Visualizing Ice Sheets in Extended Reality (VISER) for the Improvement of Polar Data Analysis

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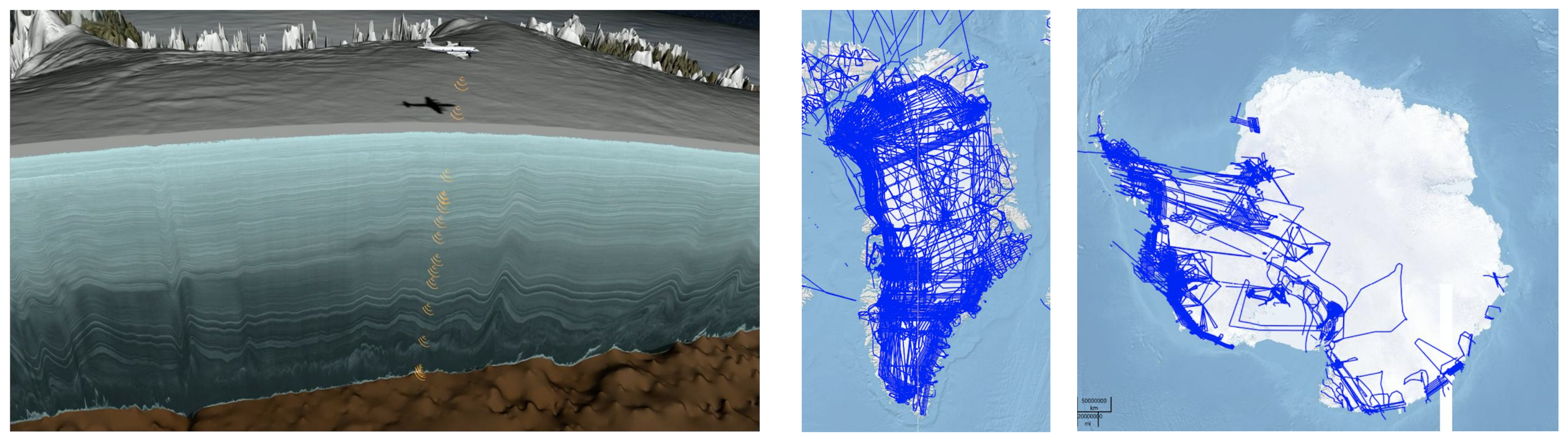
I. A 3-Dimensional Planet, With 2-Dimensional Data Analysis

Ice-penetrating radar data have been collected across Greenland and Antarctica for decades. The data allow us to peer inside the ice. Scientists can use this data to make measurements, models, and predictions about ice structure, thickness, melting patterns, and changes over time.



Left: Schematic of airborne ice-penetrating radar being collected across the Greenland Ice Sheet (National Aeronautics and Space Administration (NASA) Visualization Studio).
Middle: Locations of radar data collected (blue lines) across the Greenland Ice Sheet from 1993 to 2021 (Open Polar Server, made by the Center for Remote Sensing of Ice Sheets at the University of Kansas).
Right: Locations of radar data collected (blue lines) across the Antarctic Ice Sheet from 1993 to 2021.

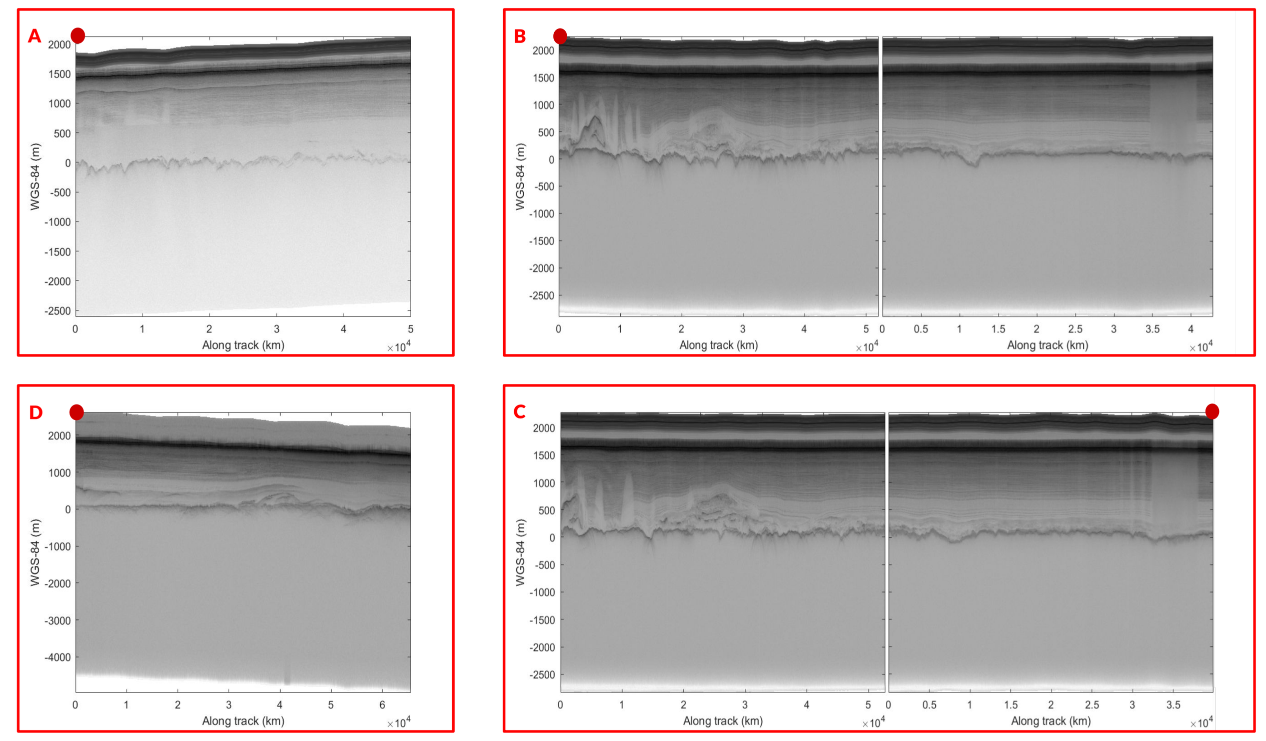
Raw radar data are processed and visualized as **cross-sectional images of the ice** below the sensor. These **radargrams** are used to interpret the structure and features within the ice. Glaciologists often interpret and analyse ice-penetrating radar by displaying individual radargrams on a computer screen and manually digitizing visible features, which become the derived measurement.

The Challenge:

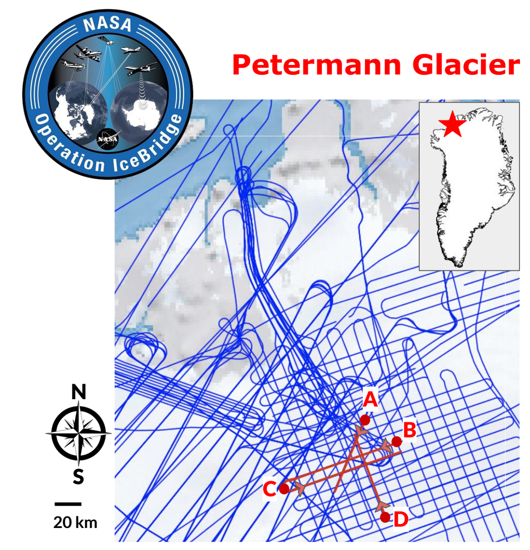
This digitization process removes the third dimension, geospatial context and relies on the analyst's pre-existing knowledge of the region, radargram frame, context, and ice properties. However, **three-dimensional geospatial thinking** is an important **skill used by earth scientists** to interpret data (*Kastens et al., 2006*).

Considering this is a routine part of their data analysis toolbox, **there is no pressing need to reintroduce the 3rd dimension… right?**

Can you figure out which radargram frame goes where, and where the aircraft turns are supposed to be?



Above are **Multichannel Coherent Radar Depth Sounder** (MCoRDS) radargrams from **Petermann Glacier, Greenland** collected by NASA's **Operation IceBridge (OIB)**. The data were captured along the denoted red lines on the map above, and revealed basal structures created by different thermal regimes which has caused a deformation of the otherwise horizontal stratigraphy (*Bell et al., 2014; Wolovick et al., 2016*).



Above: *Map from the Open Polar Server (OPS) showing all OIB flights (blue) around the Petermann Glacier region (red star). Labeled red lines show the locations of MCoRDS radar echograms pictured to the right and below.*

Helpful Hints:

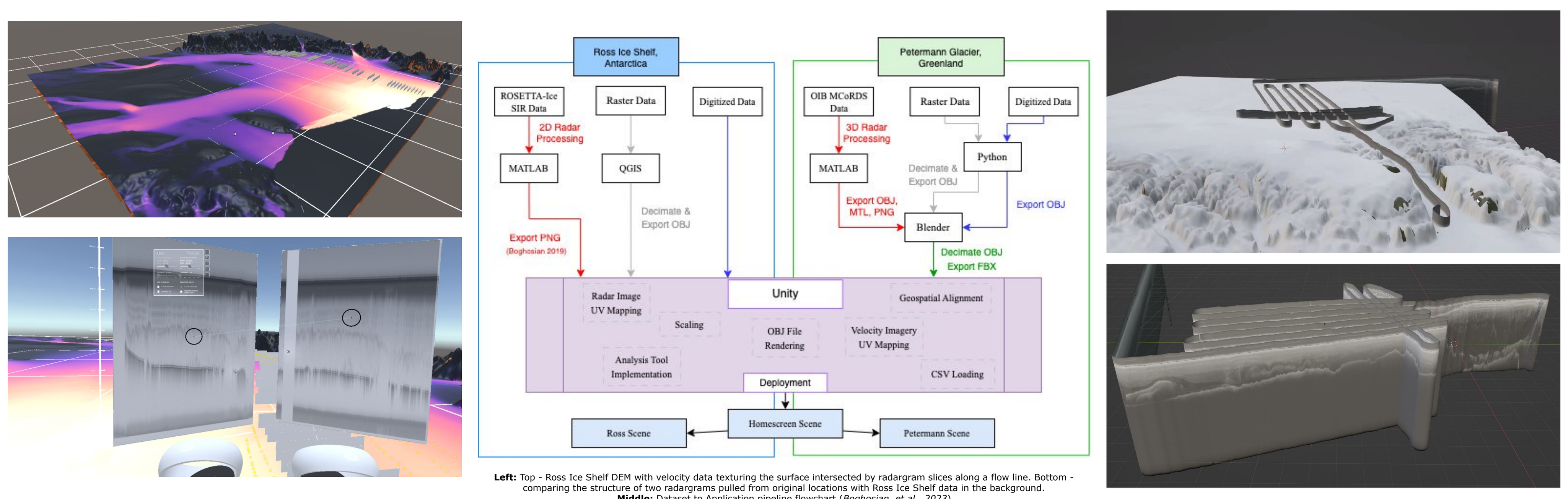
- **A** shows data collected at an oblique angle to the grid, collected in 2019.
- **B** and **C** show data collected in 2011. **B** is the northern line and **C** is the southern.
  We show the data in two frames in the West–East orientation with basal structures visible.
- **D** shows data collected along a North–South portion of the grid, collected in 2010.
  We show the data at the point where the radar crosses over the basal structures from **B** and **C**.

II. Pol-XR – An Immersive Visualization for Analysis Improvement

The Solution:

We find that immersive **Extended Reality** (XR) headset technology reintroduces the third dimension, while also effectively conveying scale and complexity – particularly when Digital Elevation Models (DEMs) are included. Data are displayed in-situ and can be viewed in the context of their surroundings and corresponding datasets.

The virtual environment and radargrams are fully interactive in the Pol-XR application. The Microsoft Mixed Reality Toolkit (MRTK) enables cross-platform development for Unity. This means handset button programming, interactive menu generation, and gesture tracking will have universal functionality on Augmented Reality (AR) and Virtual Reality (VR) headsets.



Left: Top - Ross Ice Shelf DEM with velocity data texturing the surface intersected by radargram slices along a flow line. Bottom - comparing the structure of two radargrams pulled from original locations with Ross Ice Shelf data in the background.
Middle: Dataset to Application pipeline flowchart (*Boghosian, et al., 2023*)
Right: Top - Petermann Glacier DEMs intersected by Mar 24, 2010 OIB flight radargrams. Bottom - Mar 24, 2010 OIB flight radargram meshes in 3D environment.

In order to reduce latency issues during application deployment, minimal and uniform decimation is applied to the OBJ/MTL meshes – the high resolution imagery remains untouched. This conversion and packaging process renders these datasets into a more user-friendly and accessible state without sacrificing the integrity of the data, which makes viewing them less computationally intensive.

Pol-XR Application
[4GB]

Petermann Glacier Scene
+
Ross Ice Shelf Scene

Petermann Glacier Data :
OIB Radar MAT = 1.8GB
MEaSUREs Surface DEM (Clipped) = 500MB
BedMachine Bathymetry DEM (Clipped) = 19.4MB

Ross Ice Shelf Data :
ROSETTA-Ice Radar MAT = 125GB
→ Reduced to 200MB as Images
Landsat LIMA Imagery = 2.10GB
BedMap Bathymetry DEM (Clipped) = 2.29MB
MEaSUREs Velocity = 119MB
REMA Surface DEM = 4GB

Menu Items:

Vertical Exaggeration:
- → View the original height of the radar image (in meters), the current stretched height, and calculated strain rate.
- → Users have the option to use the slider to stretch the image, instead of using motion controls.

Rotation:
- → View the current rotation of the radar image.
- → Users have the option to use the slider to rotate the image on a horizontal axis, instead of using motion controls.

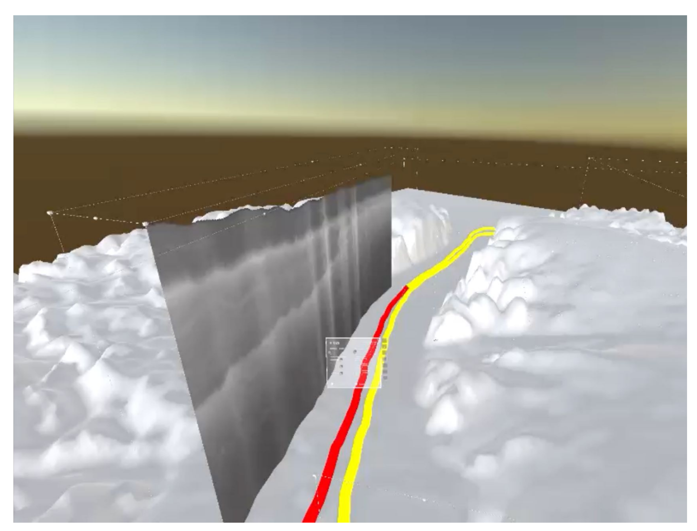
Horizontal Exaggeration:
- → View the original extent of the radar image (in meters), the current stretched extent, and calculated strain rate.
- → Users have the option to use the slider to stretch the image, instead of using motion controls.

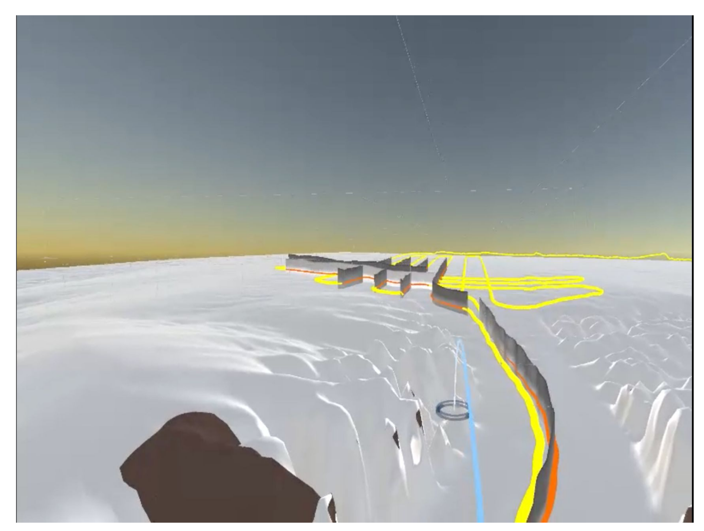
Transparency:
- → Users can enable transparency on a radar image to compare parallel images by using the transparency slider to change the opacity.

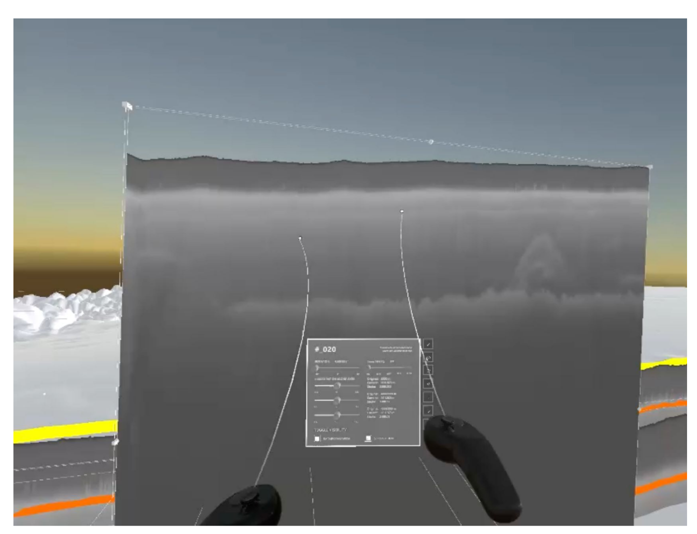
Active Objects:
- → Toggle visible objects within the environment on or off.
- → Users may turn "off" a radar image or its associated digitized thickness or surface derived from traditional reflector picking methods.

Selection Modes:
- → Users may enable a Picking Mode, which allows a measurement and snapping of a specific feature. [DEV]
- → Measurement Mode enables the user to measure the distance between two points of their choosing, by placing circular indicators on one or two radar images.

Voice Commands:
- "Menu" – Displays the menu screen
- "Measure" – Activates the measurement tool
- "Go" – Enables users to teleport to a selected radar image
- "Box" – Enables users to scale and translate the entire scene
- "Reset" – Resets the scene







The User can either grab the radar meshes using Menu Sliders or intuitive hand movements. Within the application, a User may translate, rotate, and scale radargram frames, toggle textured datasets, compare other digitized interpretations, and create new interpretations.

III. Ongoing Work

(A) Platform Hardware Compatibility
- Revisit interactions to hand tracking in lieu of controllers, like in HoloLens 2 deployment
- Update Unity build version for headset compatibility - i.e., Quest2, Quest3, HoloLens2
- Include Quest3 Augmented Reality functionality
- Upgrade current build to use latest version of MRTK v.3.0 – may enable iOS deployment.

(B) User Experience & Interface Improvements
- Redesign Menus to improve legibility and interactive feature functionality.
- Create controller button function for vertical "elevator" movement as an alternative to physical crouching.

(C) 3-D Radar Layer Interpretation / Tracing
- Developing in-app 3D radar interpretation by adapting traditional methods to game engine technologies and XR headset use. (*Boghosian, et al., 2023; Tack, et al., 2023*).
- Implementing in-app radar interpretation standard output with standard formatting for derived data distribution, reuse, and testing.

(D) Headset Networking for Collaborative Data Exploration & Analysis
- Test implemented headset networking feature
- Test user experience of synced virtual environment for collaborative data exploration

IV. Acknowledgements

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V. References

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