Modifications to the EOS1sc module in iTOUGH2

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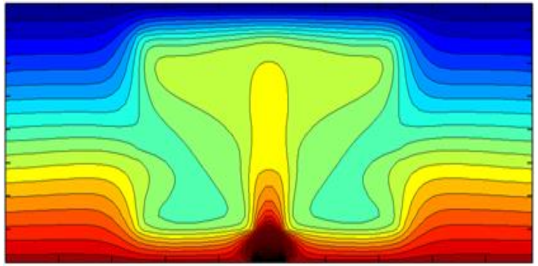
Outline

Objective



EOS1sc

Convergence Issues

Backward Equations for IAPWS-IF97

Interpolation Between Thermodynamic Regions

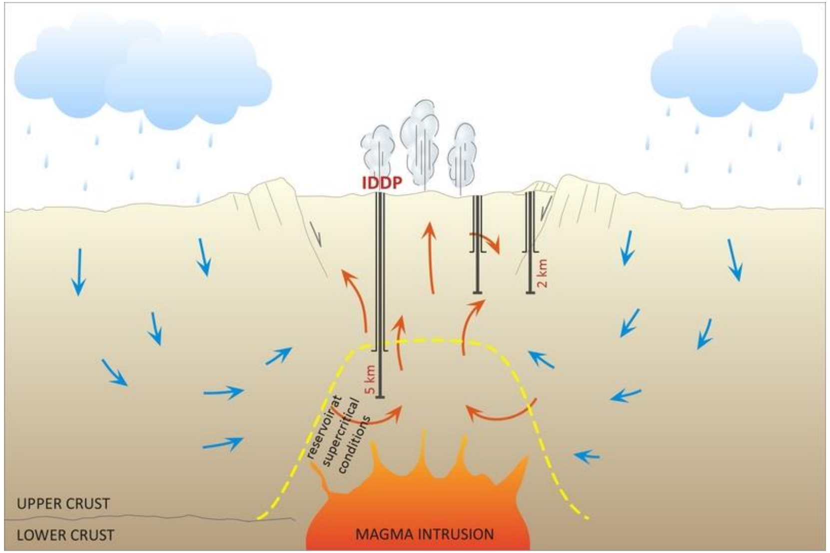
- Linear Interpolation
- Bézier Curves

Weigthing procedures

Summary

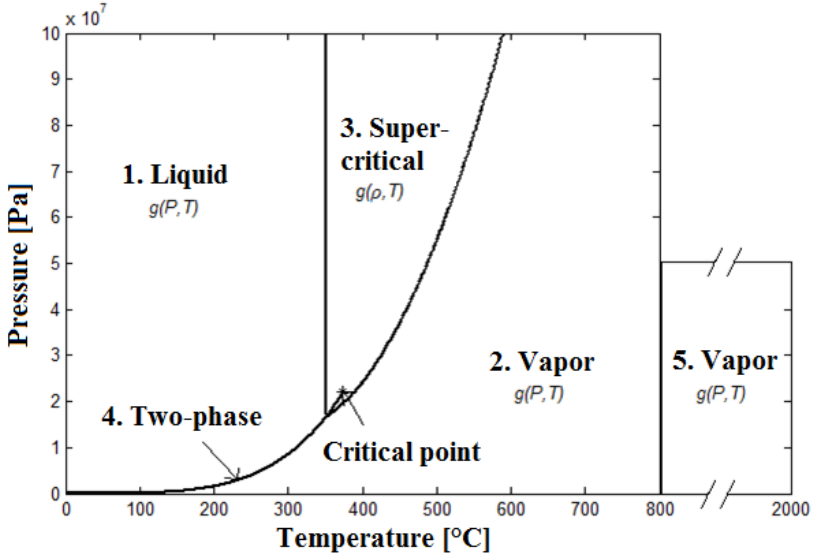
Objective

Improve the reliability of the supercritical EOS1sc module to aid model convergence of full-scale magmatic geothermal reservoirs



Ref. Orkustofnun.is

EOS1sc



IAPWS-IF97

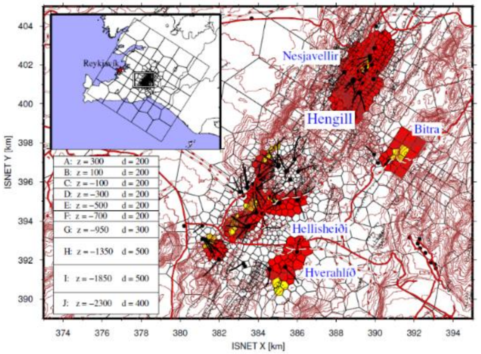
Primary variables

- Single phase: P, T
- Two phase: P_g, S_g
- Supercritical: ρ, T

Temperature and depth dependent rock properties

- Permeability and heat capacity can change linearly and log-linearly with temperature and depth

Convergence Issues



Ref. Gunnarsson, G.

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EOS1sc works well on several examples tested

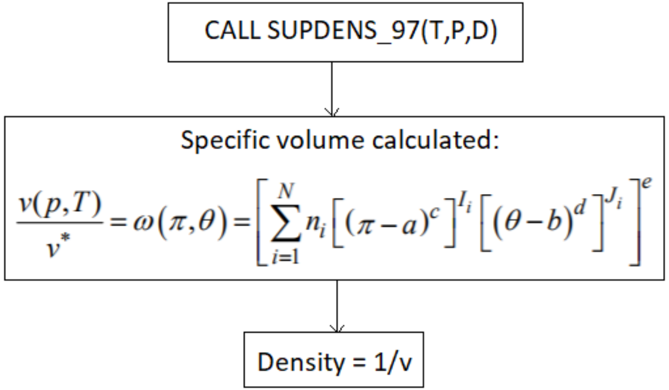
- 5-spot geothermal problem
- Cooling pluton
- Full-scale supercritical reservoir model of Hengill

Convergence issues discoverd for some large-scale supercritical models

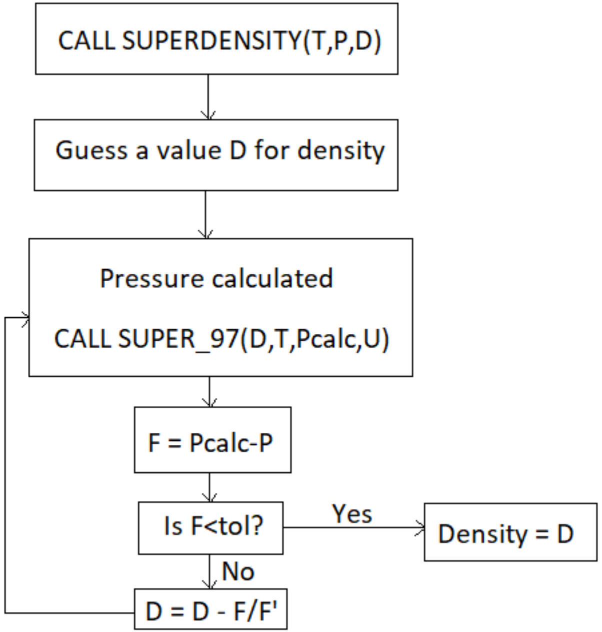
Smoothness of objective function important for Newton-Raphson to converge

Backward Equations vs. Newton Raphson

Backward Equations



Newton-Raphson



Backward Equations – Range of Validity

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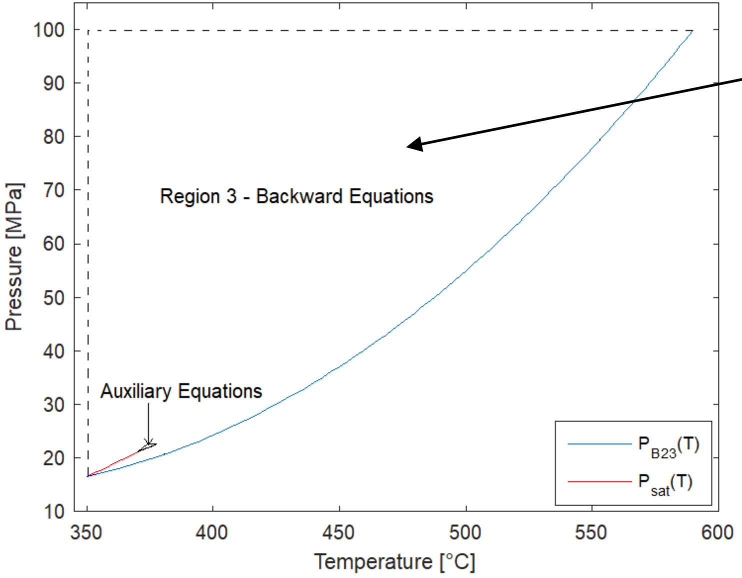

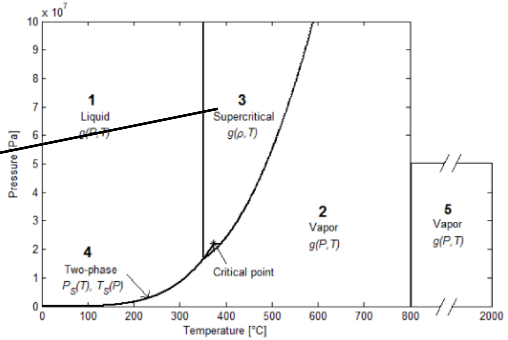

Range of validity:

$$p_{B23}(T) < p < 100\,MPa$$

$$623.15 < T < 863.15$$

Backward equations for specific volume as a function of pressure and temperature for Region 3 of IAPWS-IF97

Backward Equations – Increase in Computational Speed

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Newton-Raphson iteration eliminated

Computational speed tested

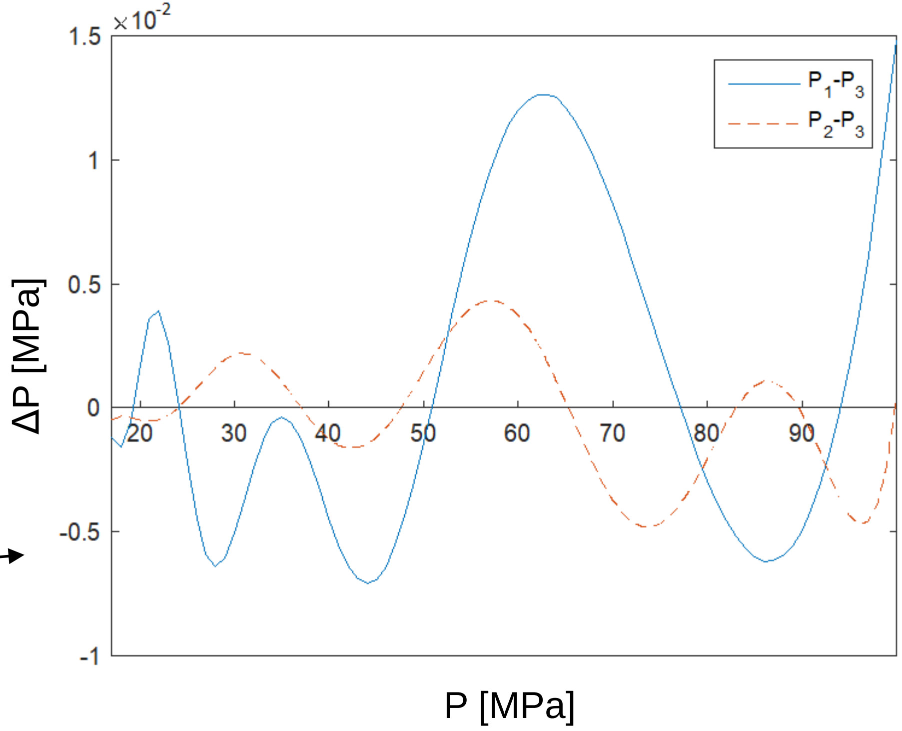
- 100,000 data points
- **8 times faster** than before

Backward equations used in EOS1sc except for auxiliary equations in order to meet consistency requirements

Discrepancy in Thermodynamic Formulations

Newton-Raphson can fail if function is not differentiable and continuous

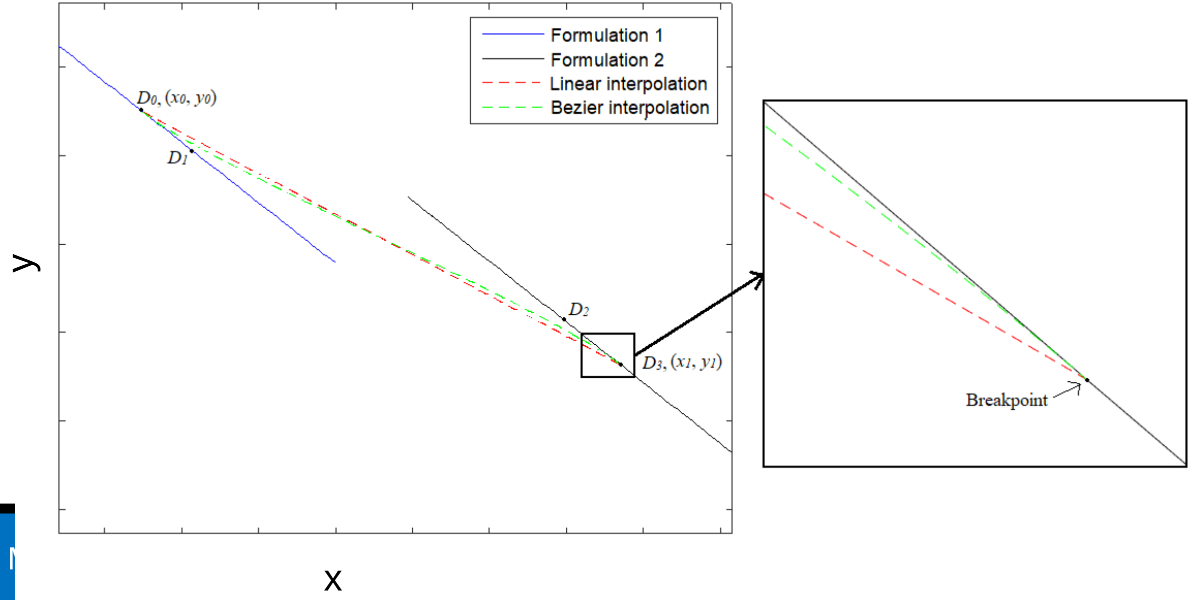
Discrepancies in P between Region 1 and Region 3



Linear Interpolation vs. Bézier curves

Linear: $y = y_0 + (x - x_0)\dfrac{y_1 - y_0}{x_1 - x_0}$

Bézier: $B(t) = (1-t)^3 D_0 + 3(1-t)^2 t D_1 + 3(1-t) t^2 D_2 + t^3 D_3 \ , \ 0 \le t \le 1$



Density Interpolated Using Bézier Curves

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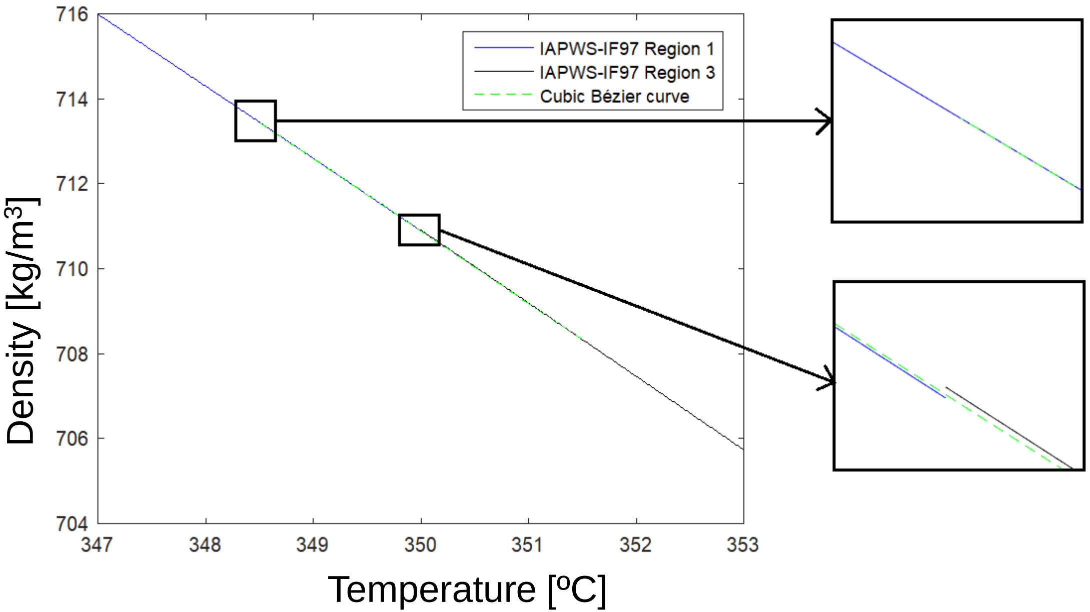
Bézier curve implemented to eliminate discontinuities across boundaries of the thermodynamic regions



	Slope
Region 1	1.708
Region 3	1.715
Linear	1.594
Bézier 1	1.708
Bézier 3	1.715

Weighting procedures at cell faces

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Flow and transport properties evaluated at cell faces

Unstable situations may arise when phases (dis-)appear

MOP(11) determines evaluation of mobility and permeability at interfaces.

- 0: mobilities are upstream weighted with WUP (see PARAM.3), permeability is upstream weighted.
- 1: mobilities are averaged between adjacent elements, permeability is upstream weighted.
- 2: mobilities are upstream weighted, permeability is harmonic weighted.
- 3: mobilities are averaged between adjacent elements, permeability is harmonic weighted.
- 4: mobility and permeability are both harmonic weighted.

transient two-phase flow

uniform medium	**composite medium**
k (constant) $\mathbf{k_r}$ (upstream)	**k**, $\mathbf{k_r}$ } upstream

steady two-phase flow

k $\mathbf{k_r}$ harmonic

single-phase flow

k harmonic

$\mathbf{k_r}$ (none)

Summary

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Backward equations implemented into EOS1sc

- Reliability increased
- Computational speed increased

Bézier curves used to interpolate density between thermodynamic regions

- Discrepancy in thermodynamic formulations eliminated
- Reliability increased

Weighting procedures at cell faces important for convergence

Acknowledgements

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Thank you!

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