Seismic Full Waveform Inversion to Recover Firn Profiles: Capability and Limitations

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1. Introduction

- Full Waveform Inversion (FWI) is a state of the art seismic modelling technique used mostly in the exploration industry to obtain high resolution velocity models of the subsurface
- Glaciology is an area that would benefit from these high resolution subsurface models, specifically glacier firn, the top region of a snow covered region, where snow gradually transitions into ice
- This poster assess the capability of FWI on firn profiles to see if we can recover these high resolution velocity models.

2. Theory

- Firn forms in a region where snow is preserved annually
- Depending on the surface temperature and rate of snow accumulation, the rate of snow densification changes
- Characterizing this densification profile can give insight into the past and present climate conditions
- Seismic waves are sensitive to changes in the snow's compaction/densification

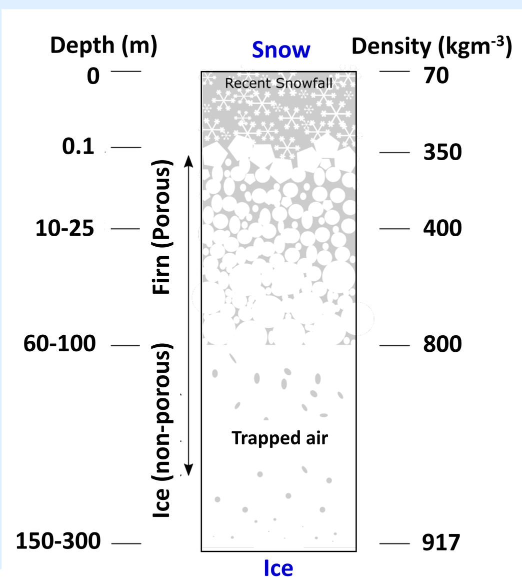

Fig 1

- The change in velocity of the wave can be used to model the firn
- FWI has the ability to model higher resolution than other current seismic methods

3. Methodology

a. Synthetic data

Herron Langway Firn Densification Model
Used to generate three firn profiles observed in high, middle and low accumulation regimes.
Kohnen Approximation
To take the density profiles to velocity profiles

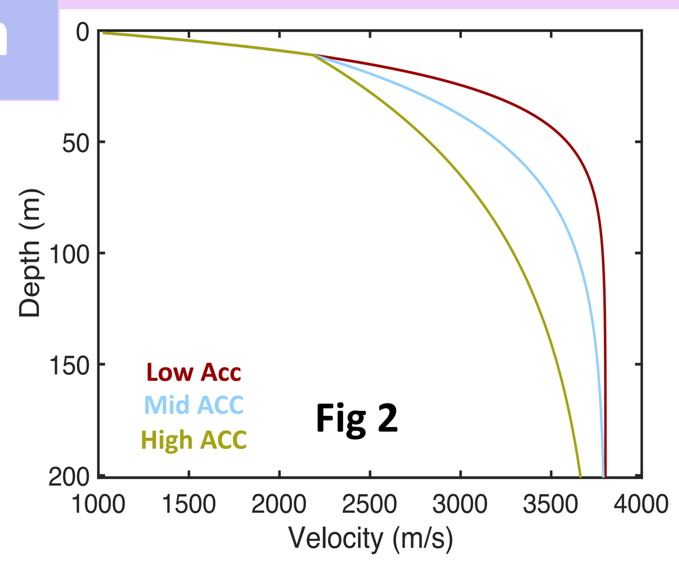

Fig 2

models are expanded to be 1000 x 200m
Acoustic forward modelling used to get synthetic datasets.

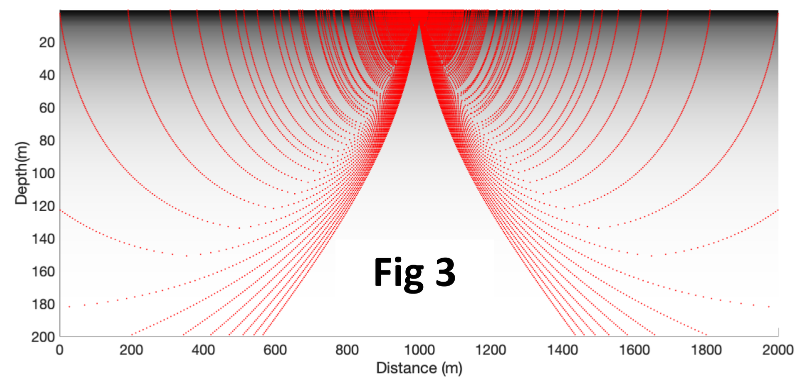

Fig 3

Ray tracing is used to show the depth of imaging we should expect to see for a 1000m offset.

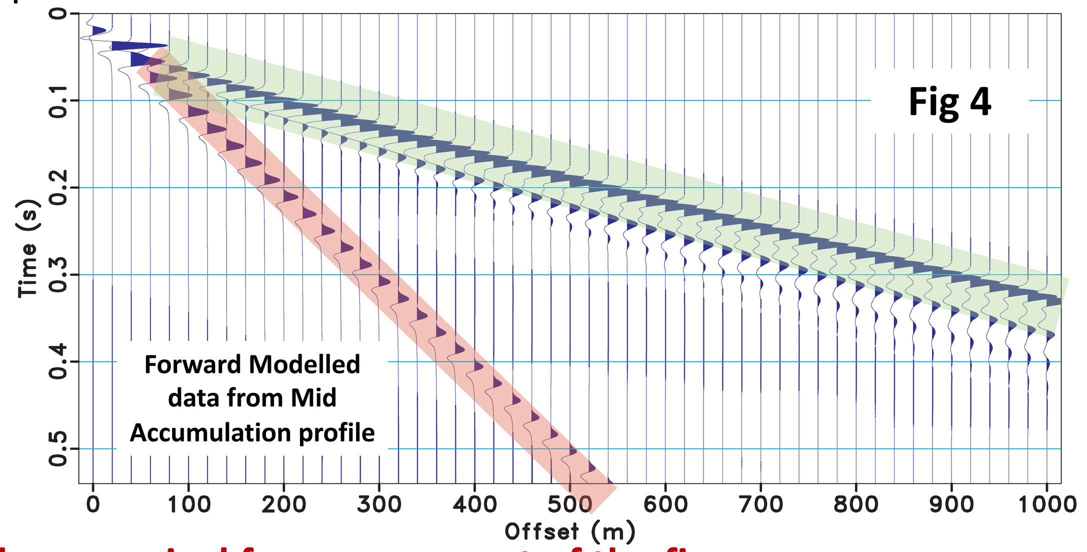

Fig 4

Slower arrival from upper part of the firn
Fast arrival from the deeper part of the firn

b. Starting model

Herglotz-Wiechert (HW) inversion
- First break pick (FBP) the synthetic 'field' data
- Obtain a velocity-depth starting model from these FBP arrival times of seismic signal

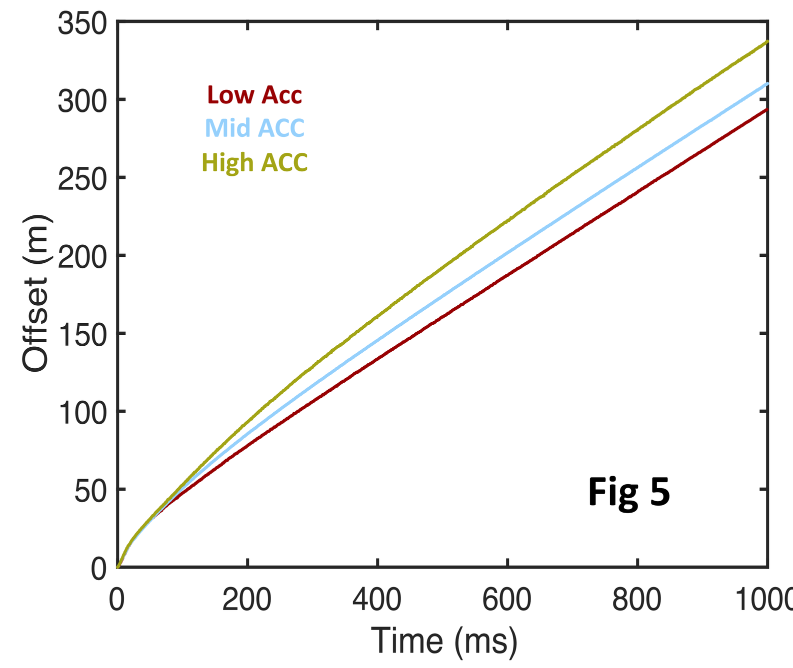

Fig 5

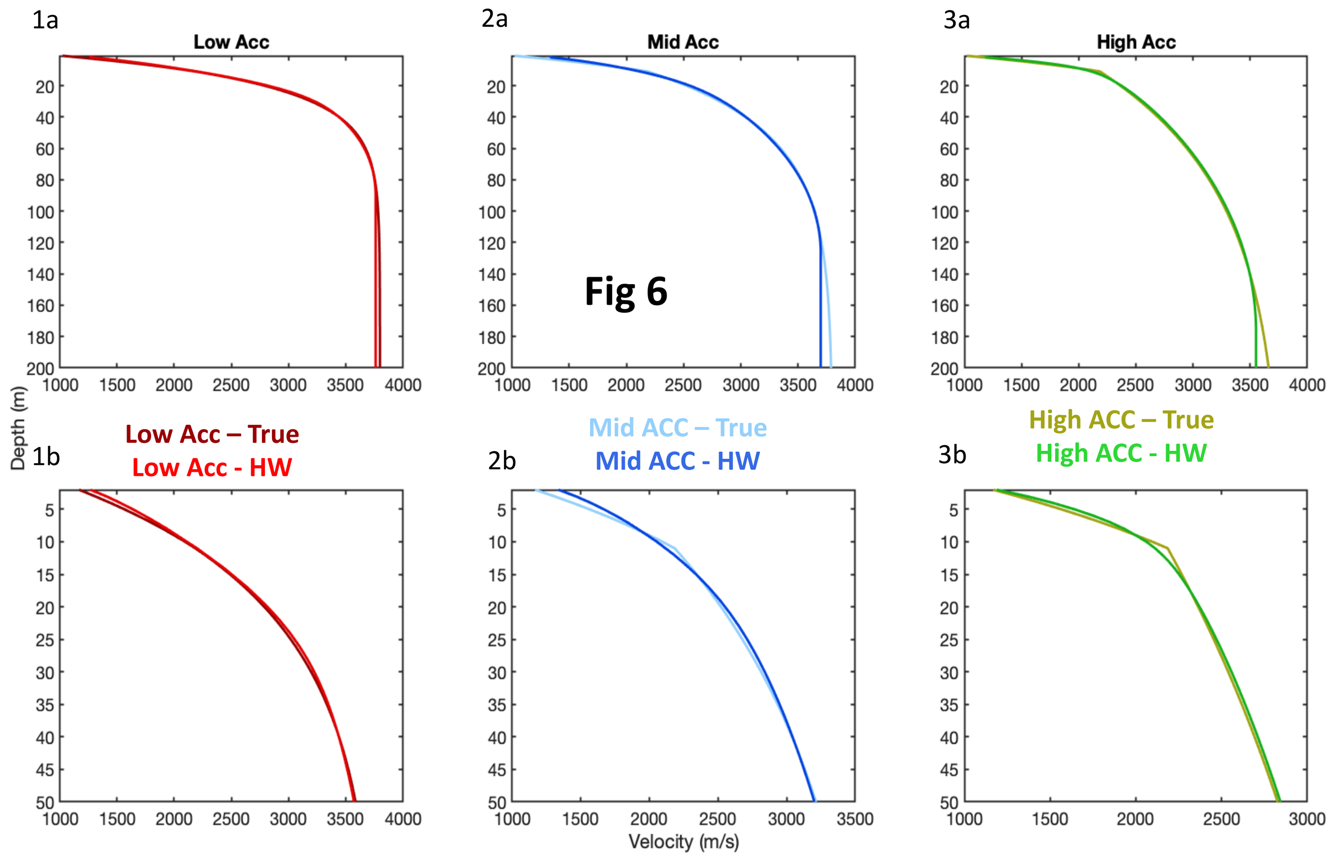

Fig 6

Comparison between the true velocity profiles and the HW velocity profiles (a), with (b) a close up of the top 50m of the model

c. FWI work flow

Geometry
- 1000m offset and 200m deep
- Receivers every 1m
- Grid spacing 1m x 1m
- Source at 0m
- Dt = 0.000125s

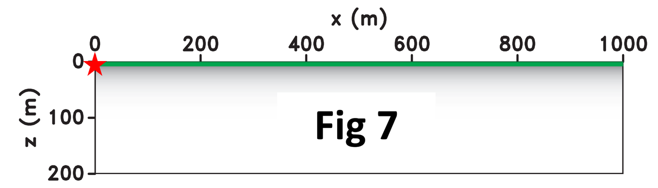

Fig 7

Modelling
1. Use HW model as the starting model
2. .Check starting data and true data, are they cycle skipped?
3. If cycle sipped adjust frequency/starting model
4. Start at low frequencies, 2Hz and increase gradually to 50Hz

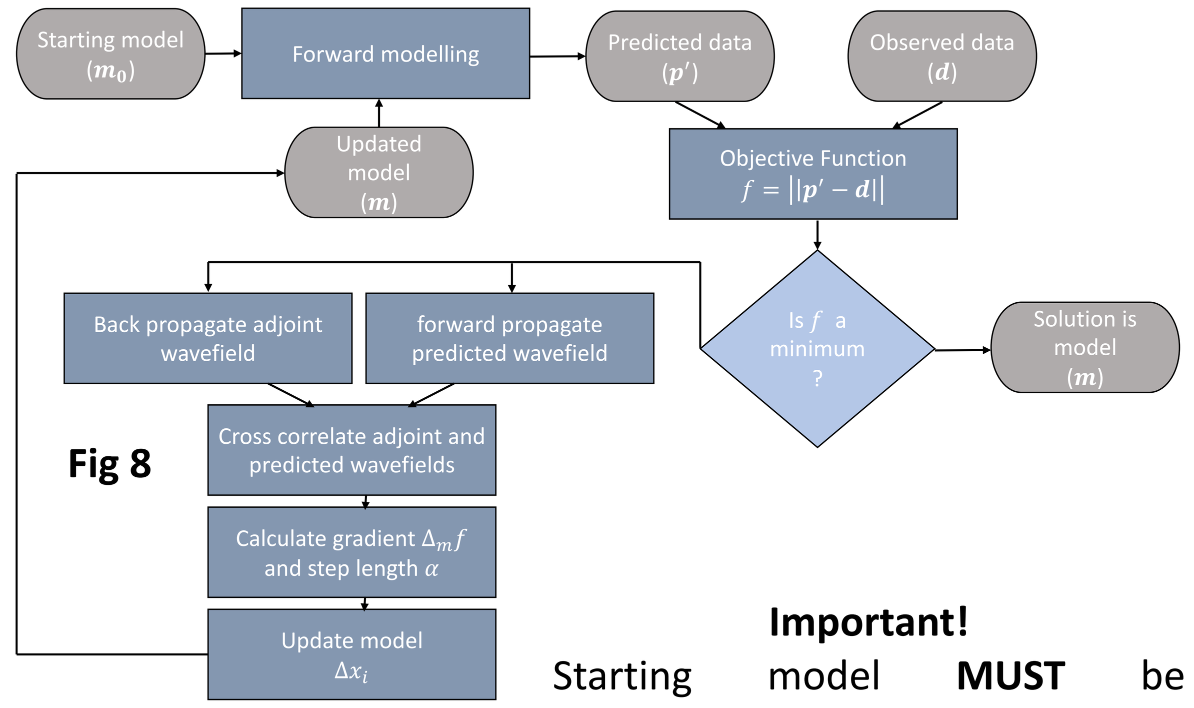

Fig 8

Important!
Starting model **MUST** be sufficiently close to the true model so that the data does not 'cycle skip'

4. Data Examples – Mid Accumulation

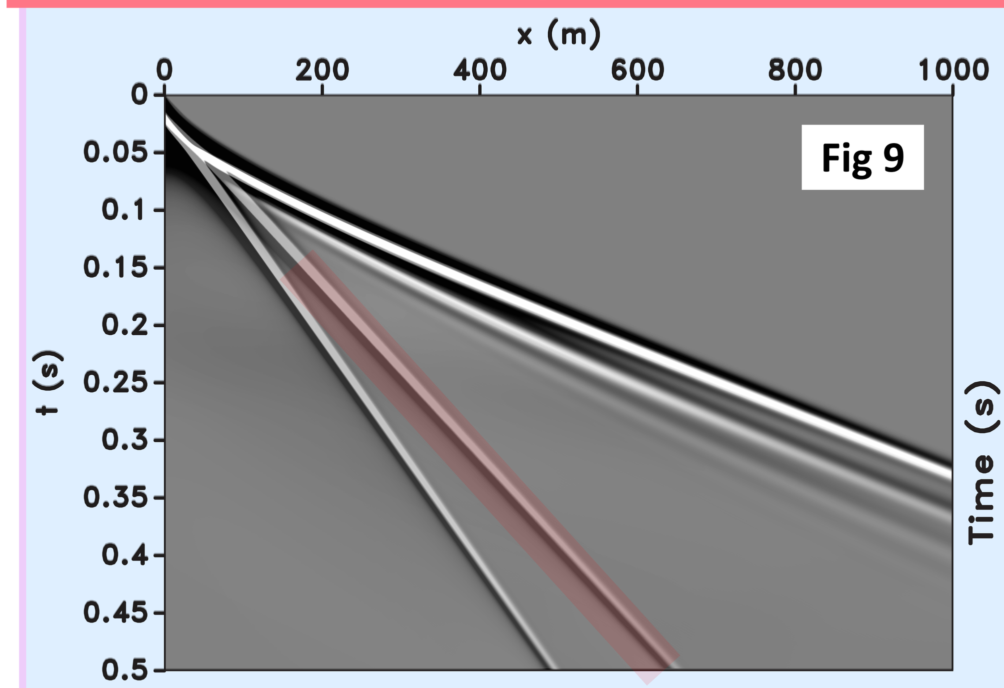

Fig 9

HW starting model data and True data superimposed on top of each other. The slow arrival (highlighted in red) varies dramatically between the two velocity models, but the fast arrival is almost identical.

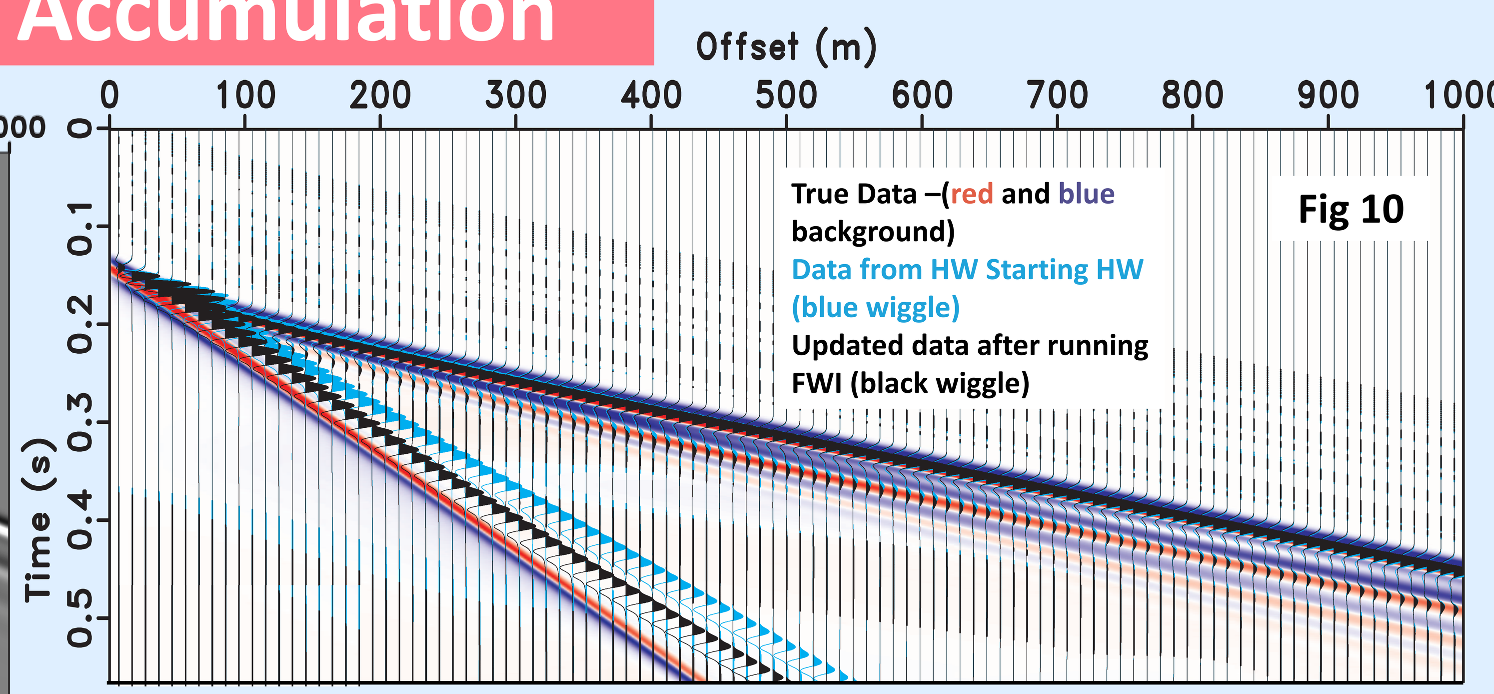

Fig 10

4a. FWI run with HW as starting model

FWI can update the data in the fast arrival successfully. Improving the data match. In the slow arrival, it can push the data update in the right direction, moving the starting model data (blue wiggle) towards the true arrival (red and blue). As it is too far from the true data, the residual becomes meaningless and the data can not update beyond this point

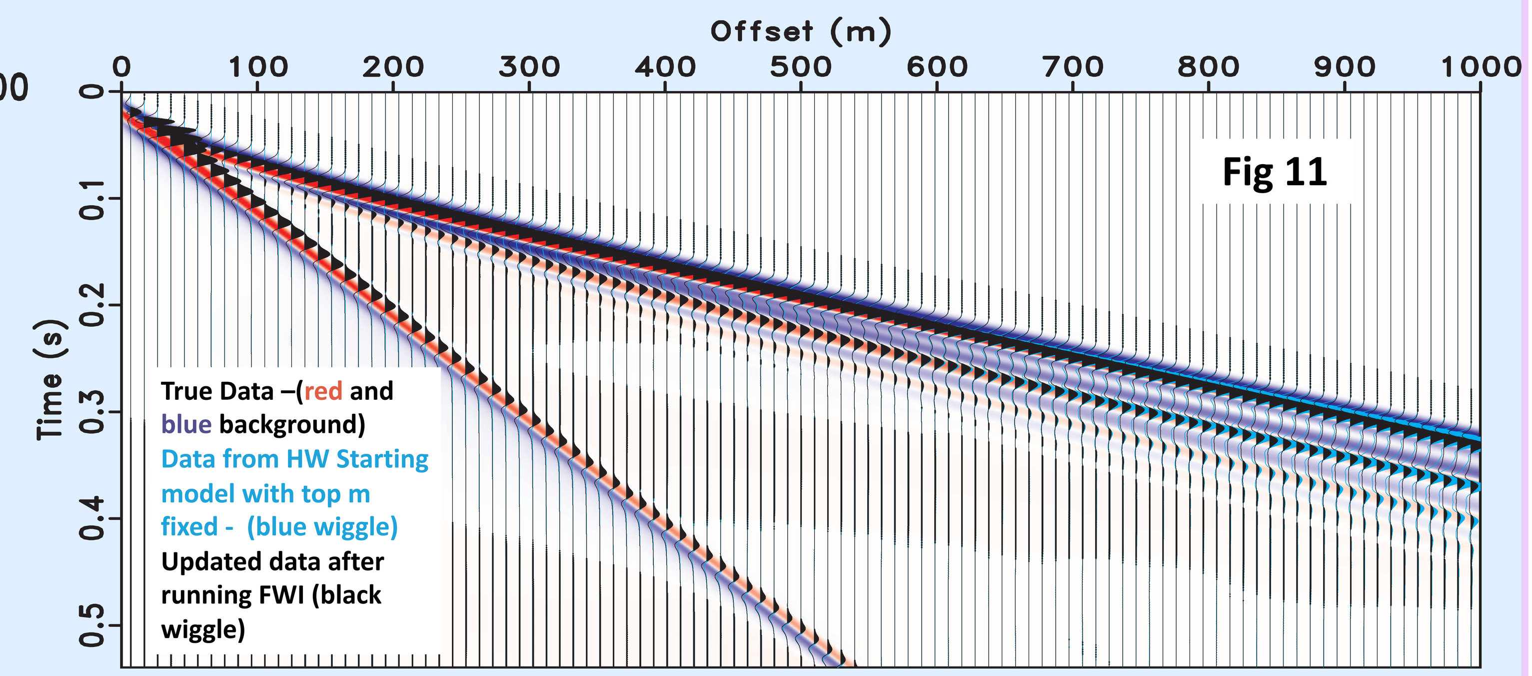

Fig 11

4b. FWI run with edited HW as starting model

By Fixing the top 1m of the HW model to be the exact velocity of the true model, the slow direct arrival matches.
The residual is dominated by the data mismatch in the fast arrivals
Data is no longer cycle skipping

5. Discussion

ISSUES!
Low velocity arrival (direct wave through the surface) fails to match with HW
Starting models for slow arrivals aren't good enough – yet are very close to the true models

SUCCESSES!
Deeper faster arrivals update with FWI and match correctly
HW can characterize this part of the model well
Update is limited by depth of ray penetration

Recommendations
Top few meters of model should be characterized by either
- **Vertical Seismic Profile (VSP)**
- **Snow pit**
- **Borehole**