Modeling Δ-age (distributions) of enclosed air in layered firn

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HELMHOLTZ
GEMEINSCHAFT

Modeling Δages in ice from the Antarctic plateau

4 problem areas for Δage-calculations

Densification

EDML: 900 years (recent)
EDC: 2000 -5000 years (Glacial)

Impurity controlled Densification model

Air diffusion within the open pore space

EDML, EDC: 30 -50 years (recent, Glacial, (Schwander et al., 1997))

neglected

Critical close-off density (percolation threshold)

EDML: 0.82-0.84gcm-3: 6m -> 70years (recent)
EDC -> 300 years (Glacial)

Lateral dimension of single layers (sealing effect of dense layers?)

EDML: 0.82gcm-3: 16m -> 190years (recent)
EDC -> 800 years (Glacial)

Outline

Lateral dimension of single layers (sealing effect?)

measurements from the last field campaign COFI (Antarctica, DML)

Critical density – pore close-off

measurements and model

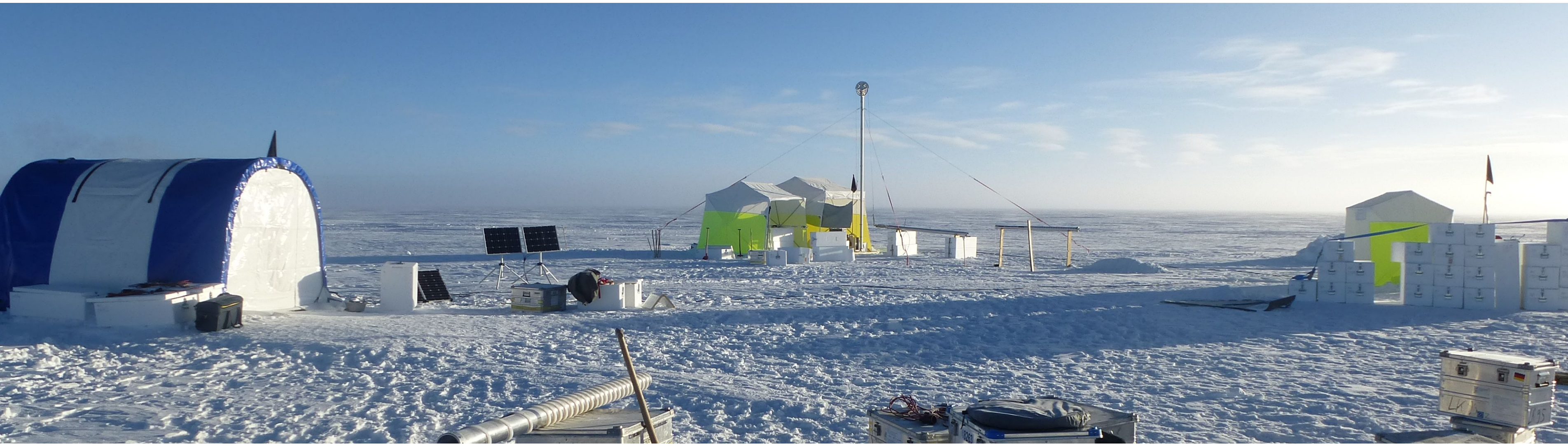
Modeling Δage for EDC and comparing it with LD2010 and AICC12 chronologies

Modeling gas-age distributions

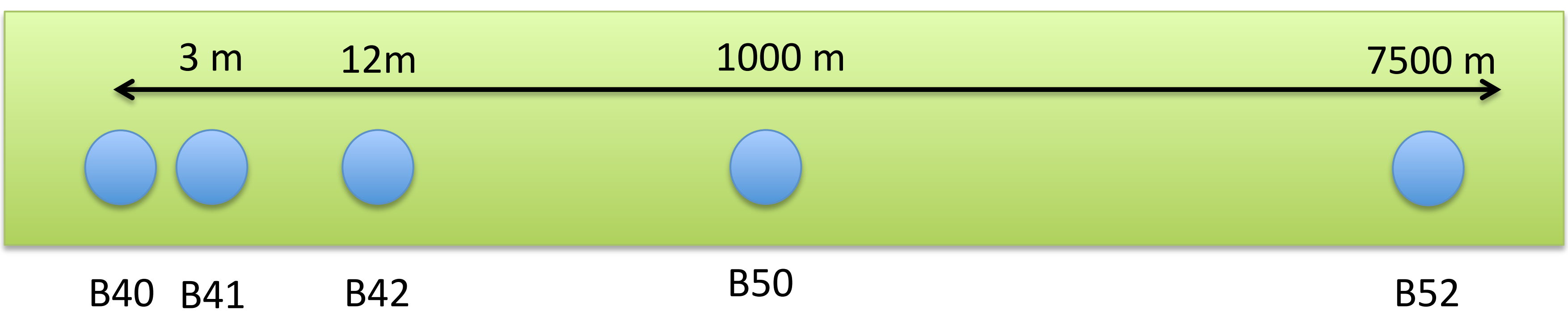
case studies using a percolation and impurity-densification model

Conclusions

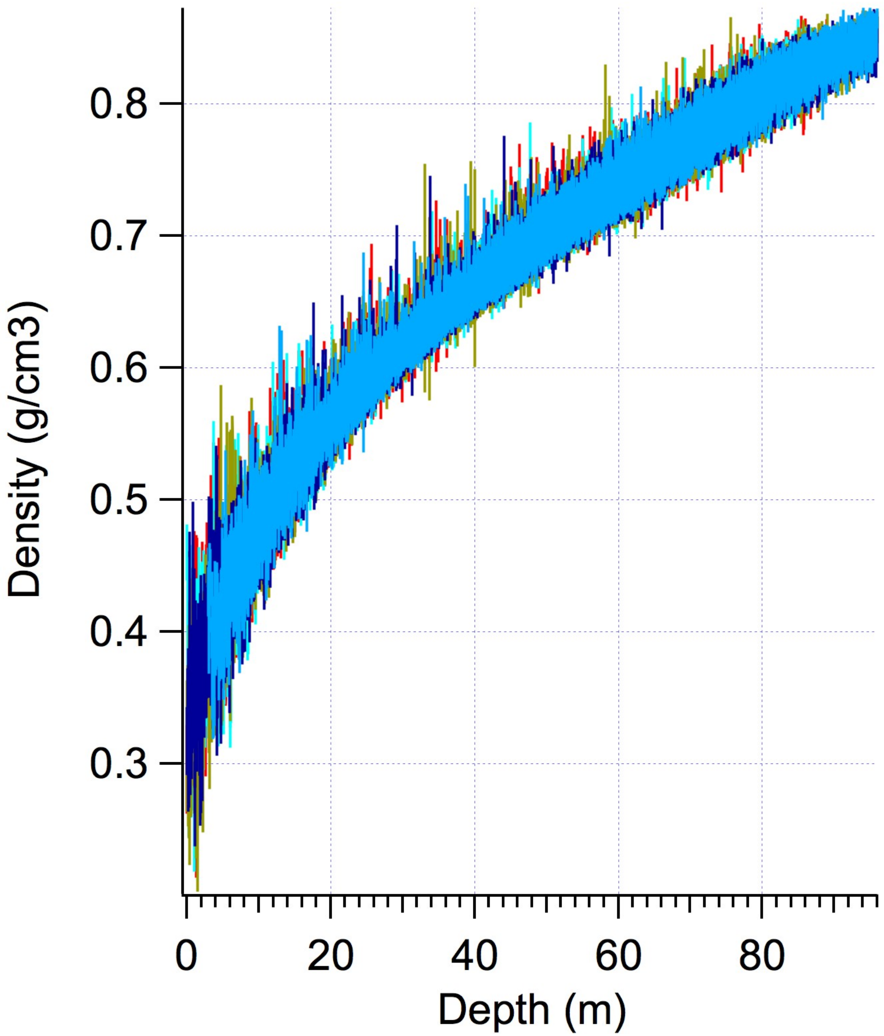
The lateral dimension of firn layers

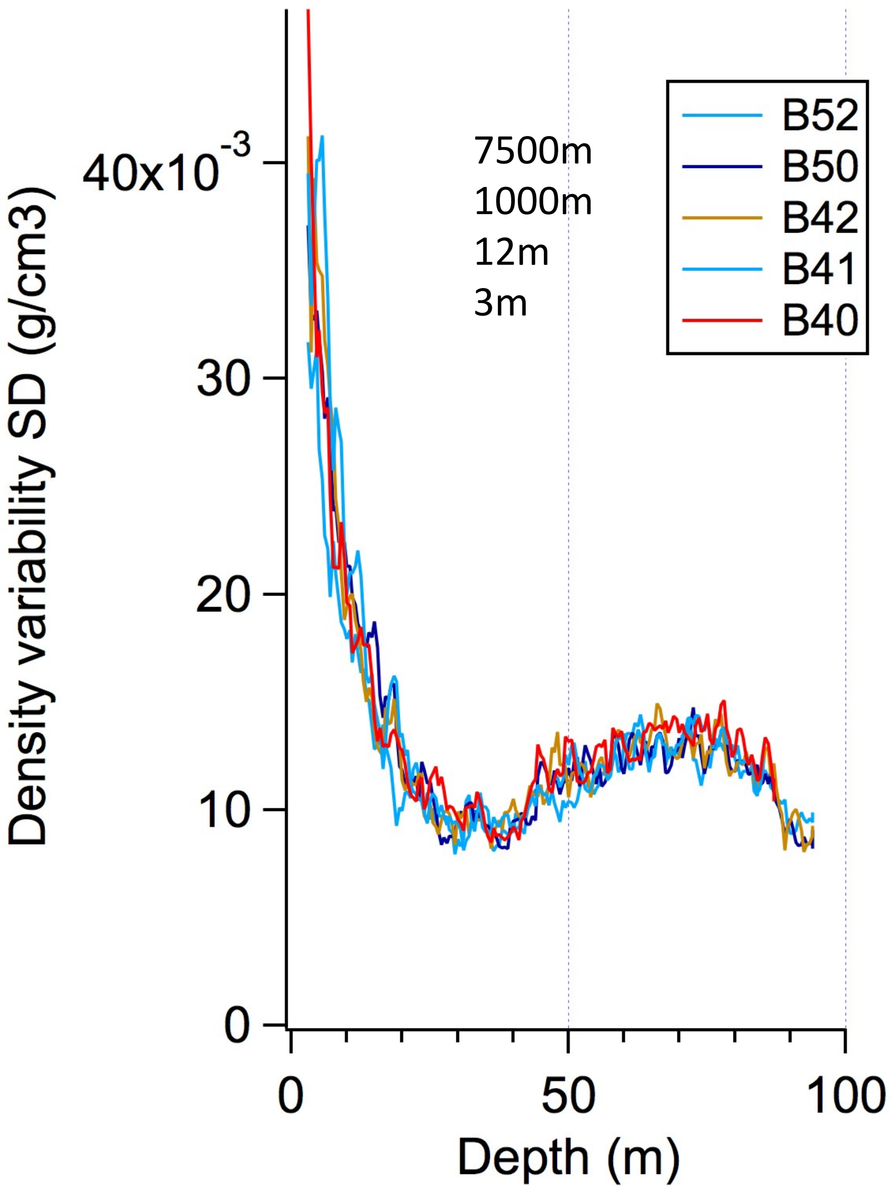


Antarctica, DML, 2013, COFI-CAMP: T≈-45°C, Acc≈70mm weq/a

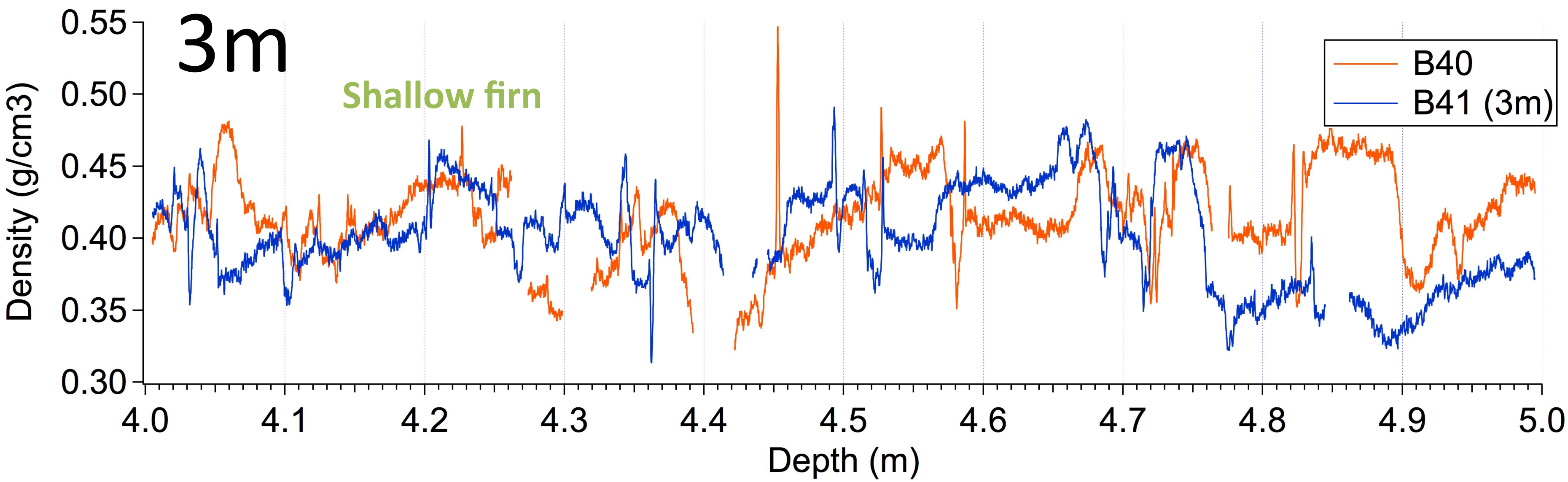


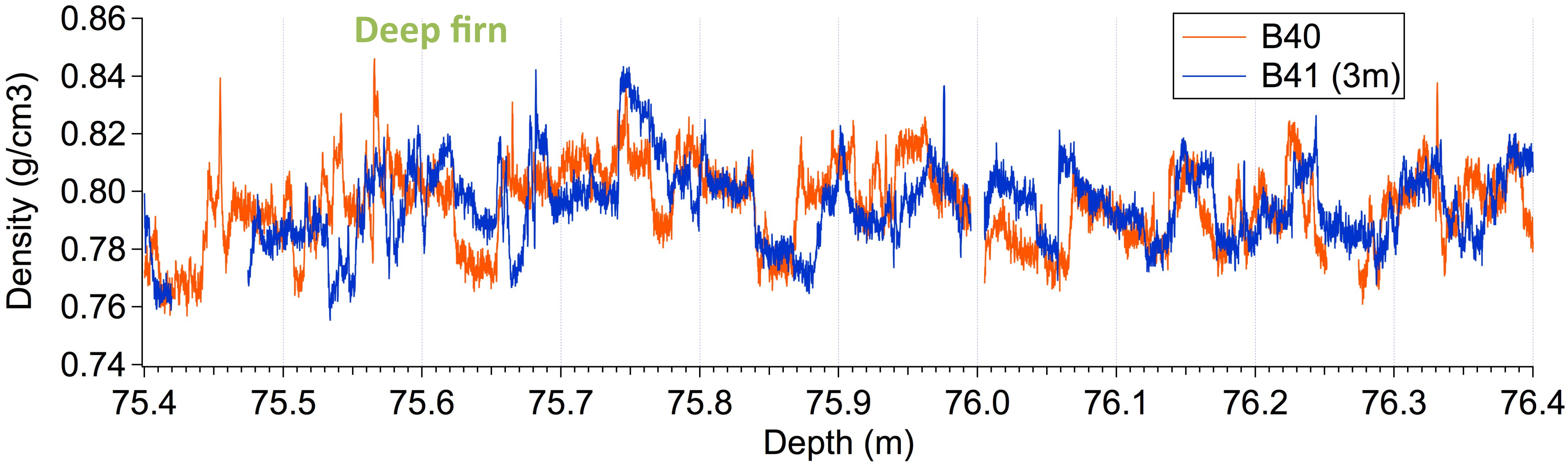
Intercomparison: similar mean and density variability



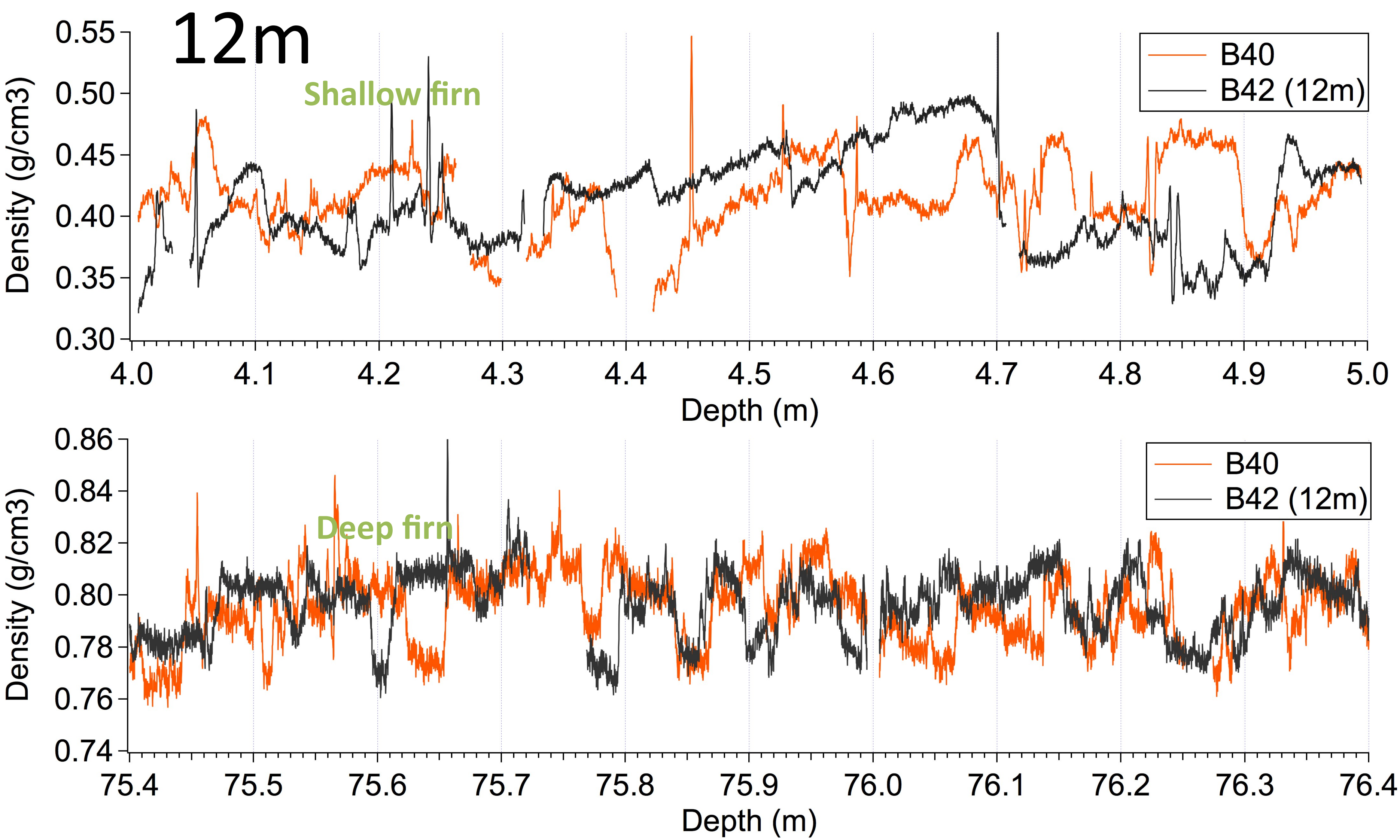


Comparison of density profiles measured in 3m distance

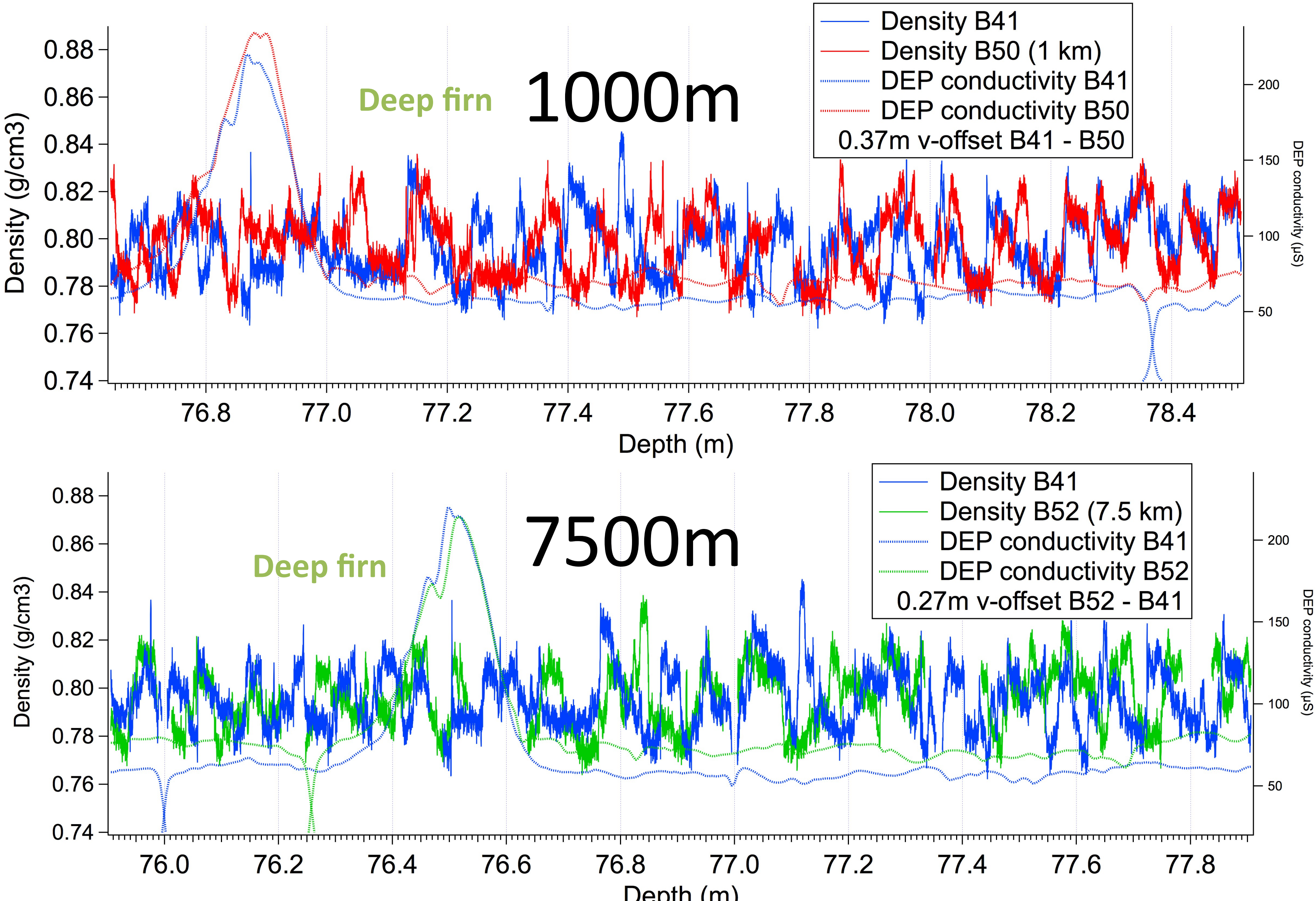




Comparison of density profiles measured in 12m distance



Comparison with (1km) and (7.5km)



Summary

Similarities in density variations in deep firn (10m ...1000m ....10000m), more differences in shallow firn

Explanation (in terms of the impurity-densification link):

Impurity concentrations seem to be laterally more homogeneous than the surface density at DML.

Implications:

Sealing effect for pore close-off

Strengthen the representiveness of an ice-core record

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neglected

Critical close-off density (percolation threshold)

EDML: 0.82-0.84gcm-3: 6m -> 70years (recent)

EDC -> 300 years (Glacial)

Lateral dimension of single layers (sealing effect of dense layers?)

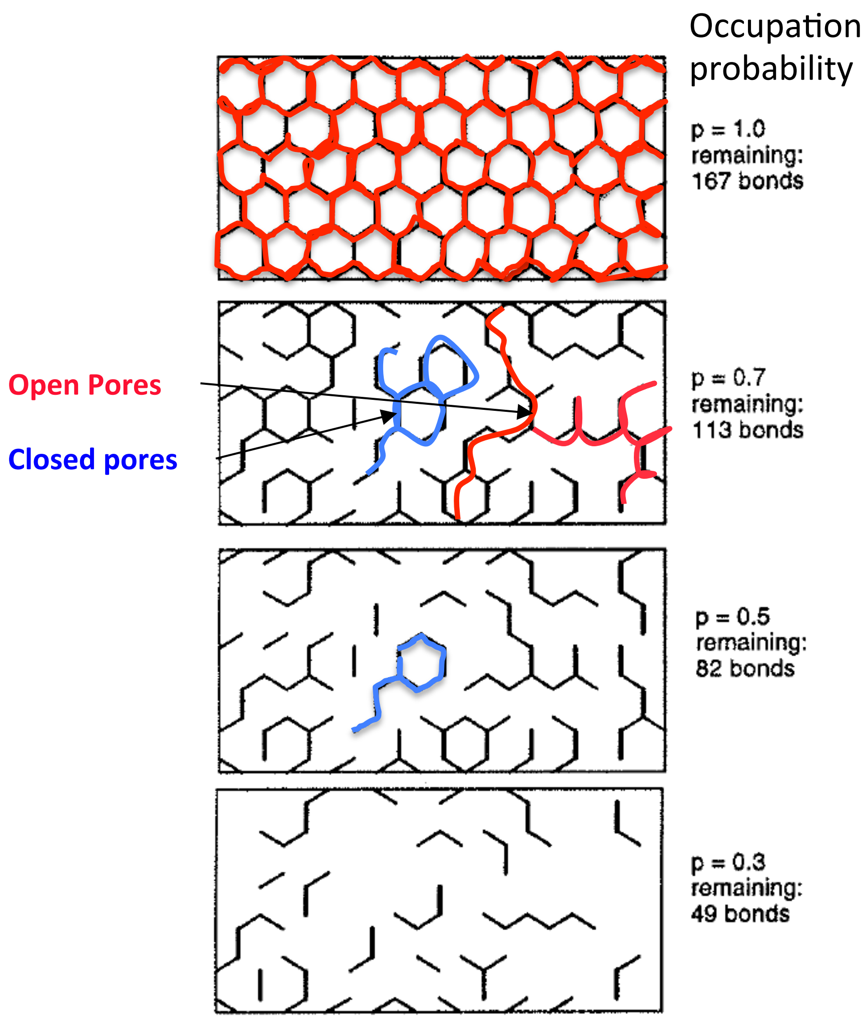
EDML: 0.82gcm-3: 16m -> 190years (recent)

EDC -> 800 years (Glacial)

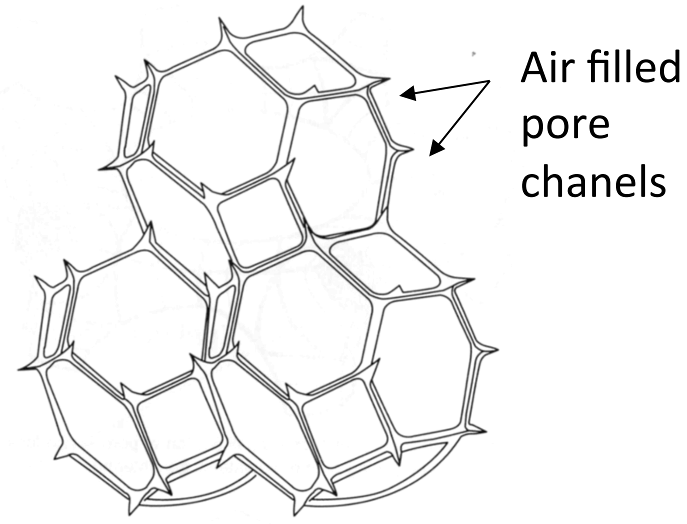
Infinite, sealing (>2cm)

The critical density (percolation threshold and pore close-off)

Gradual air enclosure: a percolation problem



(Stauffer et al. 1985 / 1995)



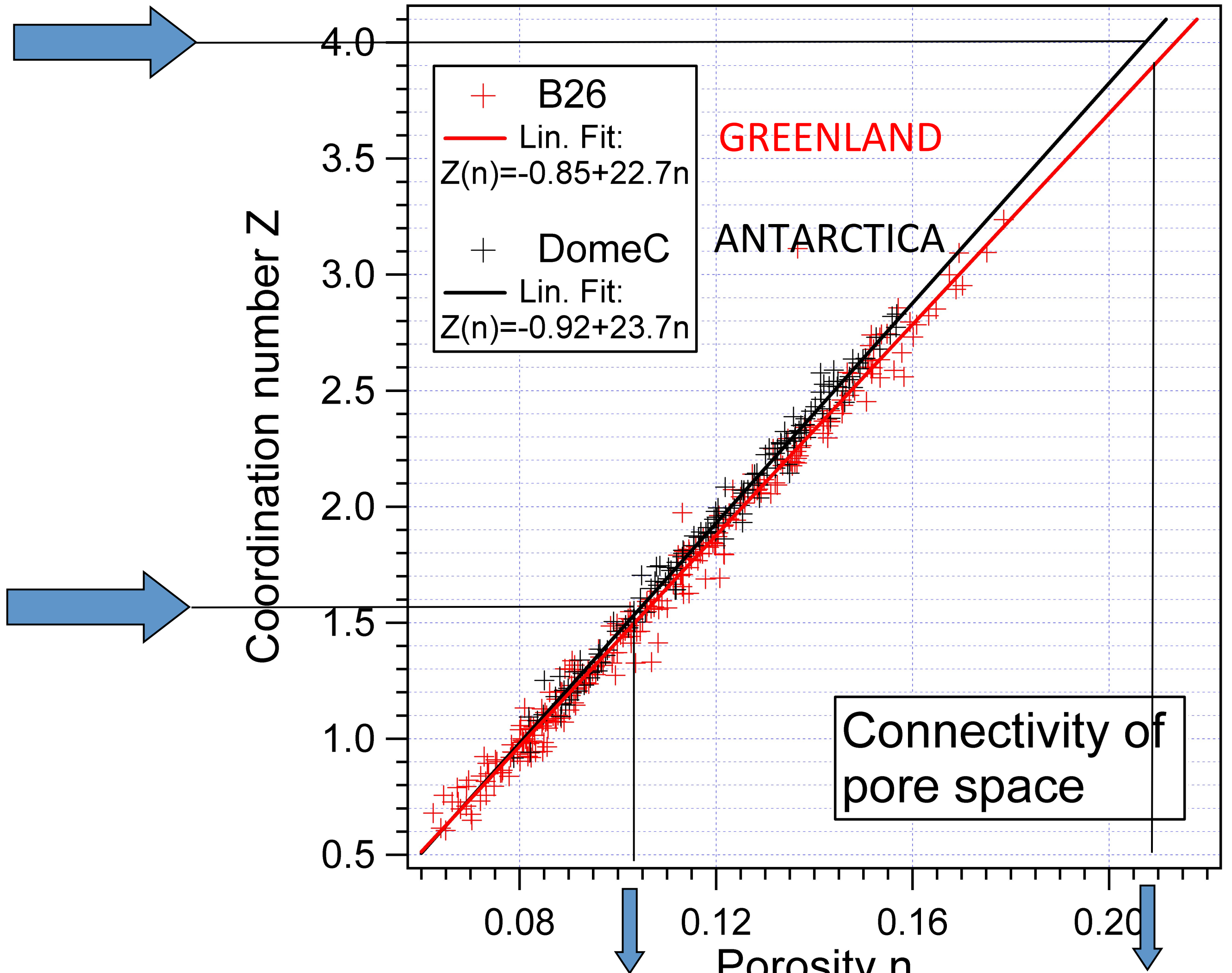
Model for sintered firn: Network of Tetrakaidecahedrons on a BCC-Lattice

$Z=4$ Fully occupied lattice (p=1):

$Z \approx 1.6$ Lattice at the threshold from permeability to impermeability (percolation threshold p_{crit}~0.4)

$Z(p) \approx$ linear

CT-measurements of pore connectivity



n=0.10 ~ ρ=830 kg/m³ n=0.208 ~ ρ=726 kg/m³

Conclusion:

Universal critical porosity (for homogeneous firn, subcm-scale)

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Critical close-off density (percolation threshold)
EDML: 0.82-0.84gcm-3: 6m -> 70years (recent)
EDC -> 300 years (Glacial)

Constant!
S=0.1, Rho=0.83g/cm3

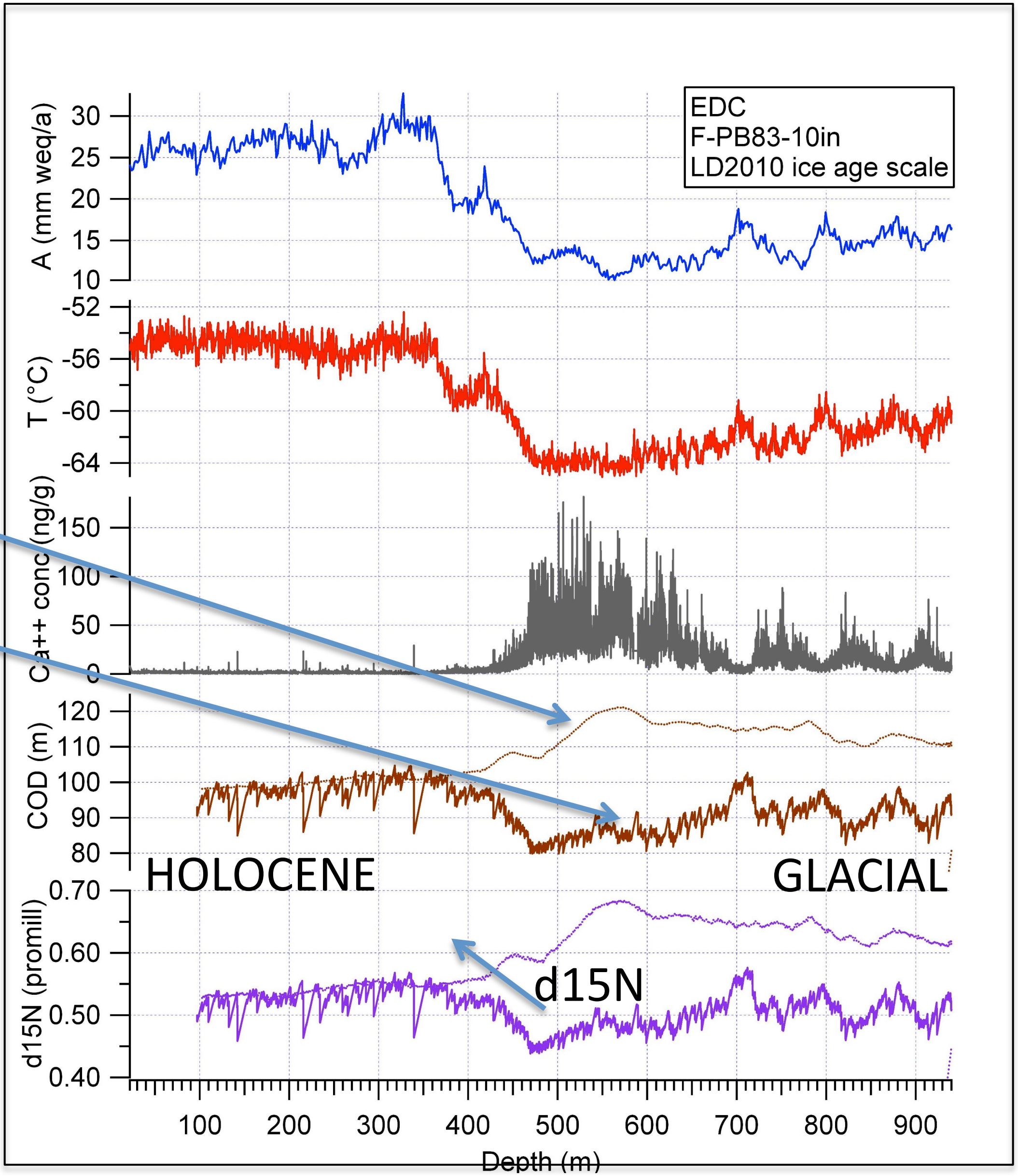
Lateral dimension of single layers (sealing effect of dense layers?)
EDML: 0.82gcm-3: 16m -> 190years (recent)
EDC -> 800 years (Glacial)

Infinite, sealing (>2cm)

Modeling Δage for EDC

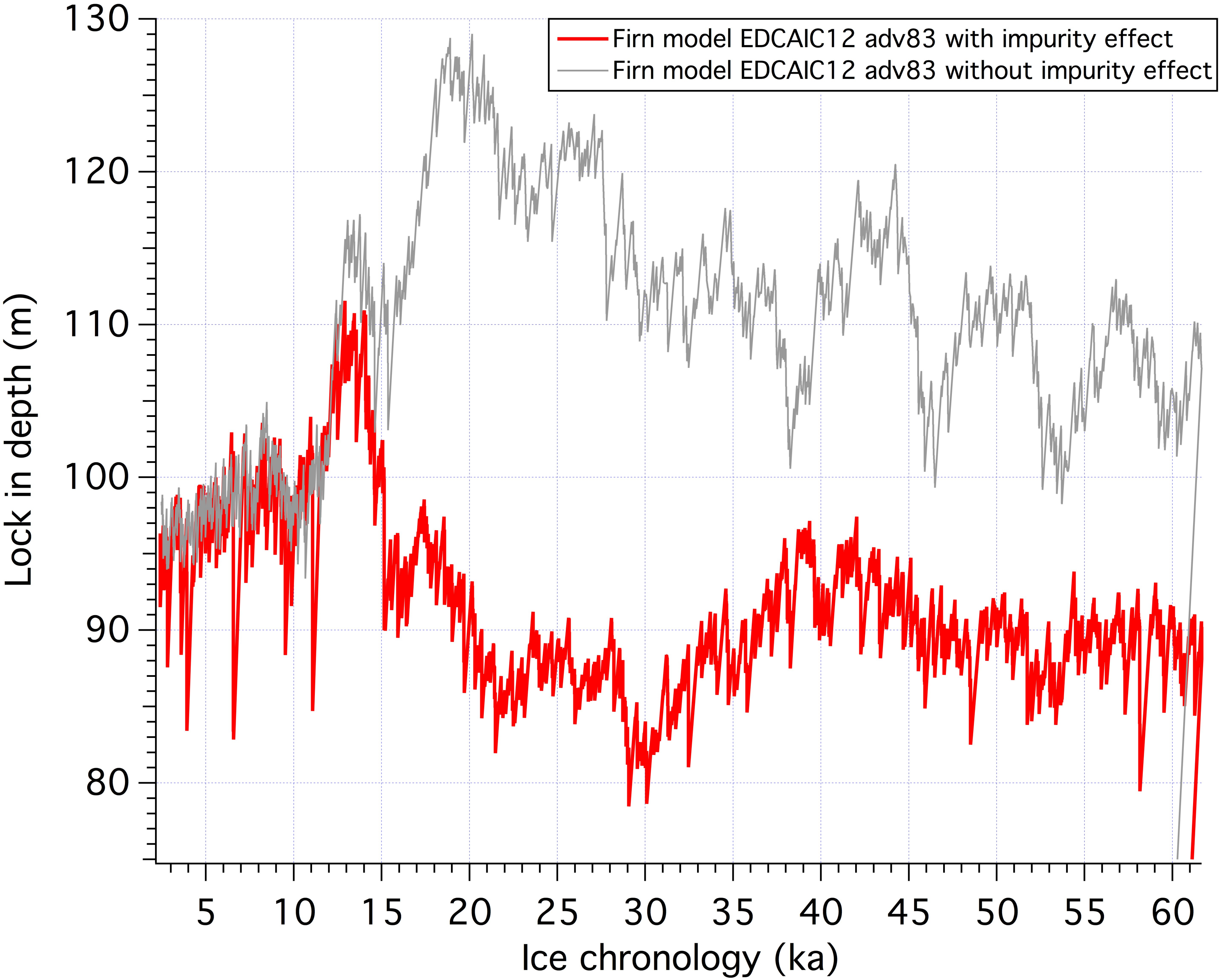
Prediction of classical densification models (HL, PB,..)

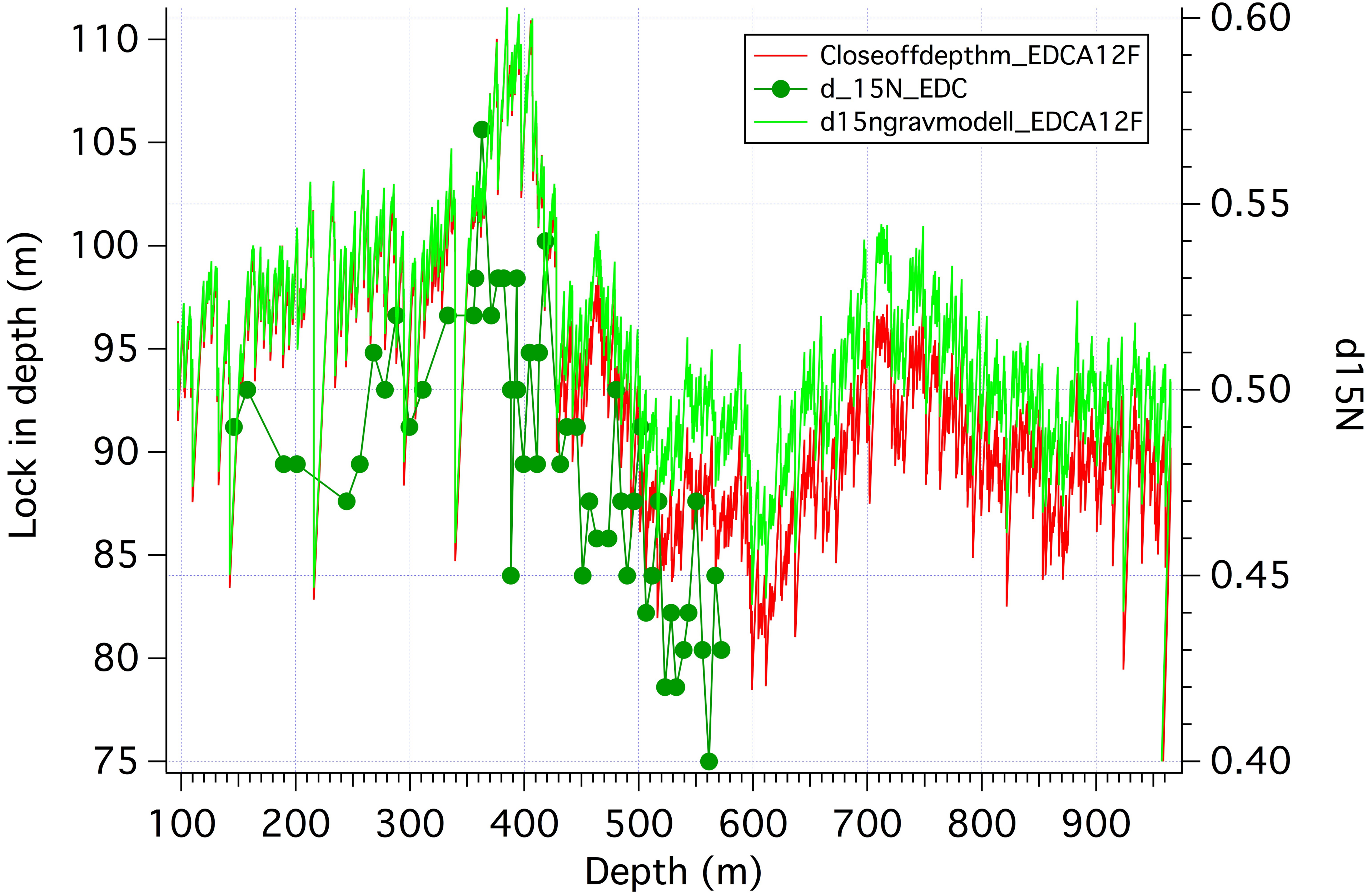
Prediction of new impurity-model



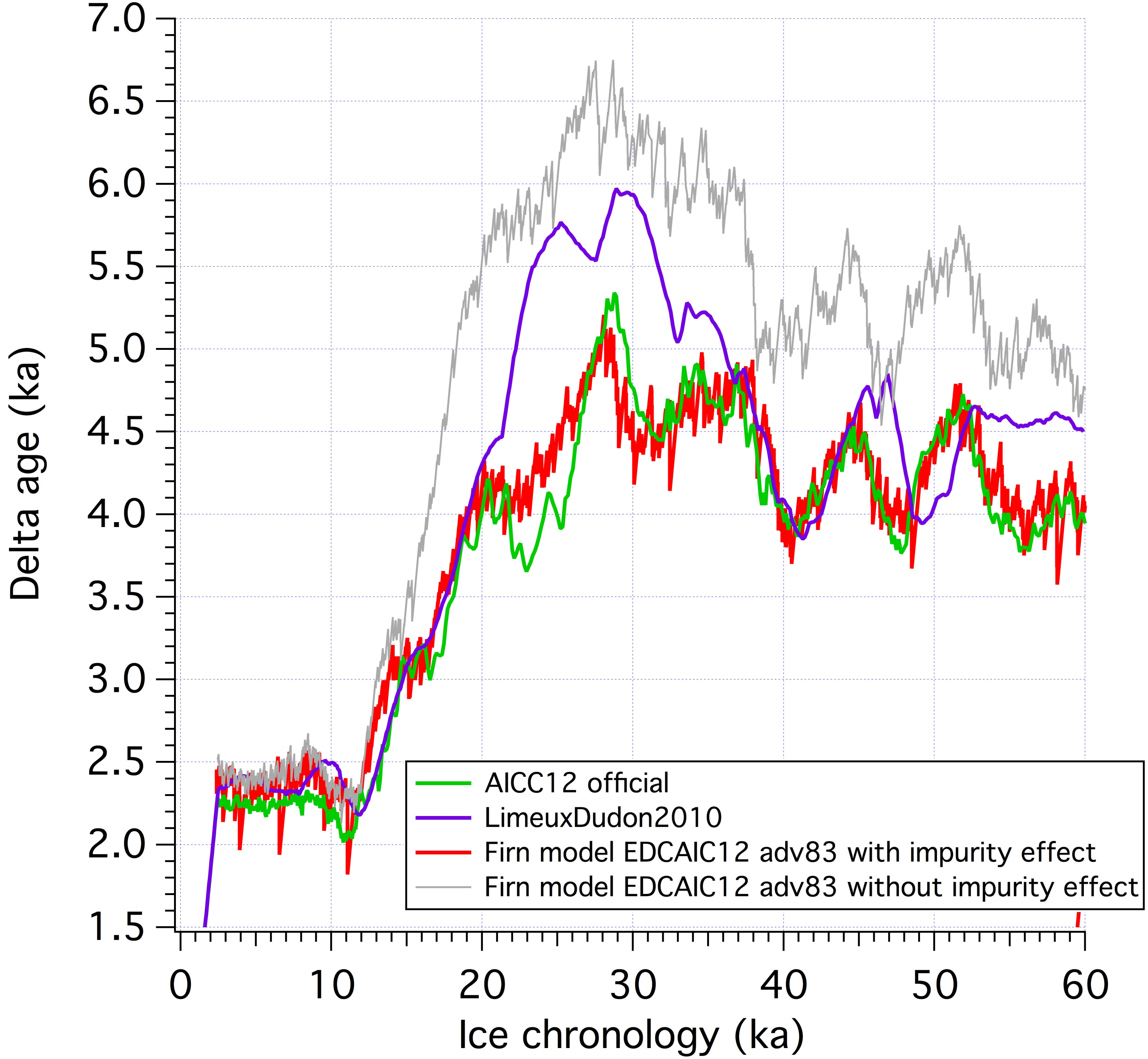
MODEL INPUT

MODEL OUTPUT

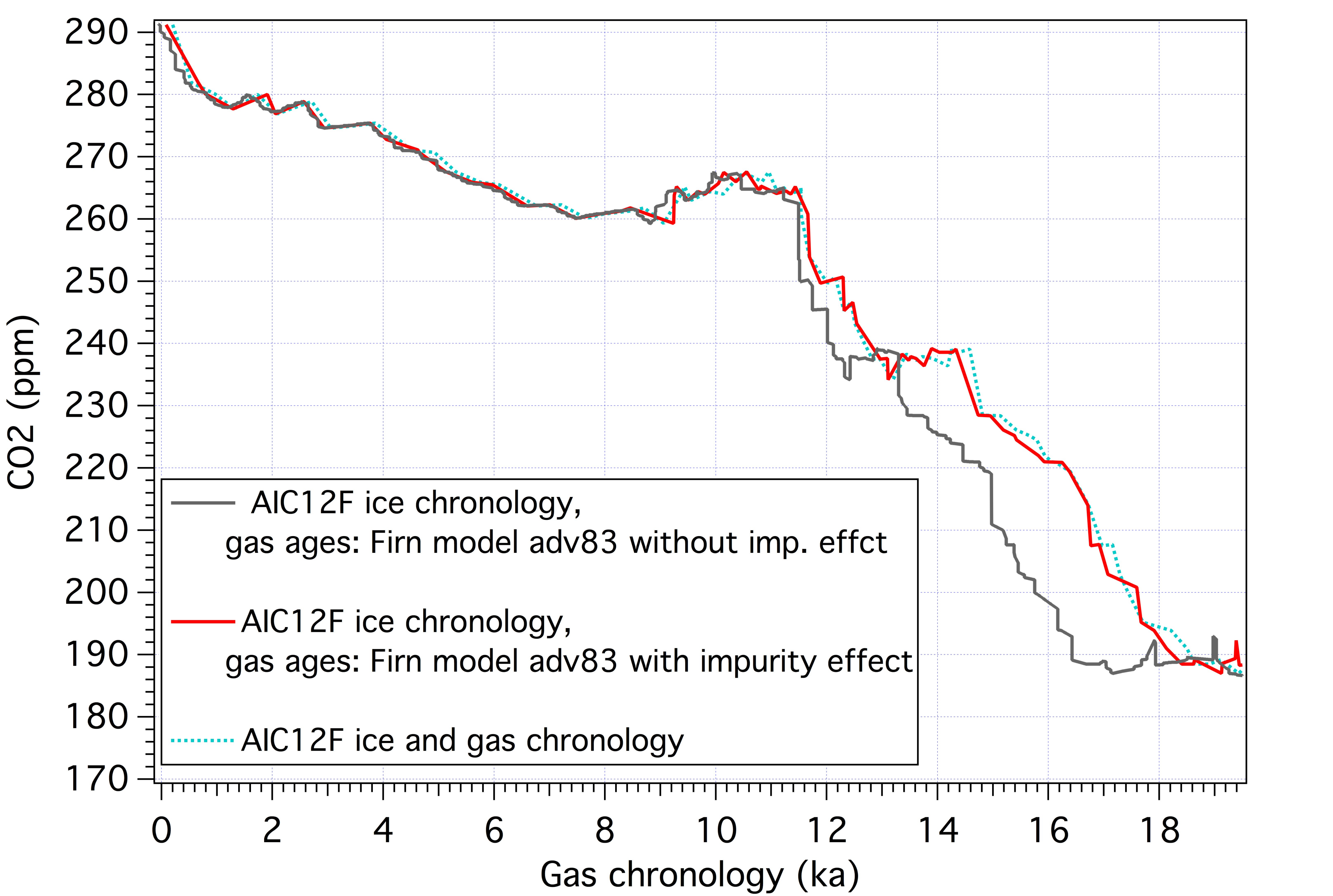

Firn model EDCAIC12 adv83 with impurity effect
Firn model EDCAIC12 adv83 without impurity effect
Lock in depth (m)
Ice chronology (ka)
130
120
110
100
90
80
5
10
15
20
25
30
35
40
45
50
55
60



Closeoffdepthm_EDCA12F
d_15N_EDC
d15ngravmodell_EDCA12F
Lock in depth (m)
Depth (m)
d15N
110
105
100
95
90
85
80
75
0.60
0.55
0.50
0.45
0.40
100
200
300
400
500
600
700
800
900



Delta age (ka)
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
0
10
20
30
40
50
60
Ice chronology (ka)
AICC12 official
LimeuxDudon2010
Firn model EDCAIC12 adv83 with impurity effect
Firn model EDCAIC12 adv83 without impurity effect



CO2 (ppm)
290
280
270
260
250
240
230
220
210
200
190
180
170
0
2
4
6
8
10
12
14
16
18
Gas chronology (ka)
AIC12F ice chronology,
gas ages: Firn model adv83 without imp. effct
AIC12F ice chronology,
gas ages: Firn model adv83 with impurity effect
AIC12F ice and gas chronology

Summary

Multi-core drilling suggest continuous density layers in deep firn

Universal critical density for pore close-off on the cm-scale

Extended impurity-firn model predict dages of the EDC-core similar to the AIC12-chronology
– the missing model for dage-calculations?

3d-percolation-model for calculating closed porosity in layered firn

Narrow age-distributions in holocene and glacial firn due to layering, occurence of small-scale inversions on the gas age scale