The Maine Automated Density Gauge Experiment: Design and Data from US ITASE 2006-2007

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1. Density versus Depth
2. MADGE
   - What is a Density Gauge
   - Specifications
3. MADGE Data
   - Drill Sites
   - Typical Data: Site 06-2
4. Low vs. Very Low $\dot{a}$
   - Titan Dome and 06-4
5. Conclusions
   - Site comparison

Firn and Ice Density versus Depth

Motivation

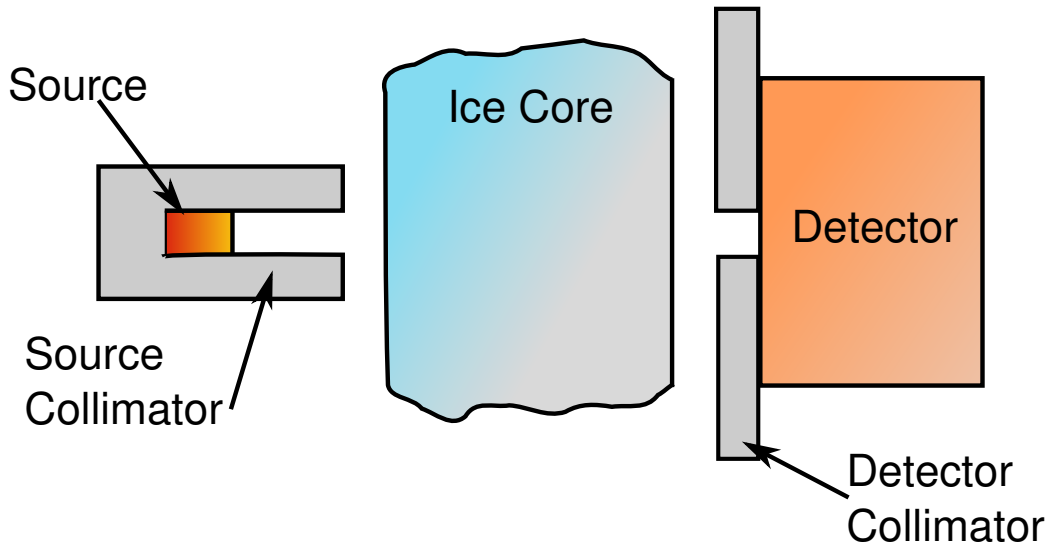
- Firn has complicated structure: density, grain size, hardness vary on mm to cm to m scales
- Precise, quantitative measurements in the field are difficult, sometimes impossible
- Firn structure related to: radar reflections (GPR), remote sensing (microwave emissivity/optical reflectivity)
- Understanding interactions between detailed firn structure and electromagnetic waves can help us understand and extend the value of these large area measurements

Why have we chosen a nuclear-related measurement method?

- Non-destructive
- Excellent precision, very good accuracy (depending on calibration)
- Gamma rays do not suffer from optical effects (reflection/refraction)

MADGE Design: What is a gamma-ray density gauge?

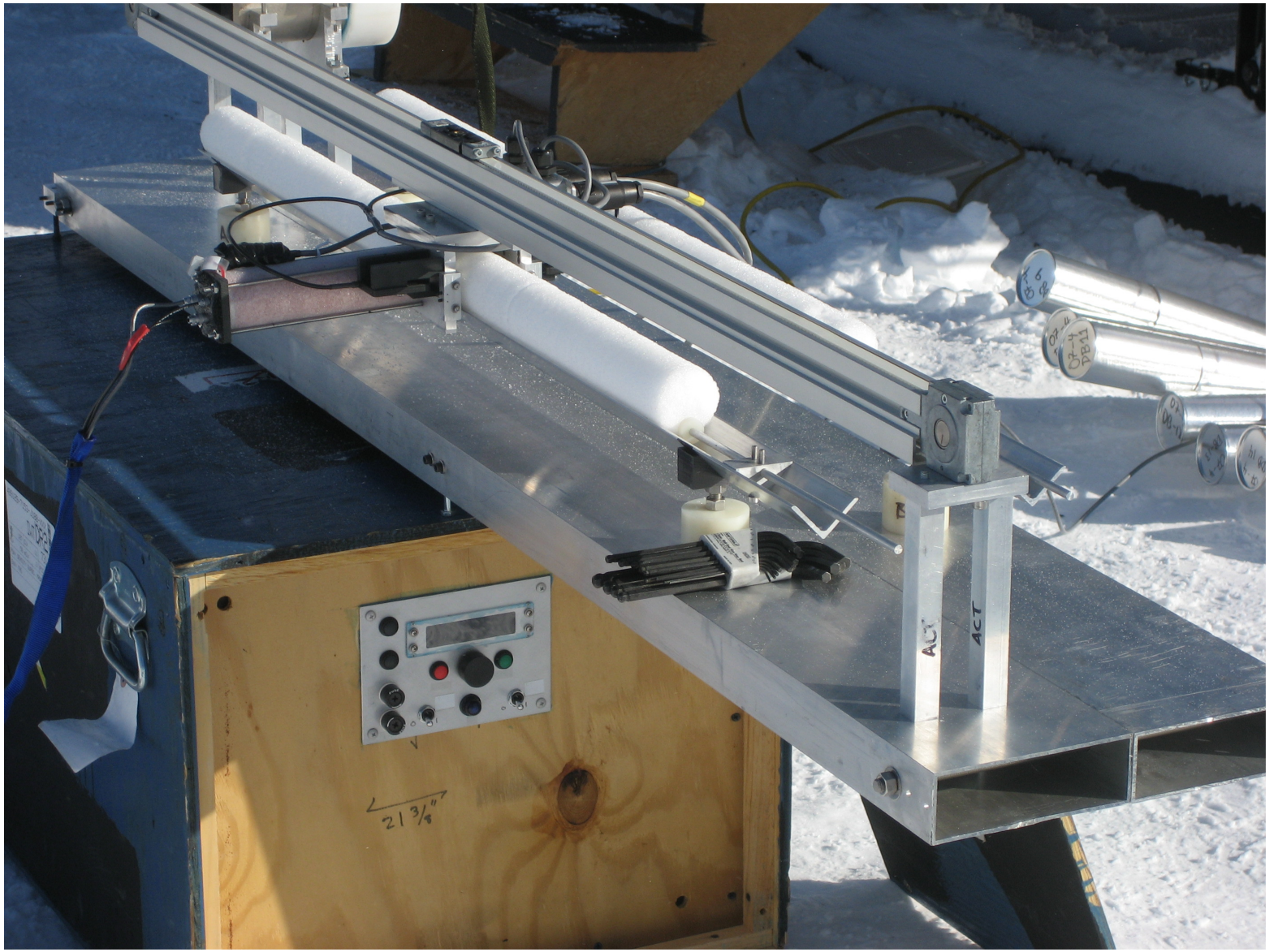
- Used to precisely measure density in a non-destructive manner
- Passes a beam of gamma radiation through the sample and measures how much *uncollided* radiation is transmitted
- Photons are removed from the beam through Compton scattering or photo-electric absorption: $C = C_0 e^{-\rho \mu_m d}$
- Three measurements are required: C_0 (no sample present), C (sample present) and d (sample thickness)

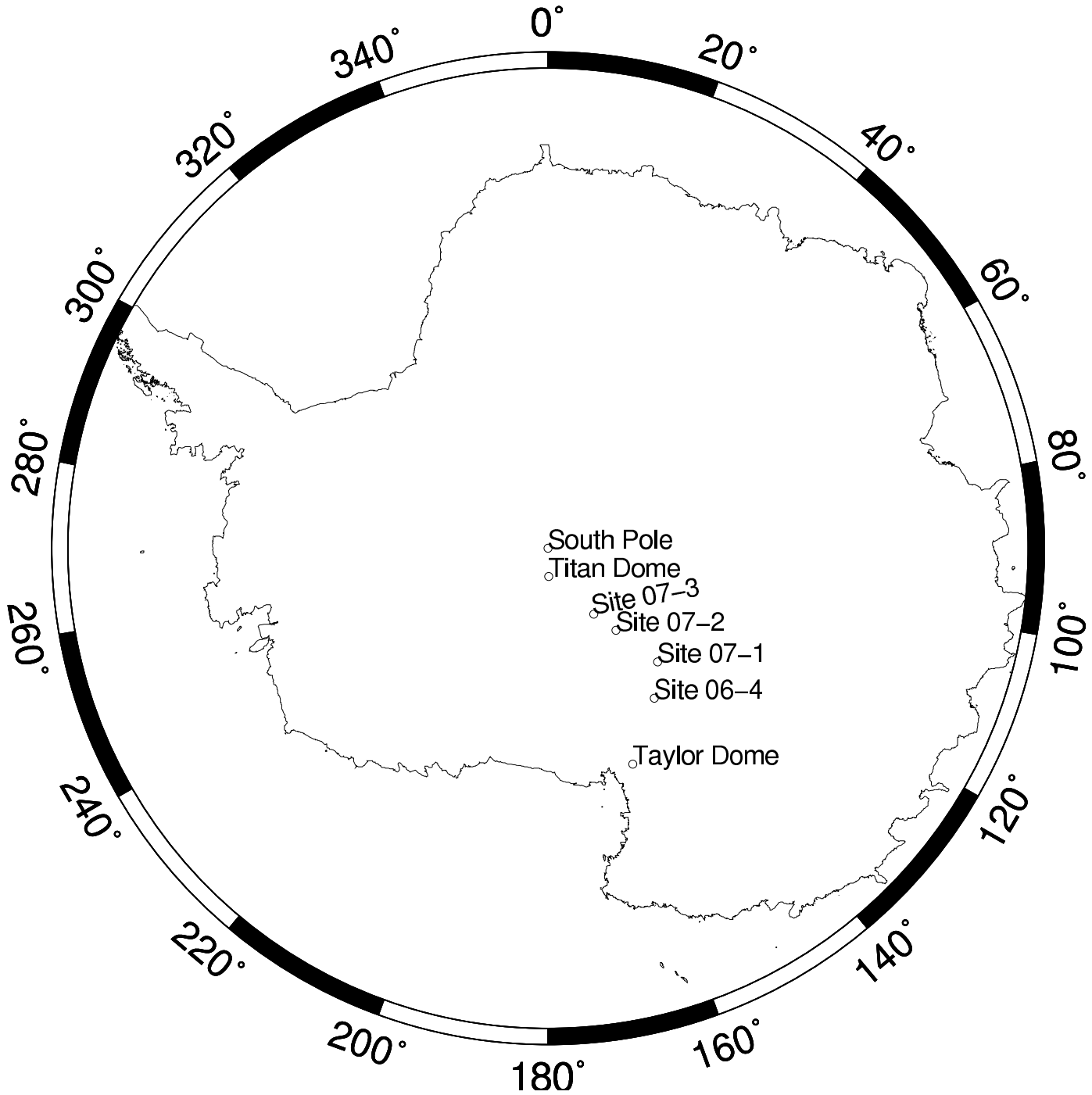


Maine Automated Density Gauge Experiment

- MADGE is a field-deployable gamma-ray density gauge, operating on 2 or (soon) 3 inch firn/ice cores
- Uses a relatively low energy gamma-ray
  - Optimizes density measurement for 2-3 inch firn→ice cores
  - Source is more easily shielded / shipped
  - Counts individual photons (low uncertainty) rather than measure detector current (allows higher photon throughput, but with much greater uncertainty)
- Typical measurements and uncertainties
  - Vertical Resolution: 3.3 mm, based on collimator size
  - Core Diameter: 30-60 $\pm$0.1 mm
  - Density: 0-0.917 $\pm$0.004 $\mathrm{g/cm^3}$
  - Throughput: 1.5 m/hr at 0.5 $\mathrm{g/cm^3}$

MADGE in Action with new workbench




0°
20°
40°
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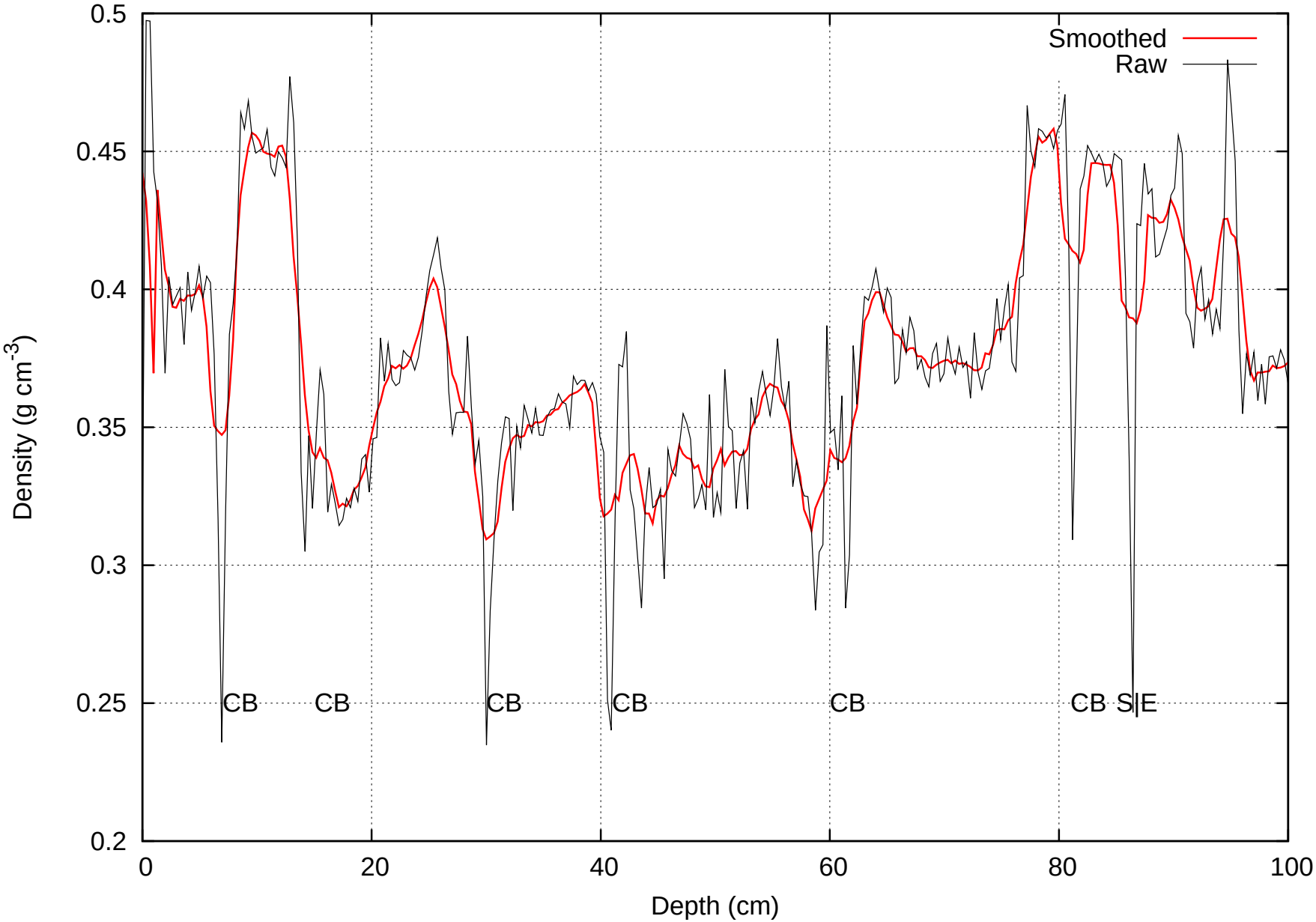
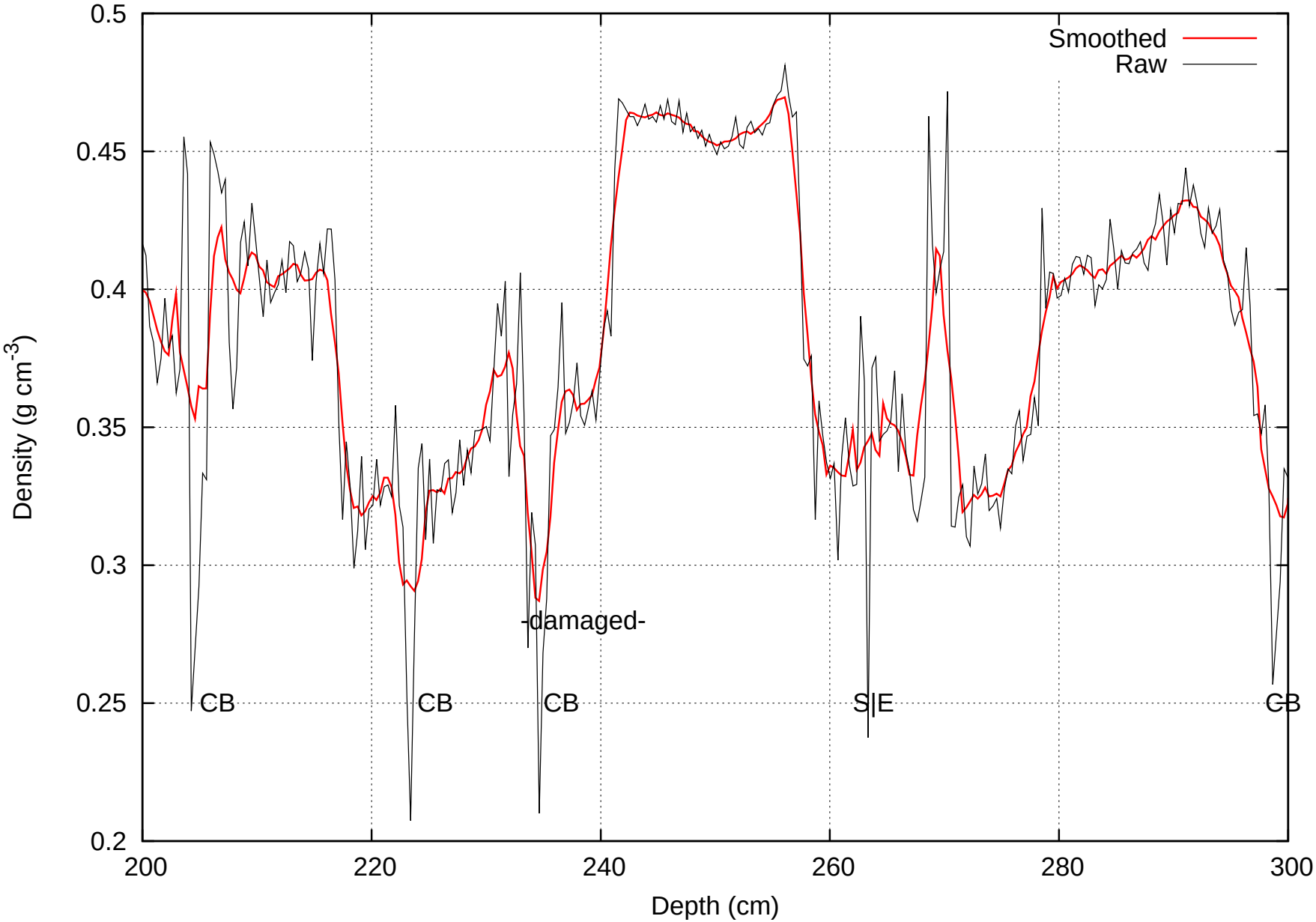
100°
120°
140°
160°
180°
200°
220°
240°
260°
280°
300°
320°
340°
South Pole
Titan Dome
Site 07–3
Site 07–2
Site 07–1
Site 06–4
Taylor Dome

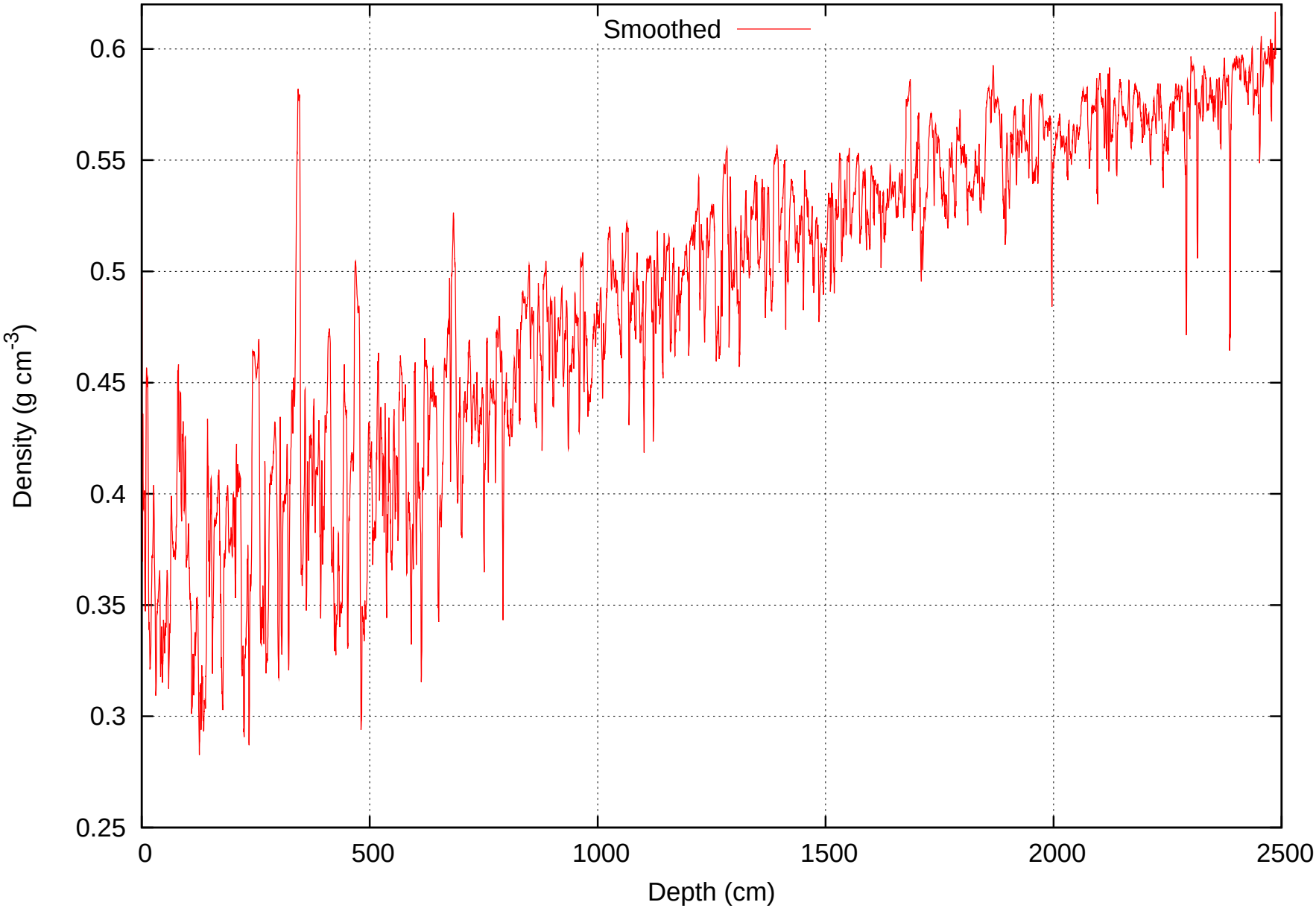
Data from site 06-2 ($\sim$ 100km from Taylor Dome)



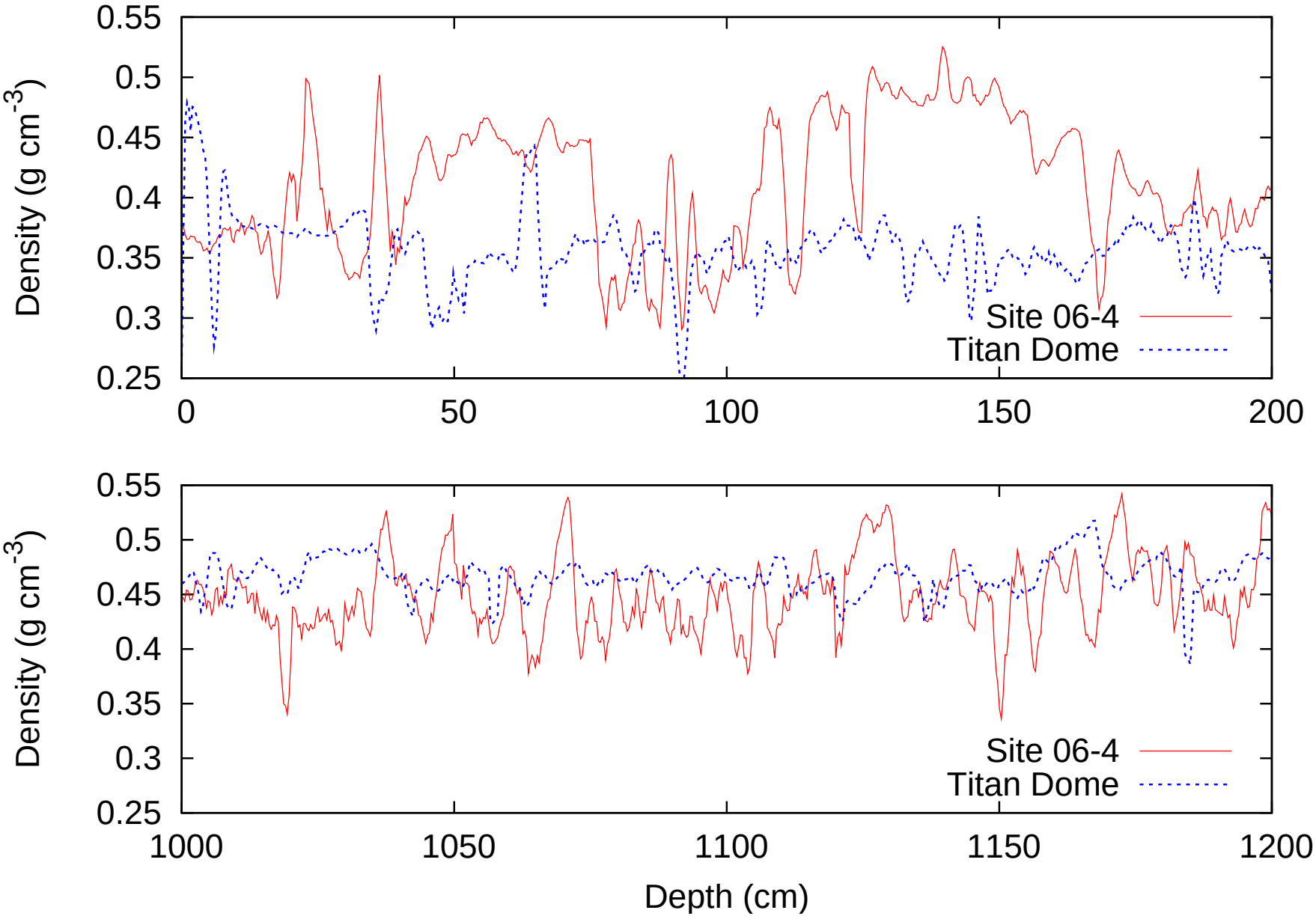
Data from site 06-2



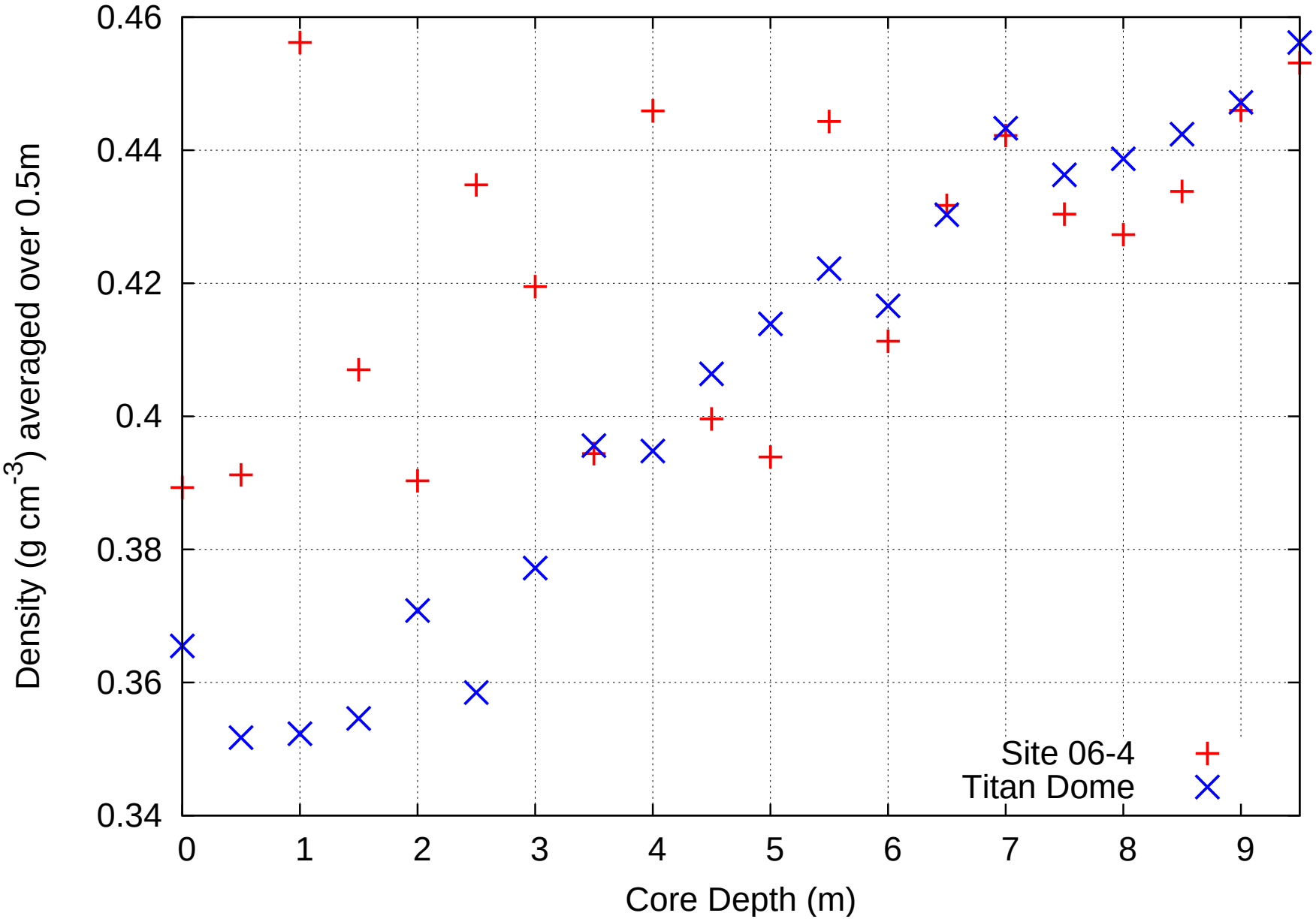
Overall Data from site 06-2



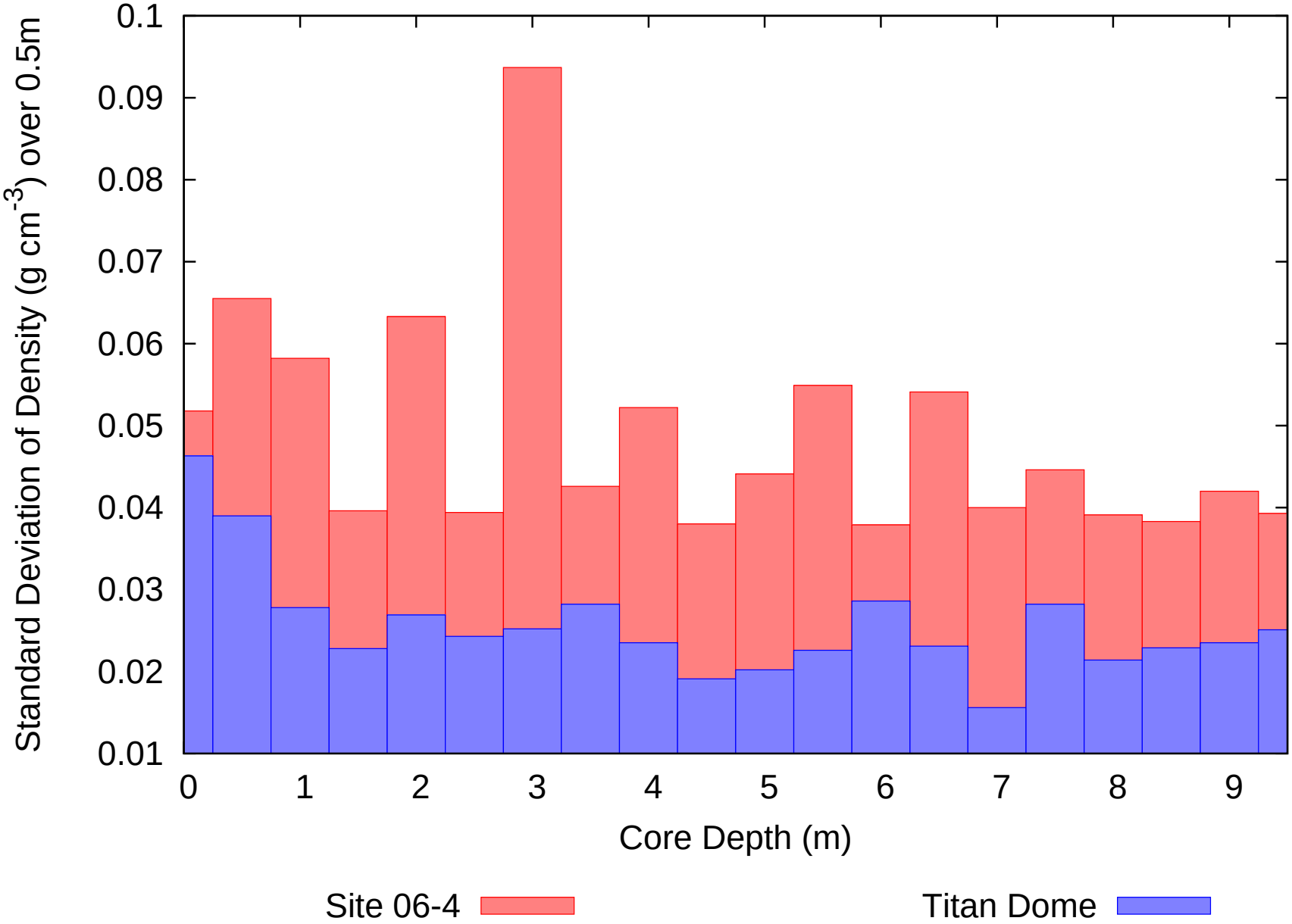
Comparison of 06-4 and Titan Dome



Comparison of 06-4 and Titan Dome density profiles



Comparison of 06-4 and Titan Dome standard deviation



Conclusions

Site 06-4

- High density layers occur shallow: what events cause glazing?
- Seems to gain bulk density by primarily compacting weak, low density layers: hard, high density layers do not seem to compact until much deeper
- Hard layers could be glazed paleo-sastrugi, weak layers could be unglazed material undergoing TGM for long time periods
- Looks like episodic accumulation: migrating sastrugi?
- How does this affect the ventilation of deeper firn layers?

Titan Dome

- Very few shallow high density layers
- Less overall variability than 06-4
- Increases in density uniformly with depth
- Looks like slow, but relatively steady accumulation

Acknowledgments

- NSF
- my ITASE shipmates