

# **Adaptive Waveform Inversion**

## **FWI without cycle skipping**

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# Overview

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- Rationale & method
- Synthetic example
- Field example without cycle skipping
- Field example with cycle skipping

# Rationale

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Avoiding cycle skipping in conventional FWI:

- requires low frequencies
- requires accurate starting model
- requires careful QC
- limits wide applicability and uptake

Want a method that is immune to cycle skipping

# FWI objective function

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minimise  $\| \text{predicted} - \text{observed} \|^2$   
*wrt model*

differencing oscillating signals  
→ cycle skipping



# AWI objective function

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step 1:

$$\text{minimise} \quad \left\| \text{predicted} * \text{filter} - \text{observed} \right\|^2$$

*wrt filter*

step 2:

$$\text{minimise} \quad \frac{\left\| \text{lag} \times \text{filter} \right\|^2}{\left\| \text{filter} \right\|^2}$$

*wrt model*

# AWI objective function

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step 1:

Wiener filter adapts predicted to observed data  
data adaption → no cycle skipping

step 2:

filter → zero-lag delta function  
predicted → observed data  
model → true model

# AWI objective function

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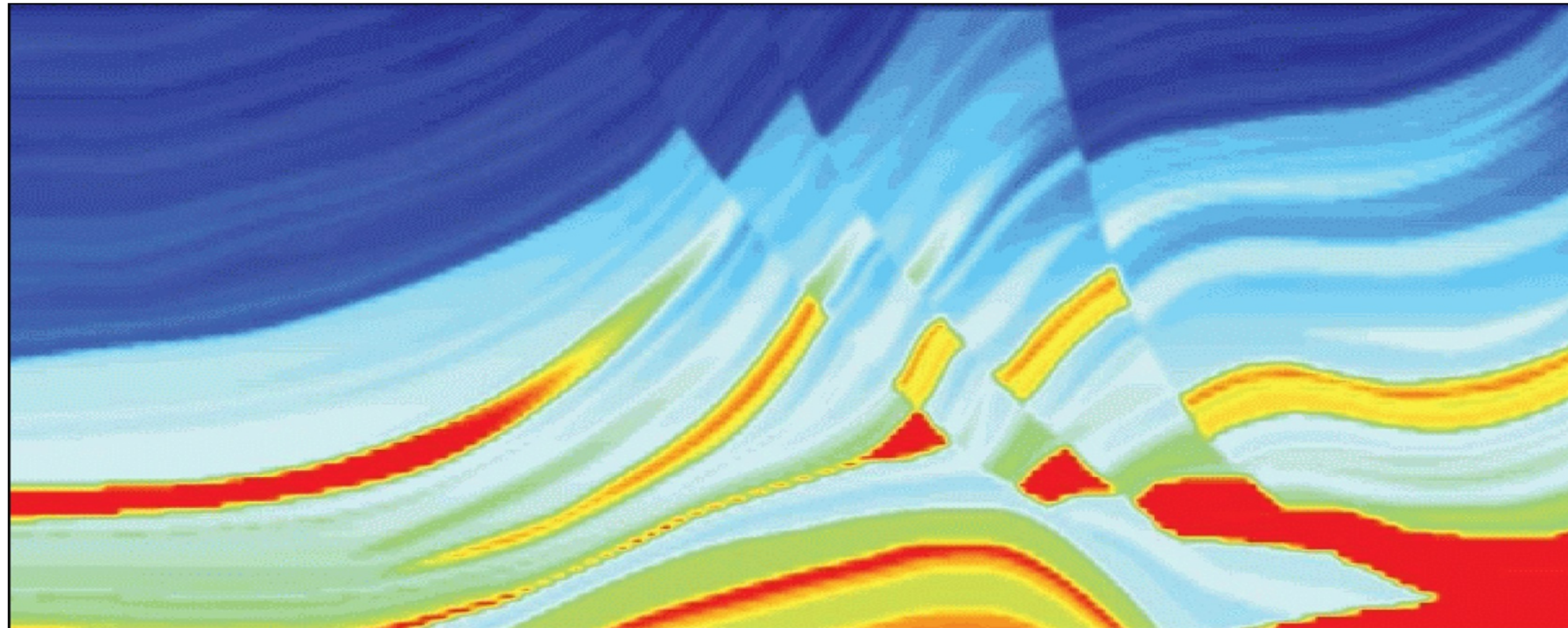
Leads to a waveform inversions scheme:

- with a modified adjoint source
- cost similar to conventional FWI
- immune to cycle skipping



# Synthetic example

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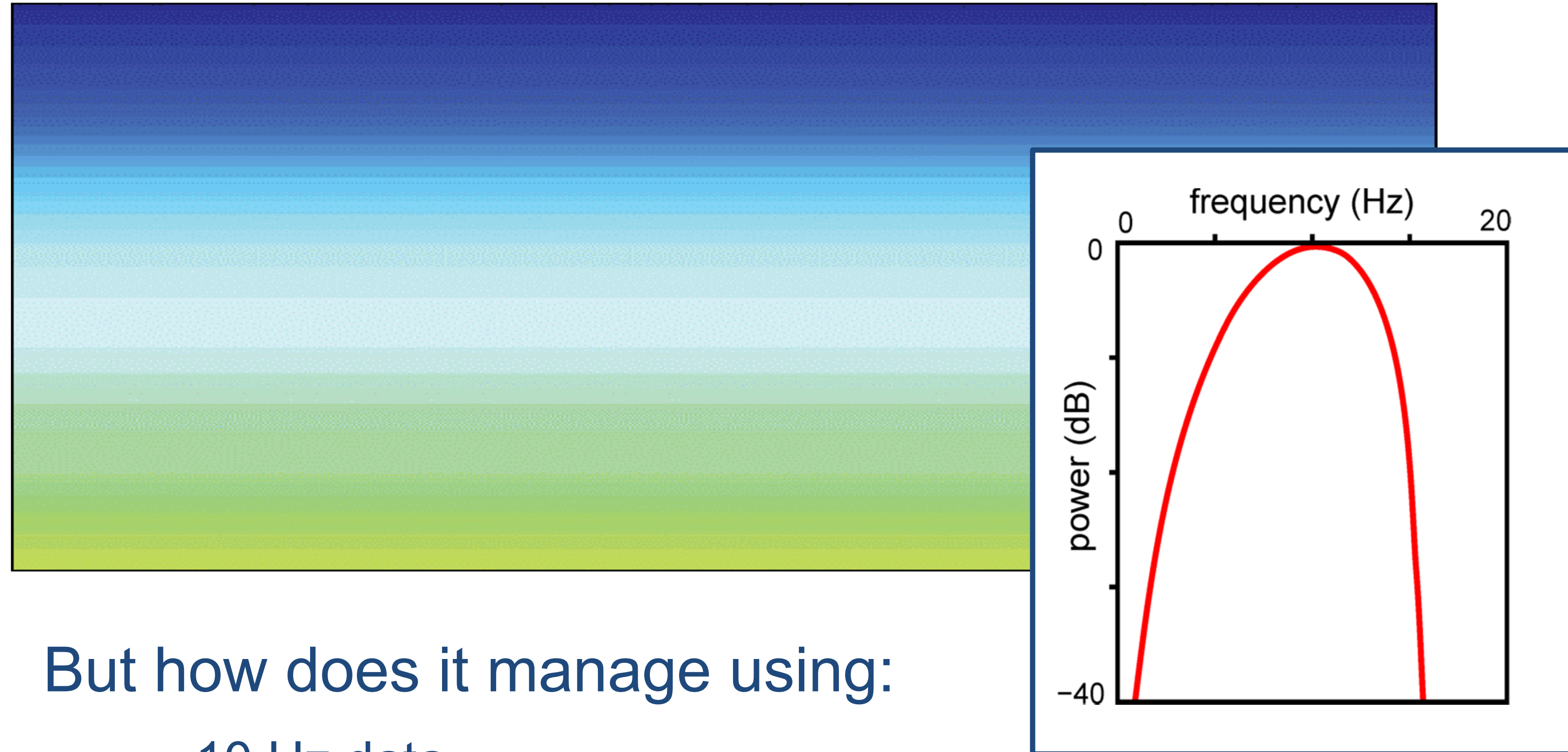


Marmousi is easy to invert given:

- low frequencies
- a good start model
- noise-free perfect data



# Synthetic example



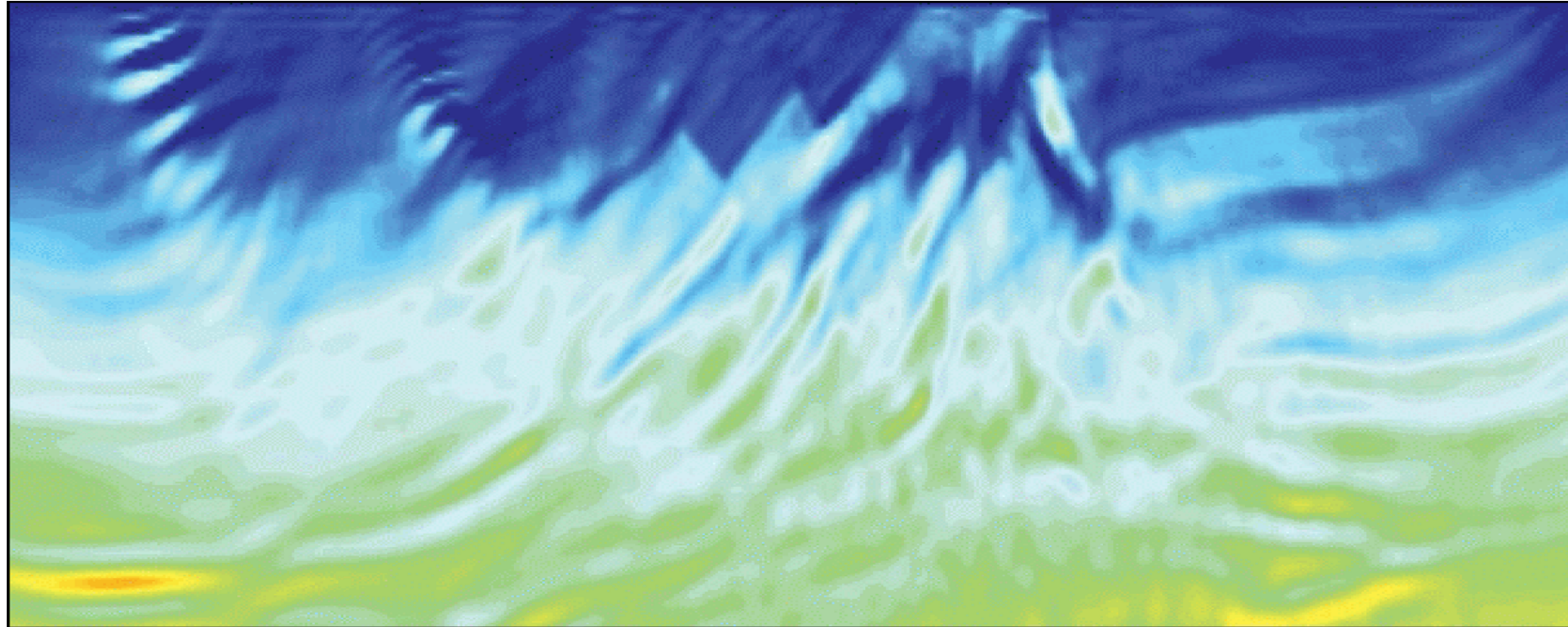
But how does it manage using:

- 10 Hz data
- 1D start model
- noisy imperfect data



# Conventional FWI

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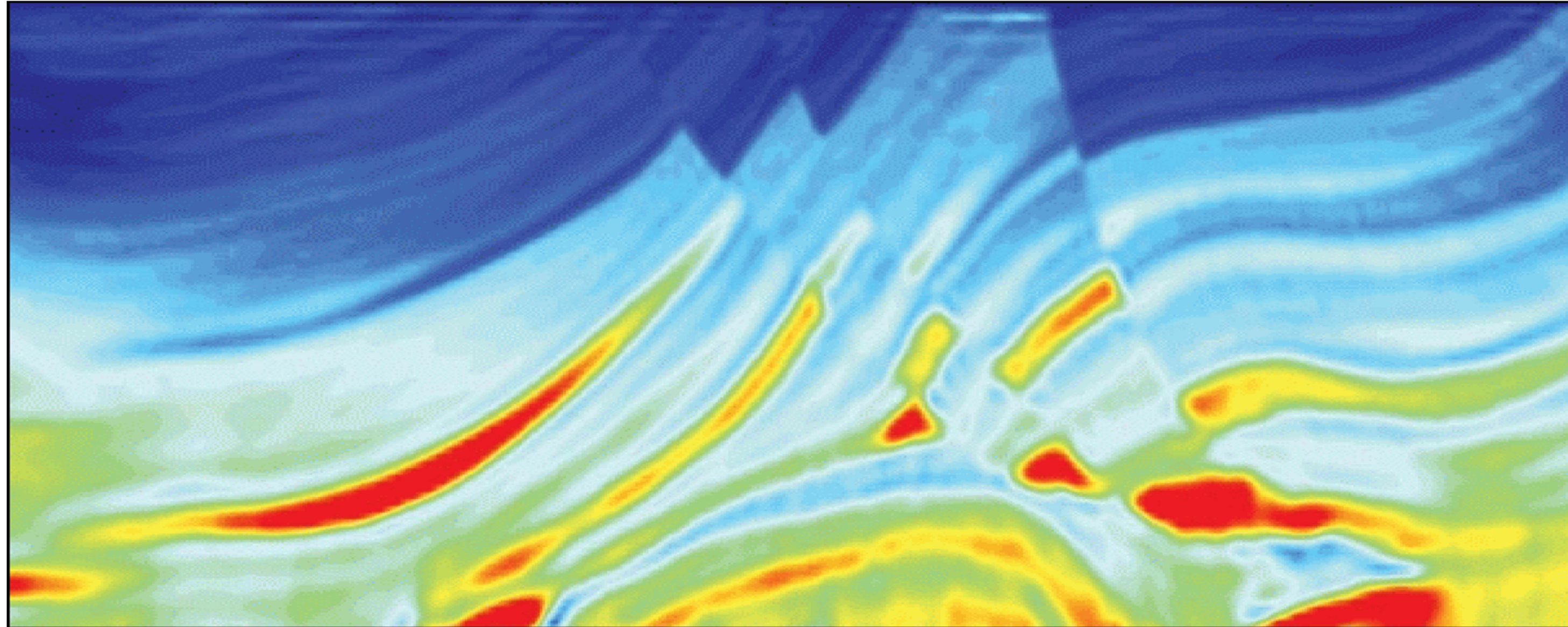
Conventional FWI fails entirely:

- the result is badly cycle skipped
- the macro-model does not change



# Adaptive Waveform Inversion

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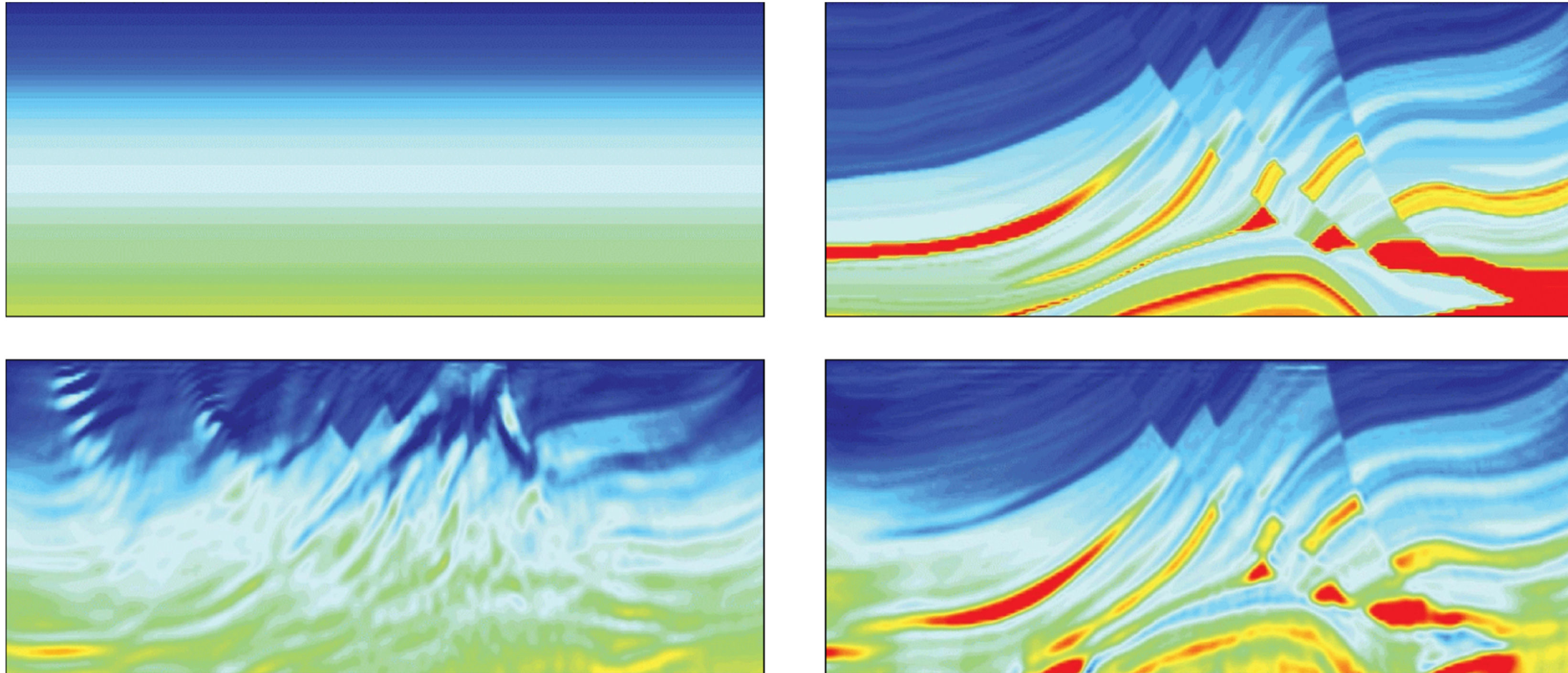


AWI using 10 Hz noisy data & 1D starting model

- unaffected by cycle skipping
- macro-model correctly updated
- fine structure correctly focused & positioned



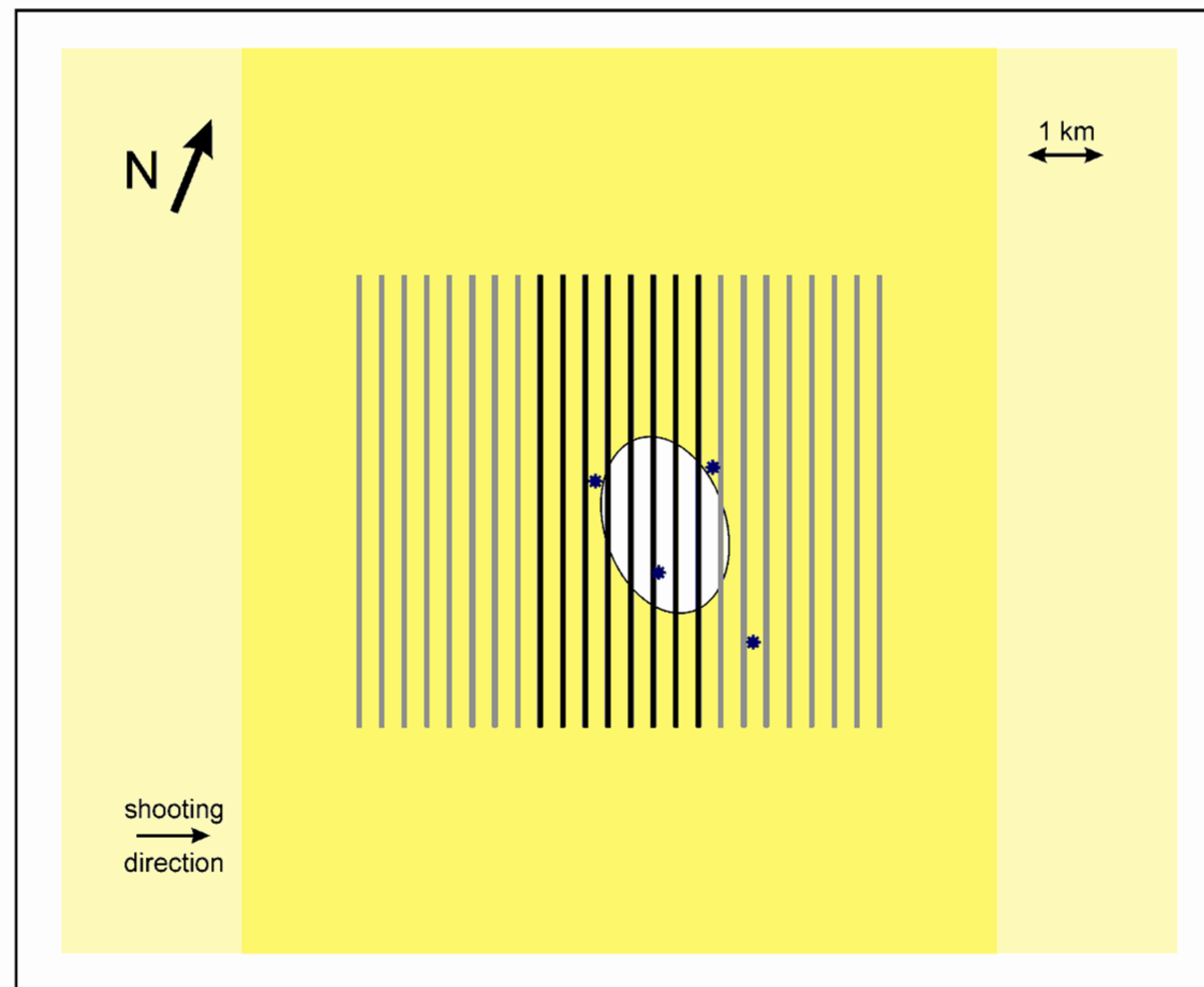
# Adaptive Waveform Inversion



- No need for low frequencies
- No need for good start model
- Does it work with field data?



# 3D OBC field example



- 4C OBC
- 3 swaths of 8 cables
- 75 m water depth
- 6 km cables
- 25 m receiver spacing
- 300 m cable spacing
- 6000 receivers
- 25 m shot interval
- 75 m shot-line spacing
- 100,000 shots
- full azimuth to 7000 m
- max offset 11,000 m
- 180 sq km

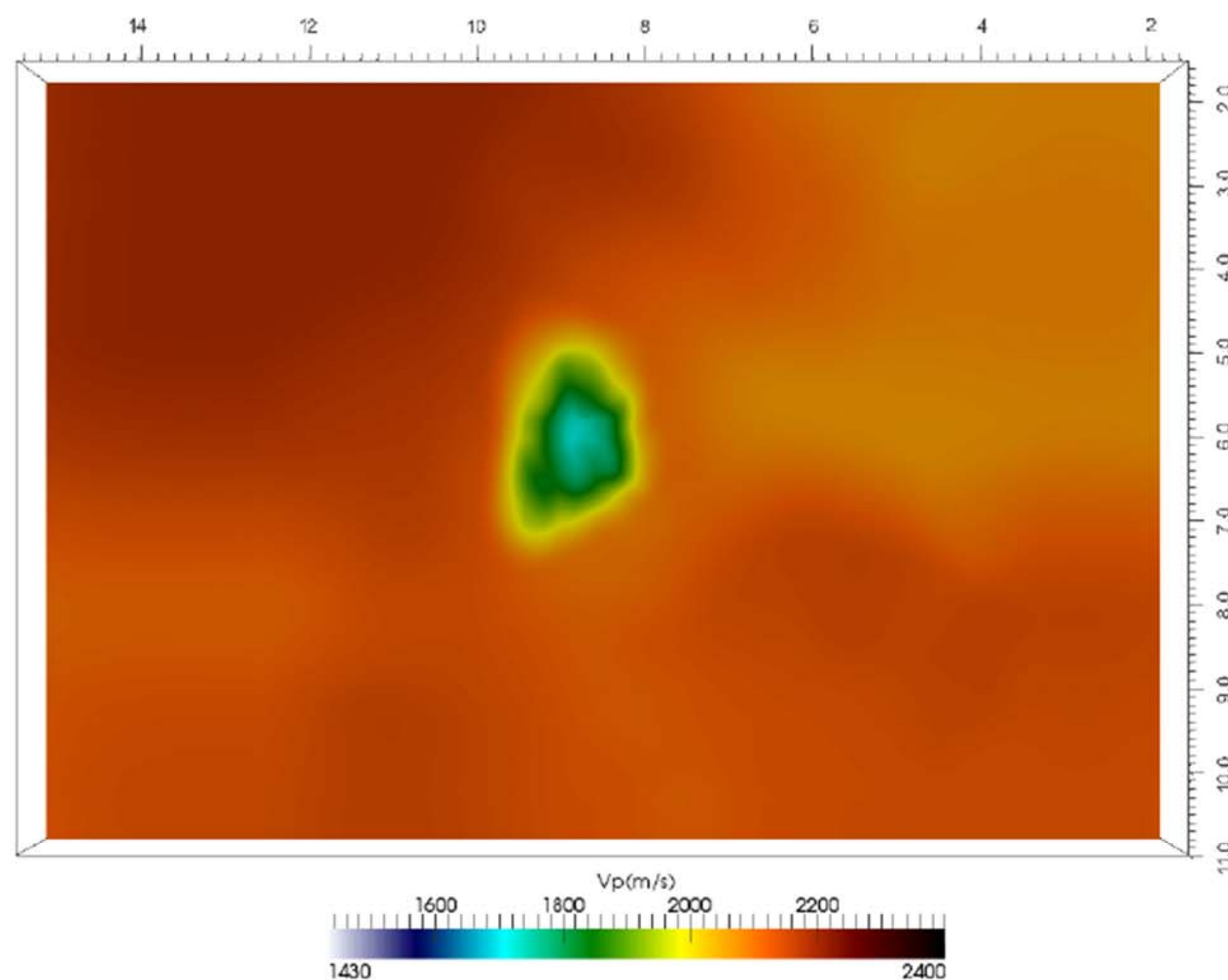
acquisition geometry

# All frequencies & good starting model

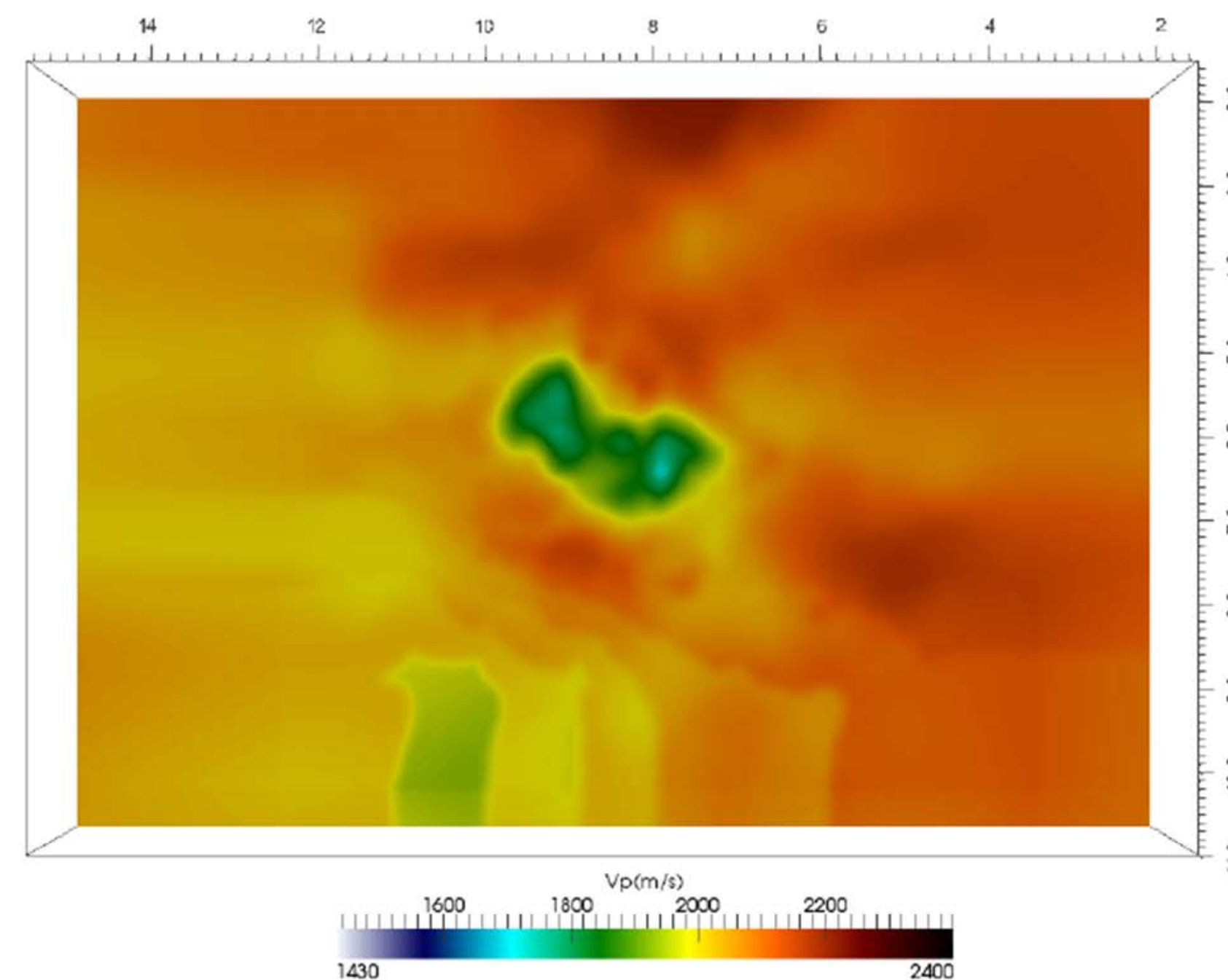
## Depth slices

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Initial model



1150 m depth



2050 m depth

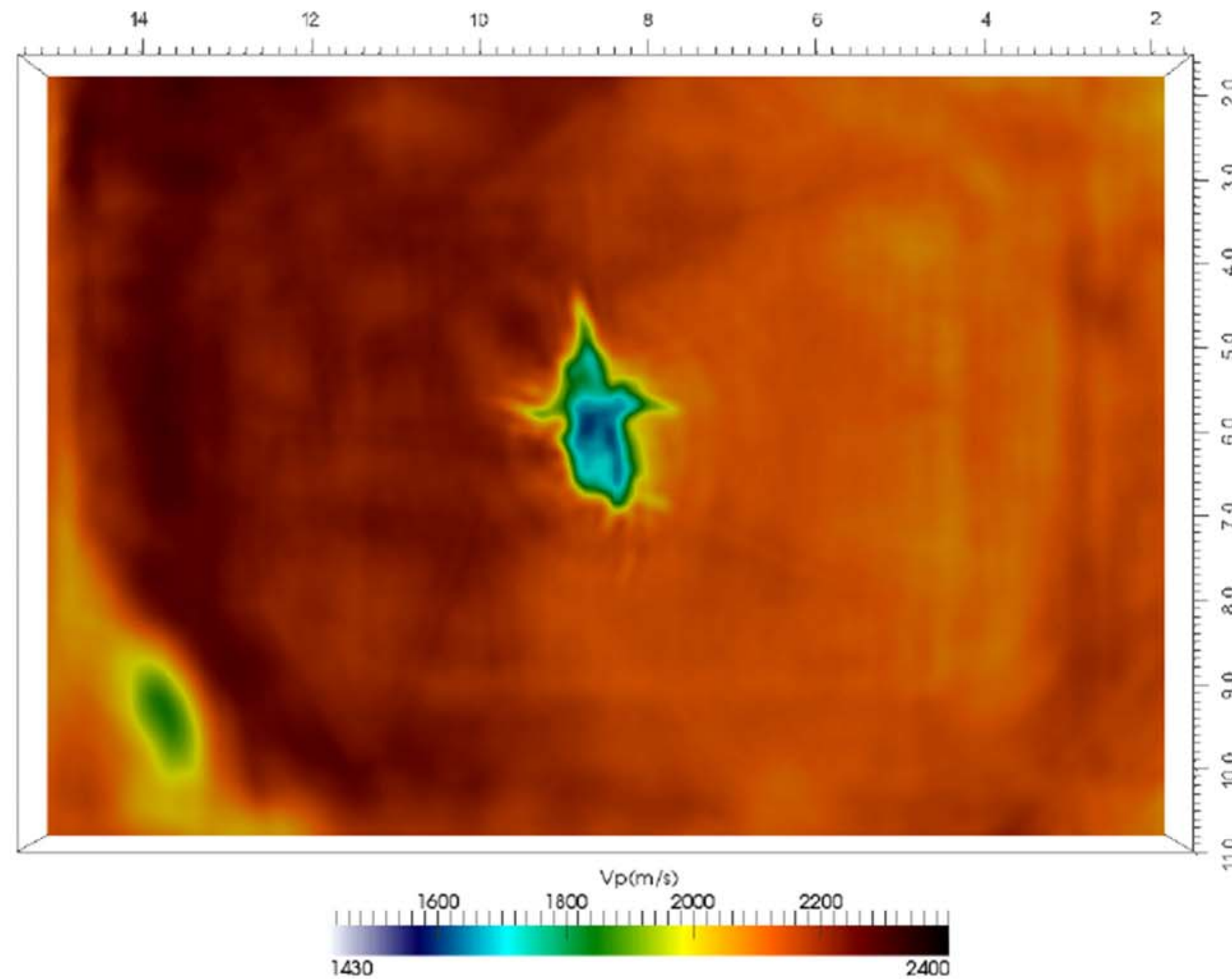


# All frequencies & good starting model

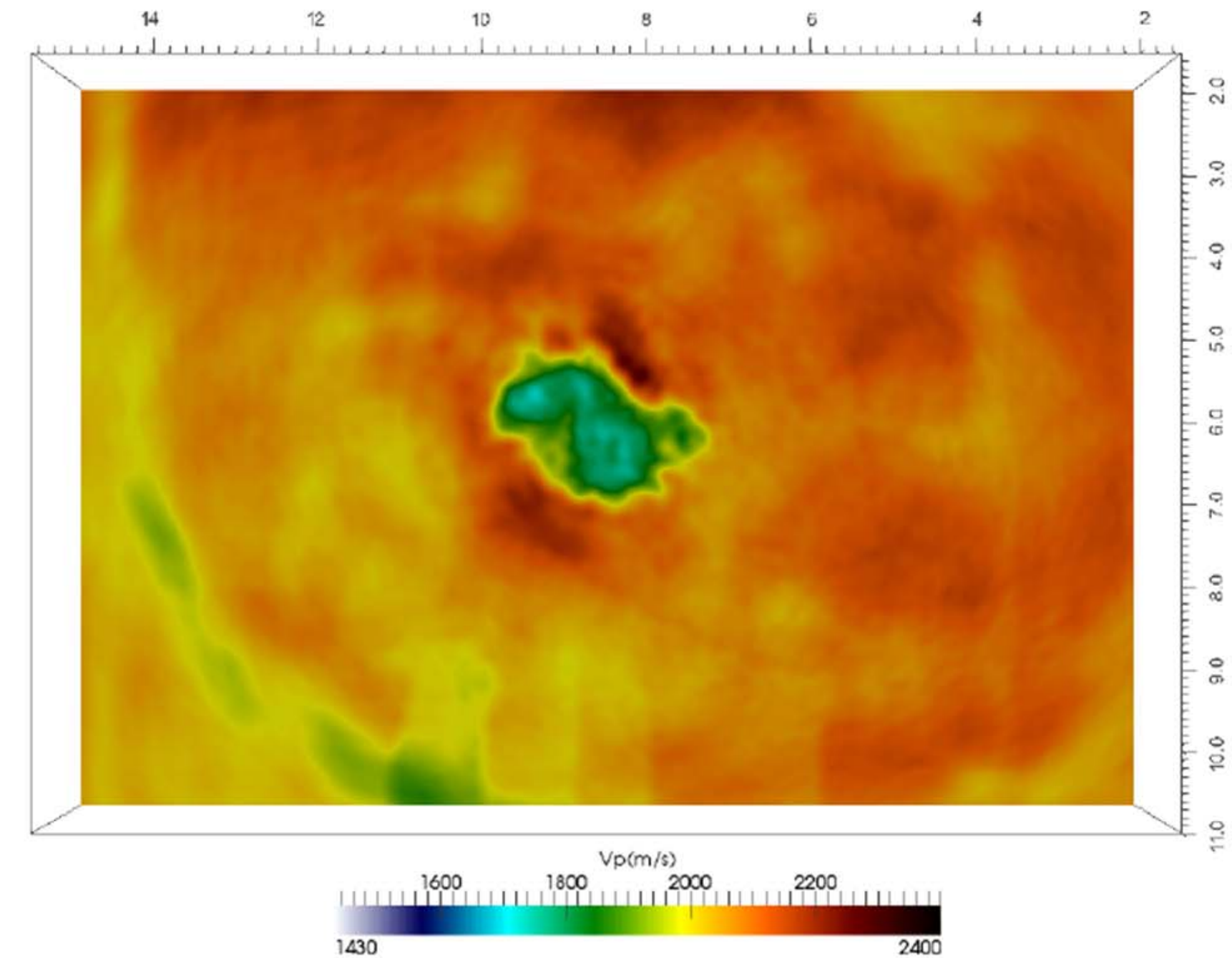
## Depth slices

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Recovered model with conventional FWI



1150 m depth



there is some  
cycle skipping

2050 m depth

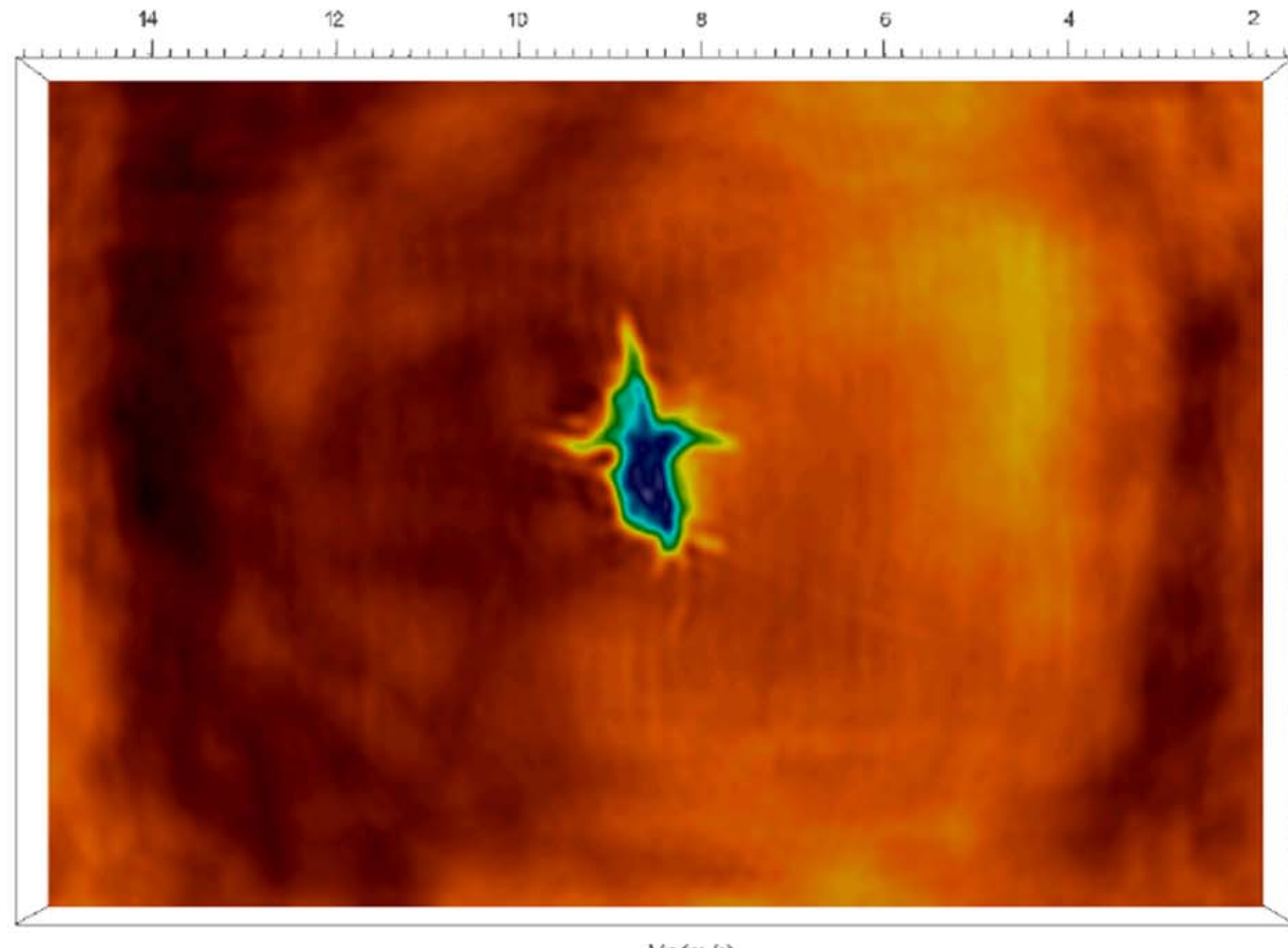


# All frequencies & good starting model

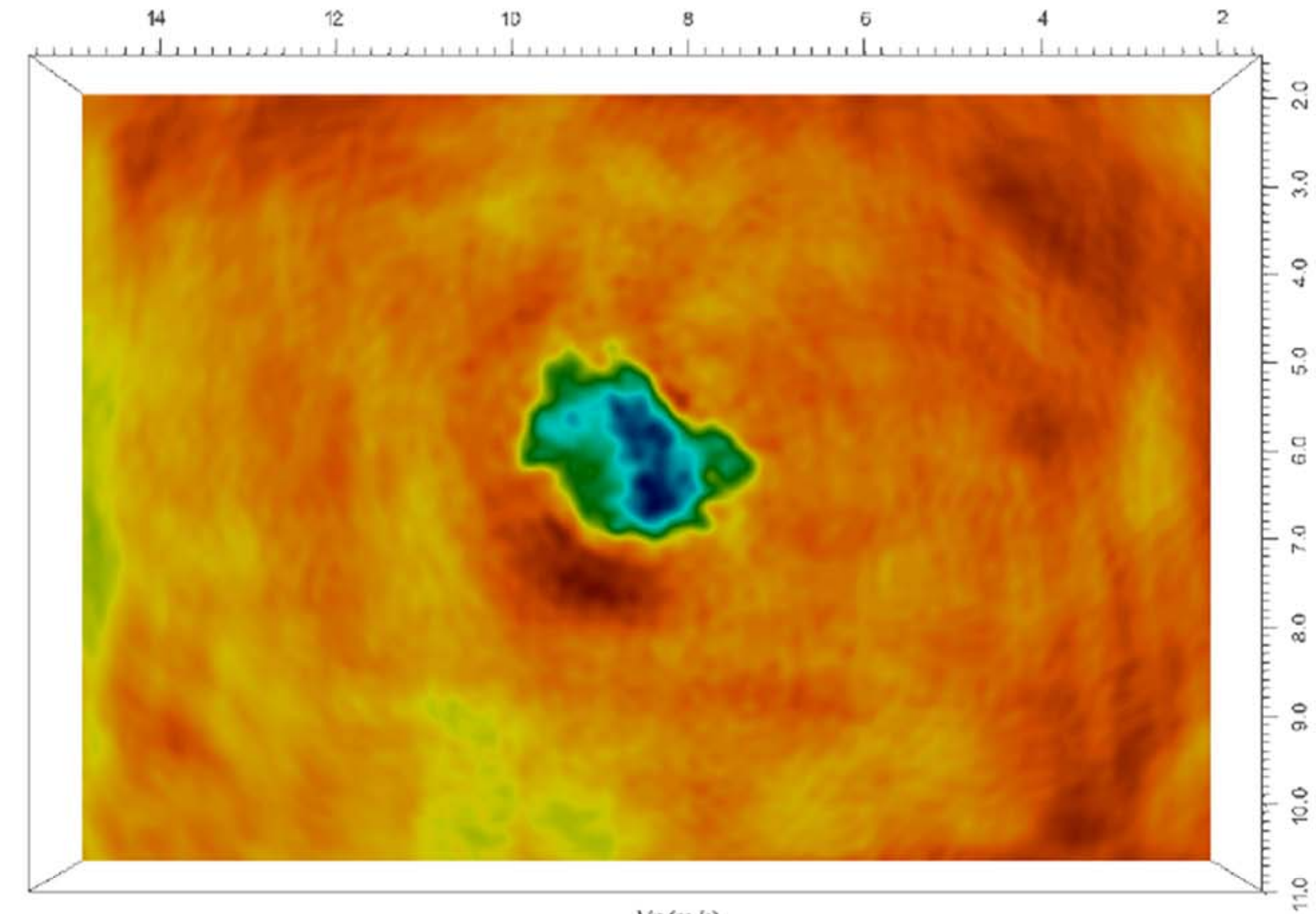
## Depth slices

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Recovered model with AWI



1150 m depth



2050 m depth

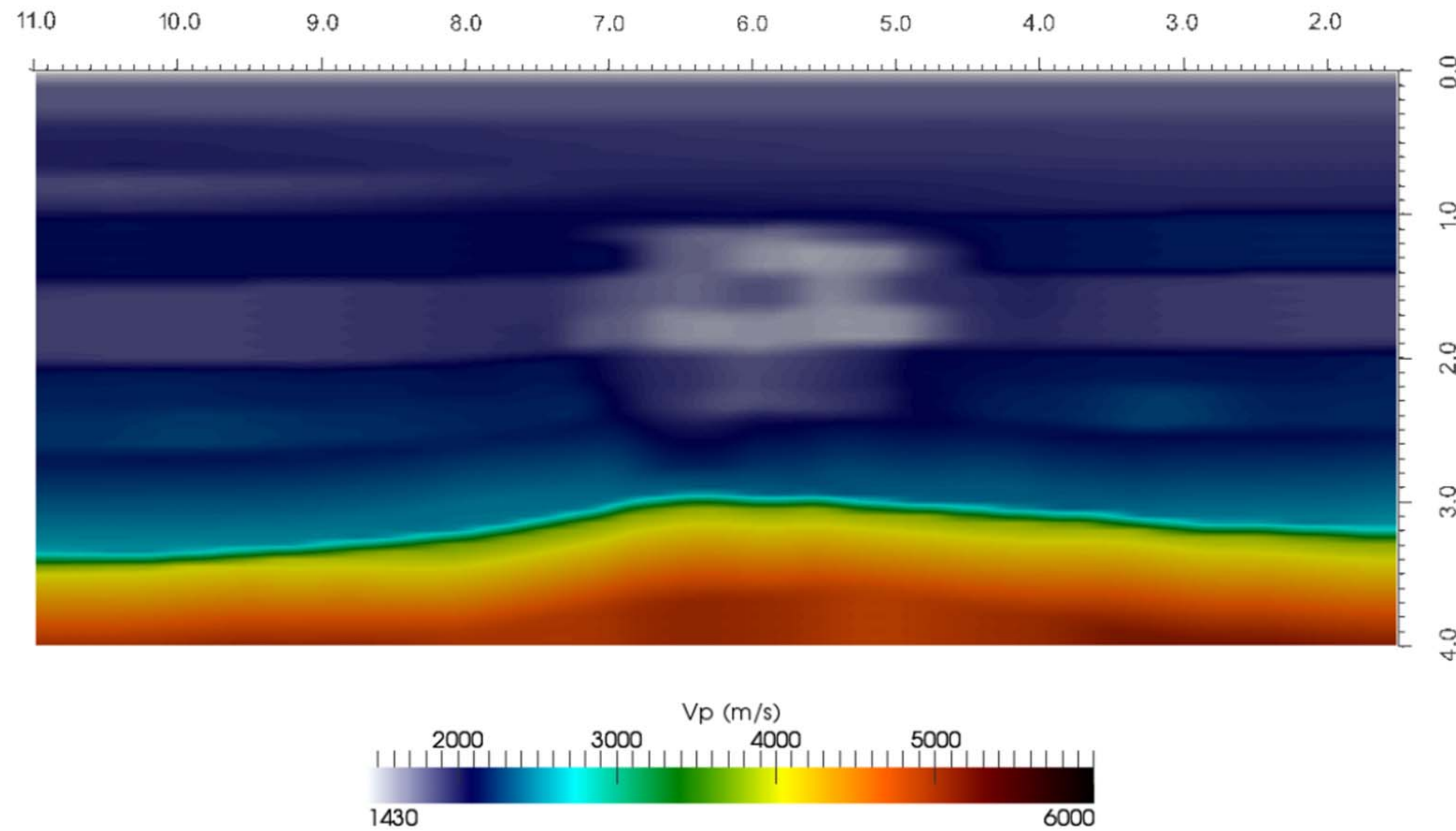
gas cloud is more  
intense

# All frequencies & good starting model

Vertical slices

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Initial model



Chalk layers not present

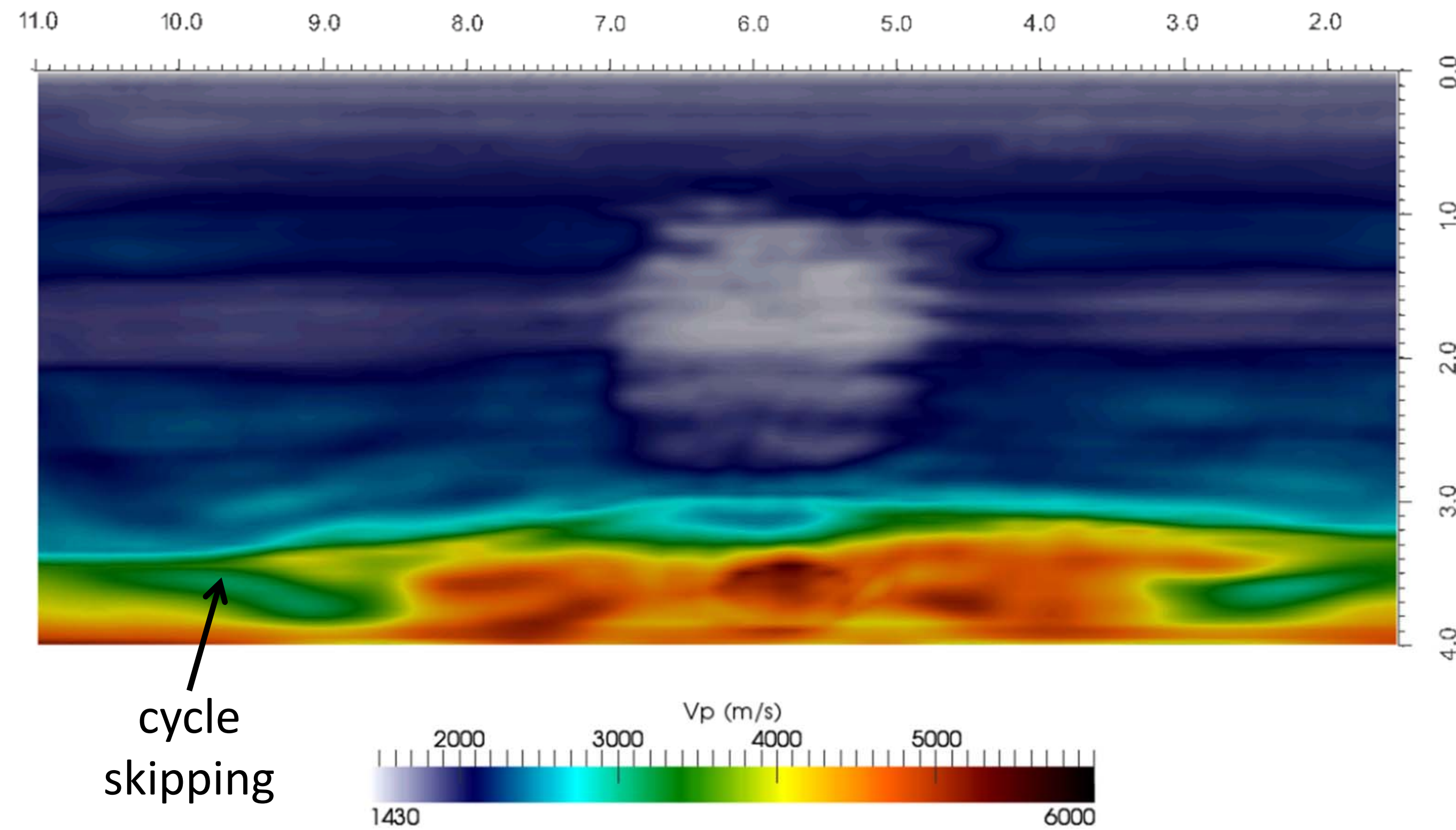


# All frequencies & good starting model

## Vertical slices

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Recovered model with conventional FWI



Cycle-skipping causes artifacts at the bottom

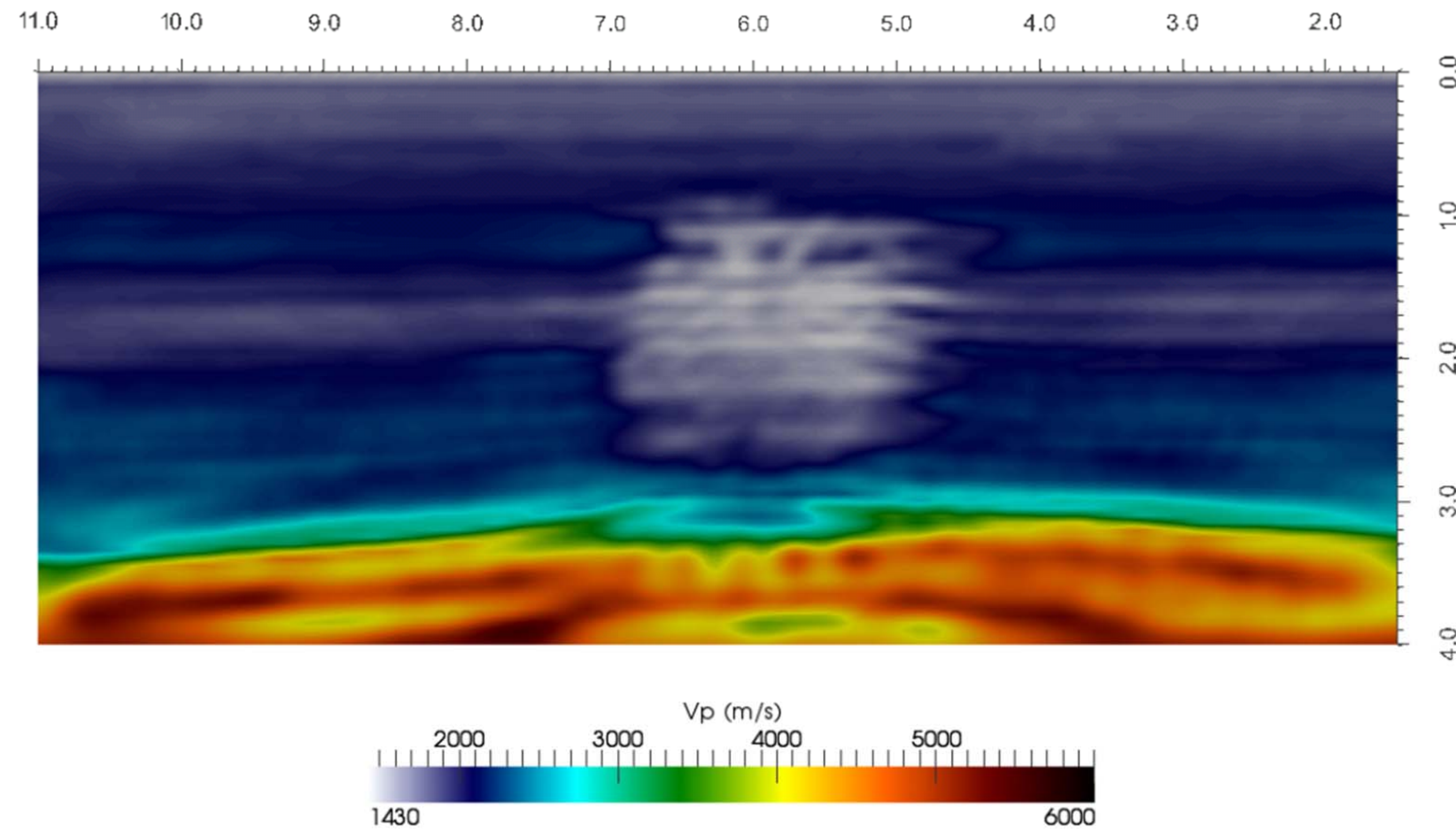


# All frequencies & good starting model

## Vertical slices

Recovered model with AWI

improved resolution  
in gas cloud



Better resolution and chalk layers recovered

# Adaptive Waveform Inversion

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That was easy, so try:

- no low frequencies
- no starting model

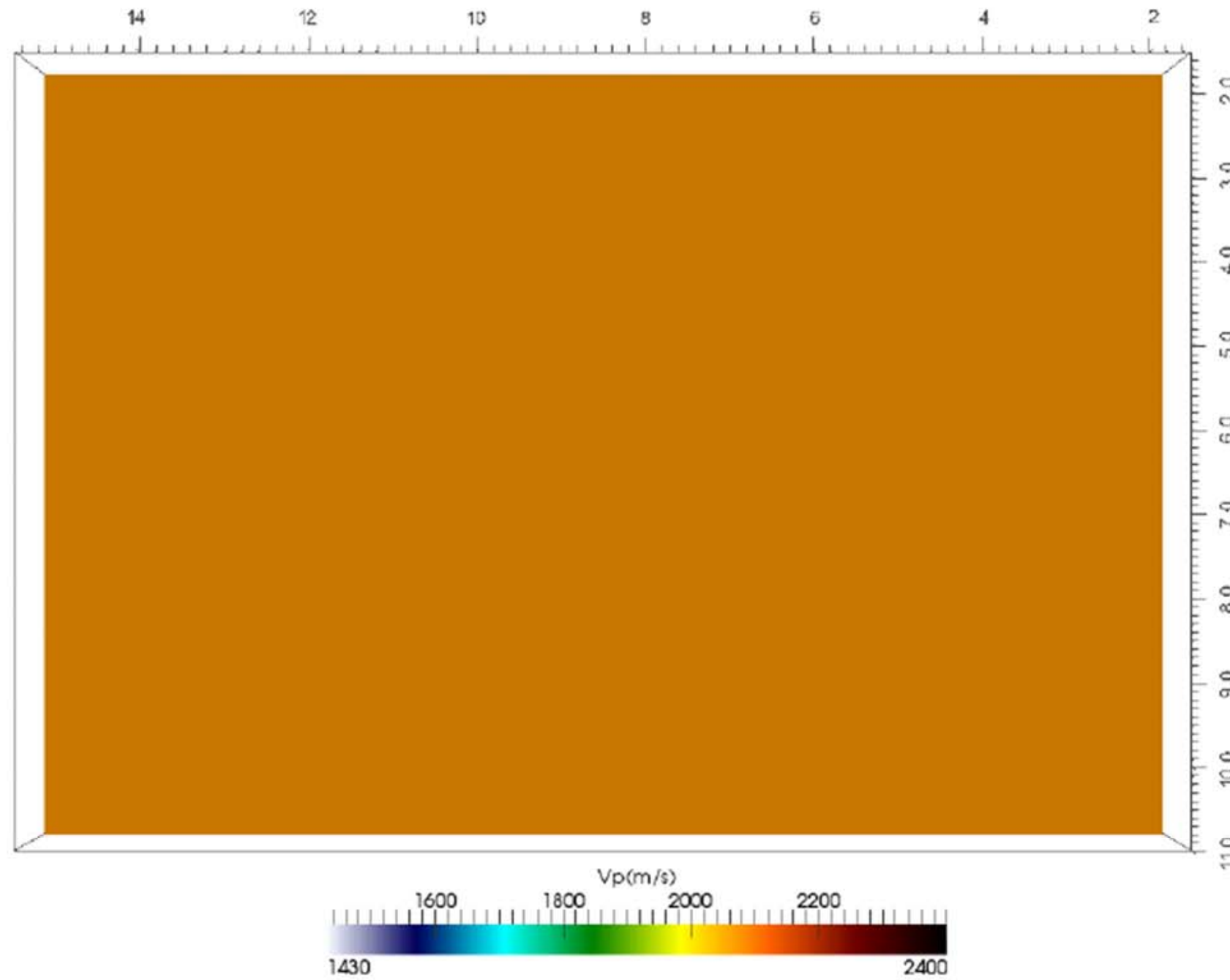


# 6.5 Hz & bad starting model

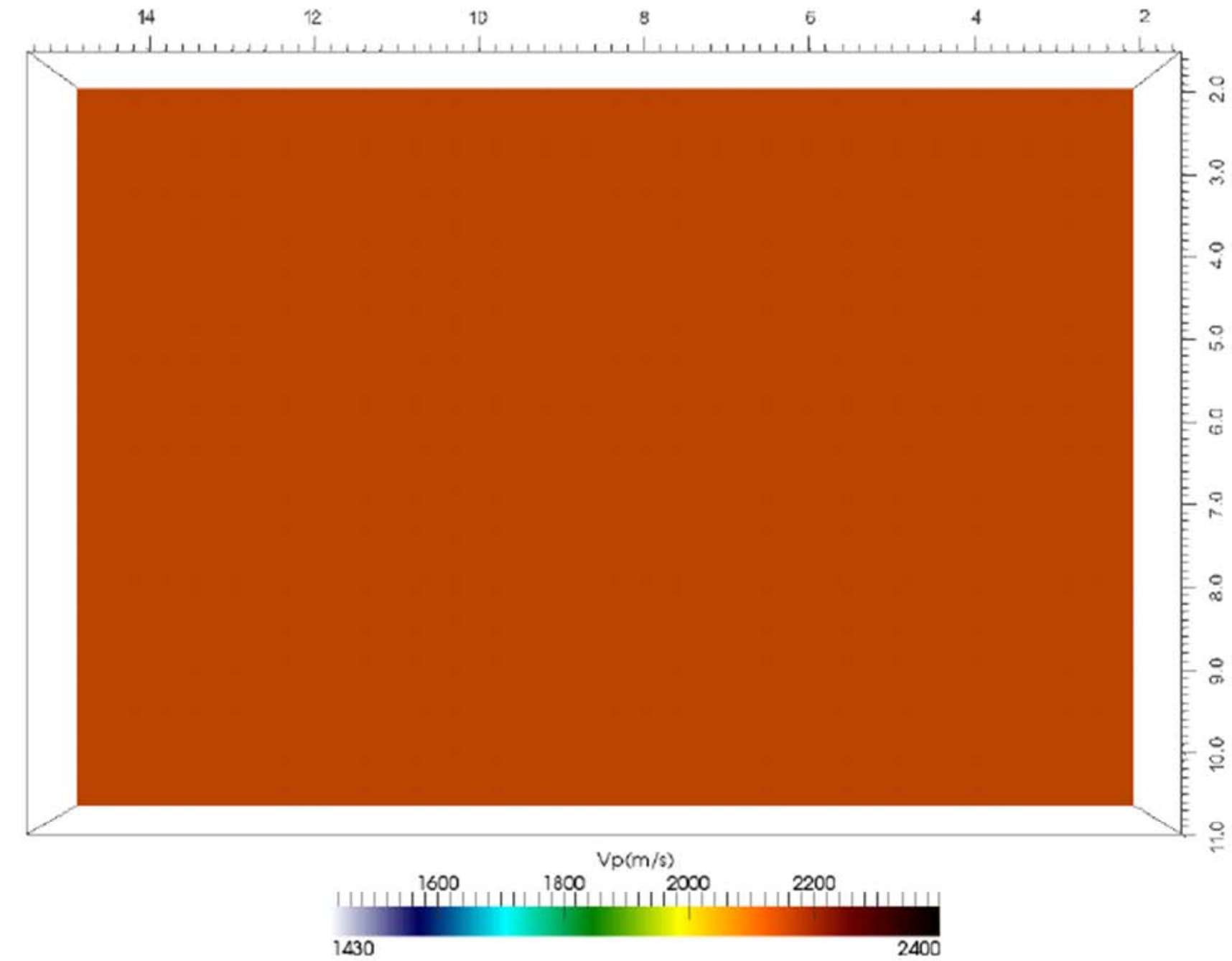
## Depth slices

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Initial model



1150 m depth



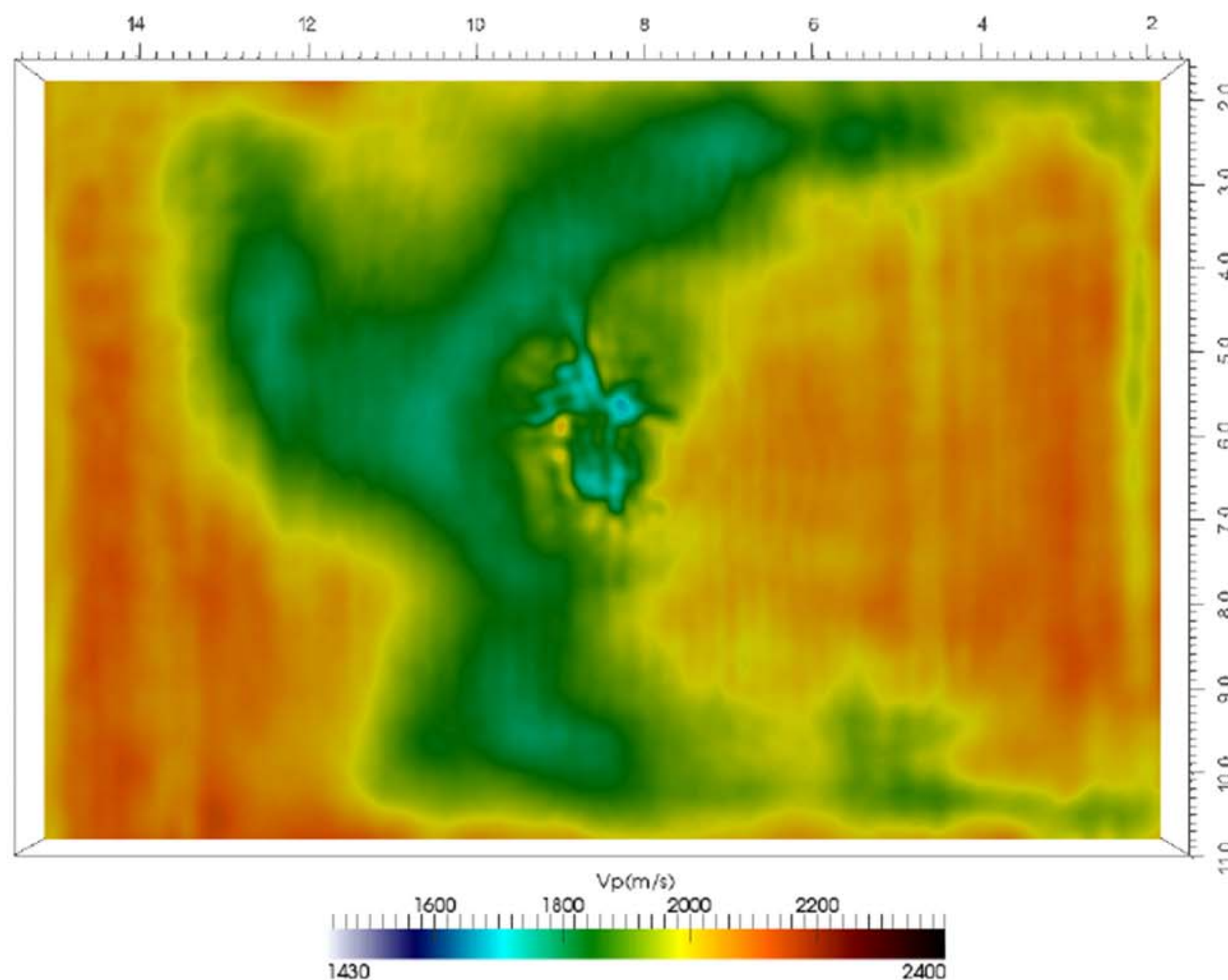
2050 m depth

# 6.5 Hz & bad starting model

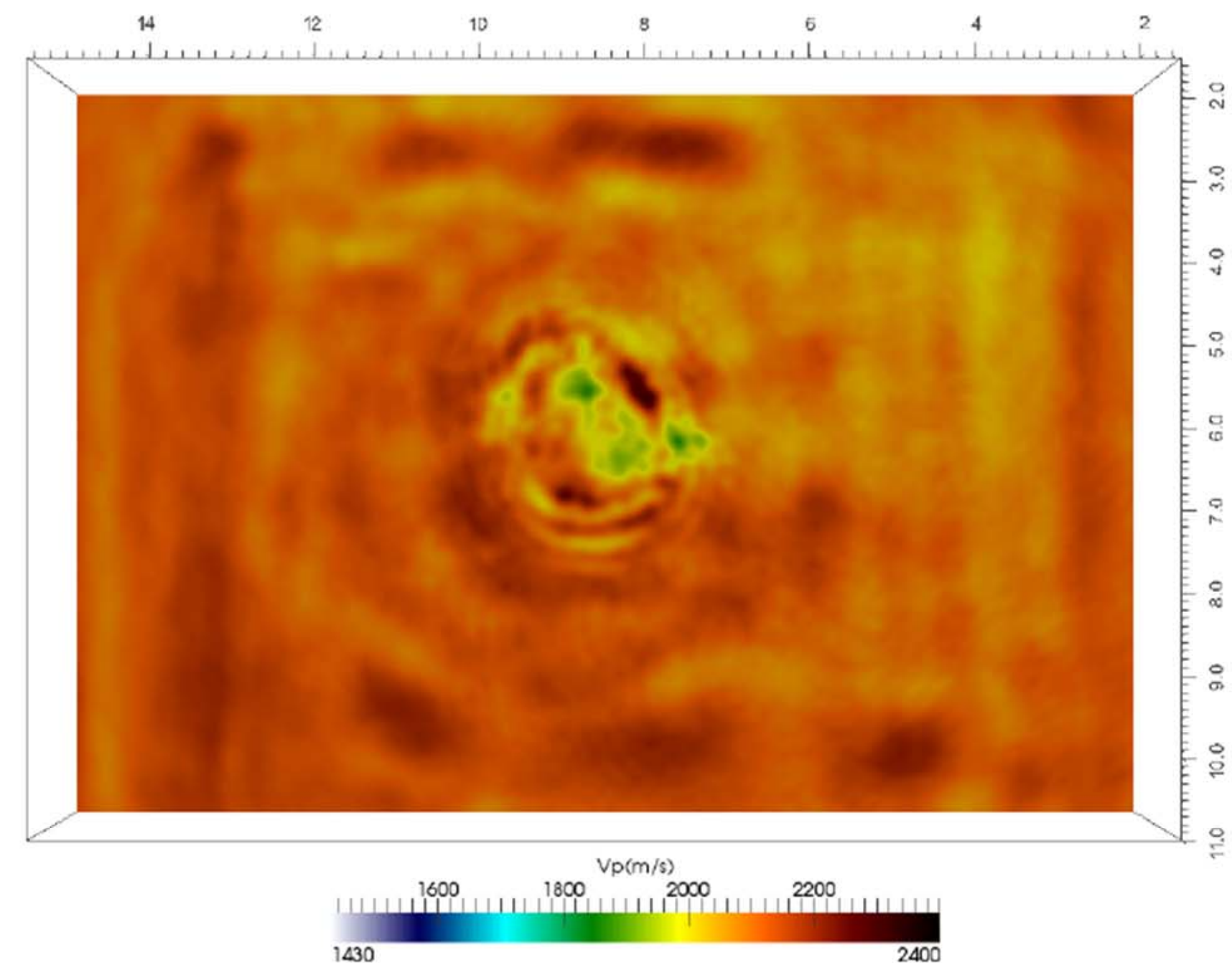
## Depth slices

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Recovered model with conventional FWI



1150 m depth



2050 m depth

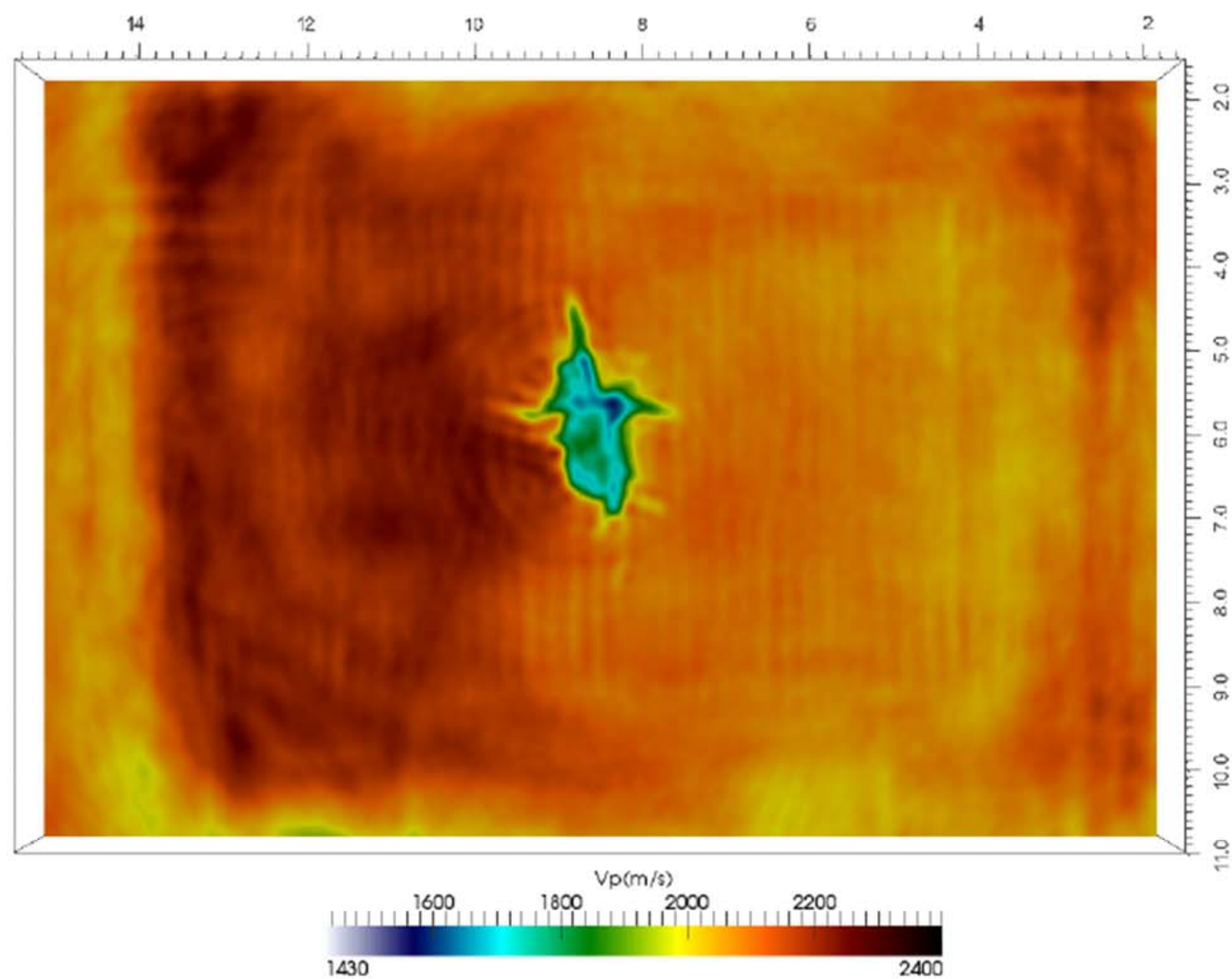


# 6.5 Hz & bad starting model

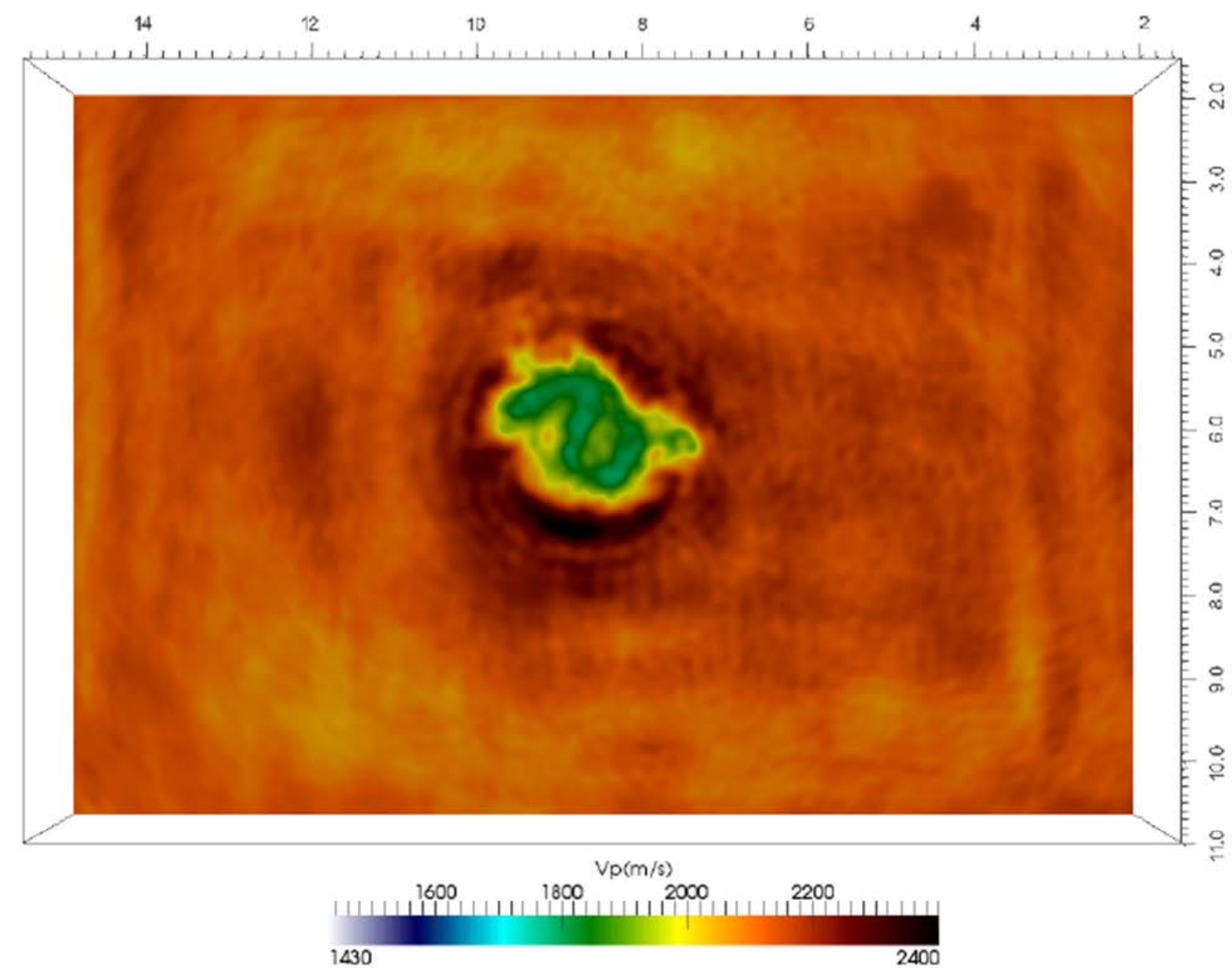
## Depth slices

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Recovered model with AWI



1150 m depth



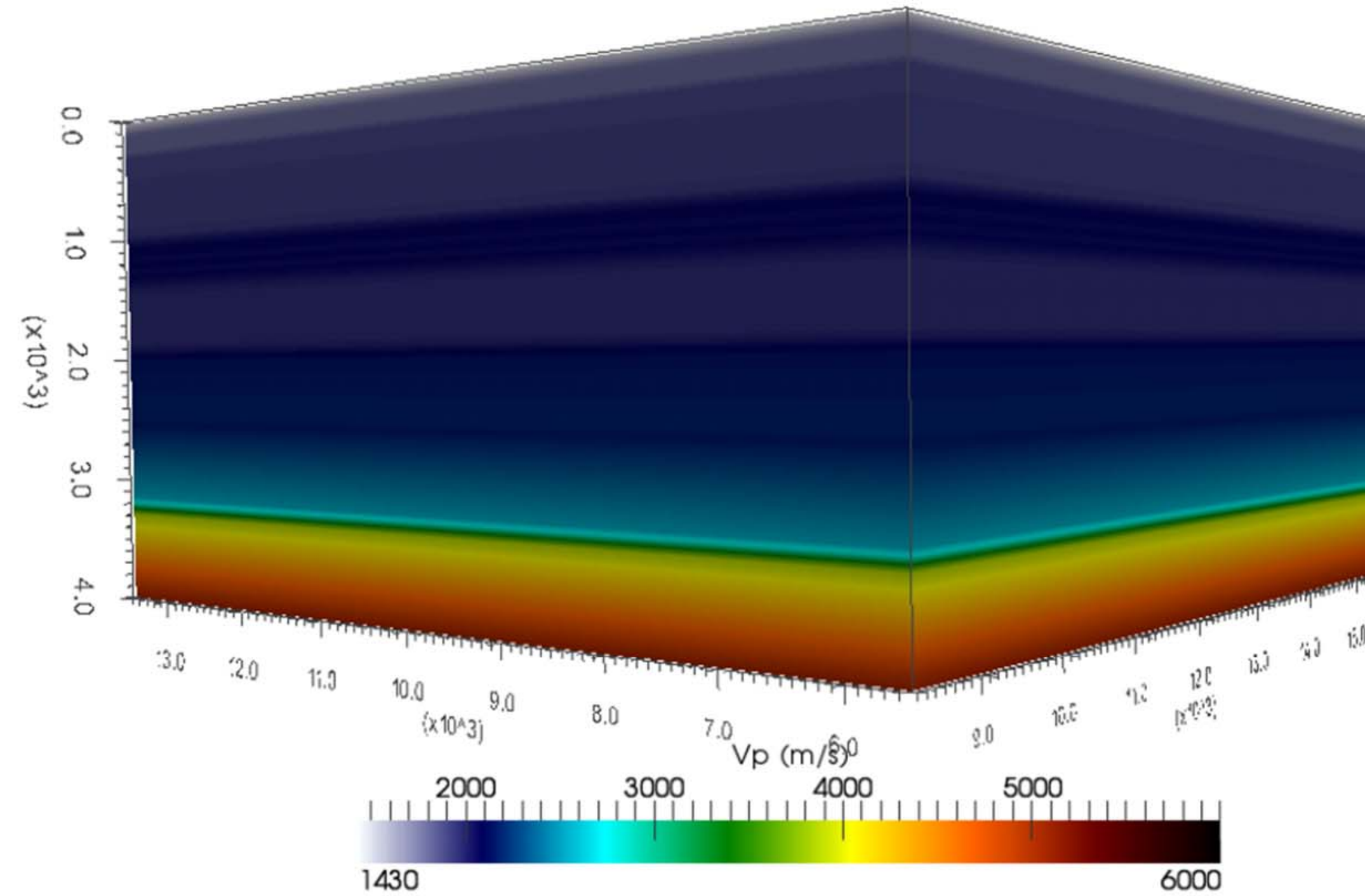
2050 m depth

# 6.5 Hz & bad starting model

## 3D cutoff

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Initial model does not contain any low velocities in the gas region



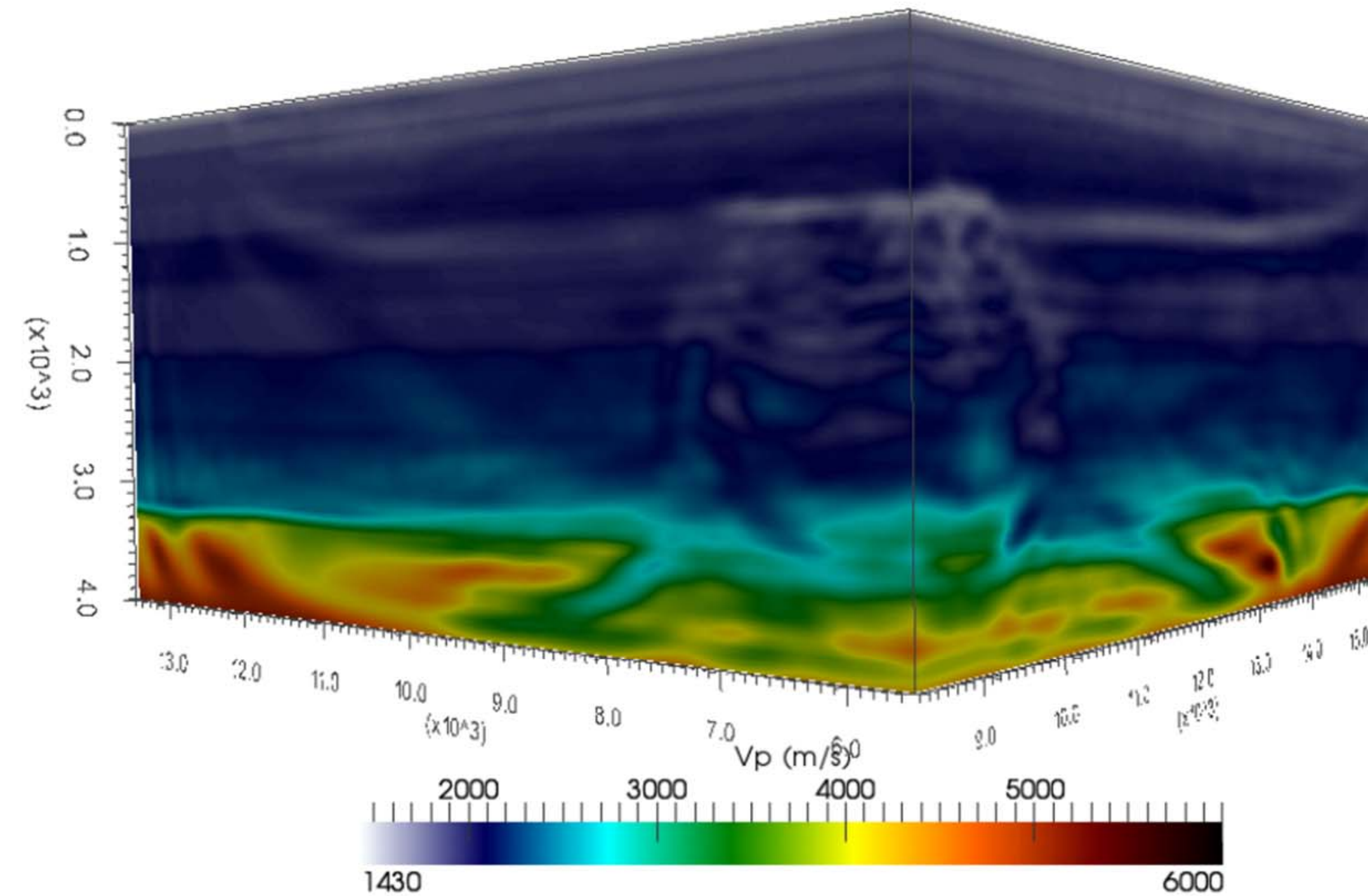


# 6.5 Hz & bad starting model

3D cutoff

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FWI cannot recover the gas cloud

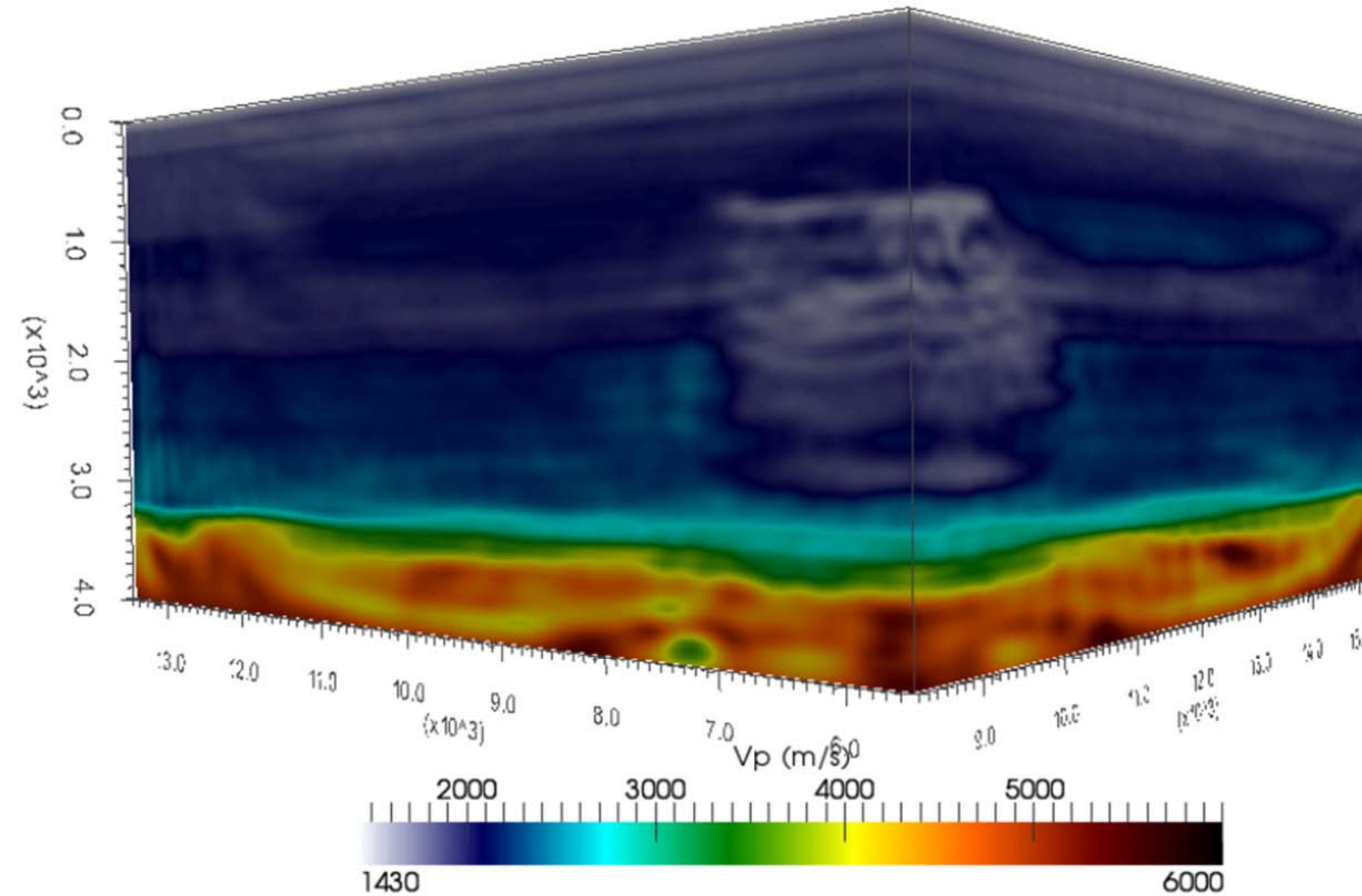


# 6.5 Hz & bad starting model

3D cutoff

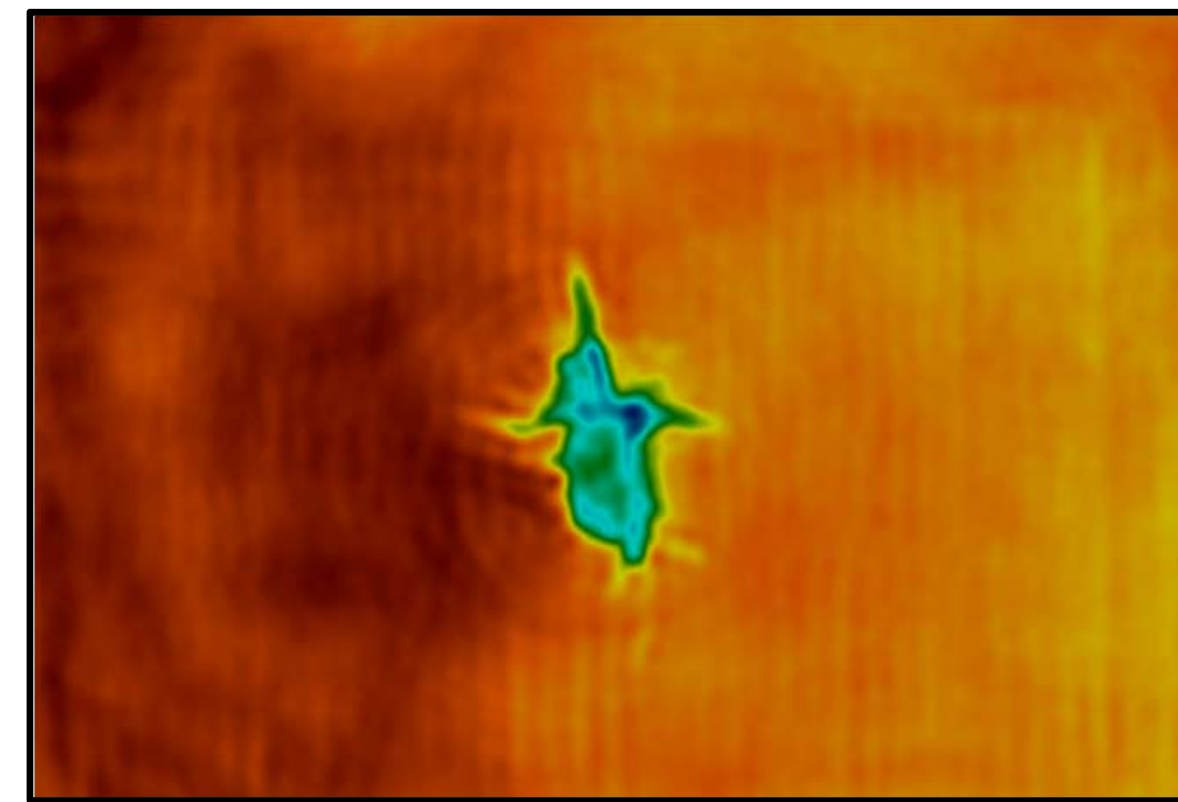
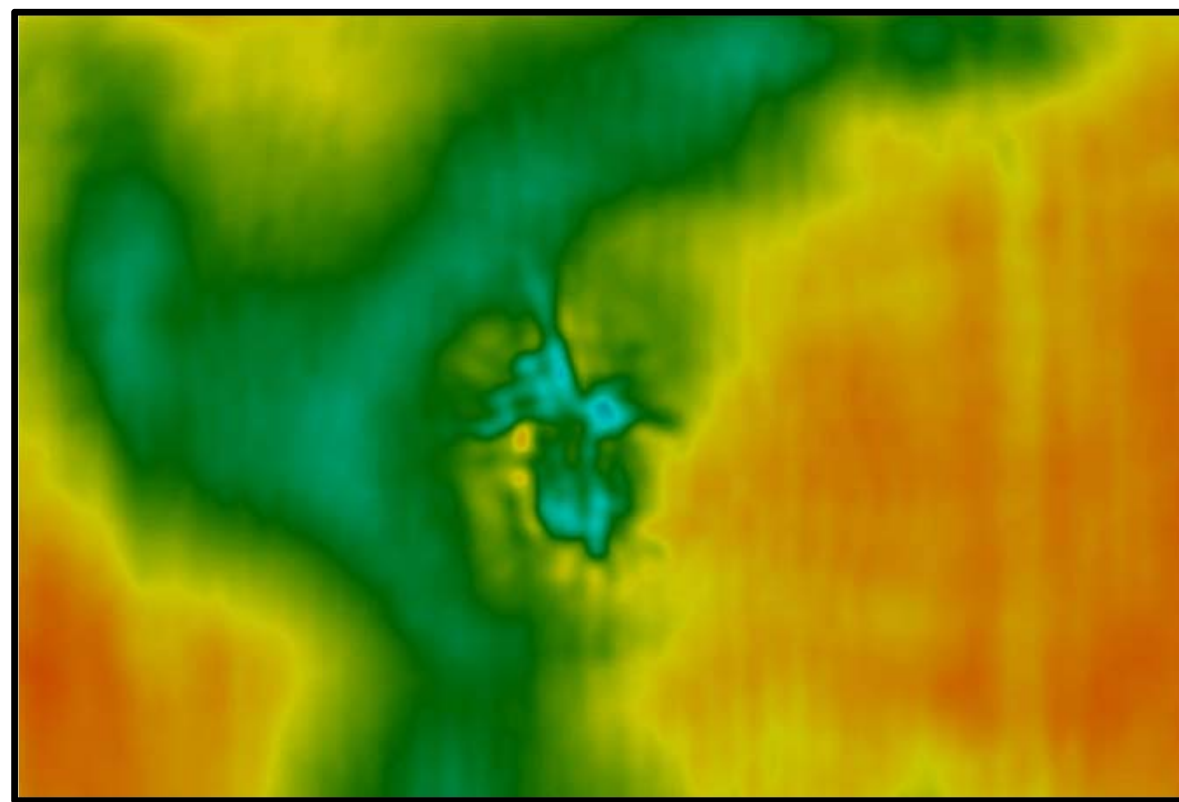
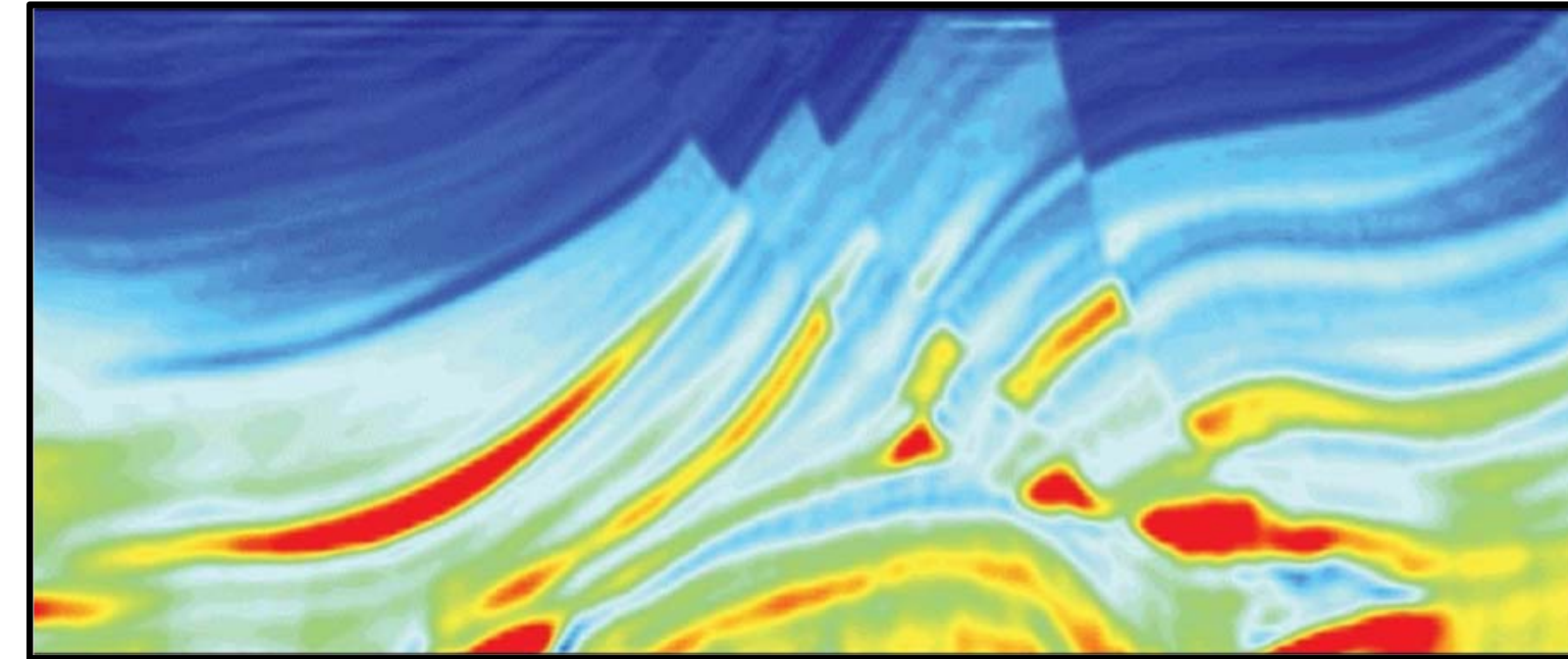
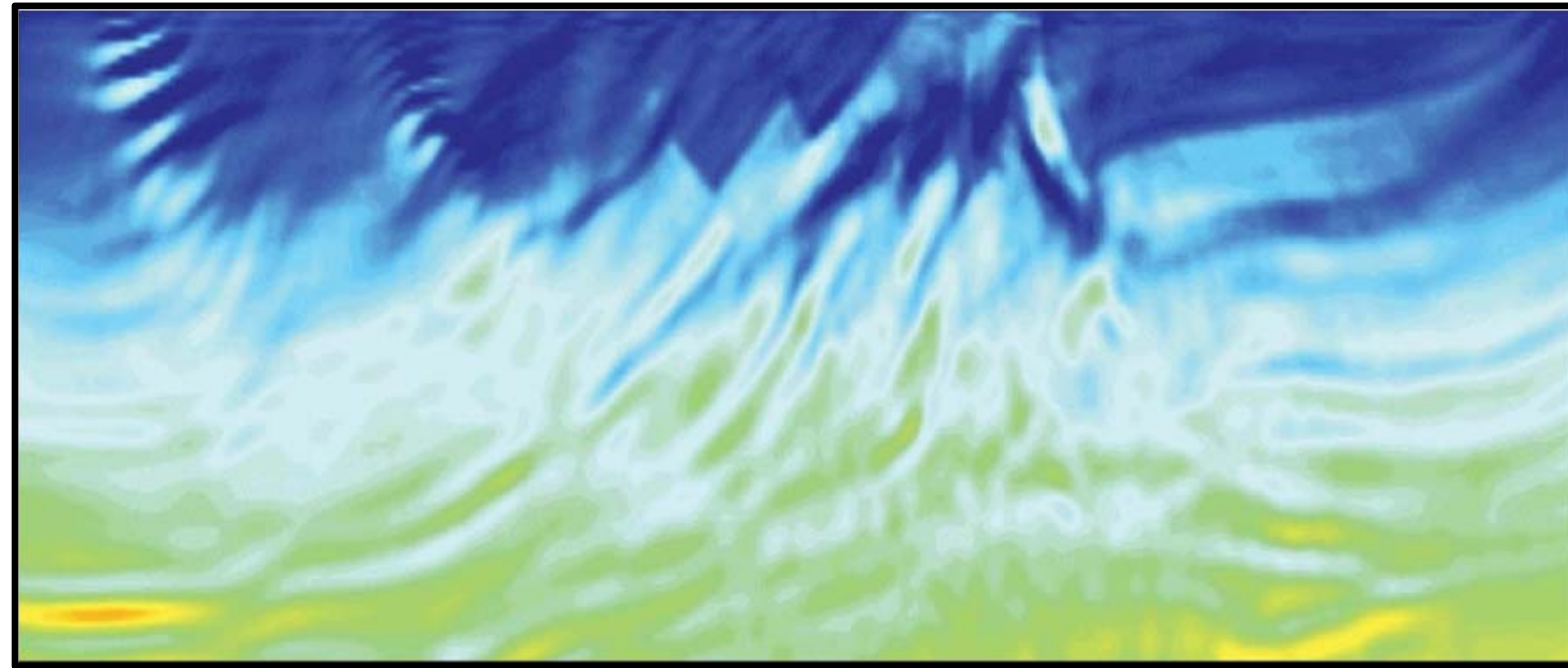
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AWI recovers the gas cloud and the chalk at the bottom

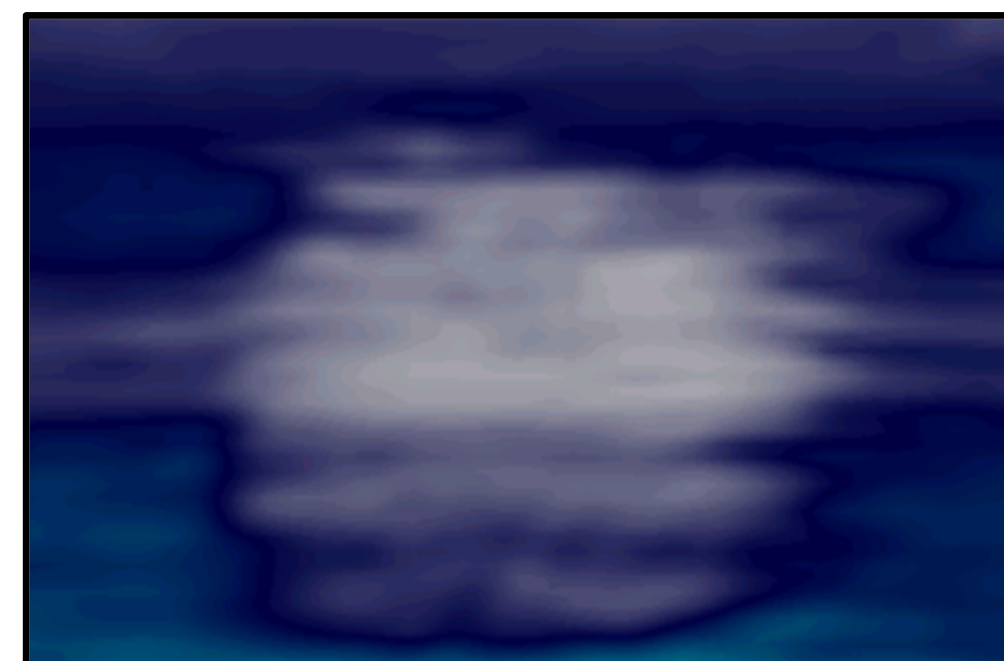




# Summary



FWI



AWI



# Postscript...

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AWI and the penalty method:

- are different approaches to similar problems
- have complimentary advantages
- will be difficult to combine
- but there are benefits if we can manage it.

We are trying...