Firn densification and ice sheet surface elevation changes

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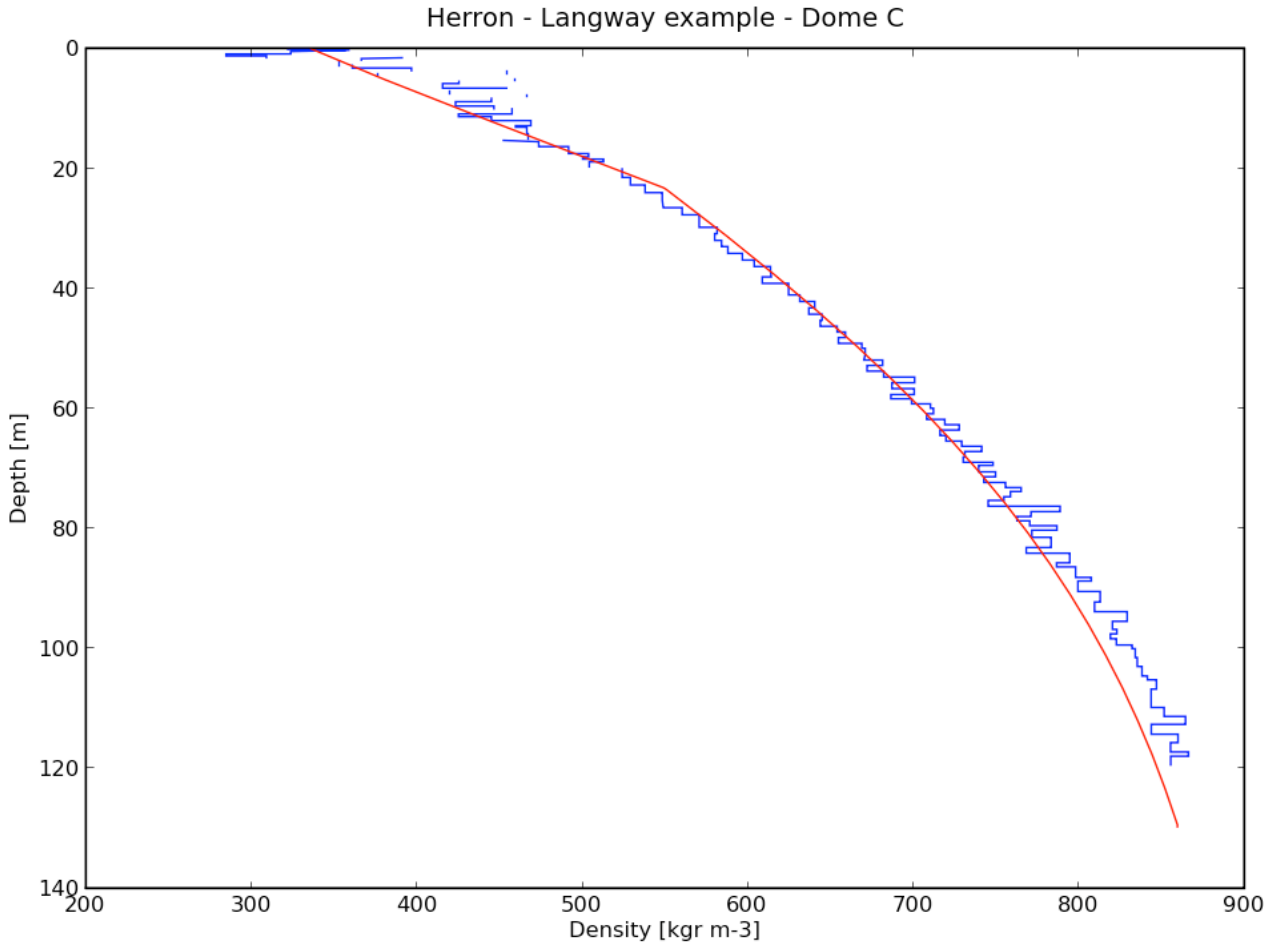
Karthaus 2008

Densification process

$\rho_o = 300\ kgrm^{-3}, \rho_c = 550\ kgrm^{-3},$

$\rho_{close-off} = 830\ kgrm^{-3}, \rho_{ice} = 917\ kgrm^{-3}$



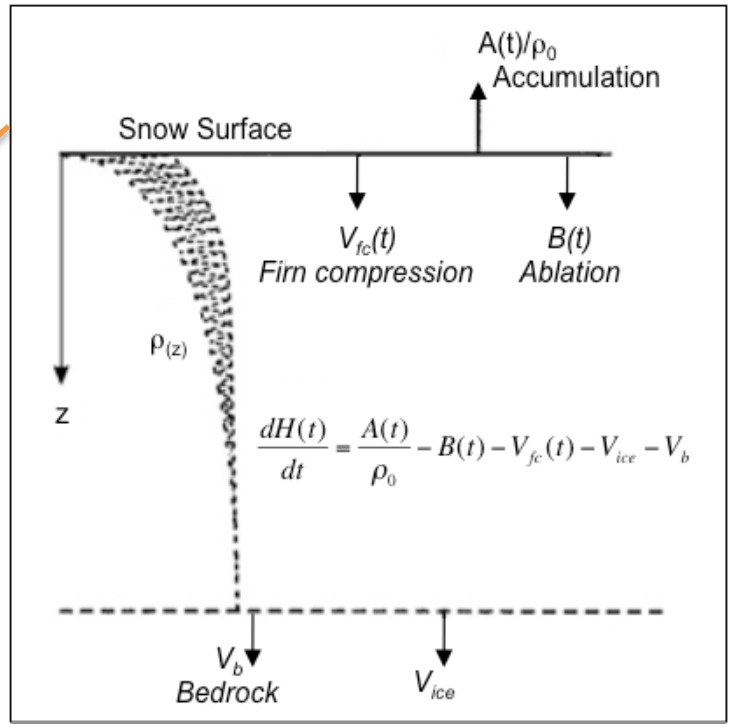
Firn Densification Model

$$\frac{dH(t)}{dt} = \frac{A(t)}{\rho_0} - B(t) - V_{fc}(t) - V_{ice} - V_b$$

constant

$$V_{fc}(z,t) = \int_{z_i}^{z} \frac{1}{\rho(z)} \frac{d\rho(z)}{dt} dz$$

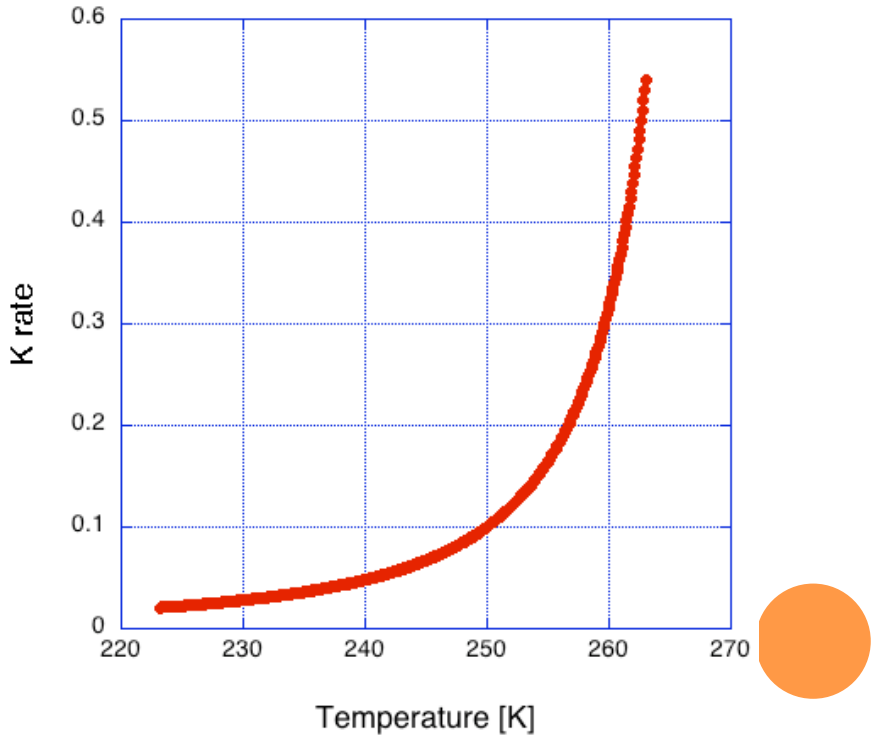
$$\frac{d\rho(z,t)}{dt} = K_{rate}(T) A^{\alpha} \frac{\rho_i - \rho(z,t)}{\rho_i}$$



Densification Rate

- Depends on accumulation (linearly)
- Depends on temperature (NOT linearly!)

$$K_{rate}(T) = K_0(T)e^{\left(-\frac{E(T)}{RT}\right)}$$



Firn Temperature

- Heat-transfer model

$$\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2}$$

- Numerical solution

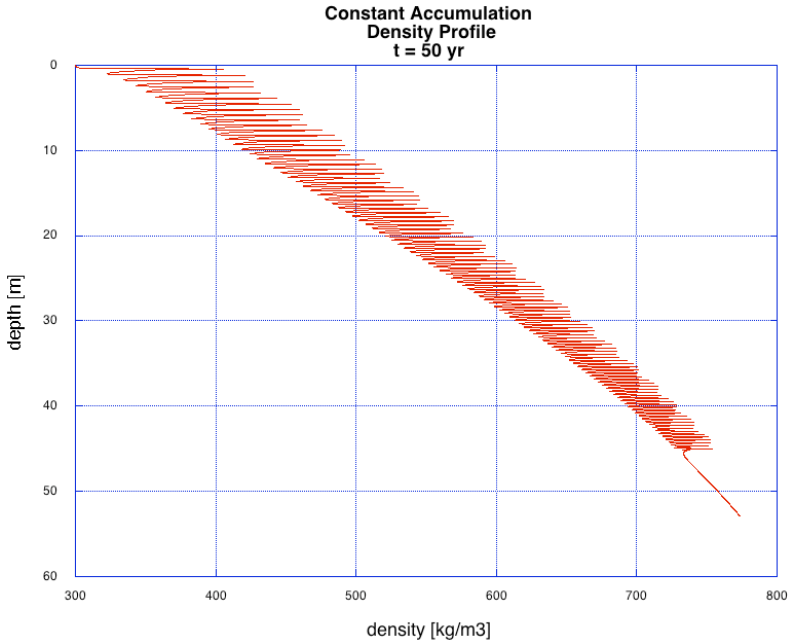
Results Part I

- Idealized simulations: Sensitivity analysis
- Model run: Focus on short (25 yr) time scales

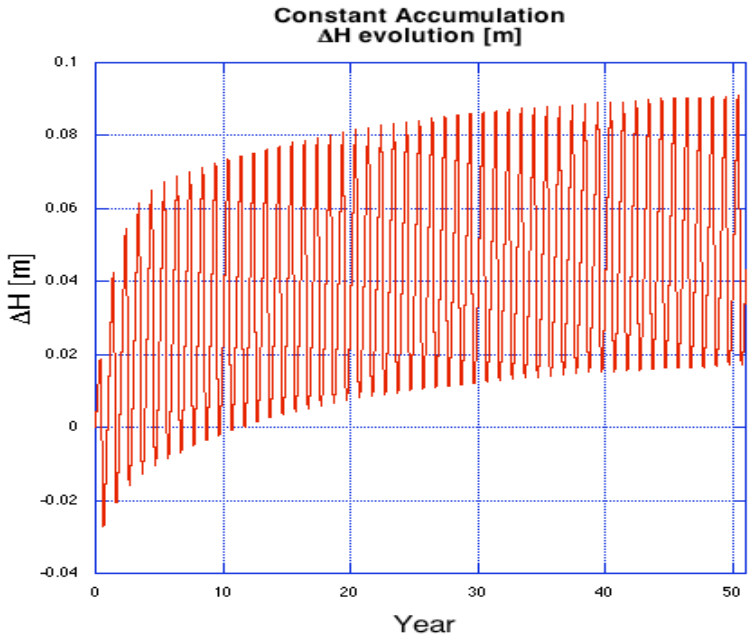
Constant Accumulation Run

- Seasonal Temperature Variation With Constant Amplitude (244.15 ± 27 K)
- Constant Accumulation Rate (250 kg m^{-2} yr^{-1})

- High Frequency Variation due to Temperature Seasonality



Density Profile



Surface height variation

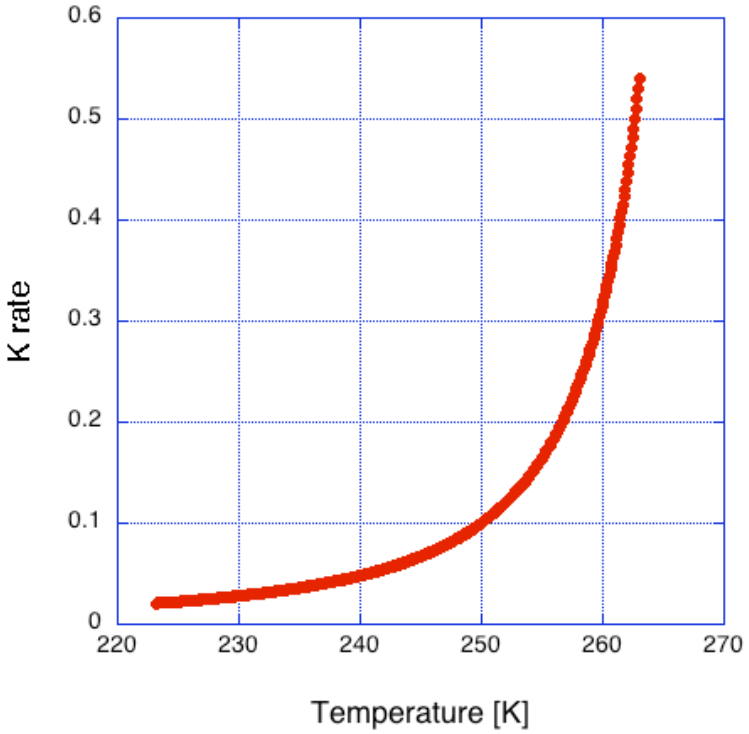
Sensitivity Analysis

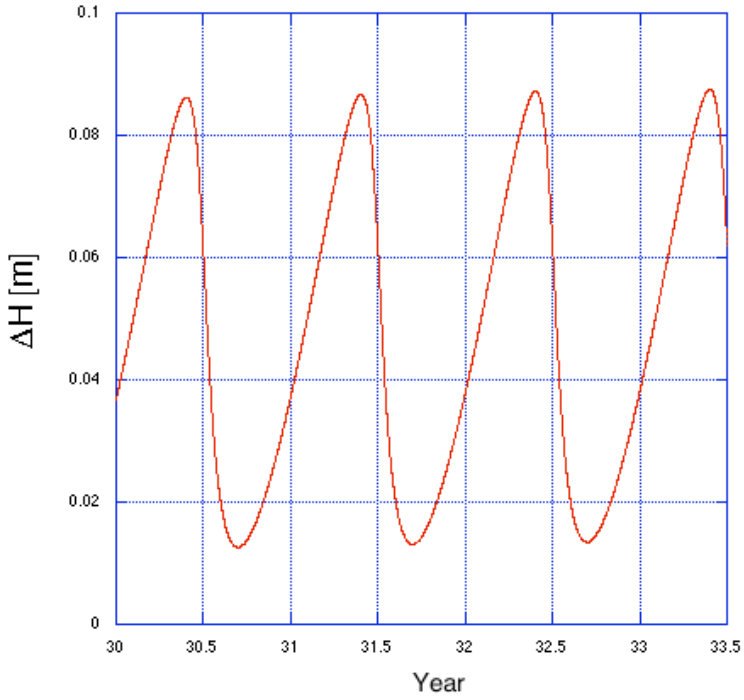
Effect of Temperature

$$\frac{d\rho(z,t)}{dt} = K_{rate}(T)A^{\alpha}\frac{\rho_i - \rho(z,t)}{\rho_i}$$

Asymmetric Line Shapes

$$K_{rate}(T) = K_o(T)e^{\left(\frac{E(T)}{RT}\right)}$$





Seasonal variation in surface height

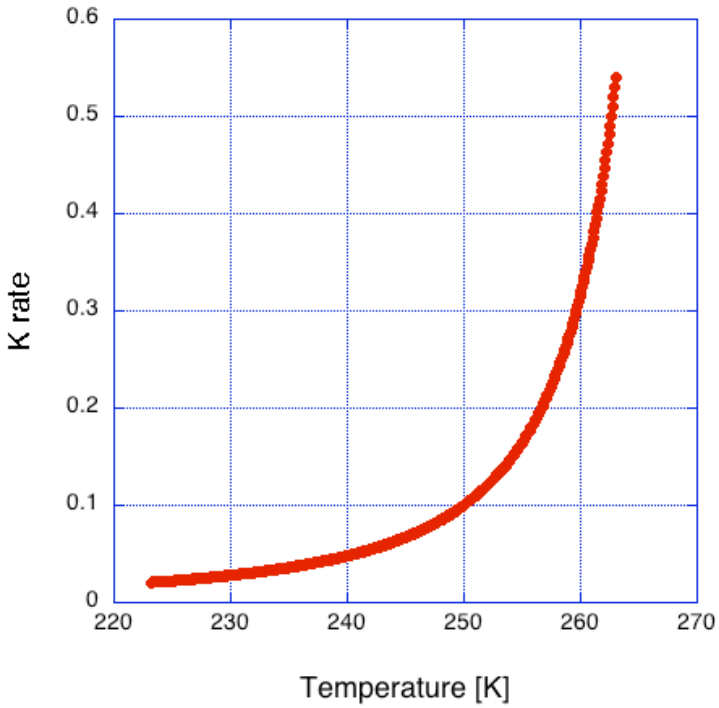
Sensitivity Analysis

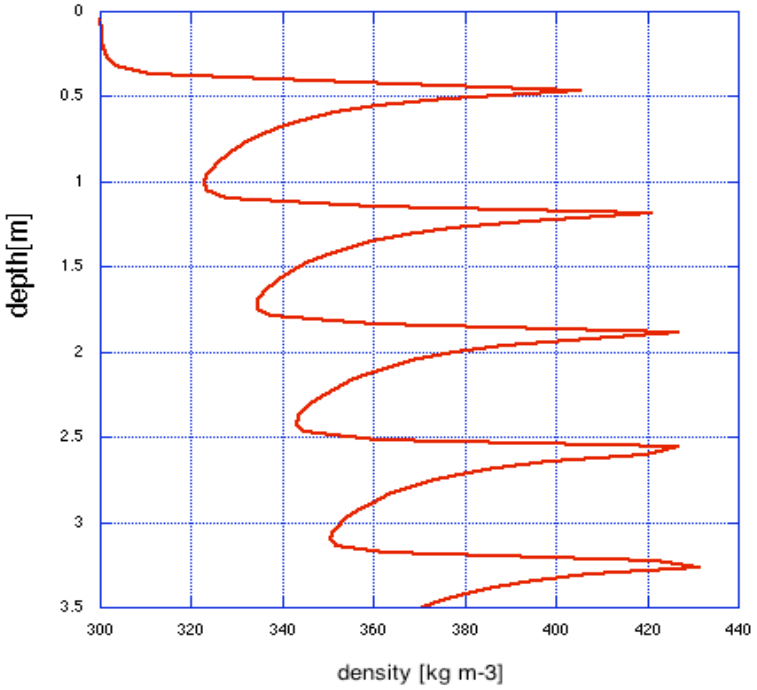
Effect of Temperature

Asymmetric Line Shapes

$$\frac{d\rho(z,t)}{dt} = K_{rate}(T)A^{\alpha}\frac{\rho_i - \rho(z,t)}{\rho_i}$$

$$K_{rate}(T) = K_o(T)e^{\left(\frac{E(T)}{RT}\right)}$$





Seasonal variation in density

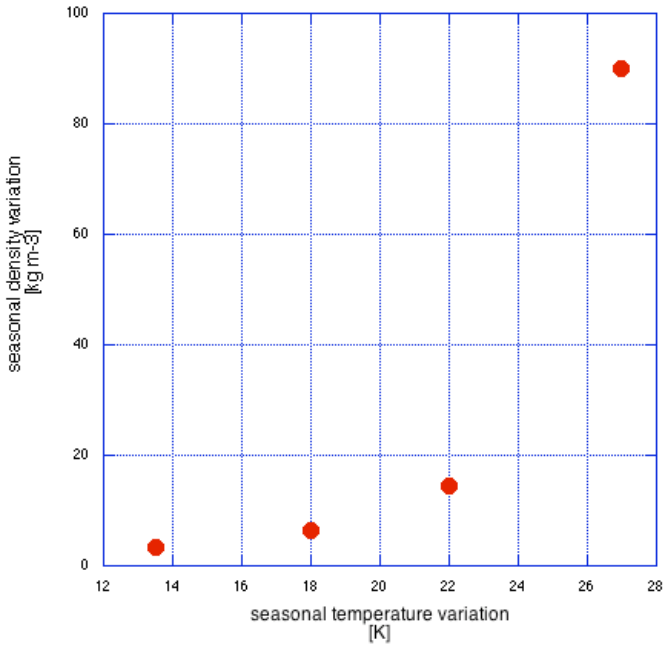
Sensitivity Analysis

Effect of Temperature Amplitude

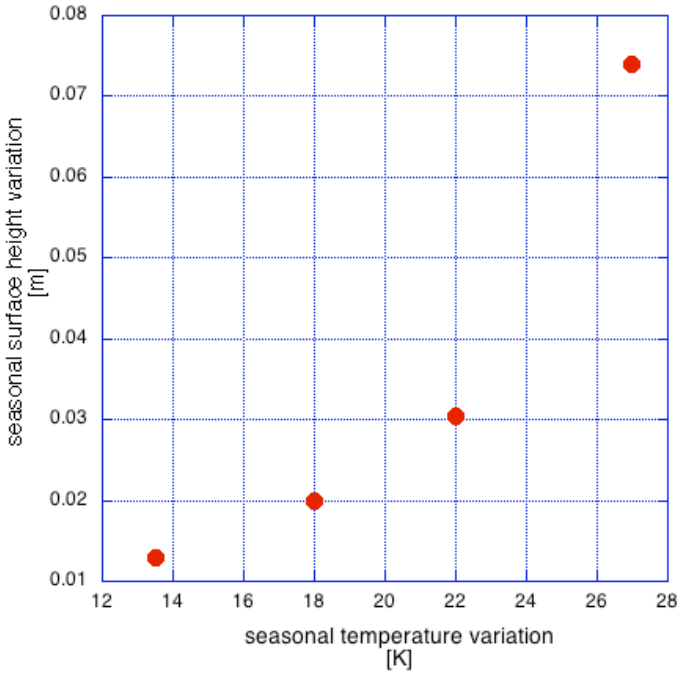
$$\frac{d\rho(z,t)}{dt} = K_{rate}(T)A^{\alpha}\frac{\rho_i - \rho(z,t)}{\rho_i}$$

$$K_{rate}(T) = K_o(T)e^{\left(\frac{E(T)}{RT}\right)}$$

Density



Surface height

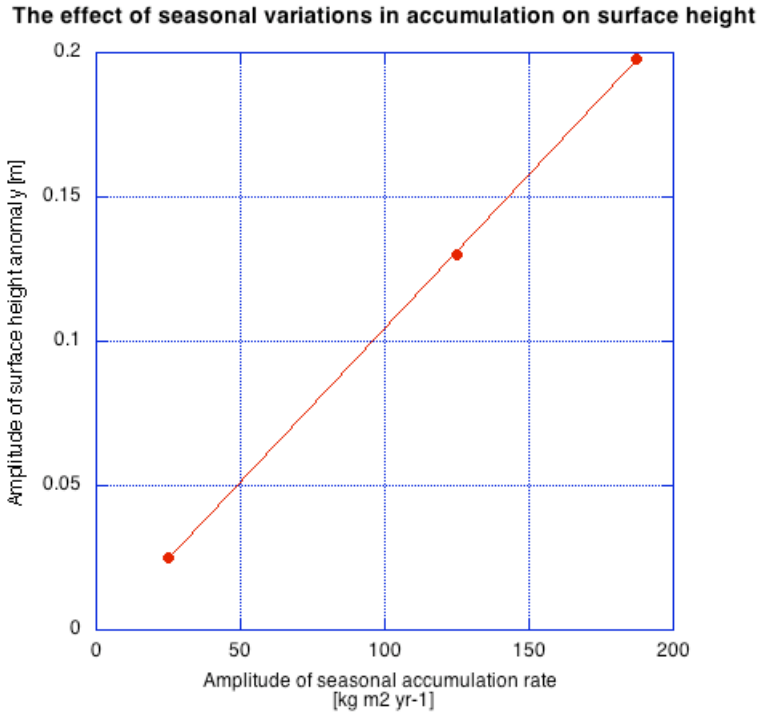


Sensitivity Analysis

Effect of Accumulation Amplitude (for a constant temperature)

$$\frac{d\rho(z,t)}{dt} = K_{rate}(T)A^{\alpha}\frac{\rho_i - \rho(z,t)}{\rho_i}$$

$$\alpha = 1$$



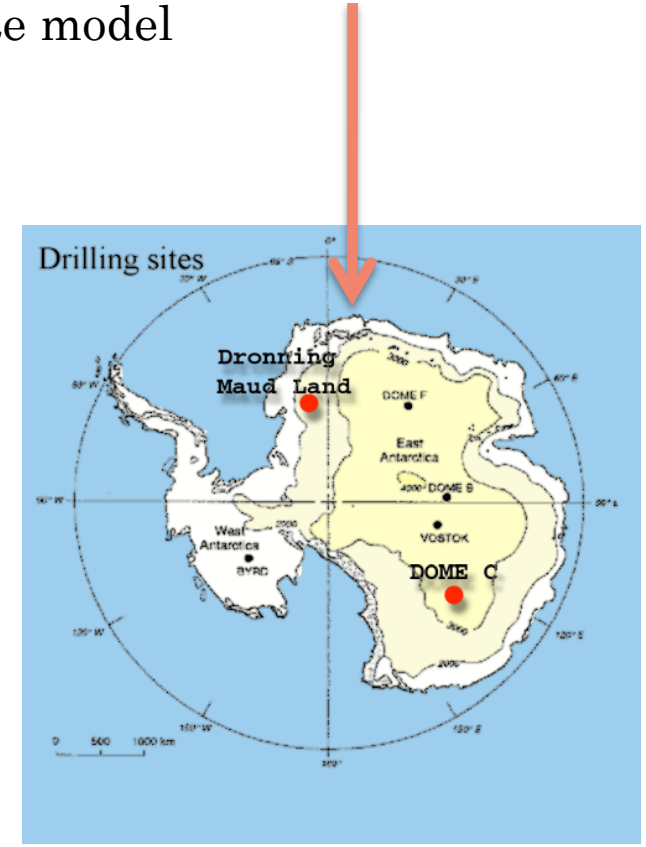
For the different accumulation amplitudes:

- Density profile amplitude remains constant and close to zero

- Surface height amplitude shows a linear relation to amplitude of A

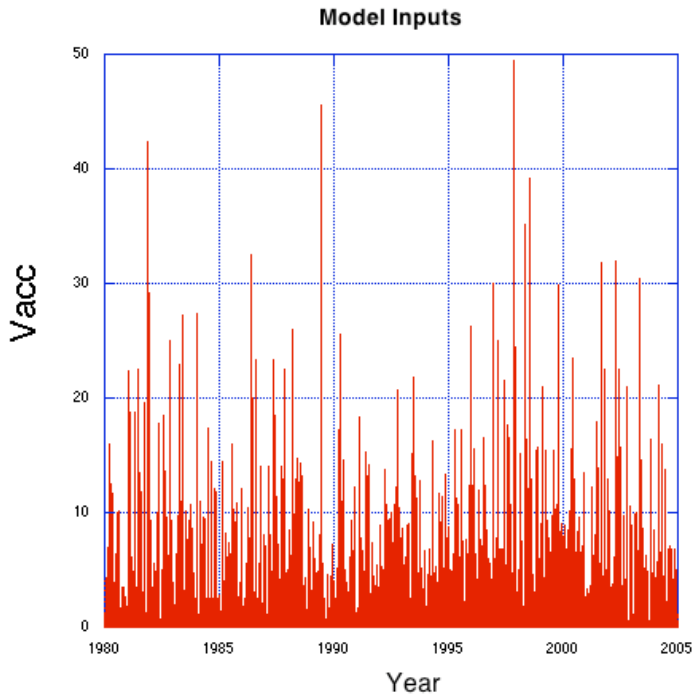
RACMO MODEL RUN

- Site: Dronning Maud Land
- 25 years run
- Input of Racmo regional climate model
  - Temperature
  - Precipitation
  - Sublimation

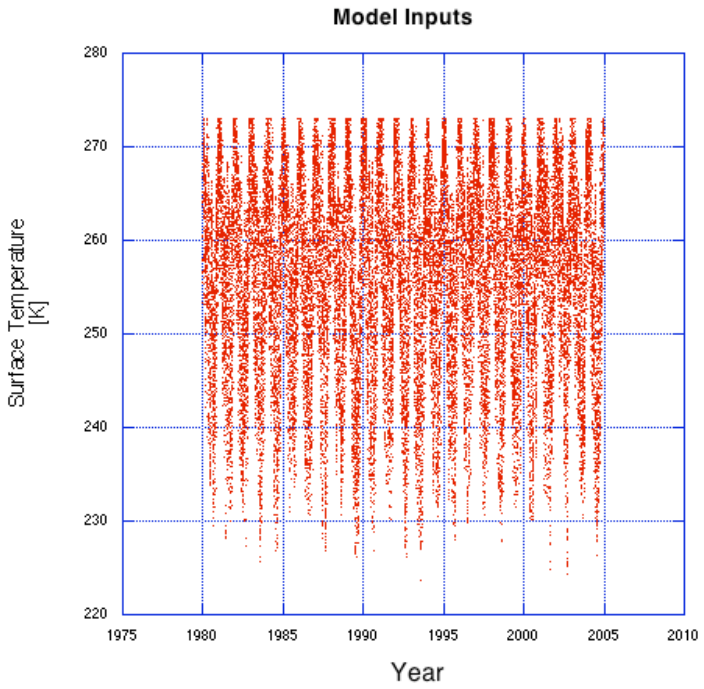


RACMO MODEL RUN

Model Inputs

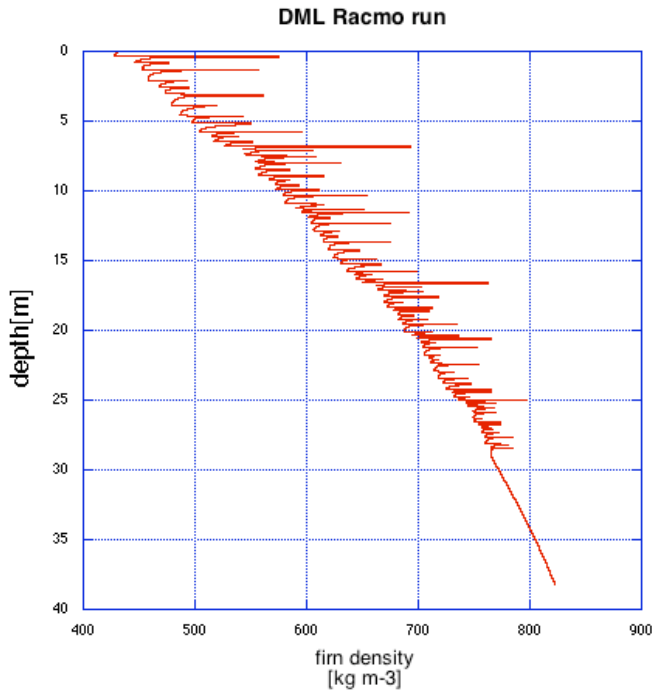


Accumulation

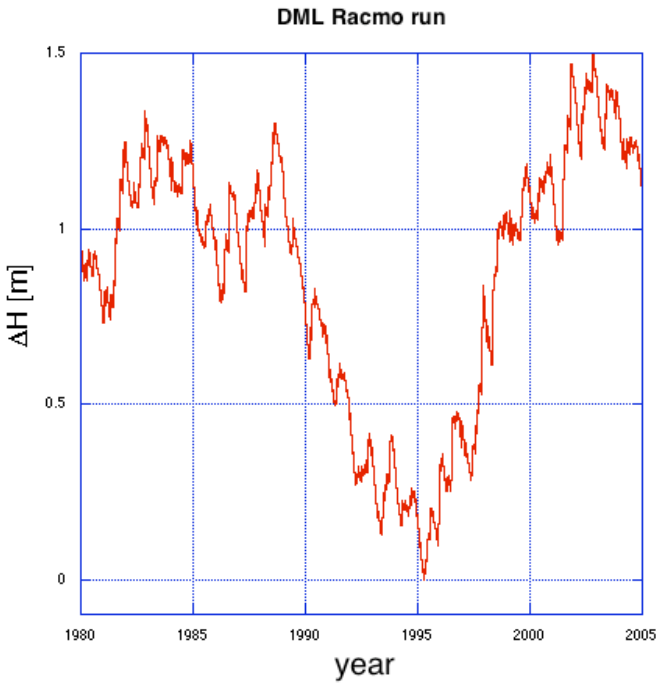


Temperature

Racmo Model Run



Density Profile after 25 yrs

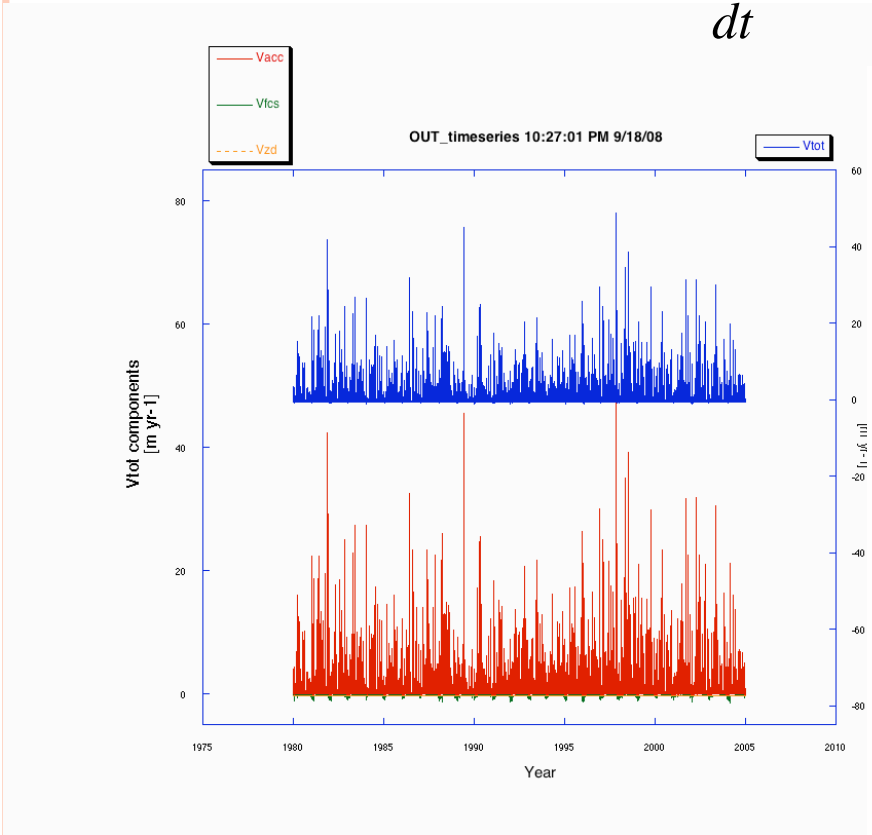


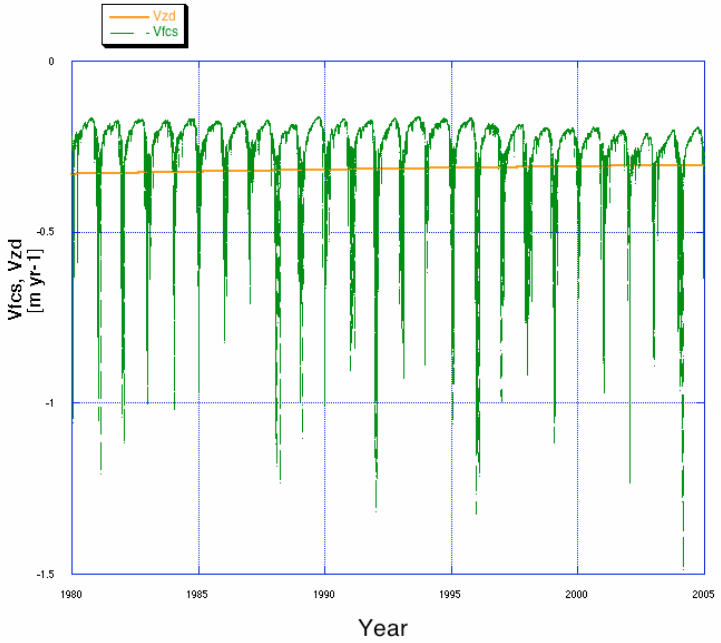
Surface height variation

RACMO MODEL RUN

Rate of surface height change

$$\frac{dH(t)}{dt} = \frac{A(t)}{\rho} - V_{fc}(t) - V_{zd}$$

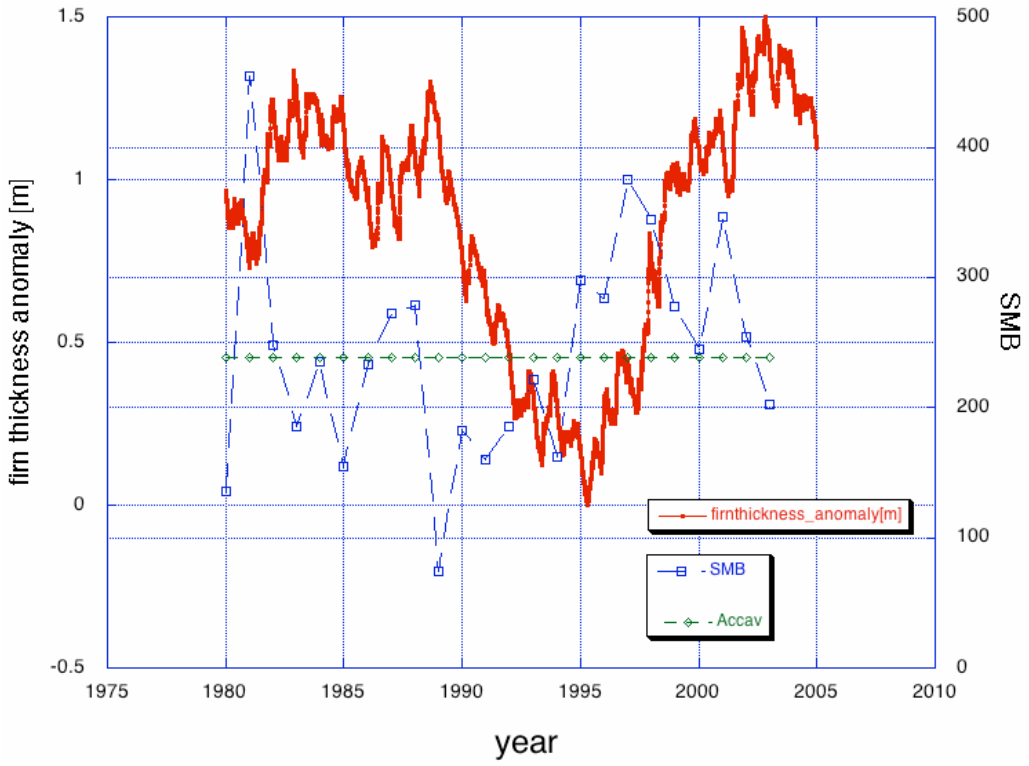




Seasonal variation in 'compaction rate'

FIRN THICKNESS

When annual accumulation below long term average then firn thickness decreases.



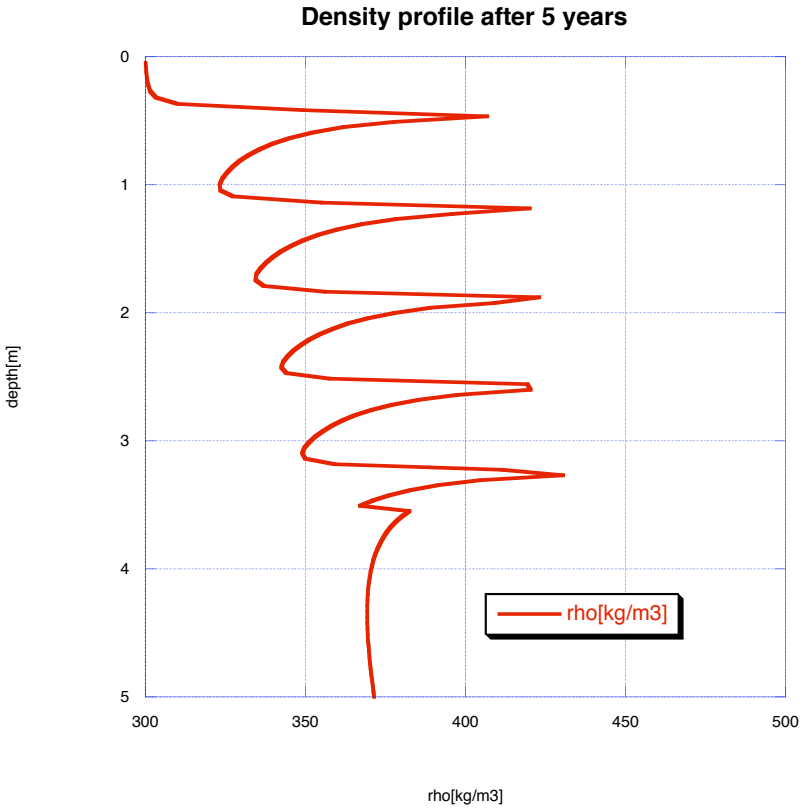
Time period over which model is run is critical for average accumulation and hence firn thickness.

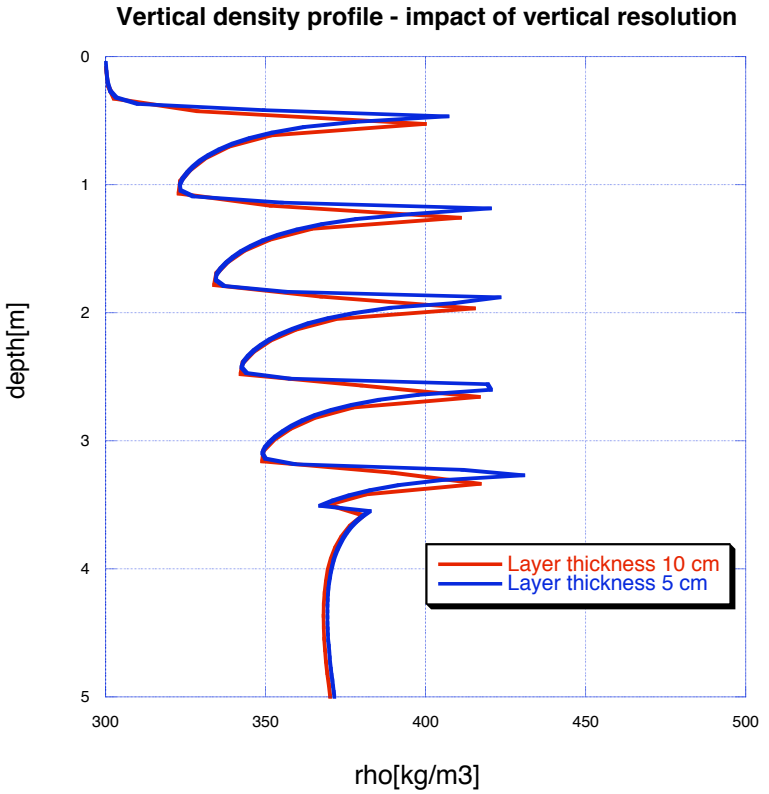
Results Part II

- Idealized simulations: sensitivity analysis
- Include observations (ice core): focus on long time scales

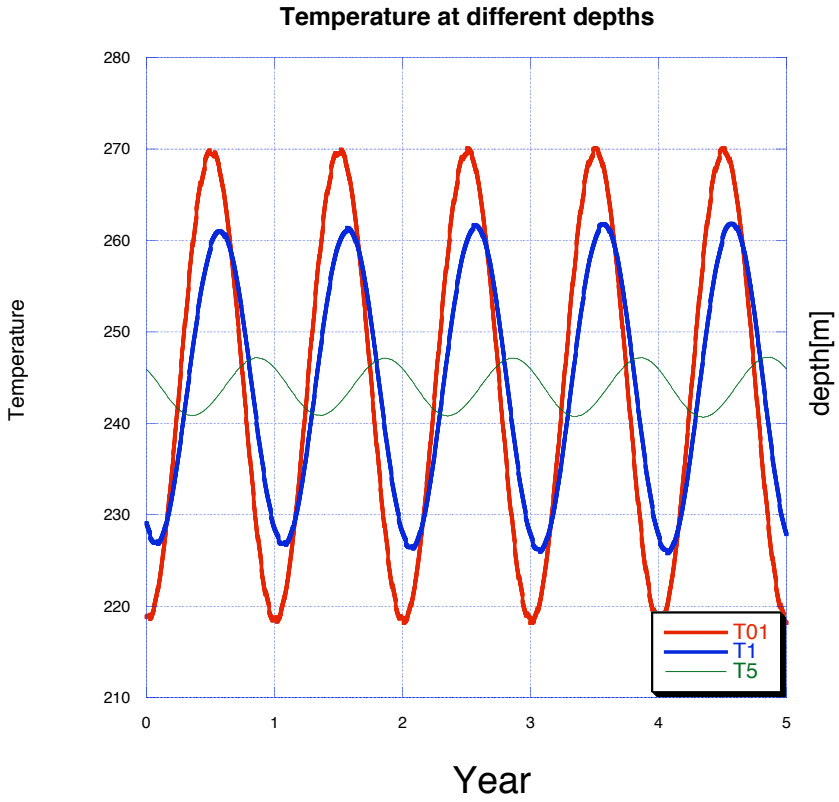
Results of the model using idealized conditions

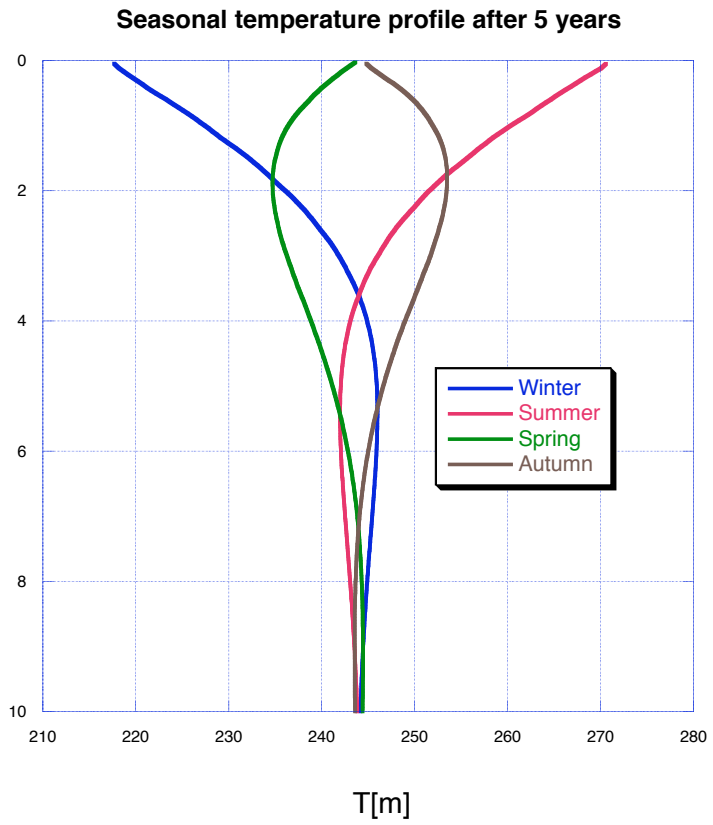
Assuming sinusoidal temperature variations (T_{avg} = 244 K, T_{amp} = 27 K) and constant accumulation rate with time (a = 250 kg m^2 yr^{-1})





Seasonal temperature variations:



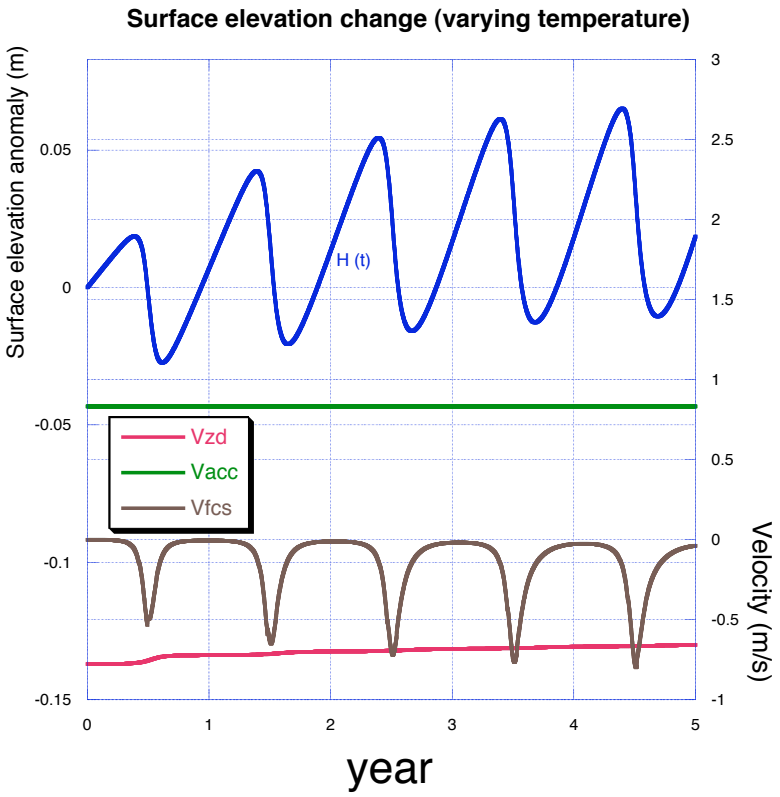


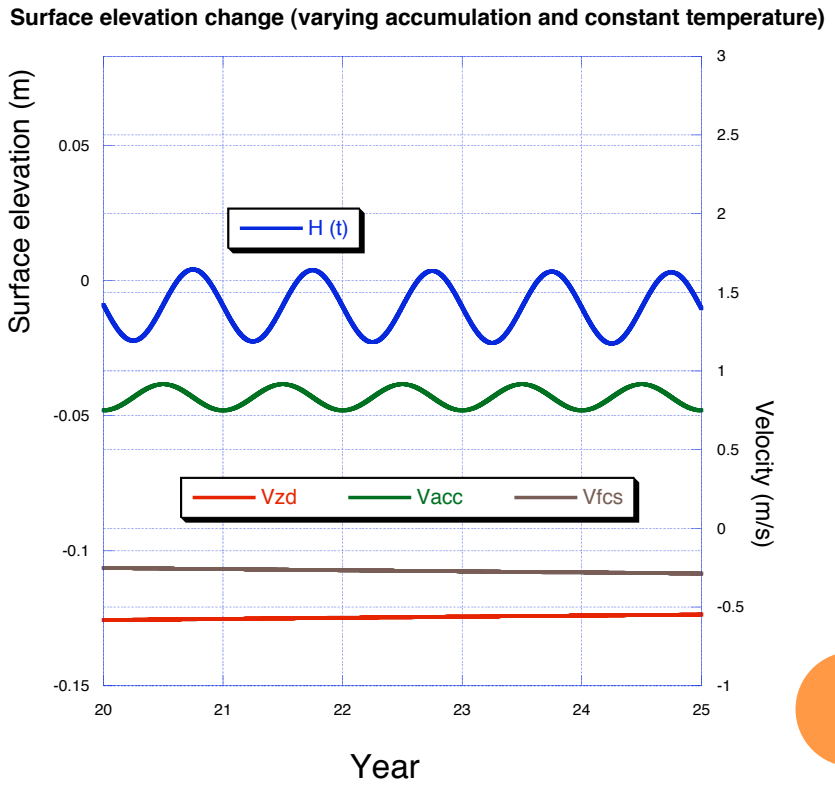
Changes in surface elevation under different conditions:

Influenced by seasonal variations in

- Temperature
- Accumulation rates

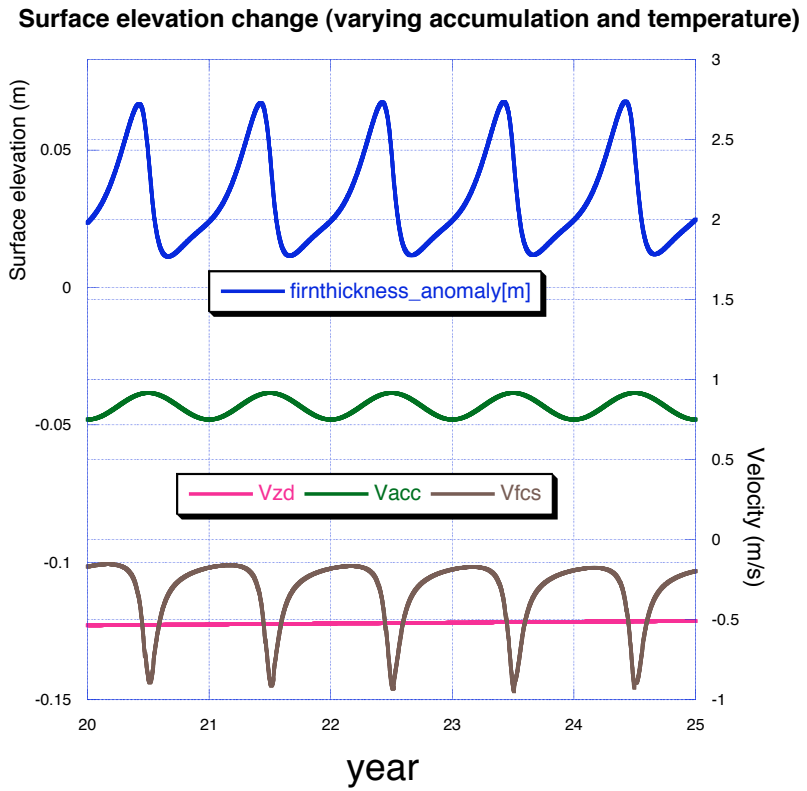
$$\frac{dH(t)}{dt} = \frac{A(t)}{\rho_0} - V_{fc}(t) - V_{ice}$$



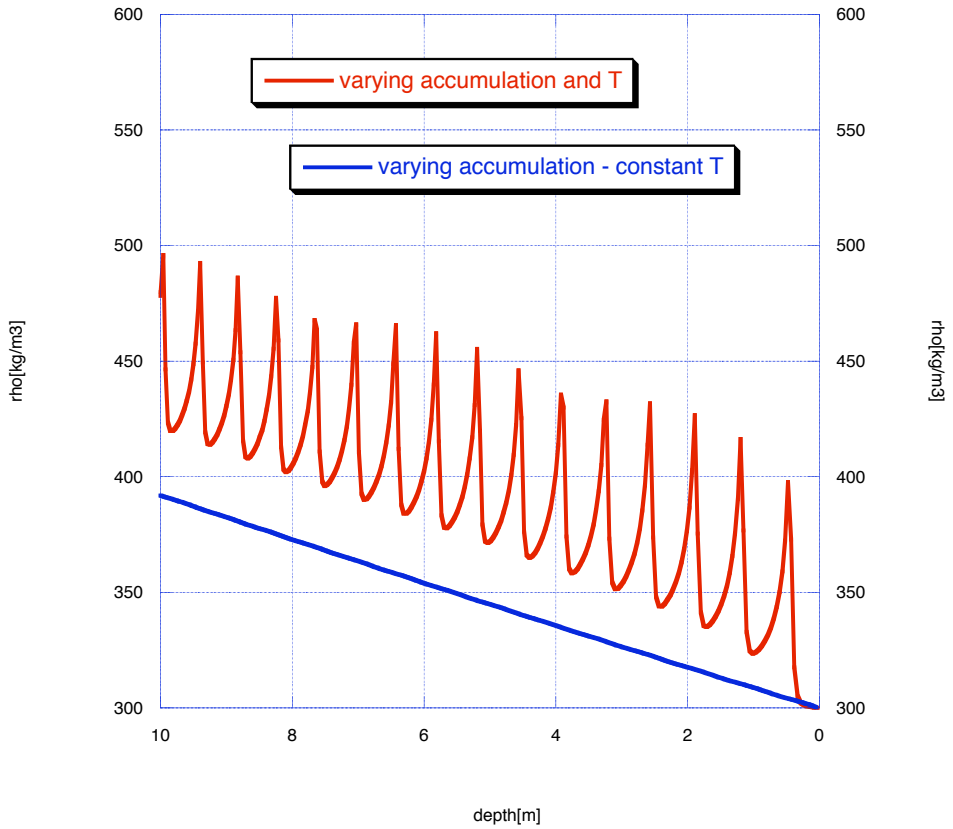


Changes in surface elevation under different conditions:

Seasonal variation in both accumulation and temperature.

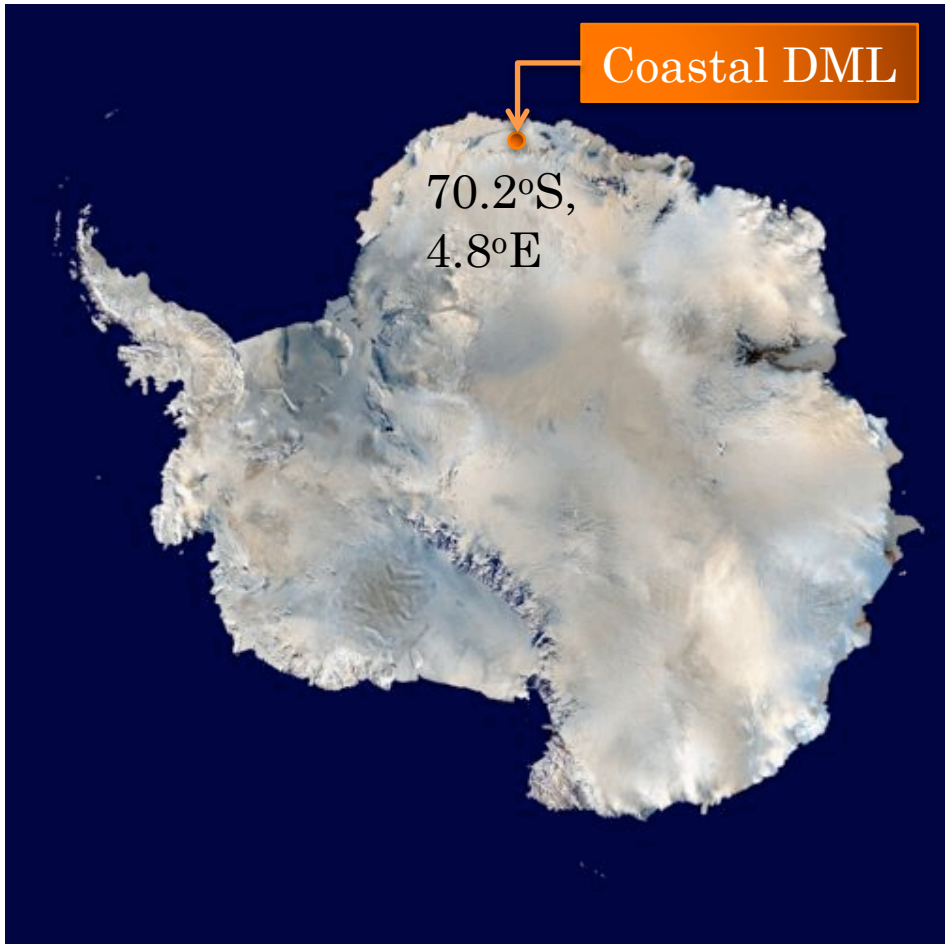


- Change in density under different conditions



Seasonal variations in accumulation alone have almost no influence on the vertical density profile.

Results of the model for antarctic conditions using accumulation data from the ice core Coastal DML

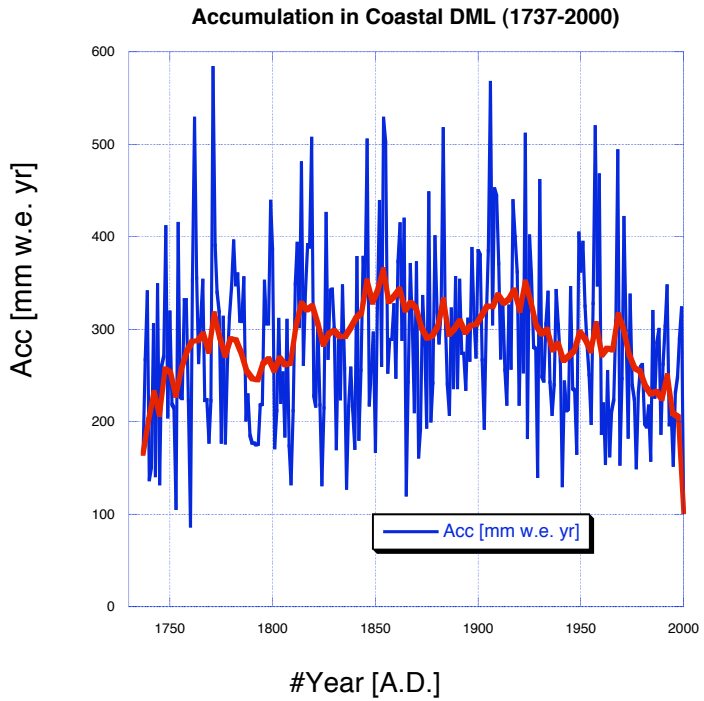


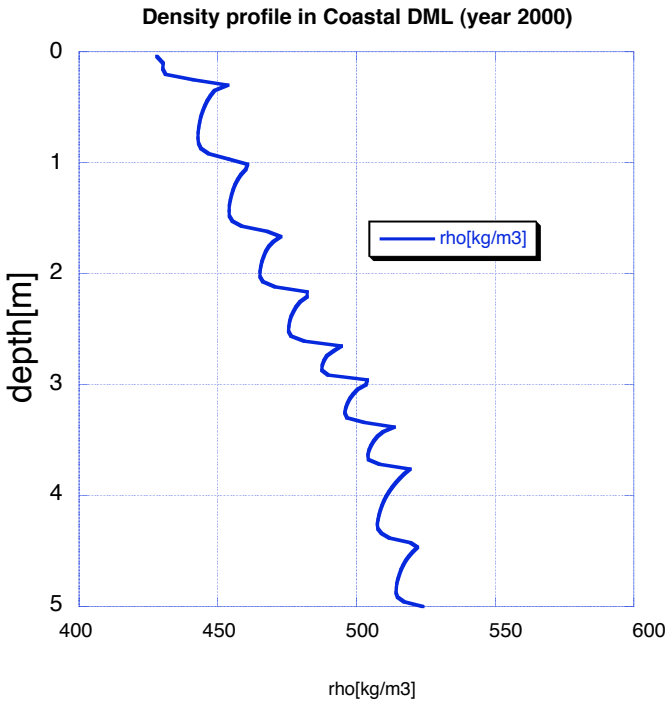
Average temperature: 256.3 K

Annual temperature variation: 13 K

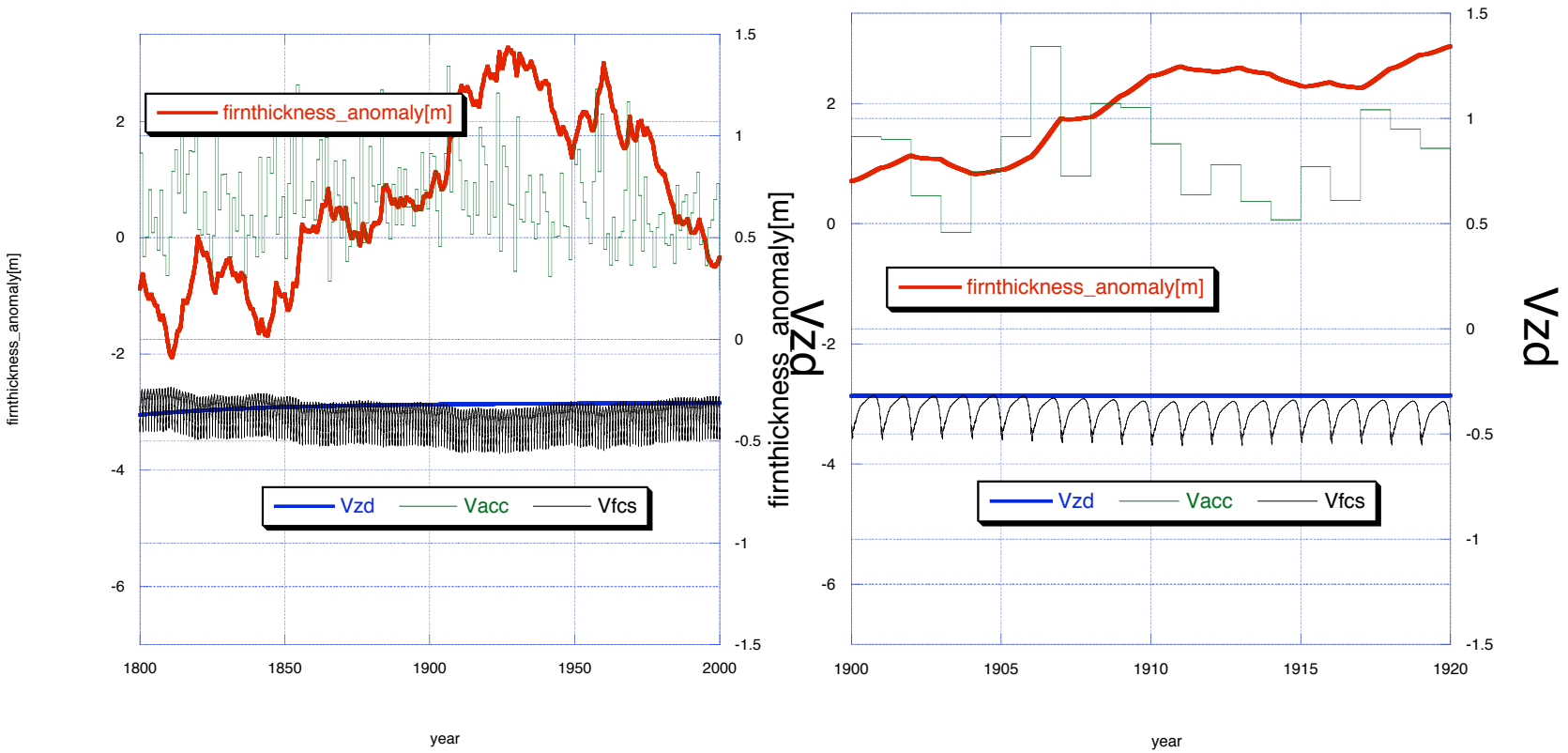
Average accumulation: 238.7 kg m^{-2} yr^{-1}

Accumulation data and the resulting vertical density profile for Coastal DML





CHANGES IN SURFACE ELEVATION



Last 200 years

Blow-up of the period 1900-1920

CONCLUSIONS

Accumulation and temperature are very important factors for the firn densification process, and hence for the surface elevation changes.

Large changes in surface elevation have occurred at the site Coastal DML during the last 200 years.


Thank you !