Challenges and Opportunities of Drone-Mounted GPR

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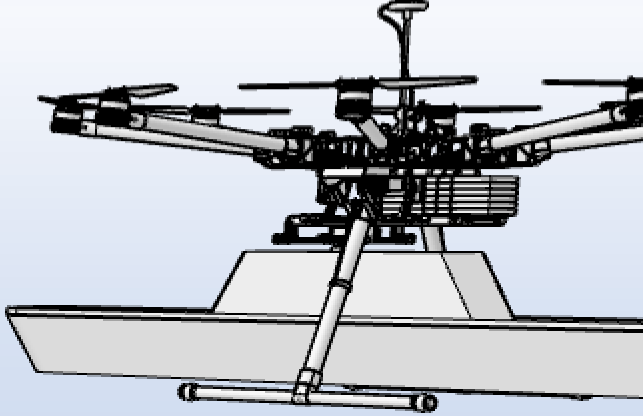


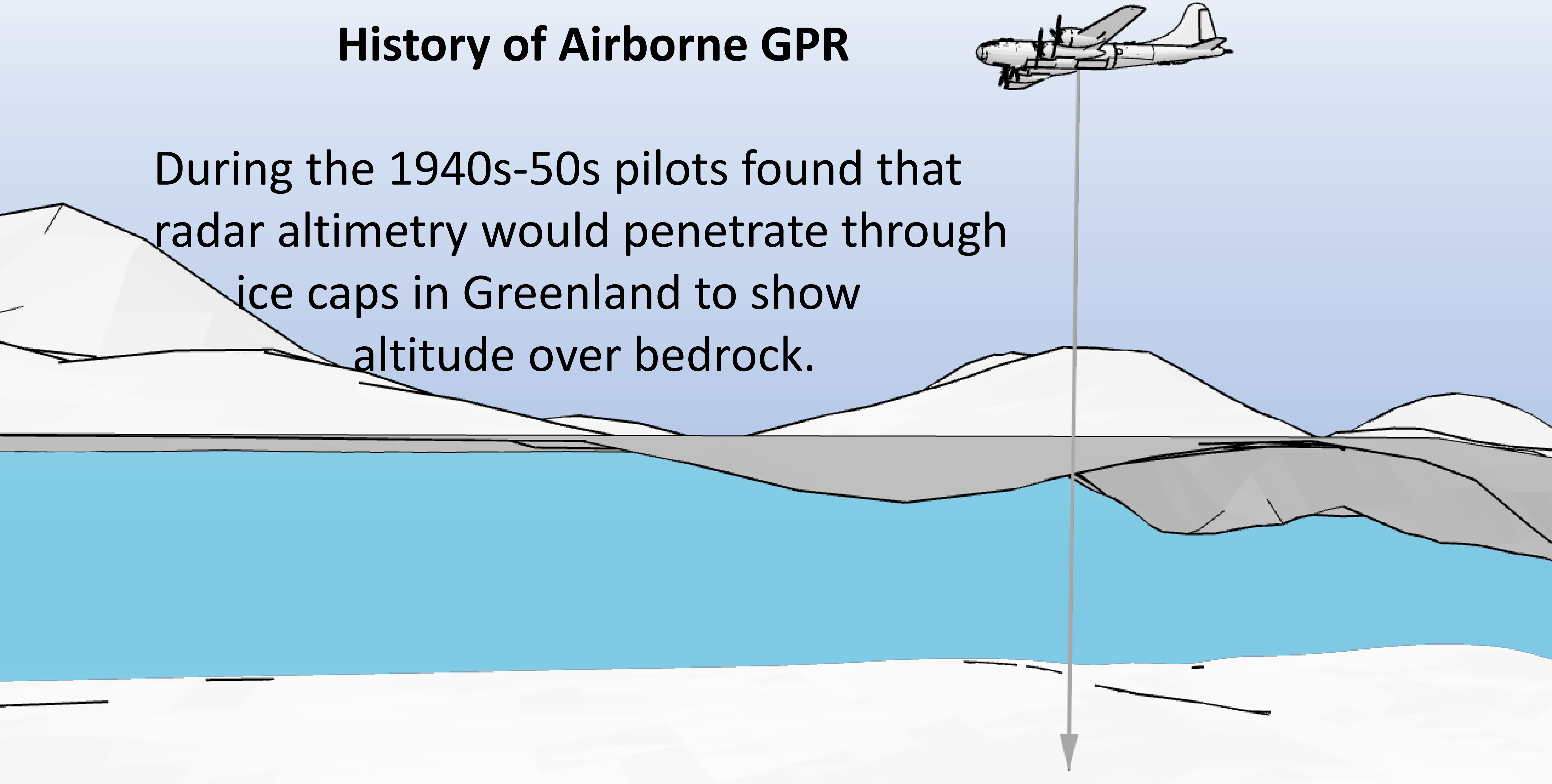
Airborne GPR

Advantages
- Automated large areal coverage
- Able to survey over rough terrain/vegetation
- Able to survey over dangerous areas

Disadvantages
- Legal limitations
- Significantly lower penetration
- Lower spatial resolution
- Complicated interpretation

History of Airborne GPR

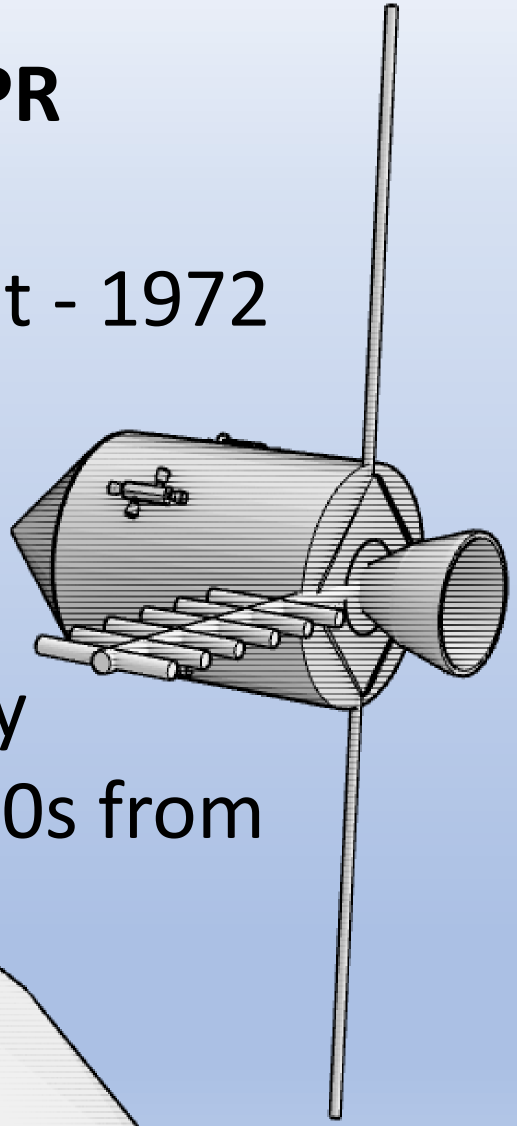
During the 1940s-50s pilots found that radar altimetry would penetrate through ice caps in Greenland to show altitude over bedrock.

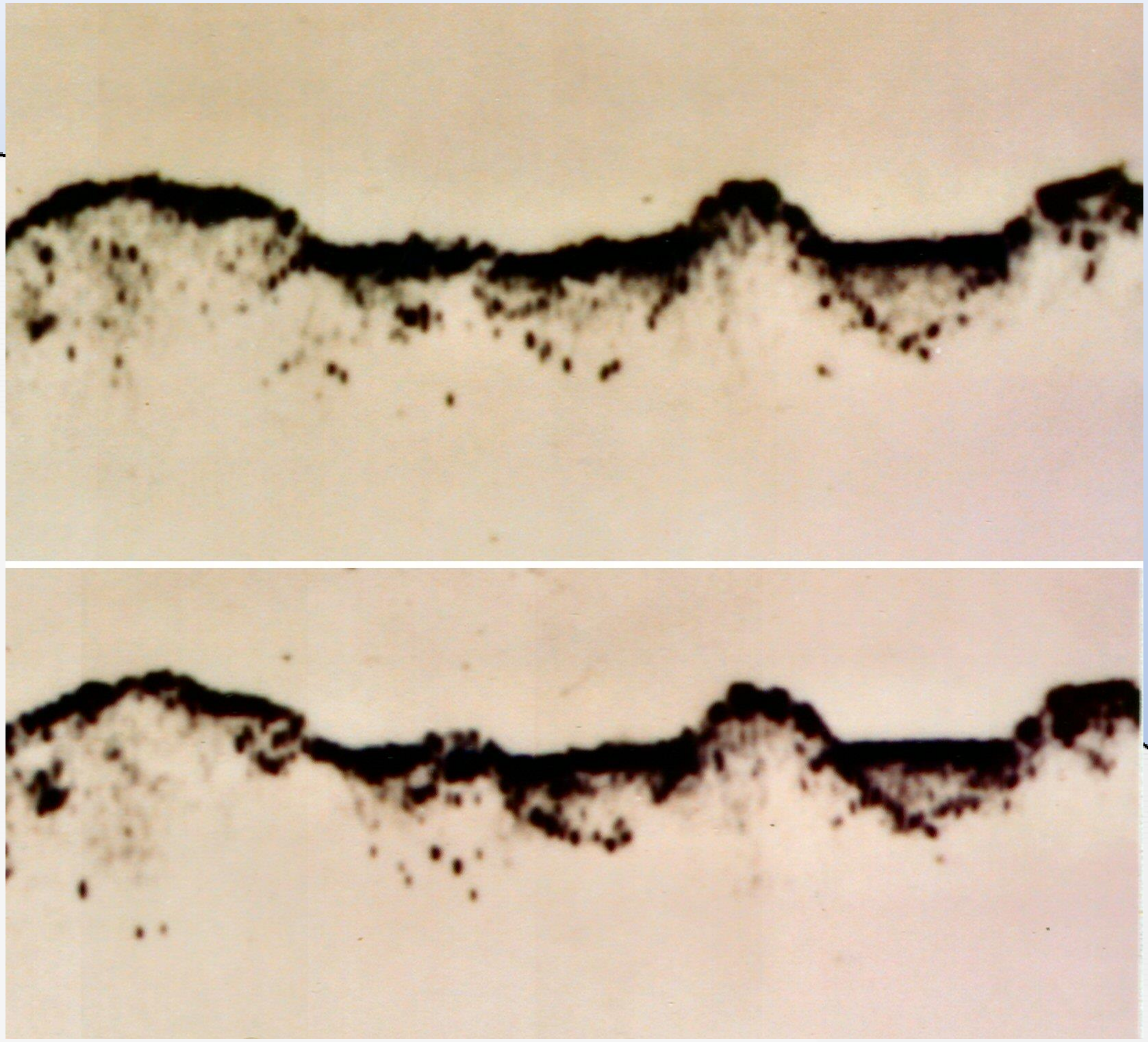


History of Airborne GPR

Apollo 17 Lunar Sounder Experiment - 1972

- 5, 15 and 150 MHz antennas
- Penetration 900 m – 1600 m
- Possible due to extremely low dielectric (2) and low conductivity
- Initial tests conducted in late 1960s from KC-135 aircraft over Greenland





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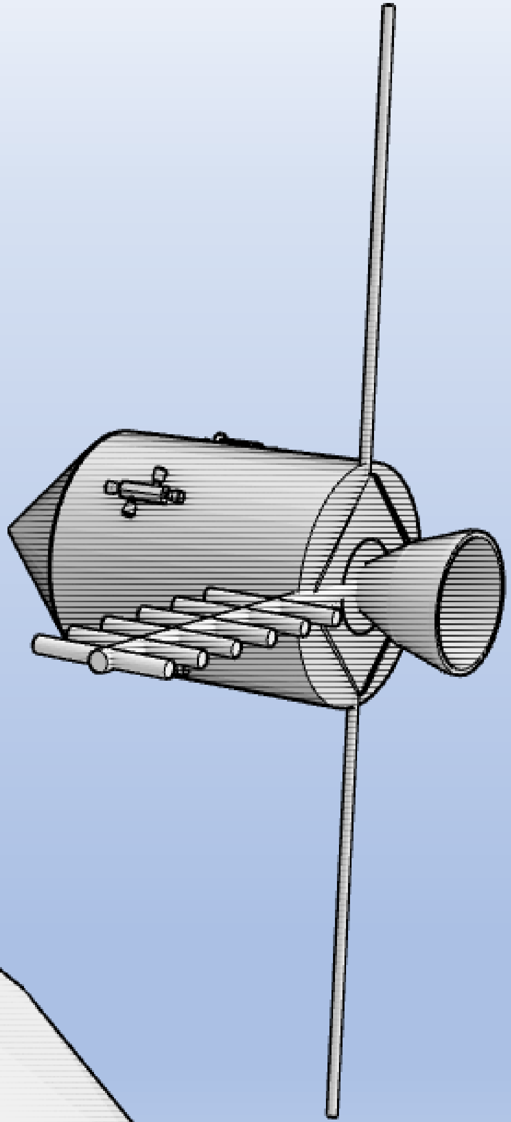
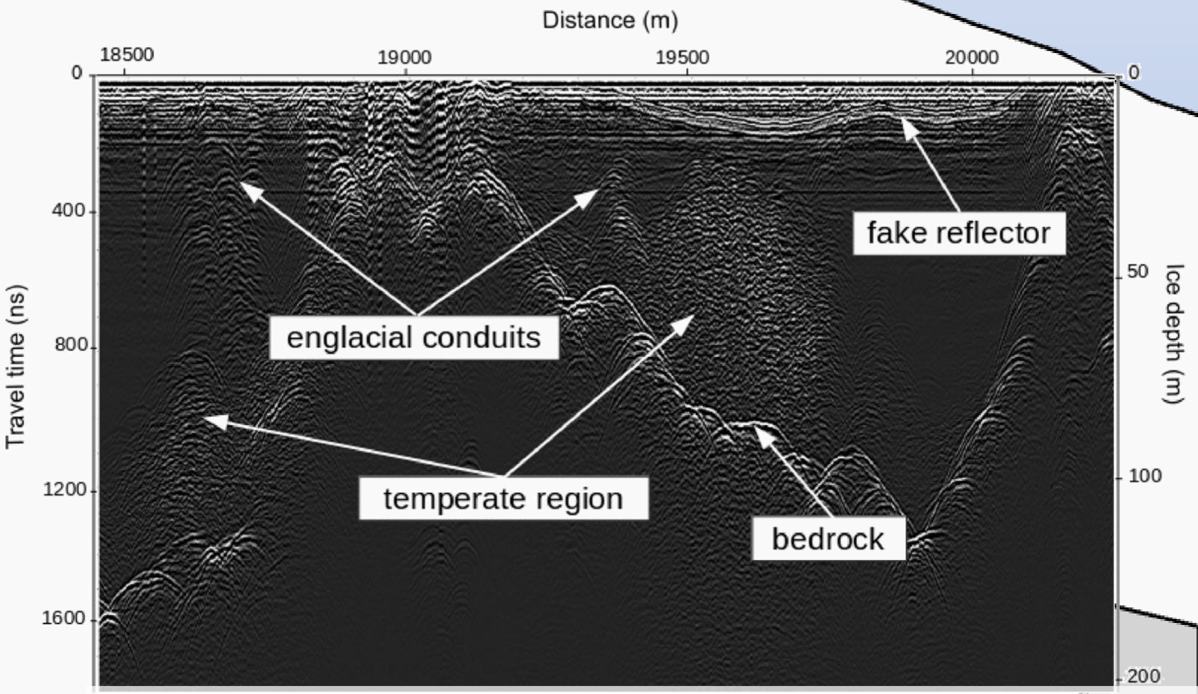
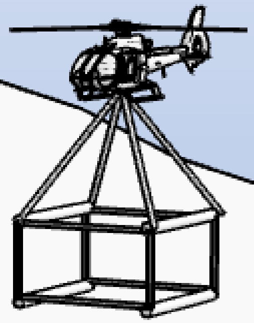


Sea ice measurements were tested during the 1970s

Radioglaciology onwards from the 1970s experimented with slinging low frequency GPRs from helicopters

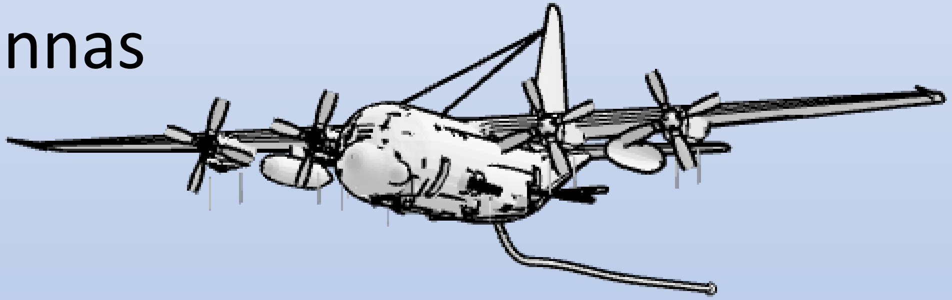


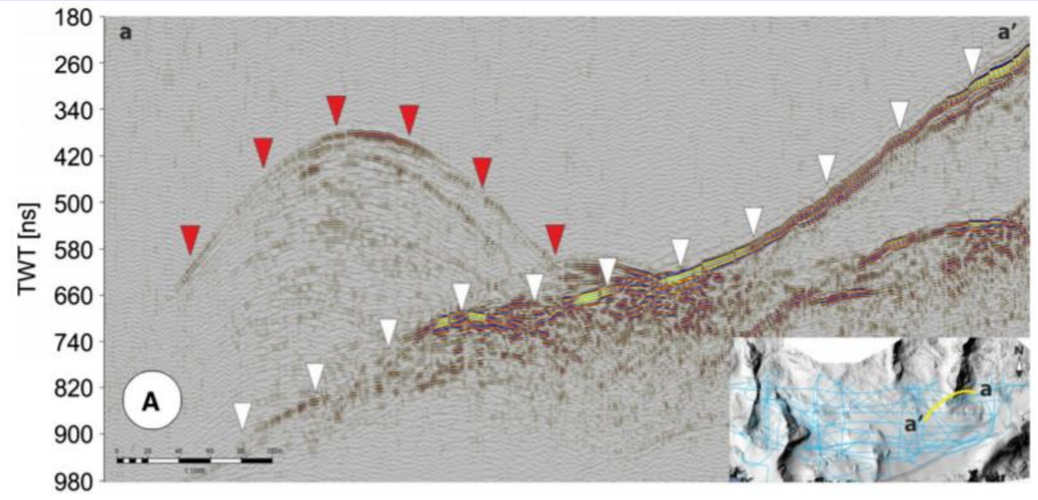


Gacitúa, G., et al (2015). 50 MHz helicopter-borne radar data for determination of glacier thermal regime in the central Chilean Andes. *Annals of Glaciology, 56*(70), 193-201.

Aircraft or helicopter-borne GPR can cover large areas rapidly, but suffer from drawbacks.

- Geometric spreading at increased altitudes leads to losses and decreased spatial resolution
- Positioning errors due to oscillating antennas
- Real-time sampling needed due to fast survey speeds





Forte, E., Bondini, M.B., Bortoletto, A. *et al.* Pros and Cons in Helicopter-Borne GPR Data Acquisition on Rugged Mountainous Areas: Critical Analysis and Practical Guidelines. *Pure Appl. Geophys.* **176,** 4533–4554 (2019)

Physics of Drone GPR

Geometric spreading losses

Energy loss with elevation is 1/*r*

Energy of the wave-front is spread over an increasingly larger area

Energy loss (spreading) is greater in air than in ground due to faster velocity

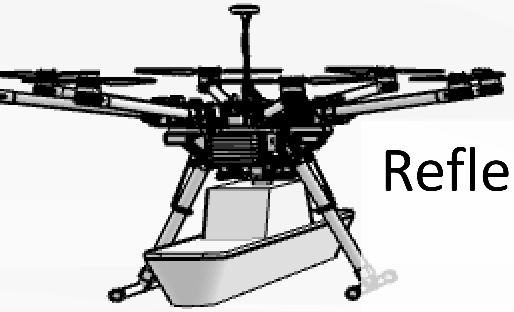
Larger Fresnel Zone

$$A = \frac{\lambda}{4} + \frac{D}{\sqrt{\varepsilon - 1}}$$

ε for air is 1, so larger Fresnel “illumination” zone

more energy reflects upwards and angles away from the receiver

Physics of Drone GPR



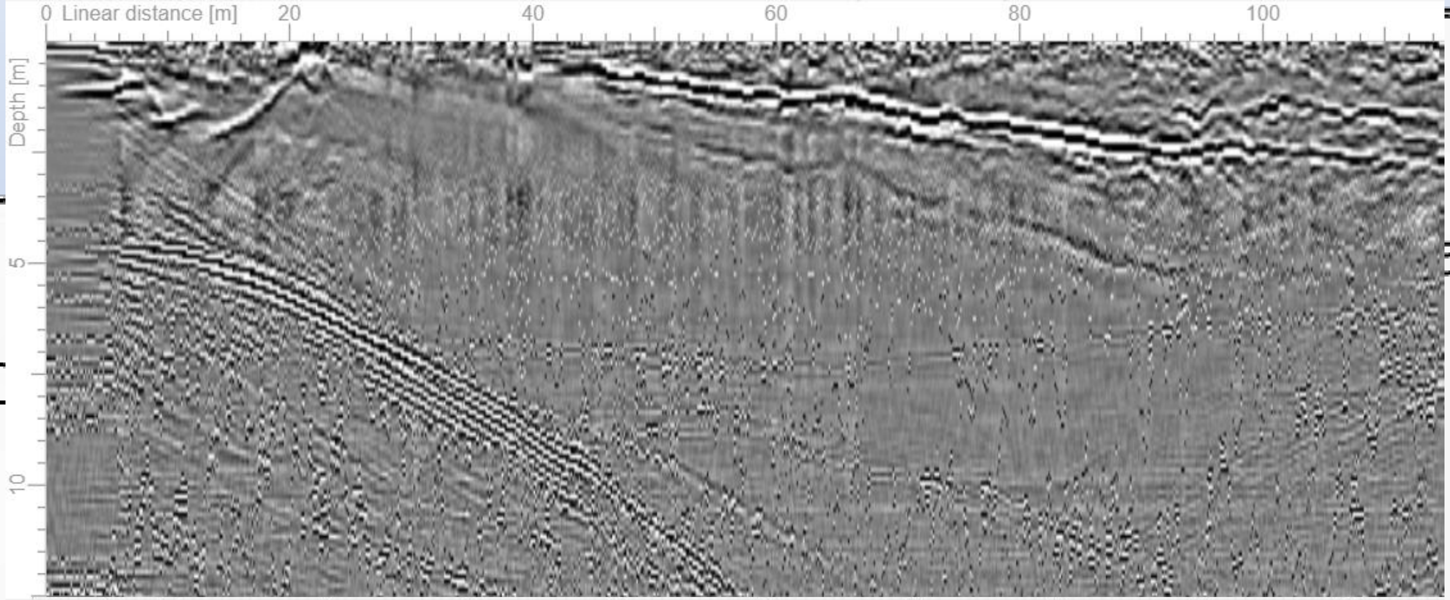
Reflection at the air-ground interface

For most soil types >> 50% of energy lost at ground interface

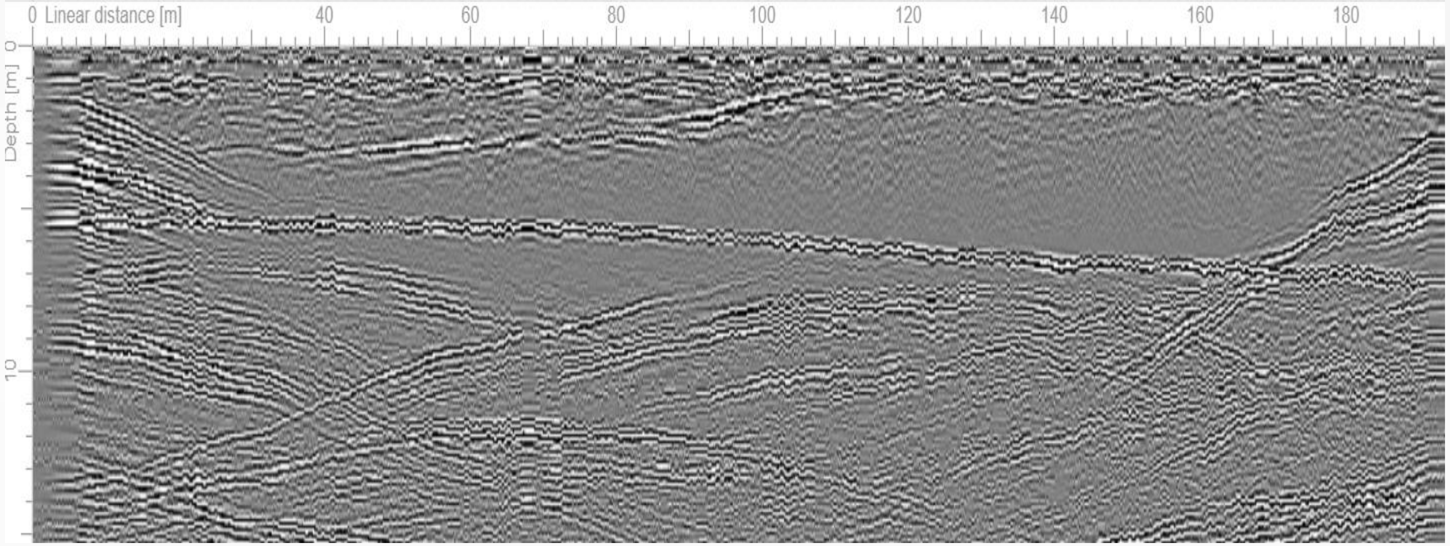
Material	Dielectric Perm.	Reflected energy at interface
Water	81	80%
Wet soils	20	64%
Typical soils	9	50%
Dry sand	6	42%
Ice	3	28%
Snow	1.3	7%

Sufficient separation to discern the direct arrival from the air-ground interface

Physics of Drone GPR



100 MHz unshielded antennas on ground (glacial till)

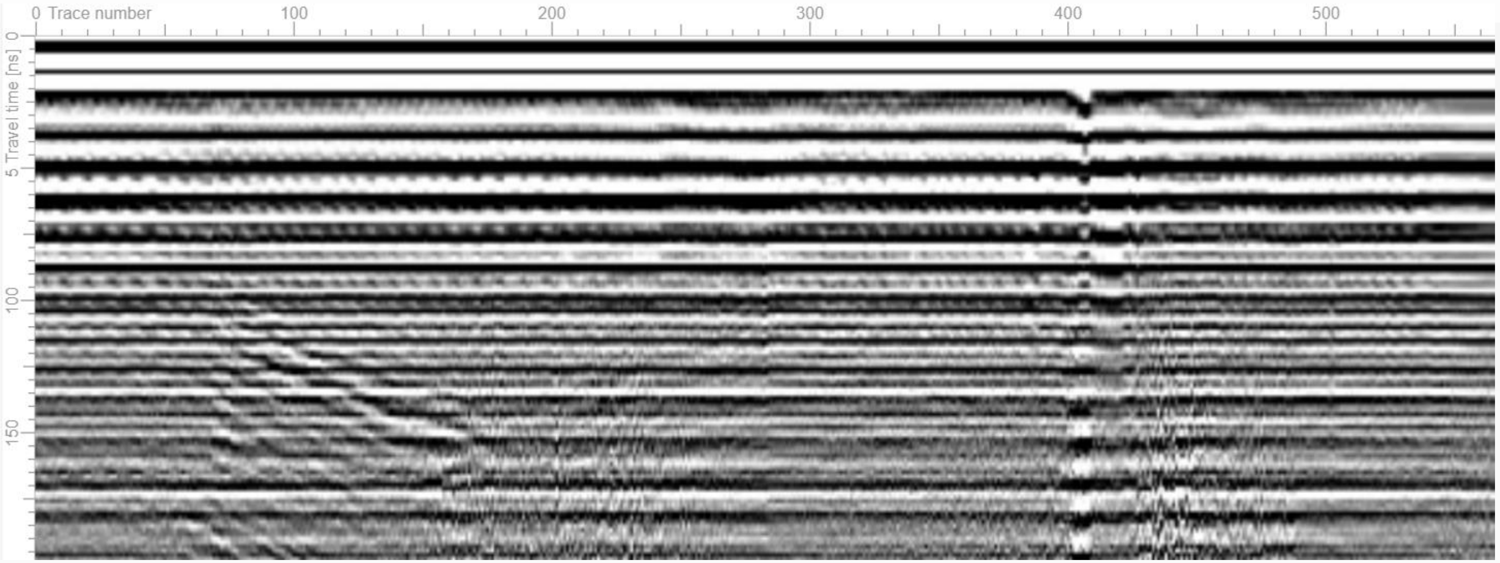


100 MHz unshielded antennas 1.5 m off ground (glacial till)

Physics of Drone GPR

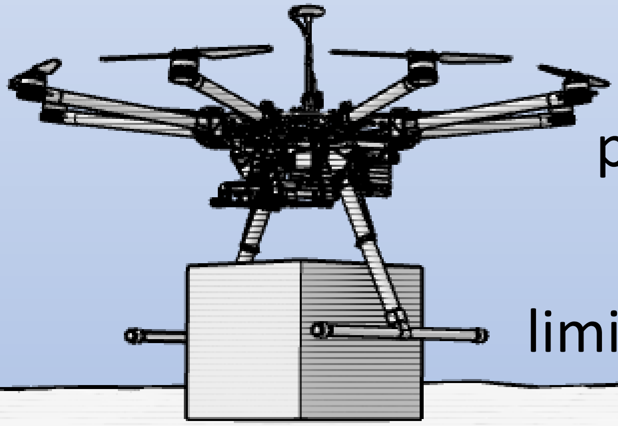
Significant EMI issues from the drone motors and telemetry

Bistatic antennas are close together or lightly shielded, producing antenna ringing effects

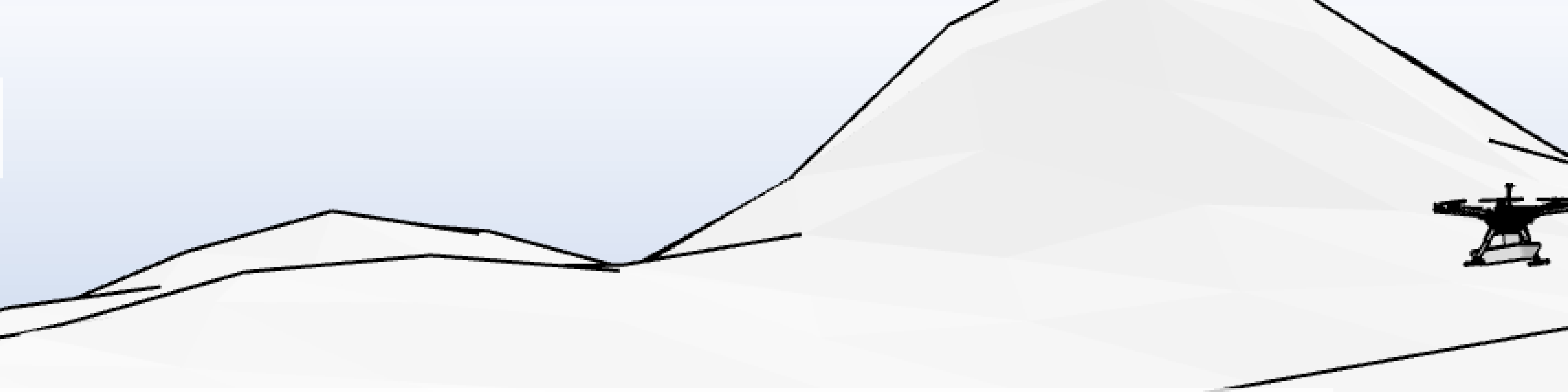


Legal Issues of Drone GPR

- Significant lobbying from the GPR industry was required in the 1990s and 2000s to allow commercial GPR operation in the US, Canada and Europe.
- Compromise was that unshielded antennas would be limited in use and GPR would be used within 1m of the ground
- Manufacturers now producing all-in-one GPR units suited for drone use
- Large risk of further limits being placed on GPR use



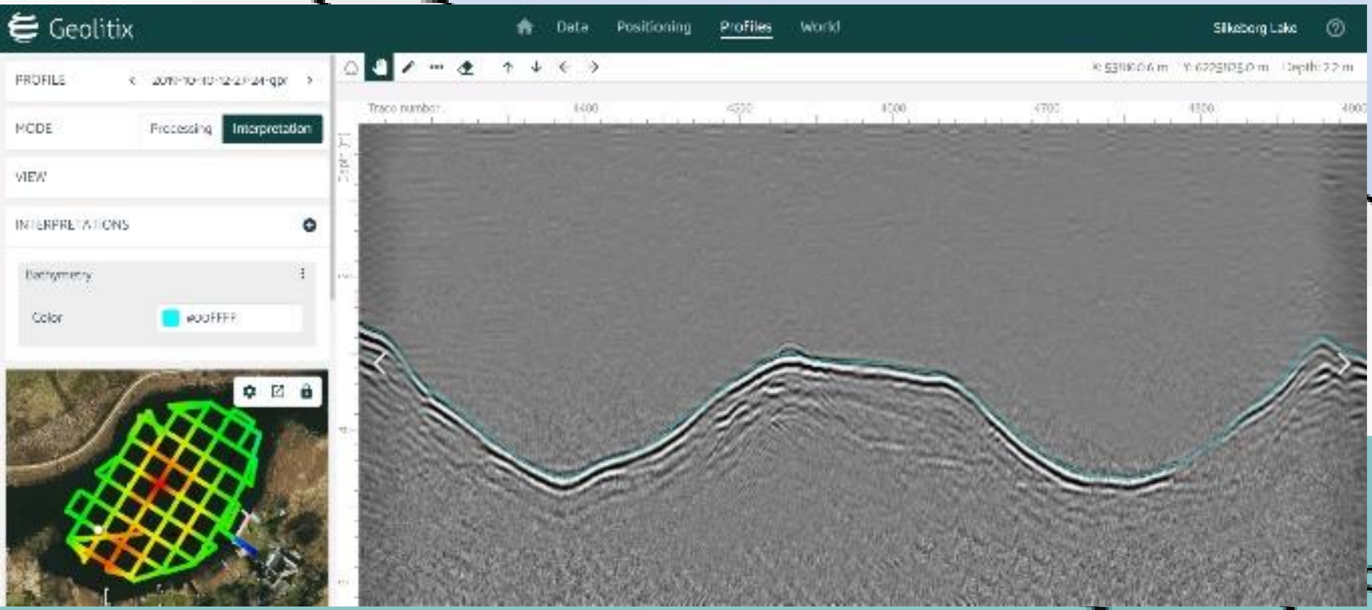
Caveats for Drone GPR

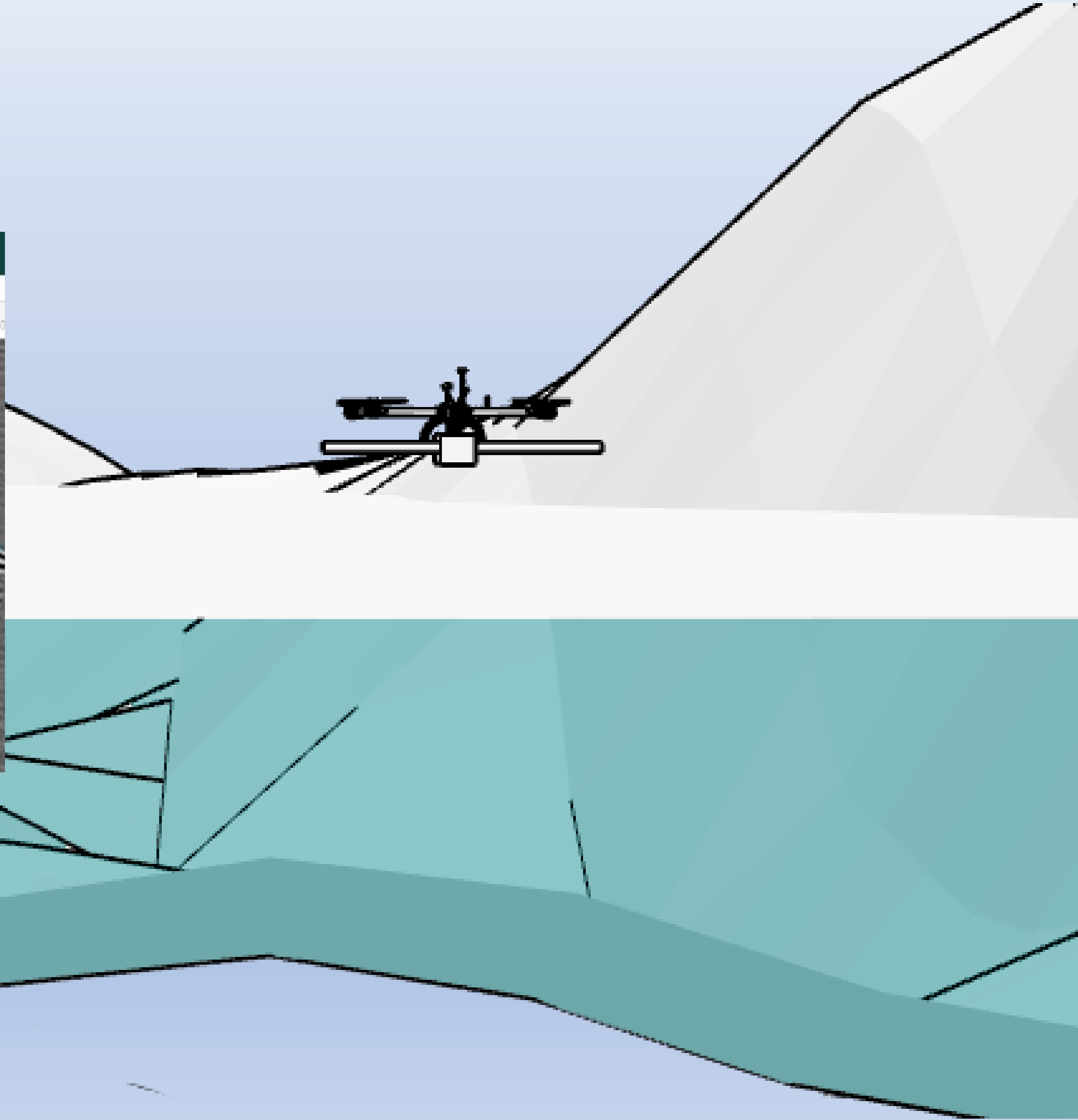


- Due to the legal and physics limitations drone should be less than 1 m off the ground
- Be aware of severe loss of penetration everywhere but ice, snow and dry ground
- Use radar altimetry to track elevation accurately for time zero correction
- Use integrated navigation system for accurate tracking for 3D grids

Drone GPR Bathymetry

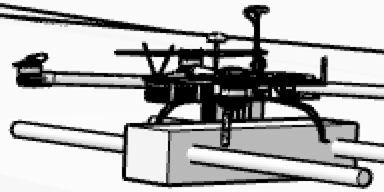
- Low frequency antennas (< 100 MHz)
- As low of possible to the water
- Requires fresh water (low e.c.)

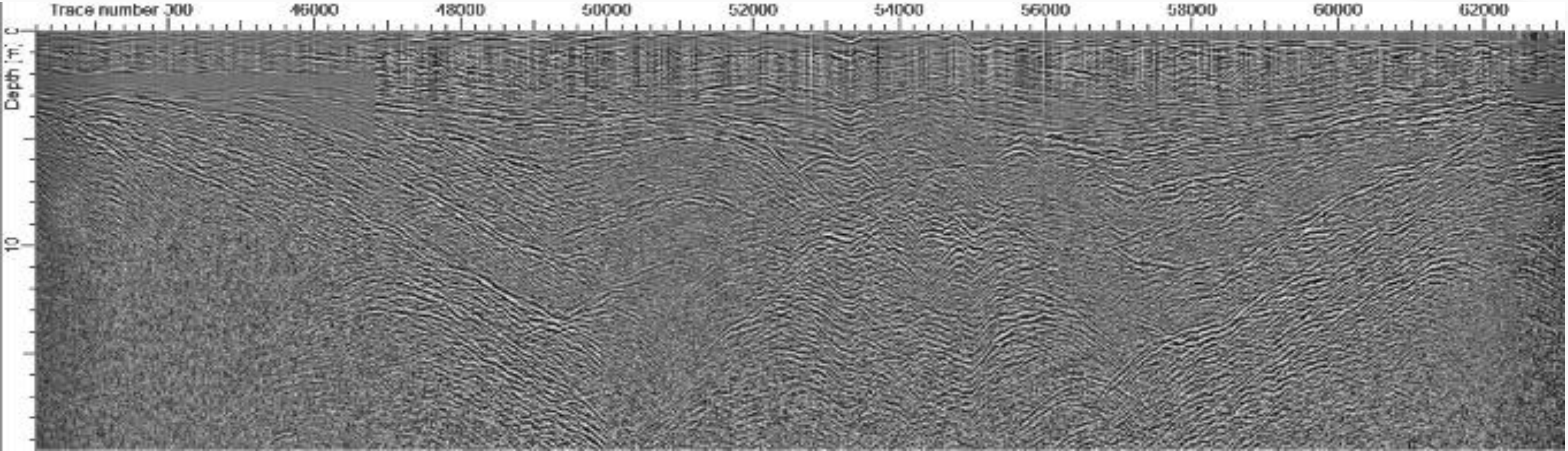




Drone GPR Glaciology

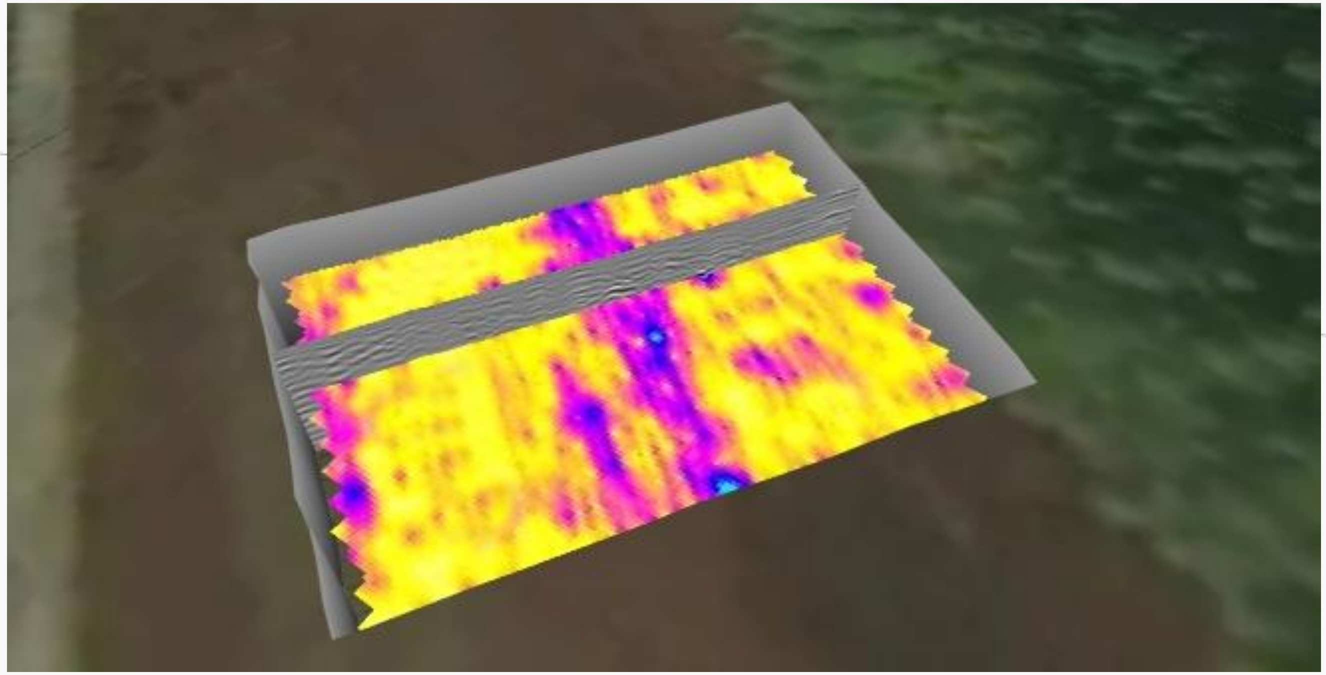
- Penetration to 20 m with 500 MHz antennas
- Height above ice less important





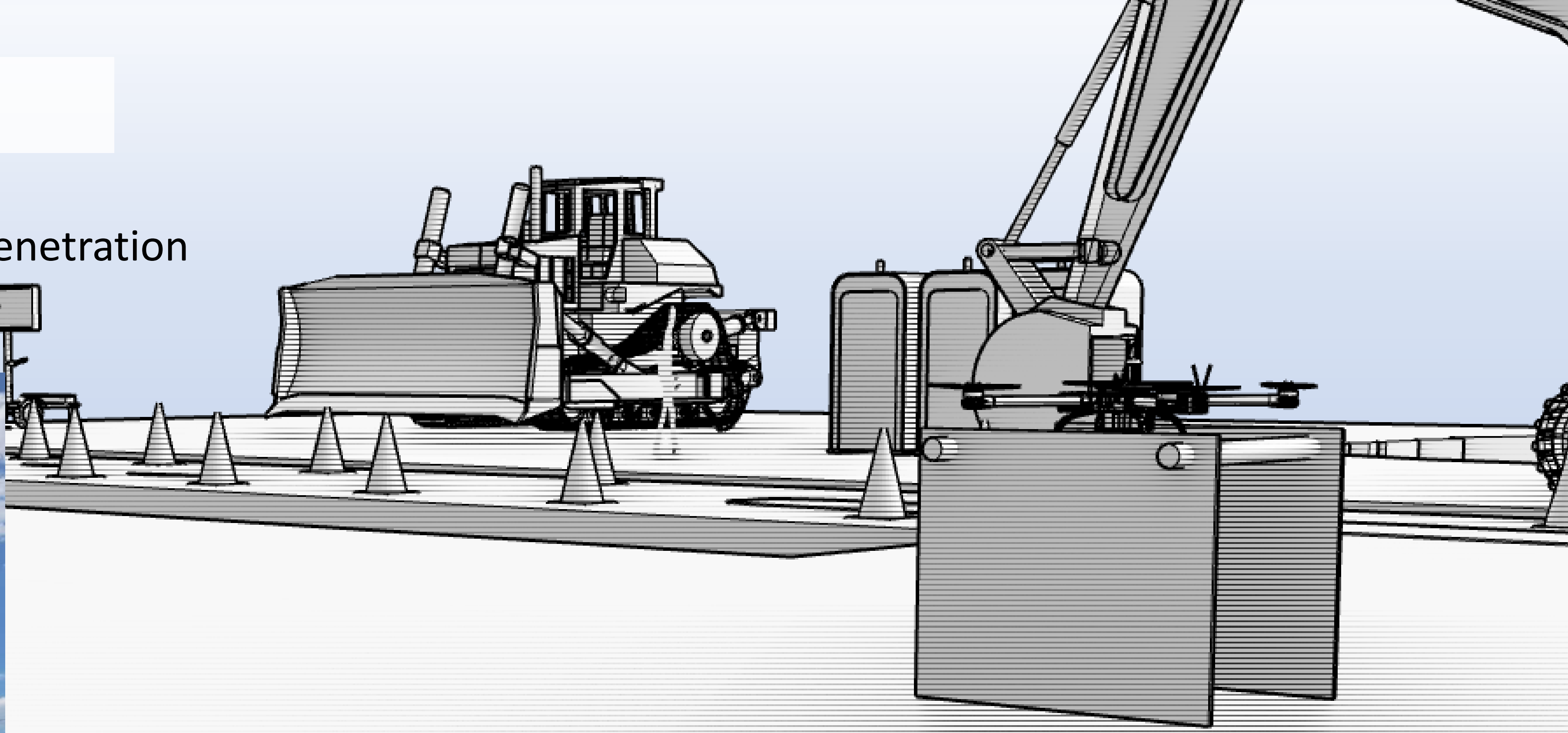
Shallow Object Mapping

- Requires very dry soils for adequate penetration
- Shielded antennas (500 MHz) to minimize side lobe reflections from objects
- May be useful for shallow UXO detection



Future Drone GPRs

- Directional UWB antennas
- Focusses energy for greater penetration
- < 2 kgs

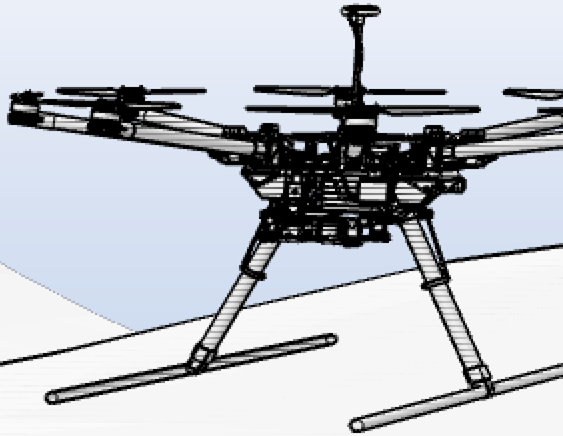


Future Drone GPRs

- High-endurance dirigibles

Future Drone GPRs

- Magnetic antennas (AMIRA P1187)
- 300 kHz – 10 MHz
- 100’s of m penetration
- Antennas built into drone skids
- < 3 kgs

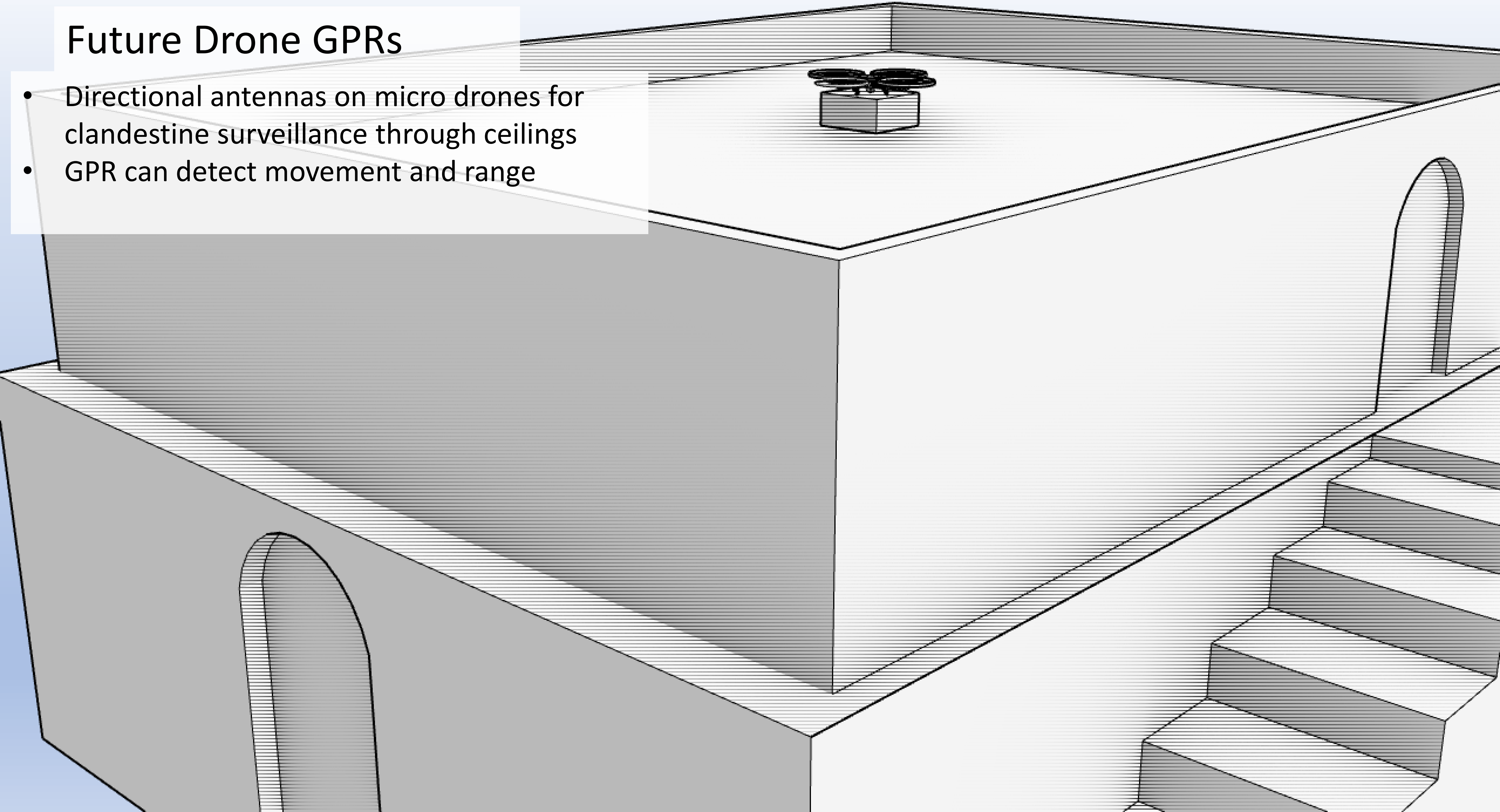


Future Drone GPRs

- 1 – 3 GHz Vivaldi antennas with 500 MSPS Rx and RaspPi controller
- Total station tracking with GNSS time synch
- On board camera and ultrasound?
- Rebar corrosion and spacing

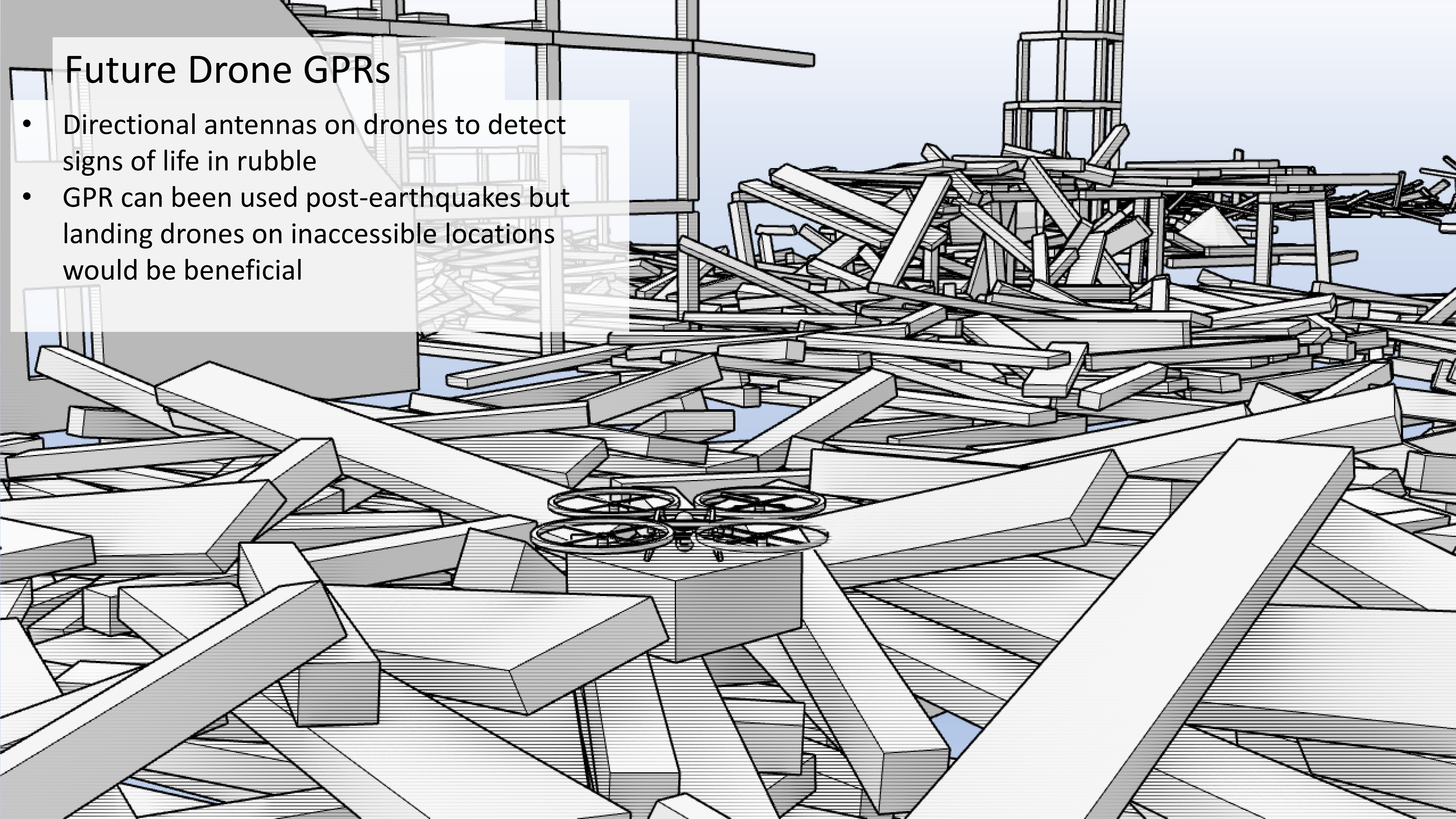
Future Drone GPRs

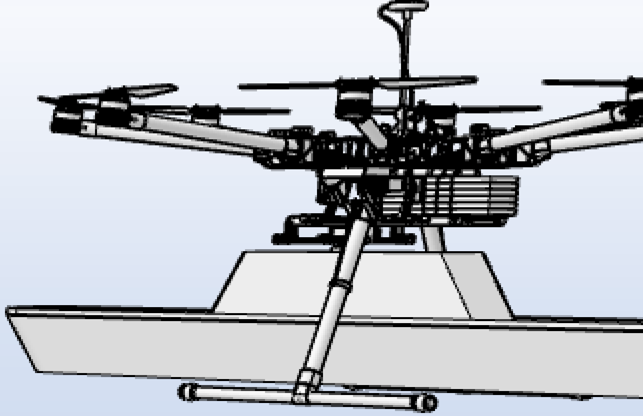
- Directional antennas on micro drones for clandestine surveillance through ceilings
- GPR can detect movement and range



Future Drone GPRs

- Directional antennas on drones to detect signs of life in rubble
- GPR can been used post-earthquakes but landing drones on inaccessible locations would be beneficial





Conclusions

- Drone GPR is advantageous in specific settings
- Radar must be flown ideally < 1m to comply with legal and physics requirements
- Specific applications where drone GPR is the only option
- Processing requires identification of ground reflection and proper time zero correction
- Interpretation must take into account side lobe reflections