Advances in Airborne Altimetric Techniques for the Measurement of Snow on Arctic Sea Ice

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Altimetry over sea ice

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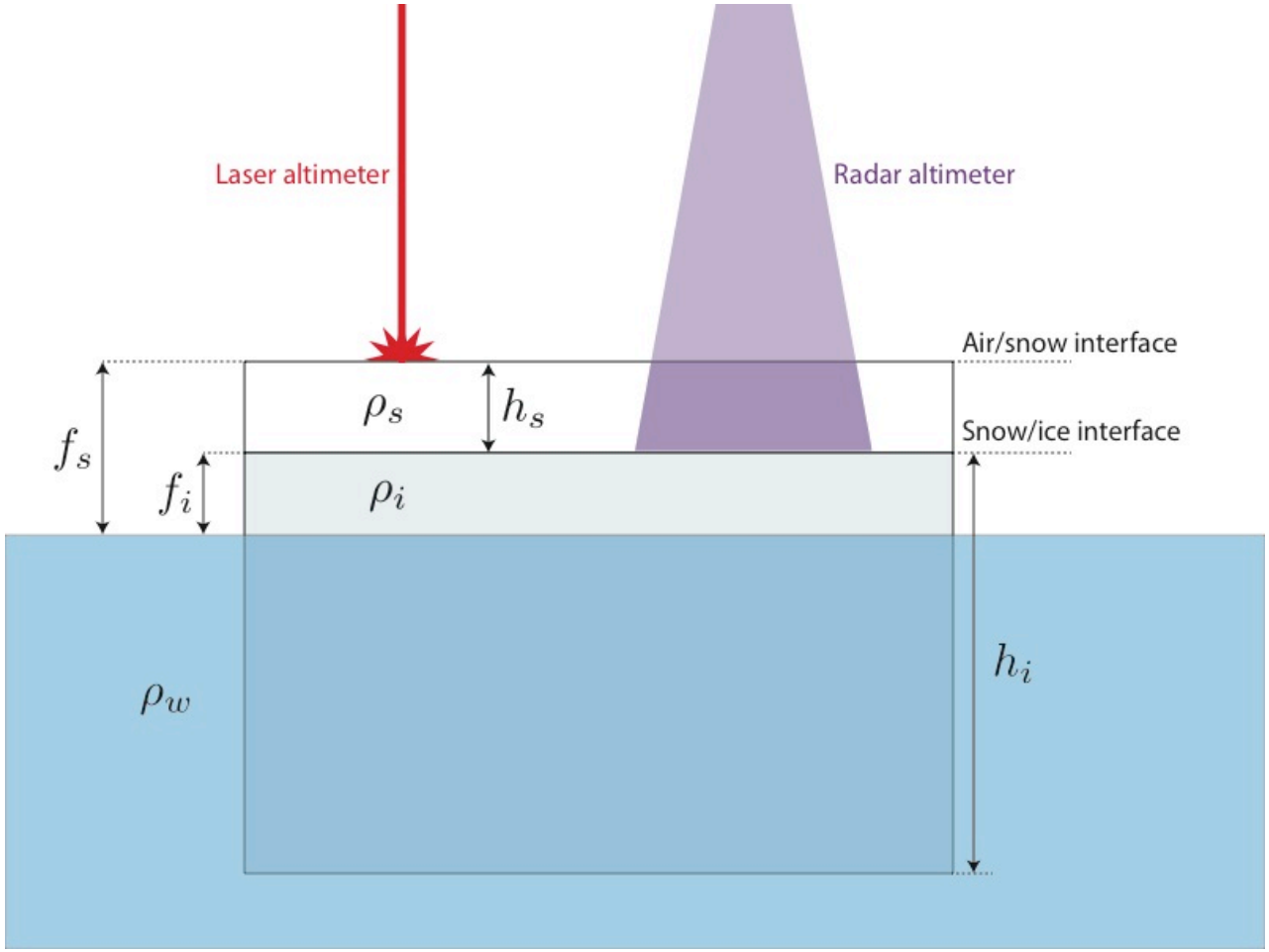


- Measure surface elevation
- Discriminate leads from floes
- Open water required for calibration
- Derive freeboard
- Assume hydrostatic equilibrium to Infer ice thickness, which is a function of:
  - Snow, ice and water density
  - **Snow depth**
  - Ice freeboard
- Ice thickness uncertainty influenced by errors freeboard and **snow depth**

Deriving sea ice thickness

Radar
altimeters

$$h_i = f_i \frac{\rho_w}{(\rho_w - \rho_i)} + h_s \frac{\rho_s}{(\rho_w - \rho_i)}$$

Laser
altimeters

$$h_i = f_s \frac{\rho_w}{(\rho_w - \rho_i)} + h_s \frac{(\rho_s - \rho_w)}{(\rho_w - \rho_i)}$$

Snow depth uncertainty

Radar altimeters

$$\epsilon_{hs}^2 \left[\frac{\rho_s}{(\rho_w - \rho_i)} \right]^2$$

$$\epsilon_{hs}^2 \times 8.62$$

Giles, K.A. et al., 2007. Combined airborne laser and radar altimeter measurements over the Fram Strait in May 2002. Remote Sensing of Environment, 111(2-3), pp.182–194.

Laser altimeters

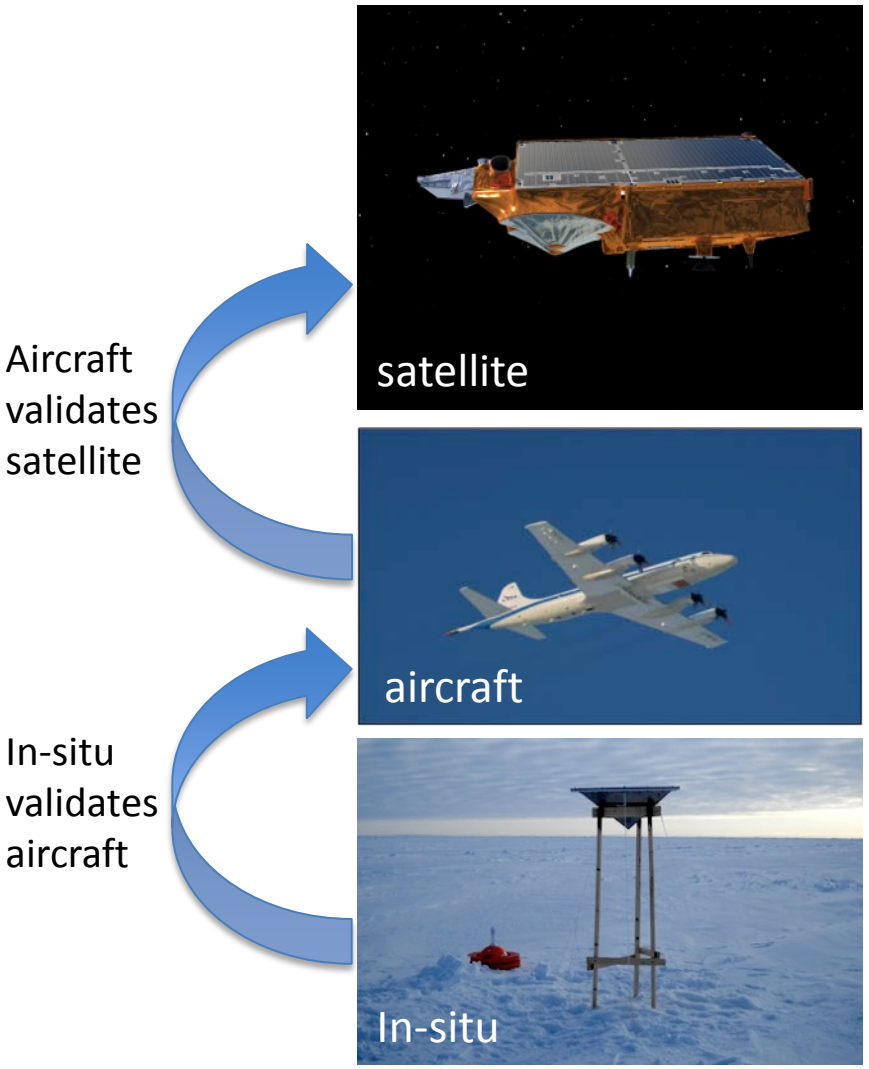
$$\epsilon_{hs}^2 \left[\frac{\rho_s}{(\rho_w - \rho_i)} - \frac{\rho_w}{(\rho_w - \rho_i)} \right]^2$$

$$\epsilon_{hs}^2 \times 41.92$$

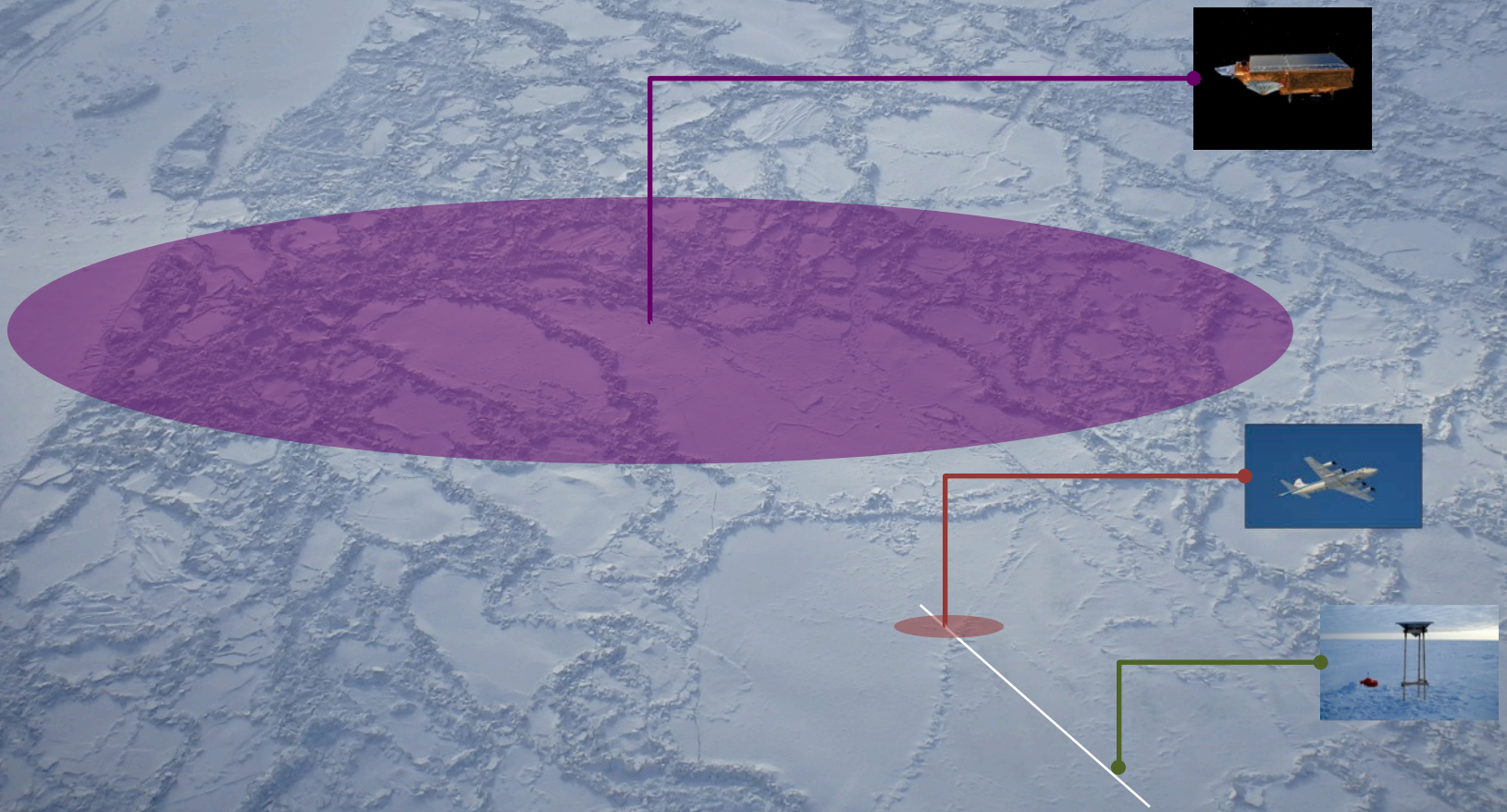
Giles, K.A. et al., 2007. Combined airborne laser and radar altimeter measurements over the Fram Strait in May 2002. Remote Sensing of Environment, 111(2-3), pp.182–194.

Nested validation approach: Theory

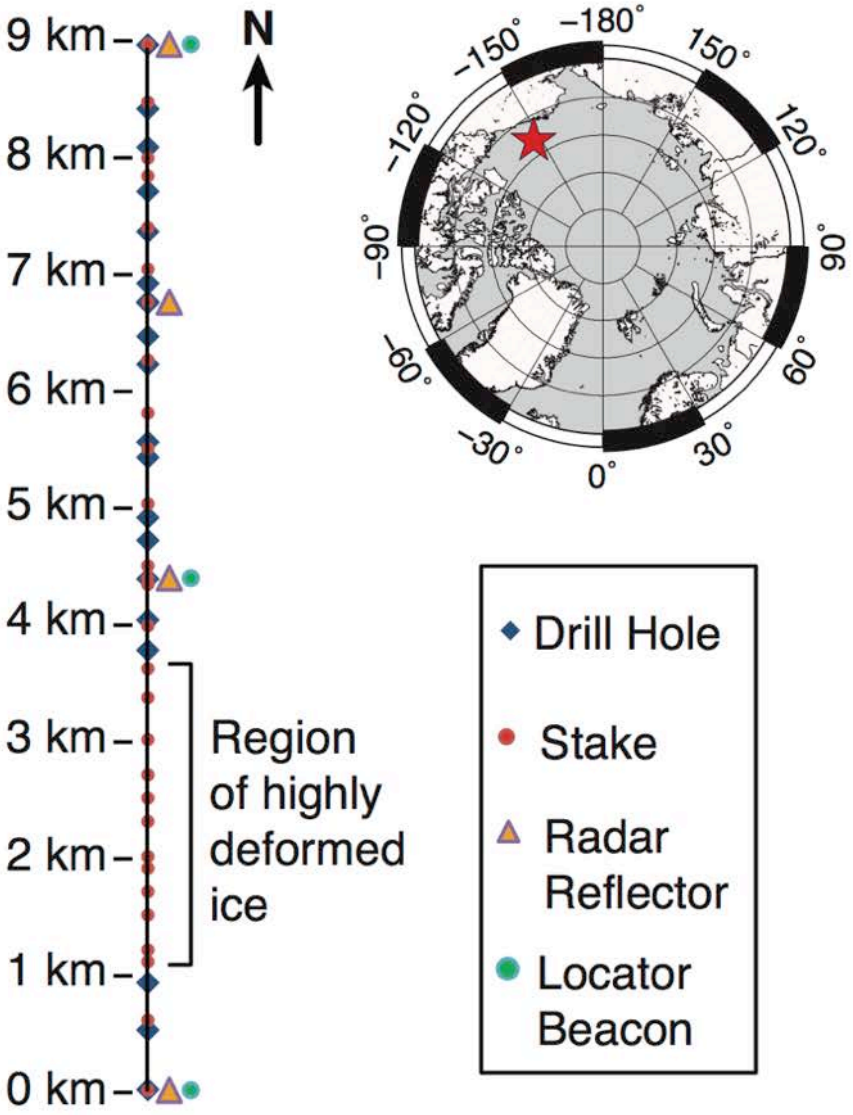
- In-situ measurements used to validate airborne measurements
- Airborne measurements used to validate satellite estimates
- NASA operation IceBridge aircraft providing yearly surveys of Arctic sea ice each March/April
- IceBridge instruments on P-3 aircraft:
  - Ku-band radar altimeter (13-17 GHz)
  - Snow radar (2-8 GHz)
  - Airborne Topographic Mapper (ATM) laser altimeter
  - Digital mapping System (DMS) digital camera



Nested validation approach: Reality



Airborne validation – ICEX 2011



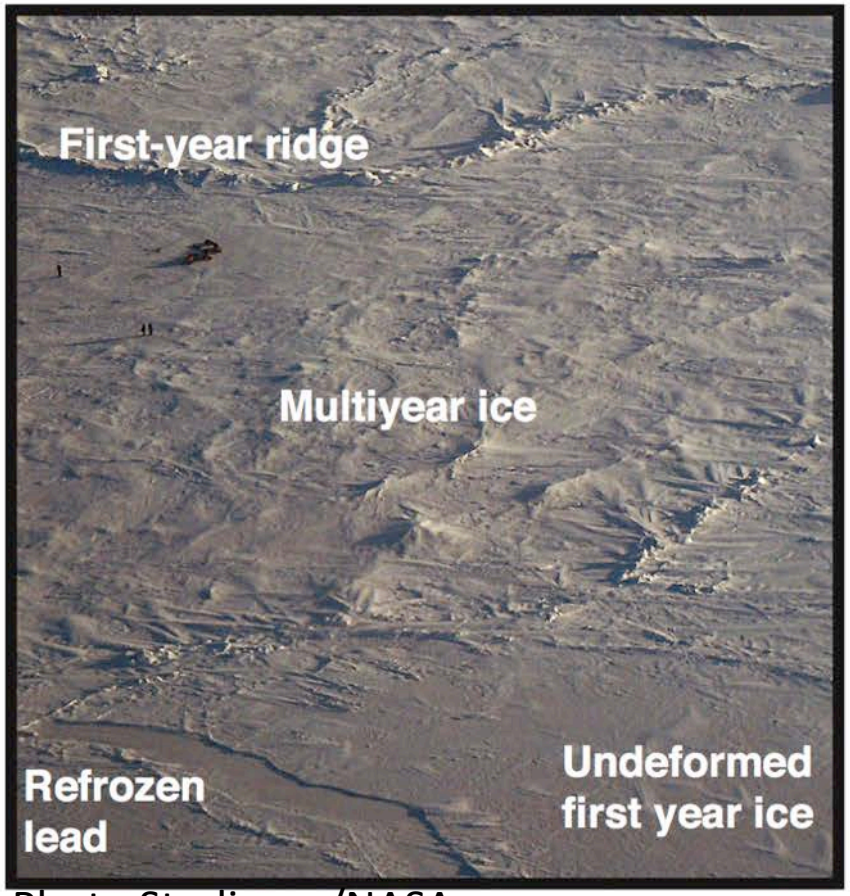
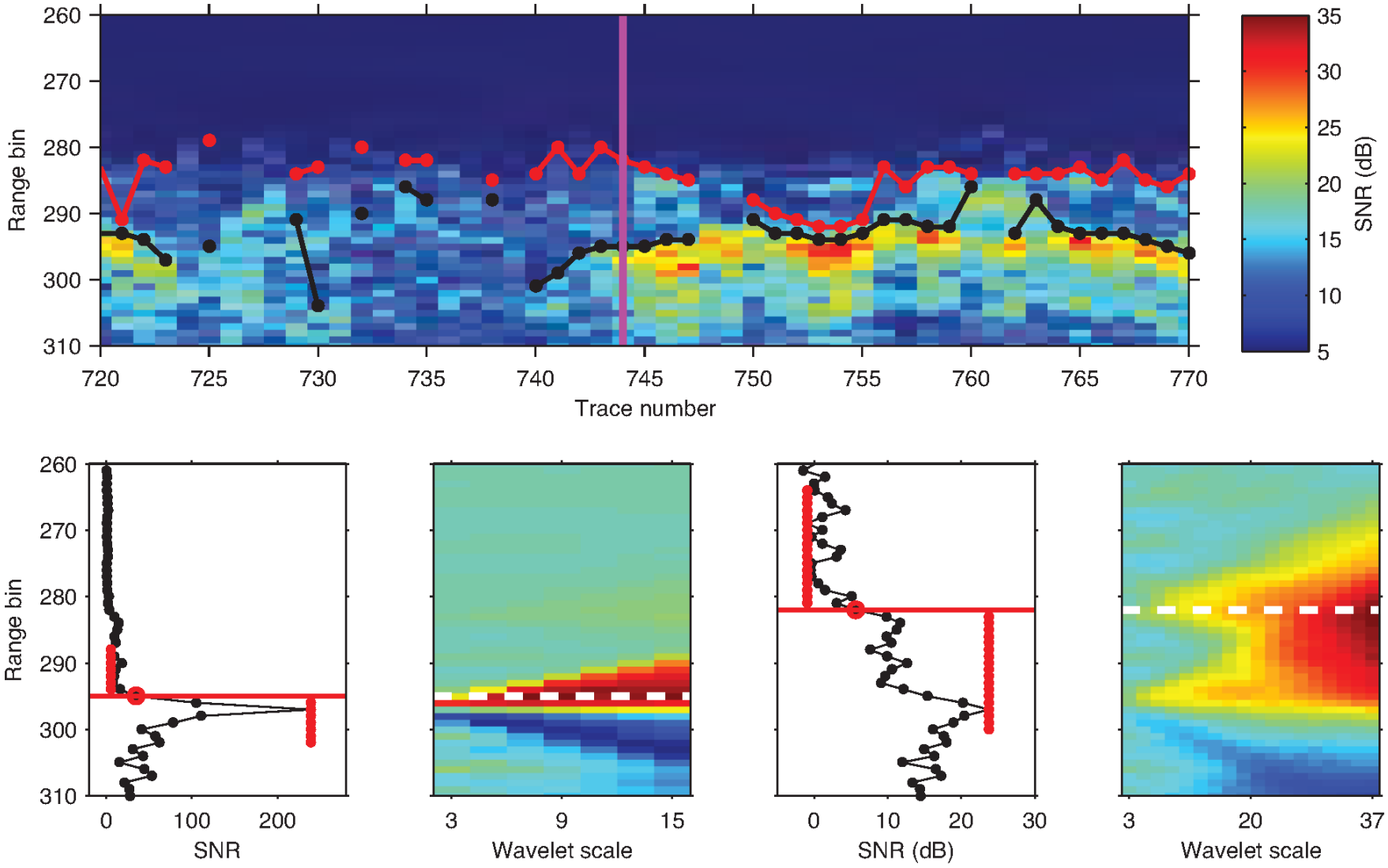


Photo Studinger/NASA

Snow radar echogram Interface detection - Wavelet techniques



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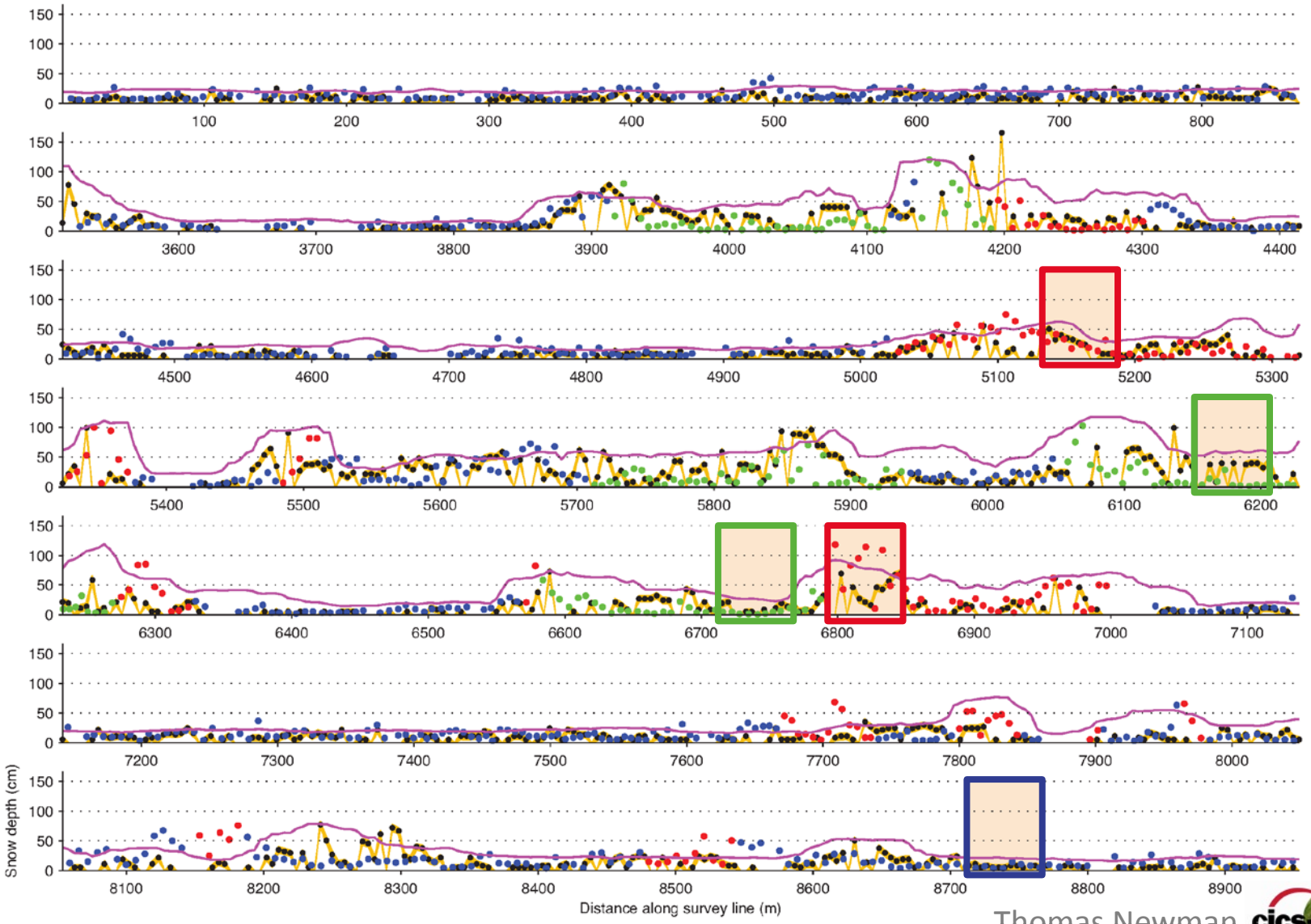
ICEX 2011 point-by-point comparison



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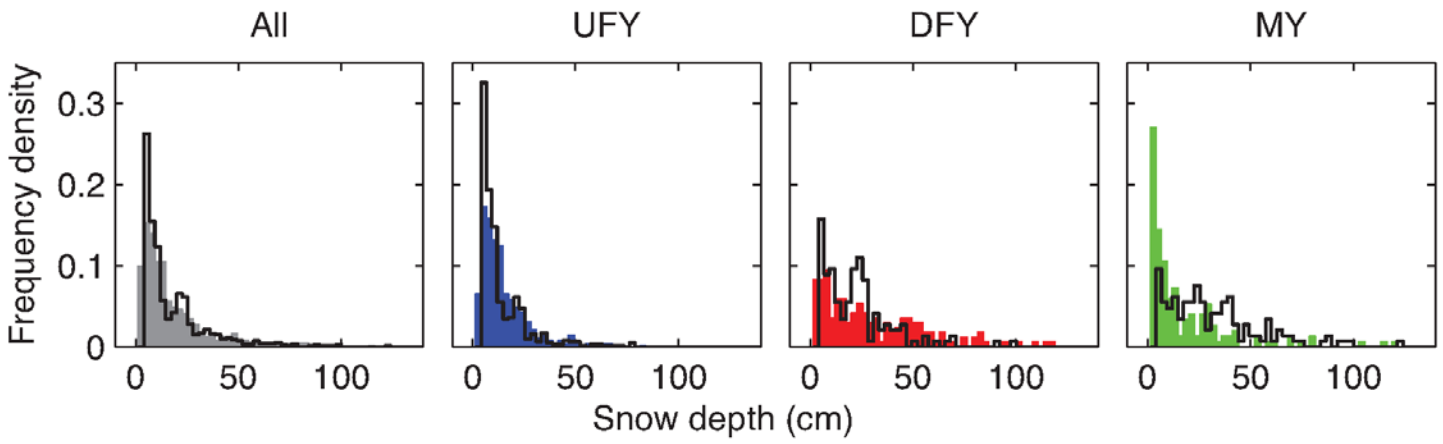
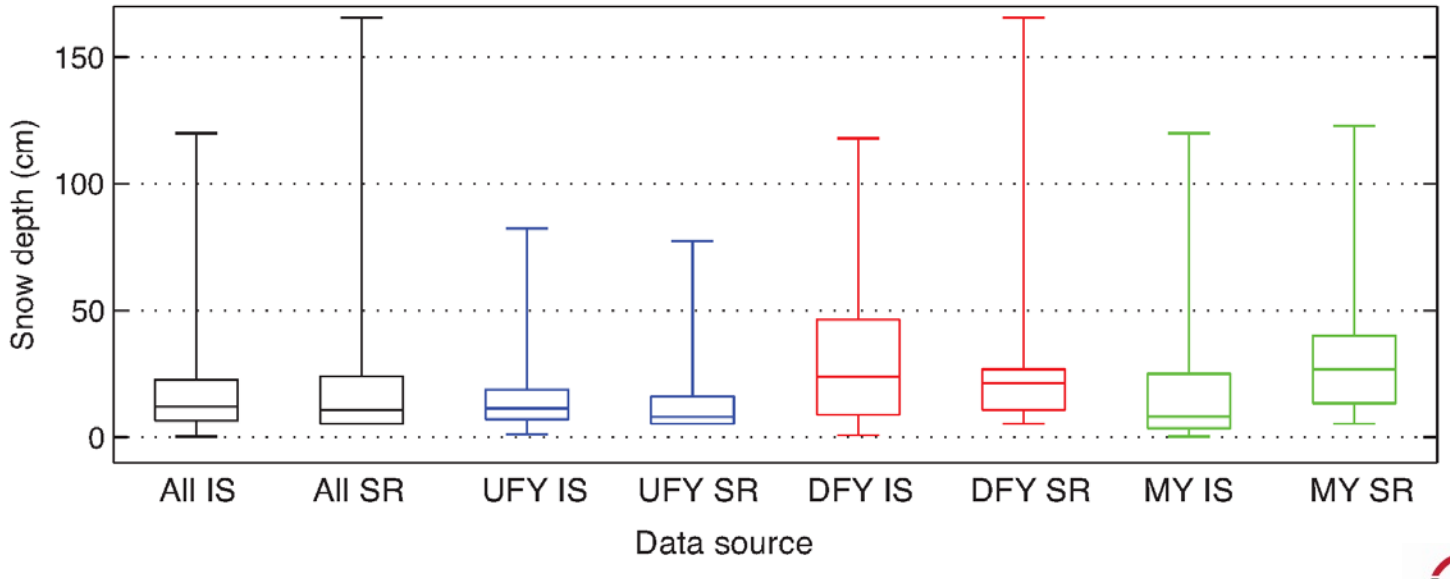
ICEX 2011 – Validation by ice type





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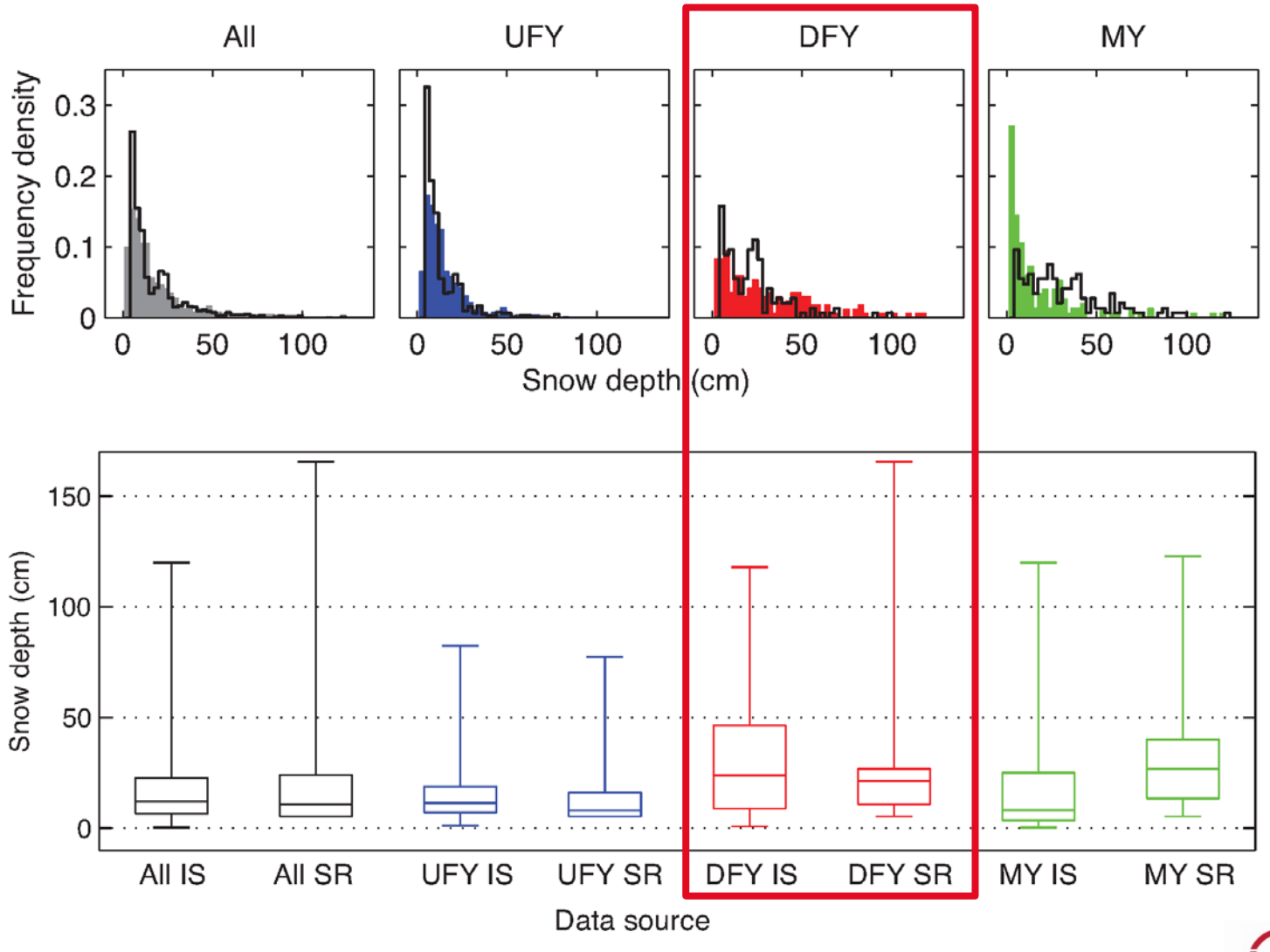
Case study - Deformed first year ice (DFY)



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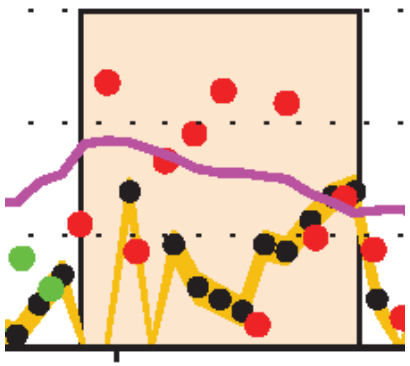

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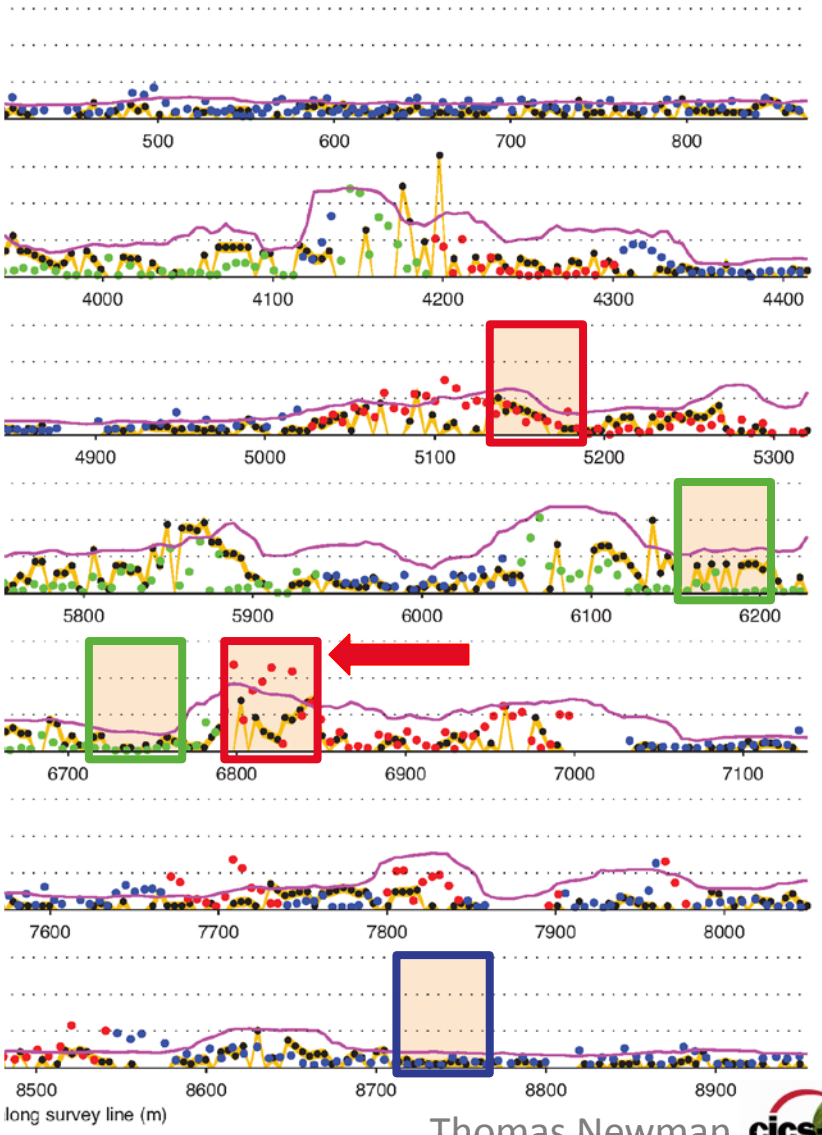

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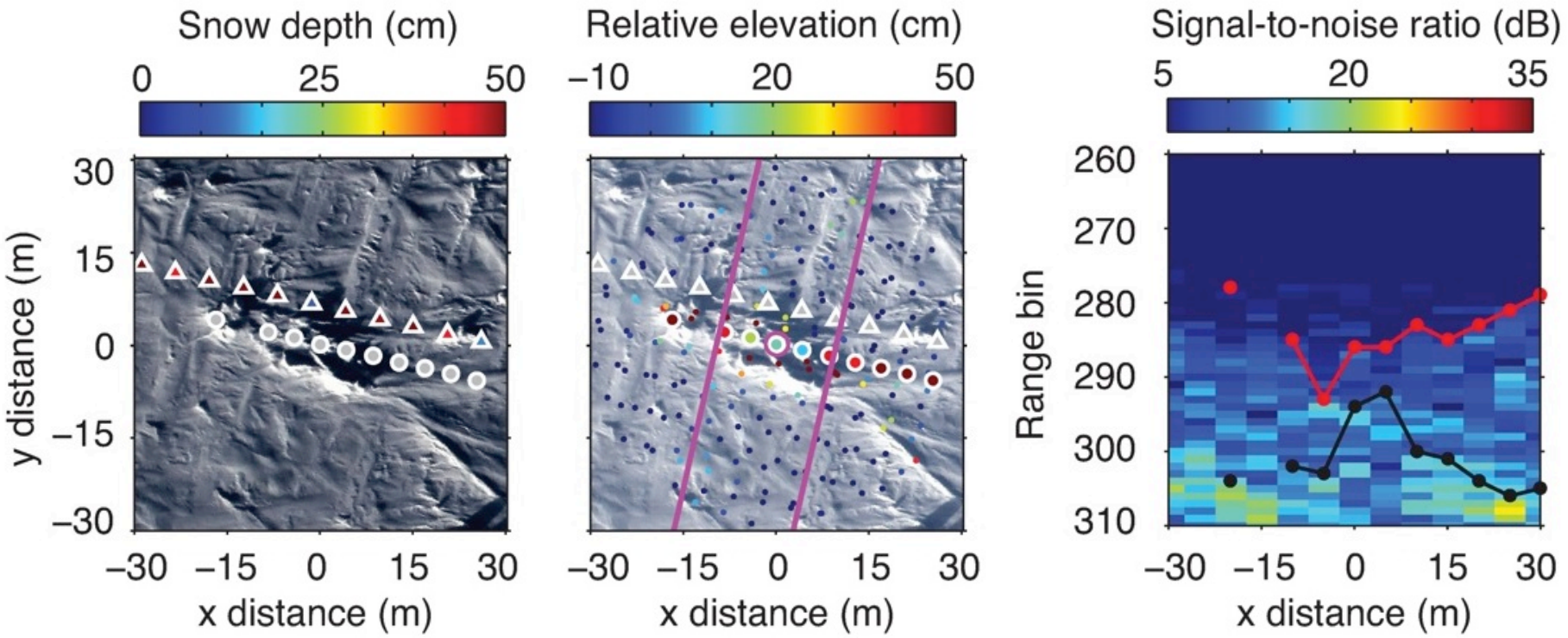
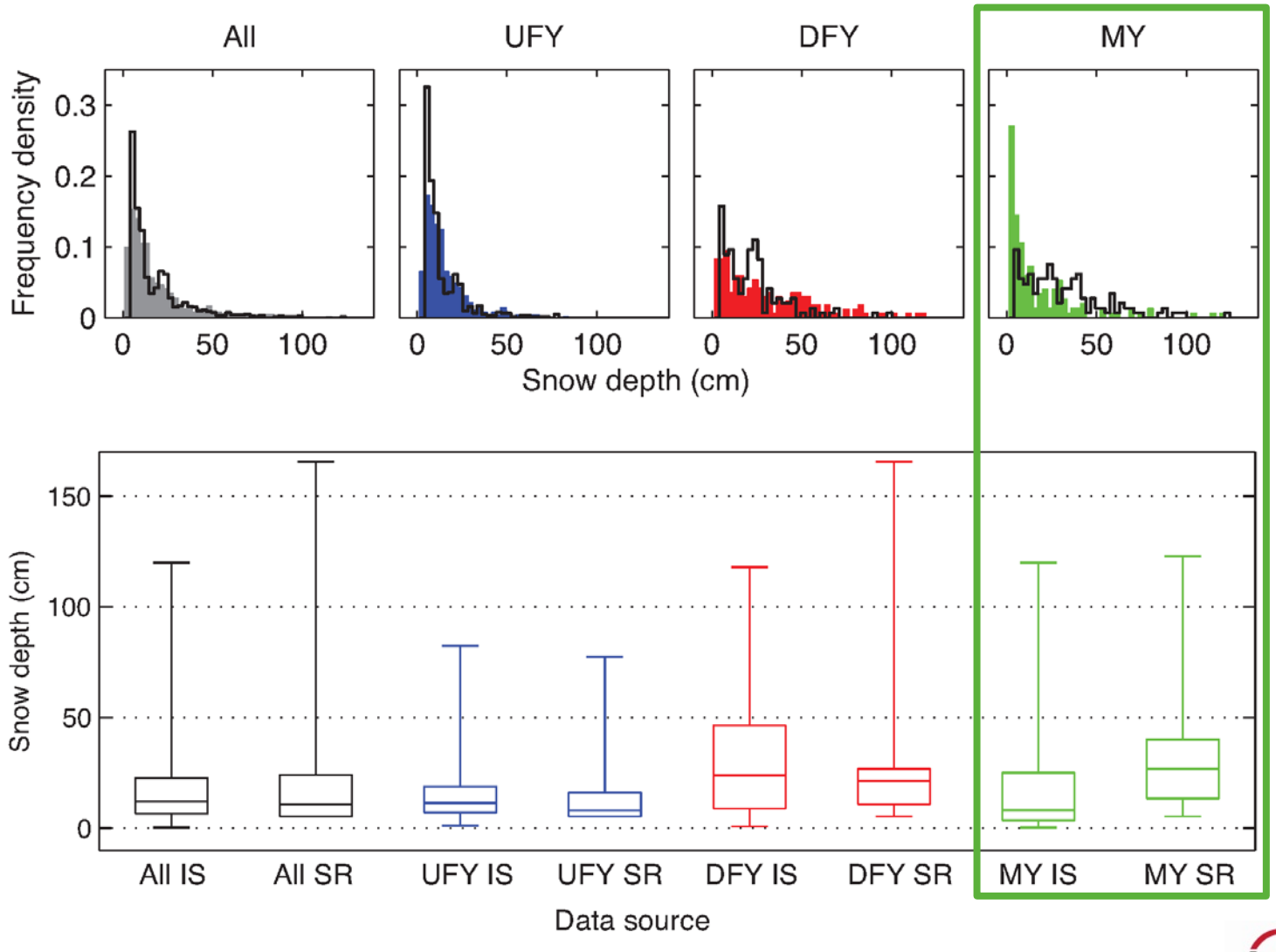


Case study - Multiyear ice (MY)



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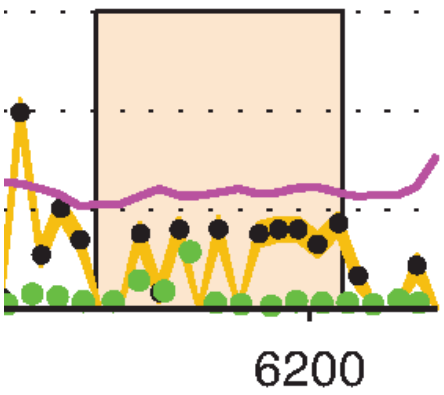

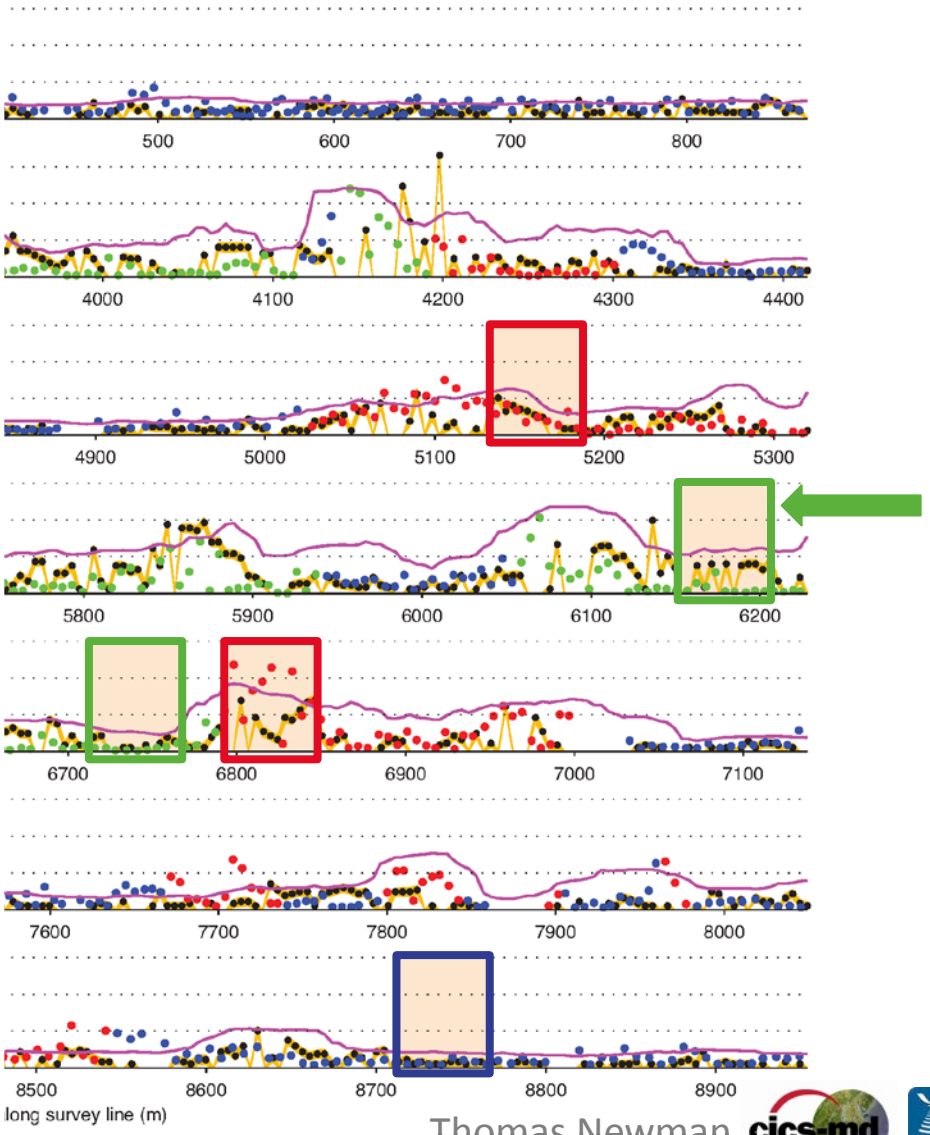

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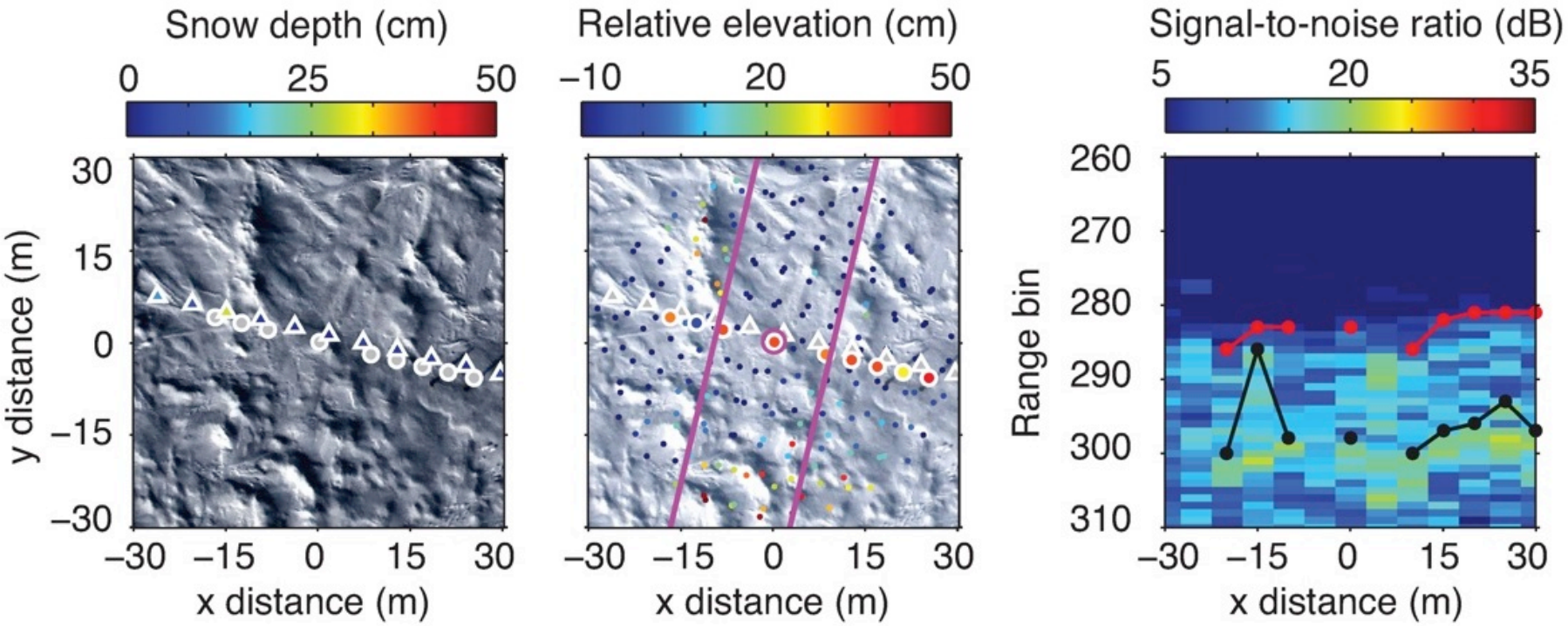
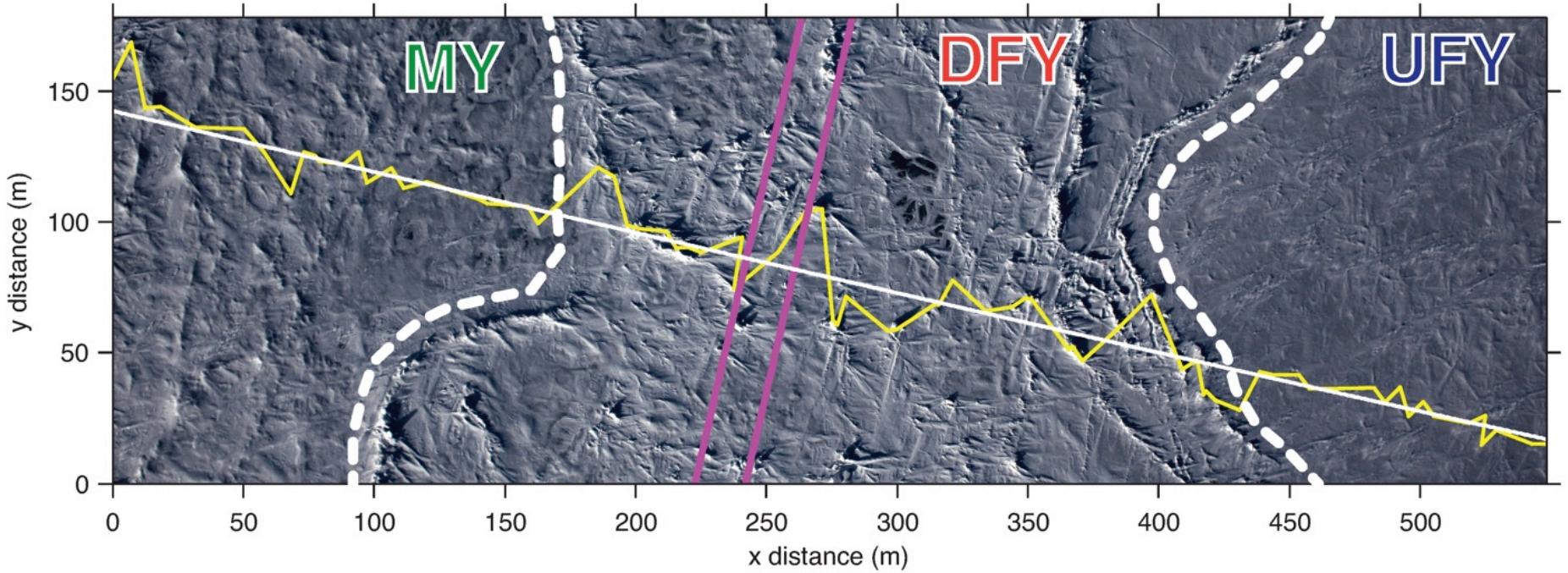


Off-nadir scattering



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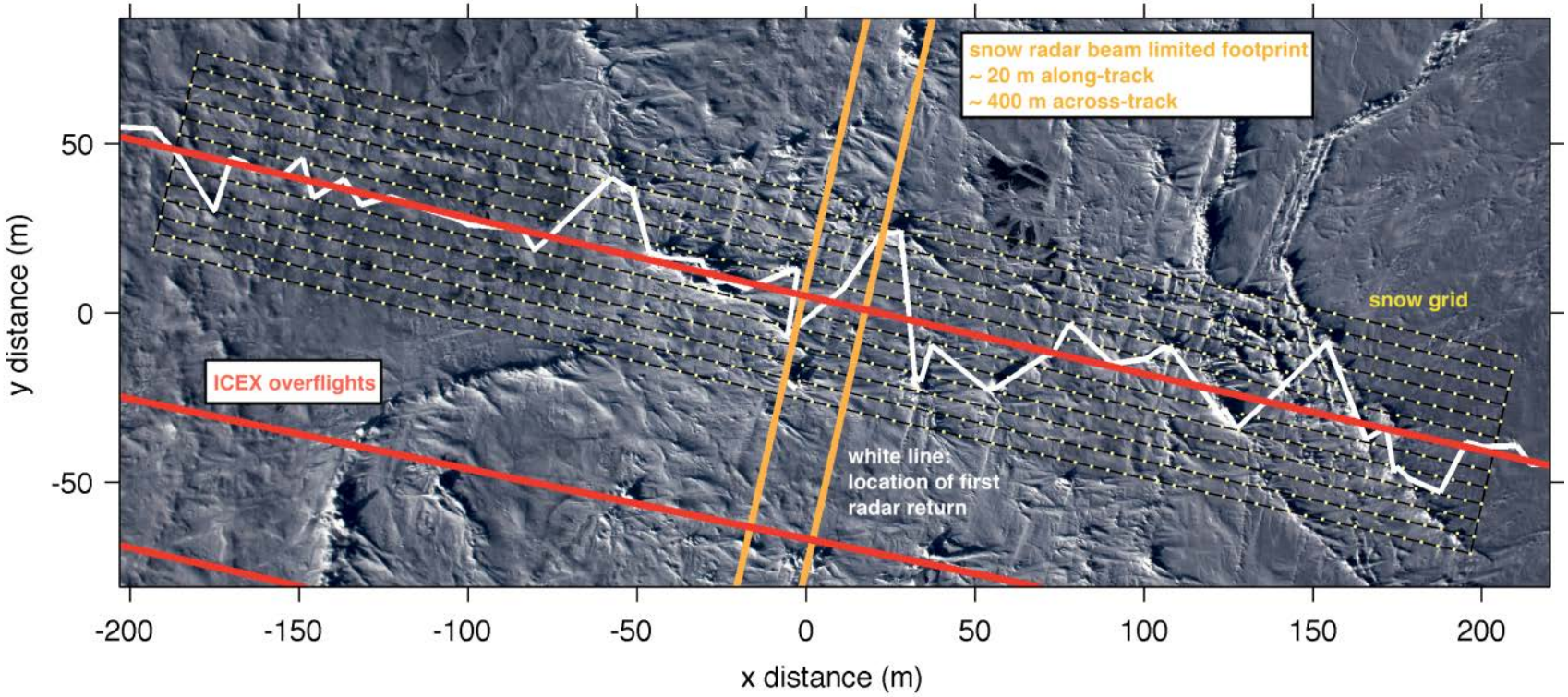
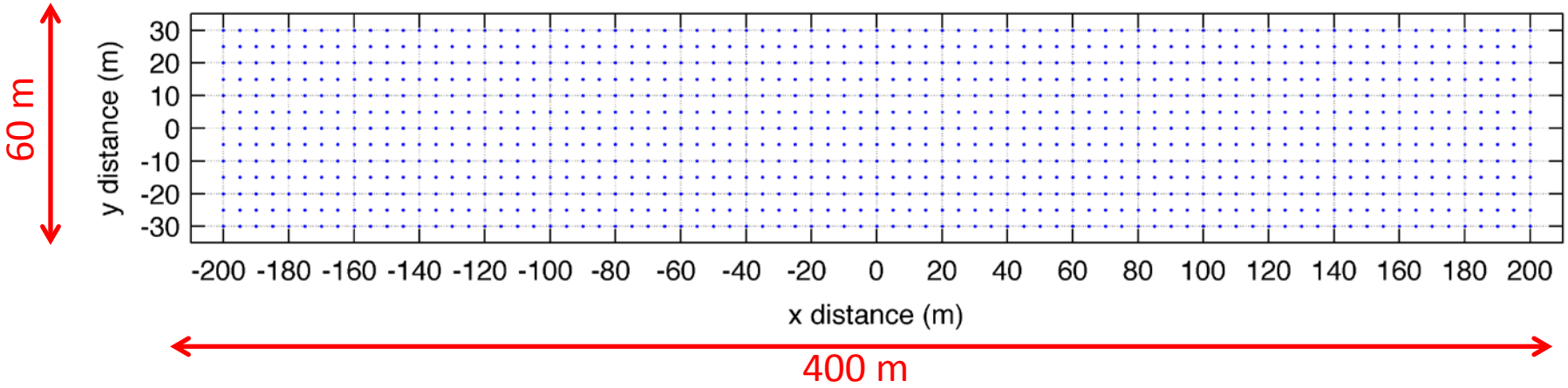
2D snow grid



5m-by-5m snow survey grid




QUESTIONS?