |
| Er | MW/K | Entropy due to Qr |
| EJ | MW/K | Ohmic dissipation |
| Ek | MW/K | Entropy due to thermal conduction |
| Eh | MW/K | Entropy due to heat of reaction |
| Ealpha | MW/K | Entropy due to barodiffusion |
| EL\_rs | MW/K | Entropy due to QL\_rs |
| EL\_snow | MW/K | Entropy due to QL\_snow |
| EL\_melt | MW/K | Entropy due to QL\_melt |
| Eg\_snow | MW/K | Entropy due to Qg\_snow |
| Eg\_melt | MW/K | Entropy due to Qg\_melt |

[File stem]\_snow:

|  |  |  |
| --- | --- | --- |
| Quantity | Units | Explanation |
| Time | Millions of years | Time. Initial time = 0. |
| Rd | Km | Depth of snow zone |
| Drsdt | Km/Myr | Rate of snow zone growth |
| Cp | Km | Conversion factor between rate of change of solid fraction in snow zone and snow zone growth rate |
| Cr | Km | Conversion factor between snow zone growth rate and snow zone cooling rate |
| CcS | Km/Myr | Conversion factor between rate of change of composition in snow zone and snow zone growth rate |
| Ql | Redundant – see energy and entropy files above | |
| Qg |
| El |
| Eg |

[file stem]\_profiles\_core:

Radial profiles throughout the core for:

r T dTadr\_c Tm P rho g psi k

Here psi is gravitational potential

[file stem]\_profiles\_core:

Radial profiles throughout the snow zone for:

r xil phi dcldT\_s Cl\_snow L

Here xil is light element fraction, phi is solid fraction, L is latent heat coefficient.