中国科学技术大学
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全波形反演程序SWIT介绍

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全波形反演程序SWIT介绍

1. SWIT简介
2. SWIT安装
3. SWIT参数设定与运行
4. SWIT模型测试

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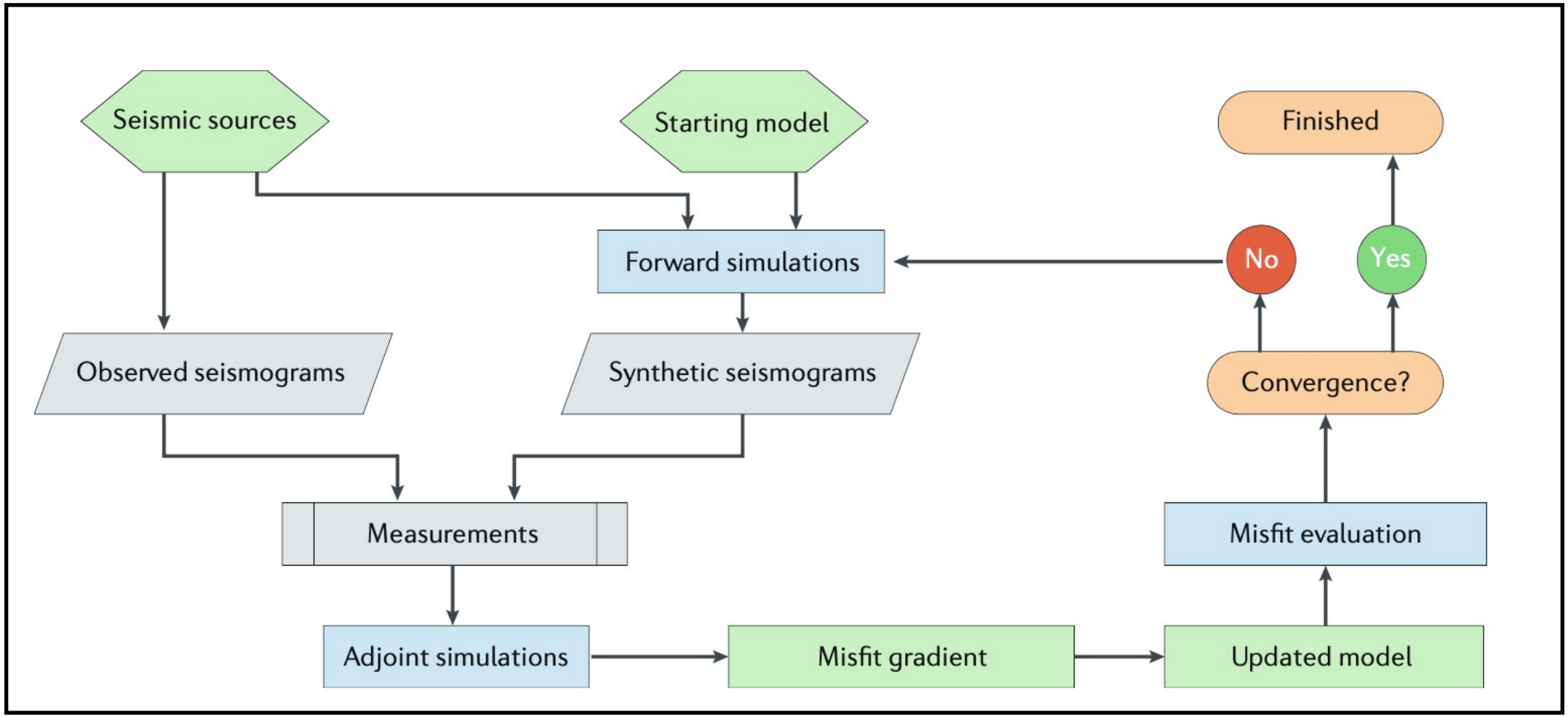
FWI基本工作流程回顾



Tromp, J., 2020, *Nat Rev Earth Environ*

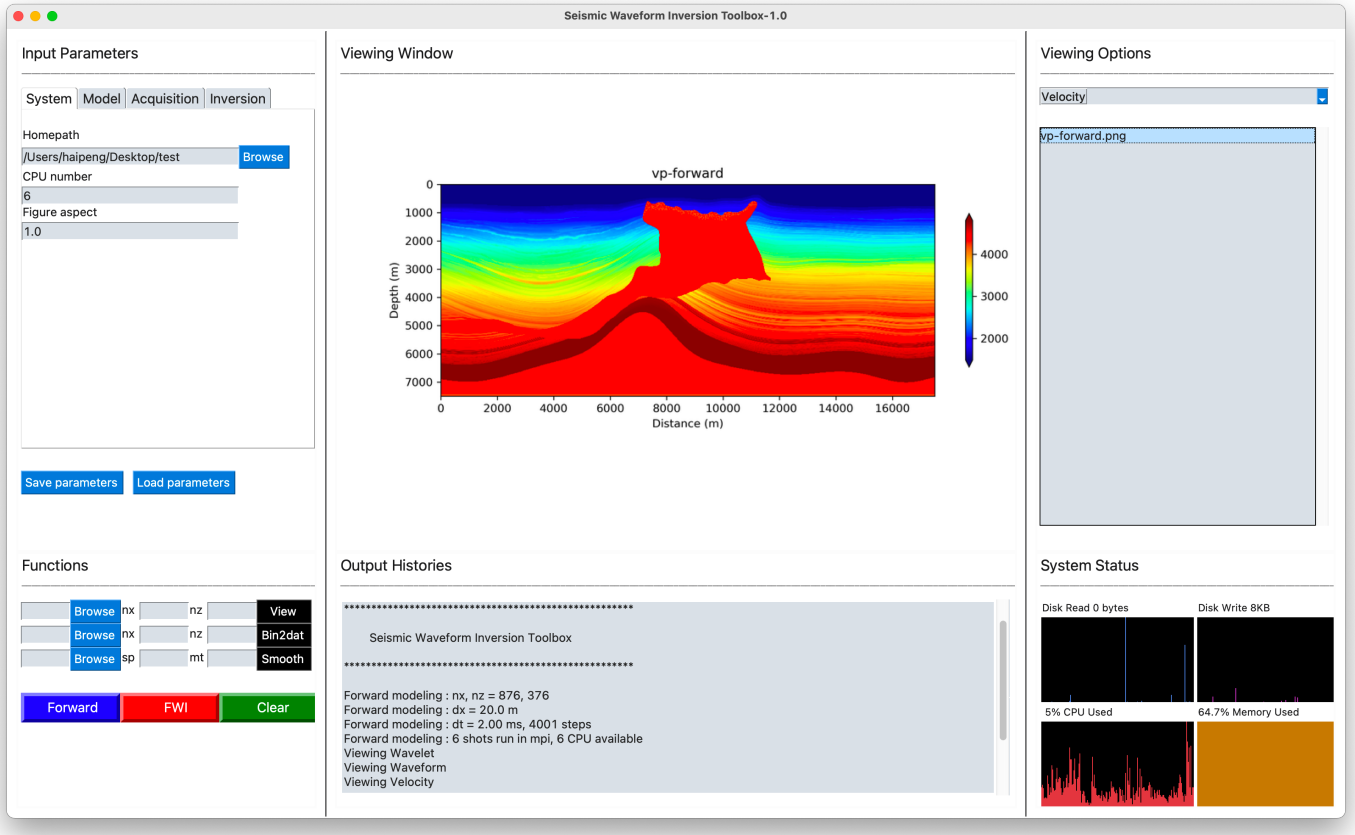
SWIT简介

SWIT主页：https://github.com/Haipeng-ustc/SWIT-1.0

(Please **star** the project for latest updates)

- ✓ 正演波场模拟（有限差分）
- ✓ 伴随波场模拟（有限差分）
- ✓ 模型梯度计算（on-the-fly）
- ✓ 梯度预处理 & 正则化
- ✓ 拟牛顿法 & 共轭梯度法
- ✓ 高效步长搜索
- ✓ 多种目标函数
- ✓ 多尺度反演

Seismic Waveform Inversion Toolbox



Haipeng Li & Junlun Li, In preparation for Acta Geophysica (IF: >2.0)

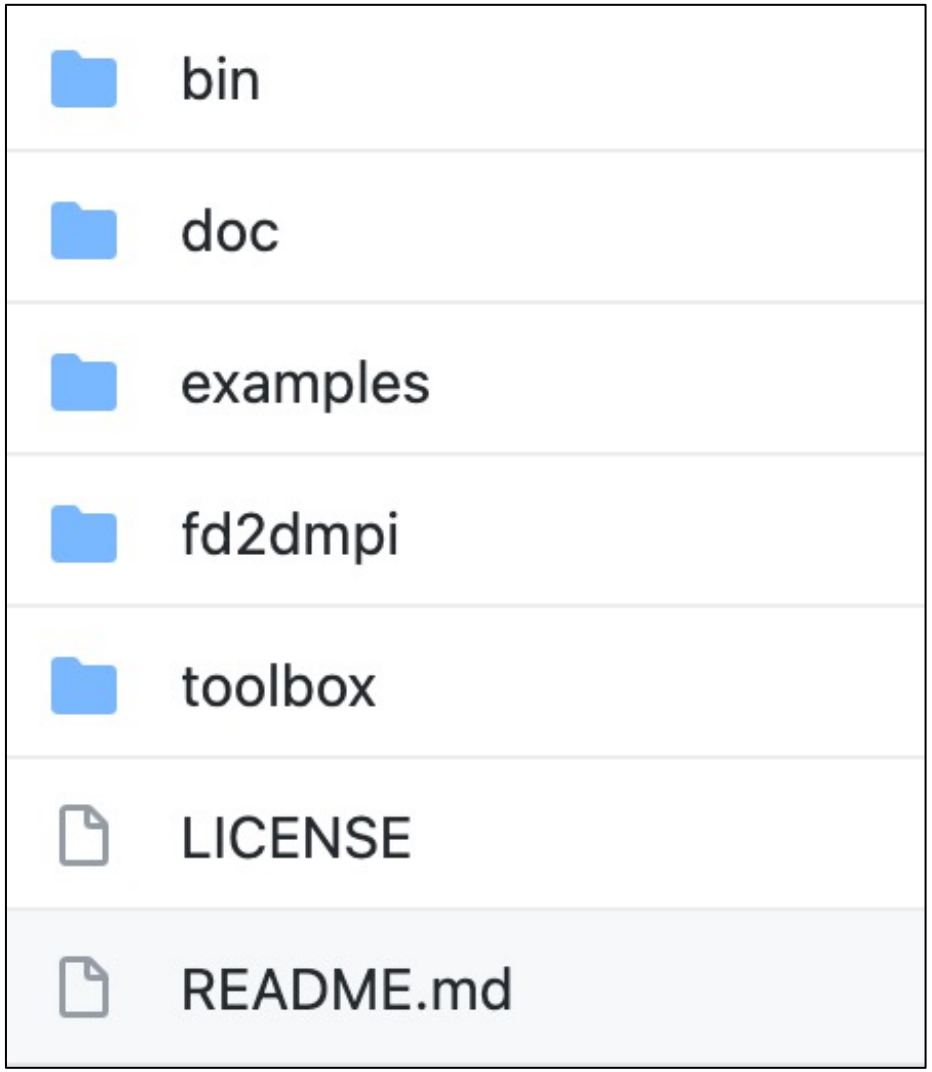
SWIT简介

SWIT主页：https://github.com/Haipeng-ustc/SWIT-1.0

(Please **star** the project for latest updates)

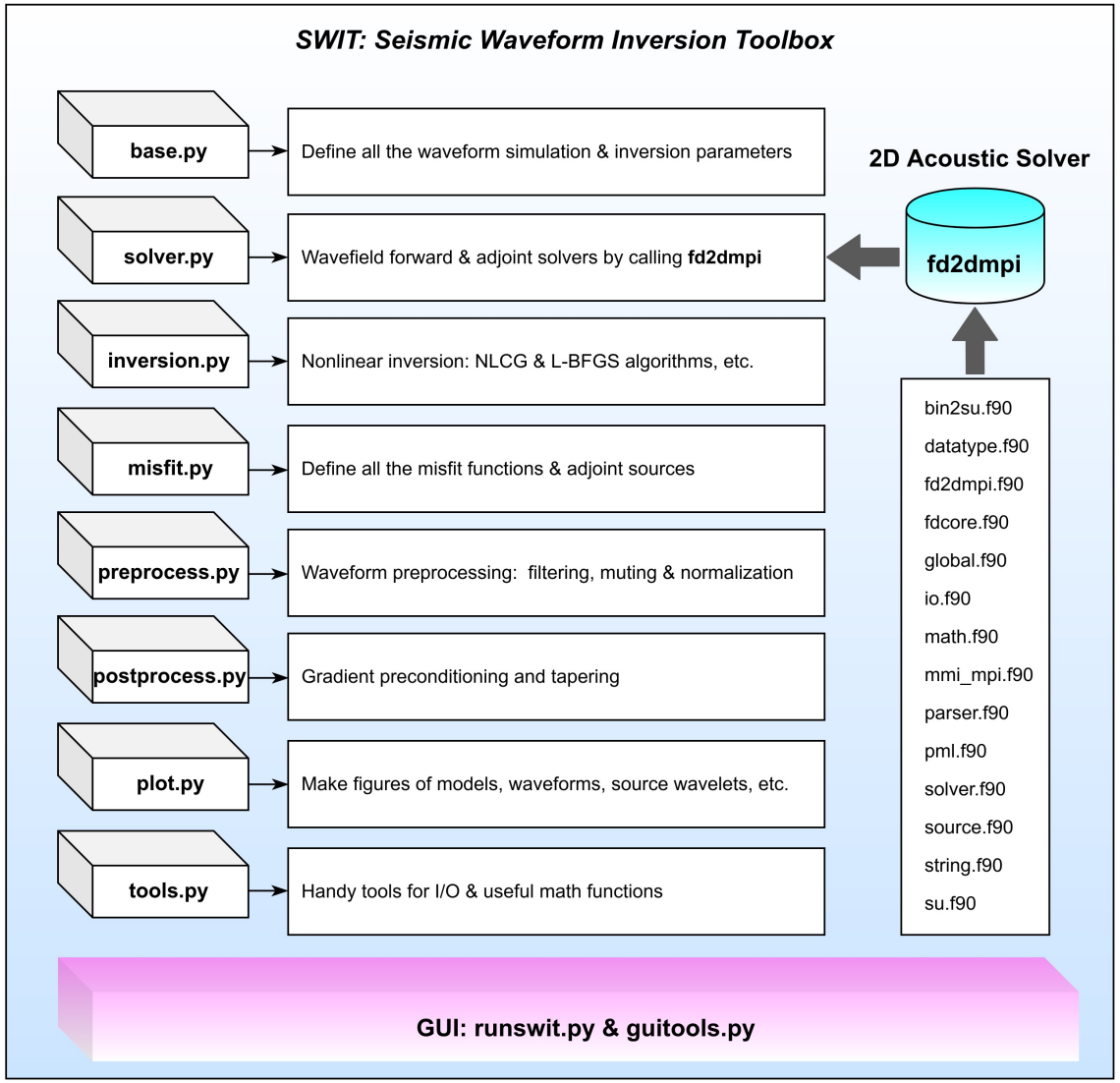
- ✓ Our in-house FWI platform (Keep updating)
- ✓ FD modeling engine (Efficient Fortran, MPI)
- ✓ State-of-the-art algorithms (Flexible Python)
- ✓ Easy definition of parameters (GUI)
- ✓ Industry-standard data format (SU data stream)
- ✓ Cross platform (Linux & MacOS)

SWIT简介：程序内容



- 编译的有限差分波场求解算子 (fd2dmpi)
- 程序使用手册 (keep updating)
- 提供的FWI案例 (keep updating)
- 有限差分波场求解程序 (Fortran)
- 全波形反演程序 (Python)
- License
- Readme

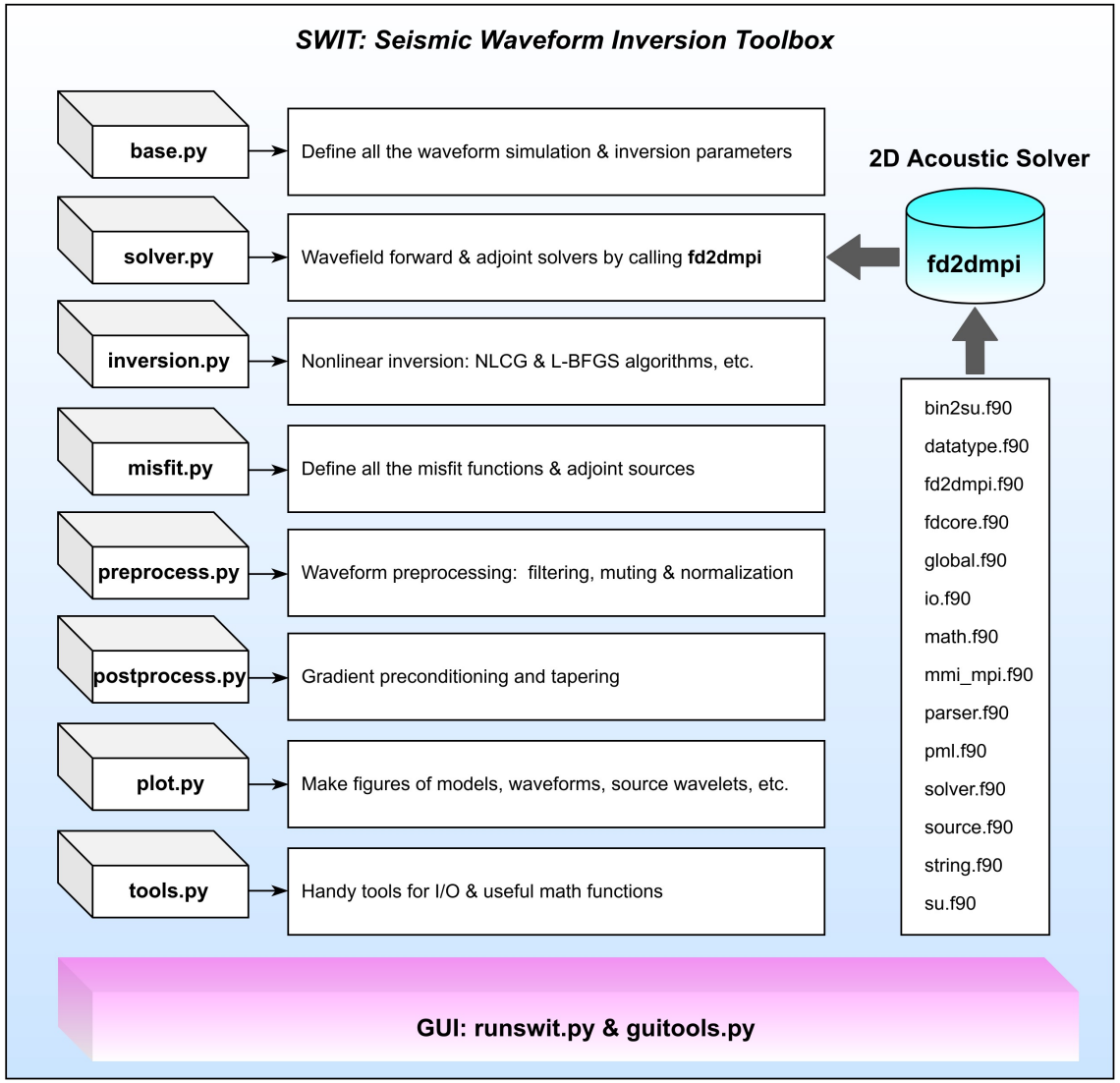
SWIT简介：程序结构



- 波形正演： **Fortran, MPI**
- 波形反演： **Python**
- 操作使用方法：
  - ✓ 方式 1: GUI
  - ✓ 方式 2: Python script
  - ✓ 方式 3: Jupyter Notebook

Haipeng Li & Junlun Li, In preparation for Acta Geophysica (IF: >2.0)

SWIT简介：程序结构



Haipeng Li & Junlun Li, In preparation for Acta Geophysica (IF: >2.0)

- 波形正演： **Fortran, MPI**

Open MPI

- 波形反演 & 使用操作： **Python**

NumPy

ObsPy
A Python Framework for Seismology

SciPy

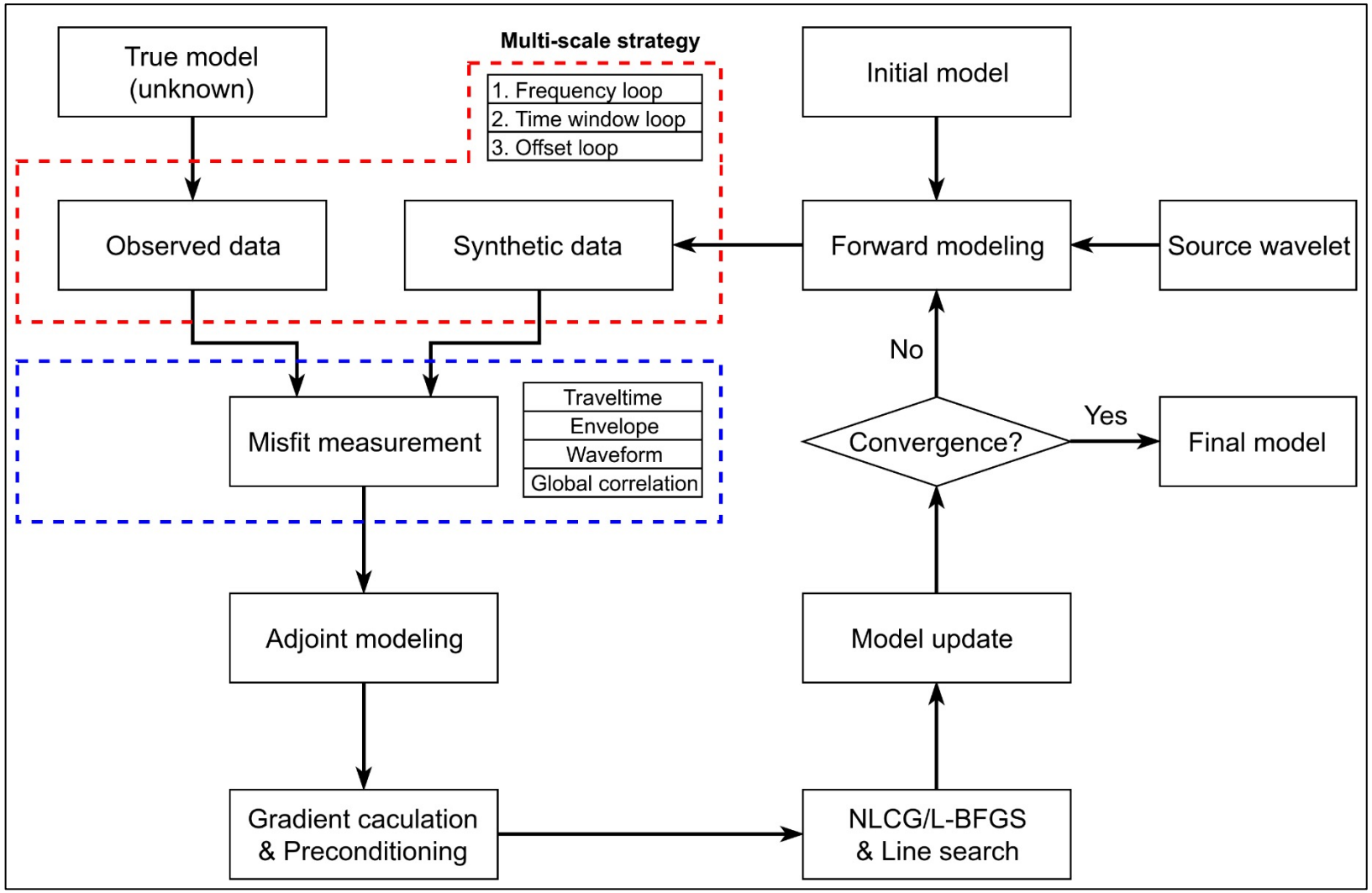
PySimpleGUI™

matplotlib ...

SWIT简介：程序流程

SWIT solves the **variable-density acoustic wave equation** in the stress-velocity form

SWIT uses a **4th-order Butterworth filter (zero-phase)**



Haipeng Li & Junlun Li, In preparation for Acta Geophysica (IF: >2.0)

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SWIT安装

（已经在Ubuntu 16.04, 18.04, 20.04 上测试）

SWIT主页：https://github.com/Haipeng-ustc/SWIT-1.0

Step 1. 安装基本编译程序（如已安装请忽略）

```
sudo apt-get install build-essential

sudo apt install gfortran
```

如果已安装gfortran, gcc, MPI, Anaconda（推荐）等基本工具，请直接：

- 跳转至**Step3**安装Python dependencies,
- 再按照**Step4**编译fd2dmpi即可

SWIT安装

（已经在Ubuntu 16.04, 18.04, 20.04 上测试）

Step 2. 安装OpenMPI（也可使用其他的MPI，请自行安装配置）

```
# 下载当前最新版本的OpenMPI，也可去官网下载其他版本http://www.open-mpi.org/software/ompi
wget https://download.open-mpi.org/release/open-mpi/v4.1/openmpi-4.1.1.tar.gz
tar xvfz openmpi-4.1.1.tar.gz
cd openmpi-4.1.1
# 配置与安装 (take some time，请耐心等待)
./configure --prefix=/usr/local/openmpi CC=gcc FC=gfortran
make    # make -j8 (用 8 核进行编译以加快速度)
sudo make install
# 添加环境变量并检查是否成功安装
export PATH=/usr/local/openmpi/bin:$PATH
source ~/.bashrc
which mpirun
```

SWIT安装

（已经在Ubuntu 16.04, 18.04, 20.04 上测试）

Step 3. 安装Anaconda以方便管理Python环境（推荐，不安装也可以工作）

```
# Anaconda的安装方法: https://docs.anaconda.com/anaconda/install/linux/

# download package from: https://www.anaconda.com/products/individual/download-success

# bash ~/your_Anaconda_package

# 为SWIT创建新的Anaconda环境

conda create --name SWIT python=3.7

conda activate SWIT

# 使用pip安装所需的python dependencies （使用科大镜像）

pip install numpy obspy scipy matplotlib -i https://pypi.mirrors.ustc.edu.cn/simple/

pip install multiprocess PySimpleGUI psutil Pillow -i https://pypi.mirrors.ustc.edu.cn/simple/
```

SWIT安装

（已经在Ubuntu 16.04, 18.04, 20.04 上测试）

Step 4. 编译有限差分波场求解算子 fd2dmpi

```
# 编译Fortran程序

cd ~/SWIT-1.0/fd2dmpi/

rm *.mod; make clean; make

# 添加环境变量 (添加至：~/.bashrc)

export PATH=~/SWIT-1.0/bin:$PATH

export PYTHONPATH=~/SWIT-1.0/toolbox

source ~/.bashrc

which fd2dmpi

python >>  import inversion
```

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SWIT参数设定与运行

（已经在Ubuntu 16.04, 18.04, 20.04 上测试）

方式1： 通过GUI运行SWIT

```
cd ~/SWIT-1.0/toolbox/

python runswit_Linux.py

# or python runswit_MacOS.py
```

方式2： 通过Python script运行SWIT

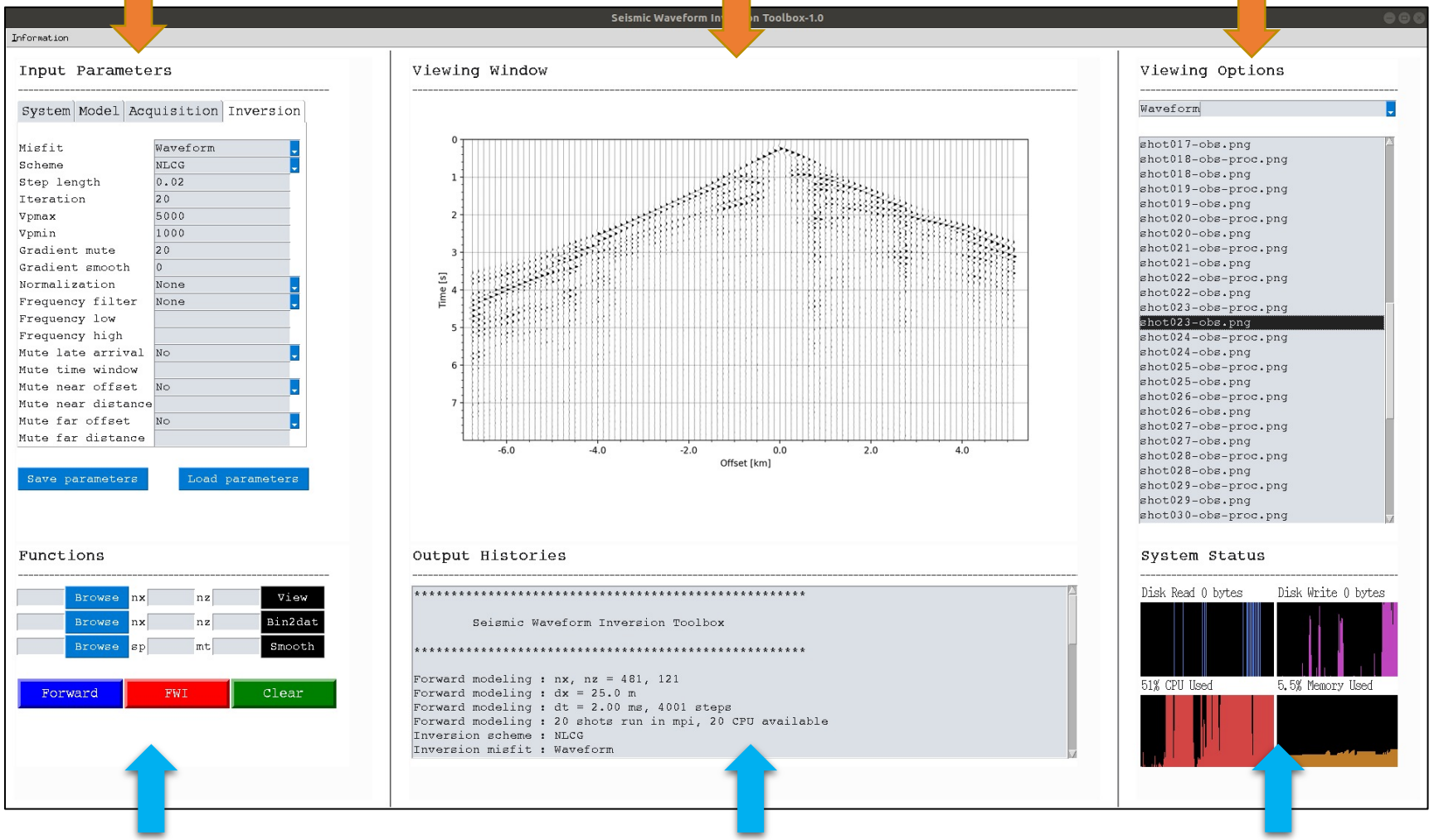
```
cd ~/example/some_case/

python -W ignore SWIT_workflow.py
```

SWIT参数设定与运行

1. 参数输入

3. 结果查看窗口

5. 结果查看选项

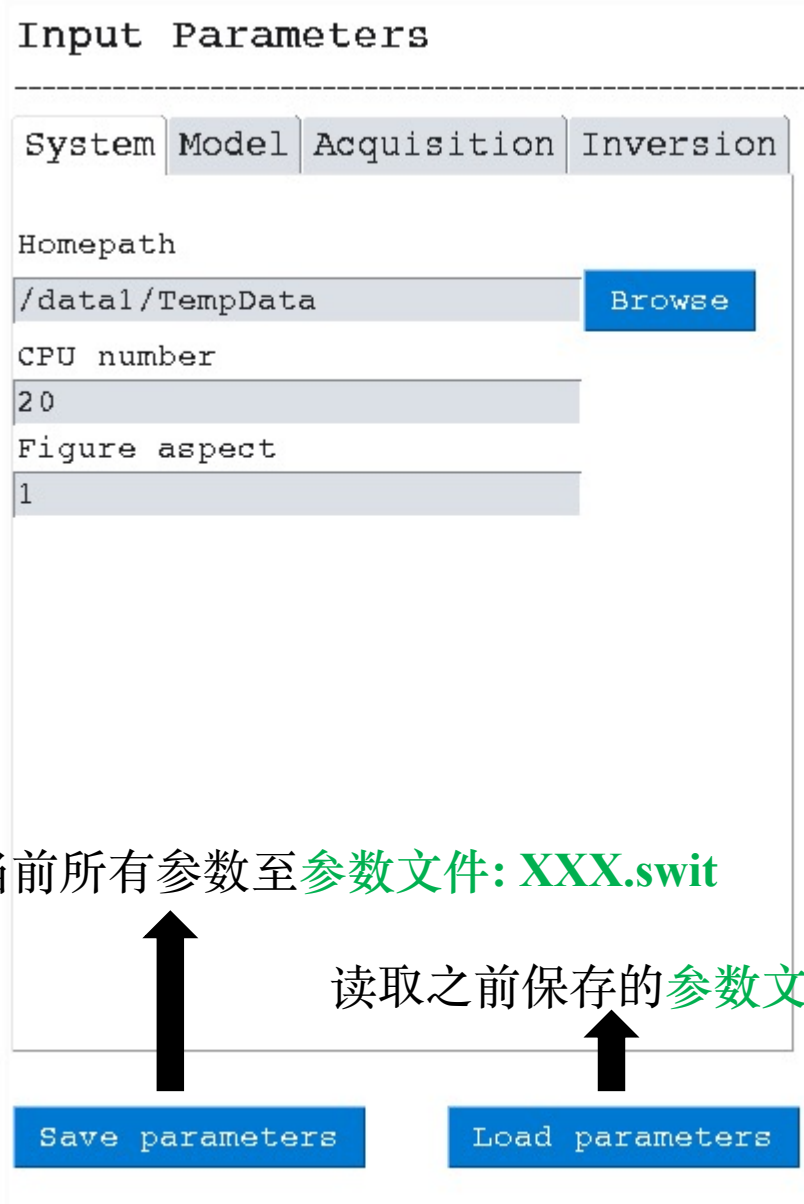


2. 功能窗板

4. 历史输出记录

6. 机器的实时状态

SWIT参数设定与运行：System



各个参数含义

Project working folder

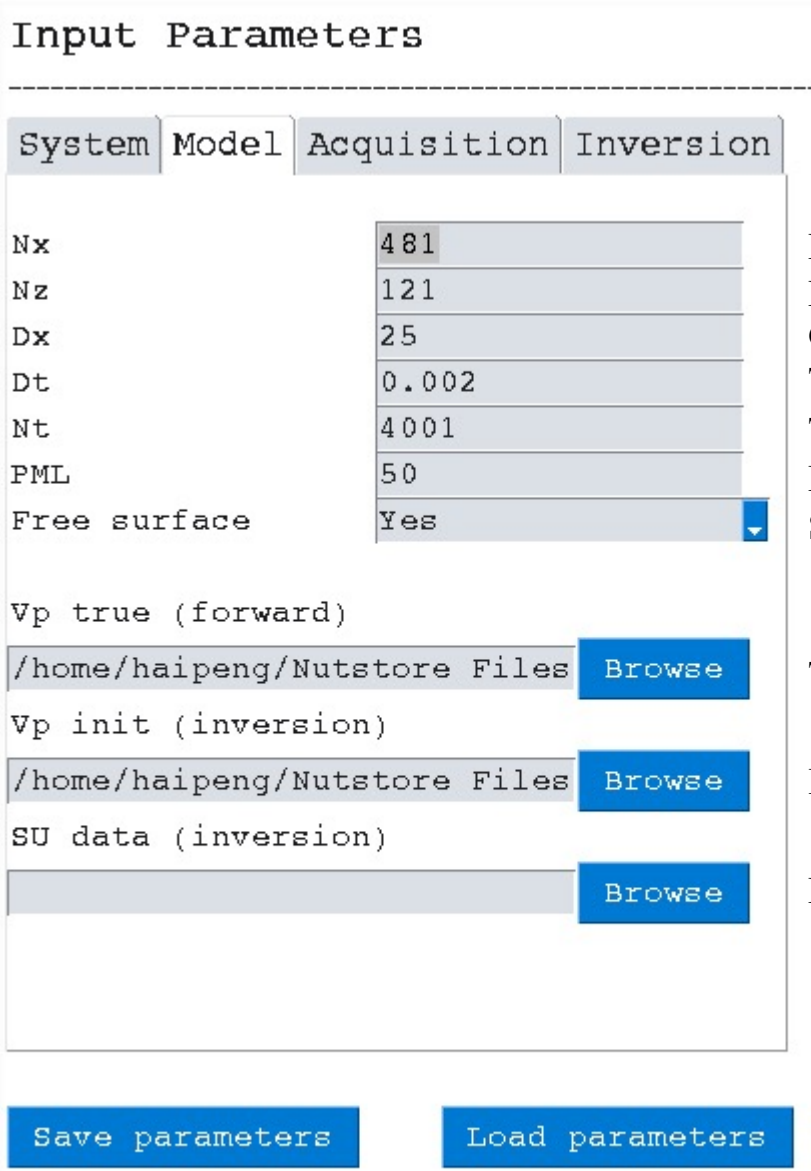
CPU number for MPI

Figure aspect for plotting

保存当前所有参数至参数文件: XXX.swit

读取之前保存的参数文件: XXX.swit

SWIT参数设定与运行：Model



各个参数含义

Model size along x direction

Model size along z direction

Grid size (in m)

Temporal step (in s)

Total time steps

PML size, use a relatively large one, i.e., 50

Set free surface or not

True Vp model saved in the **txt file**

Initial Vp model saved in the **txt file**

Field-data path, data should be named as: **src1_sg.su, src2_sg.su, ..., src40_sg.su, ...**

合成模型测试需要设置: Vp true & Vp init

实际数据反演需要设置: SU data & Vp init

SWIT参数设定与运行：Acquisition

各个参数含义

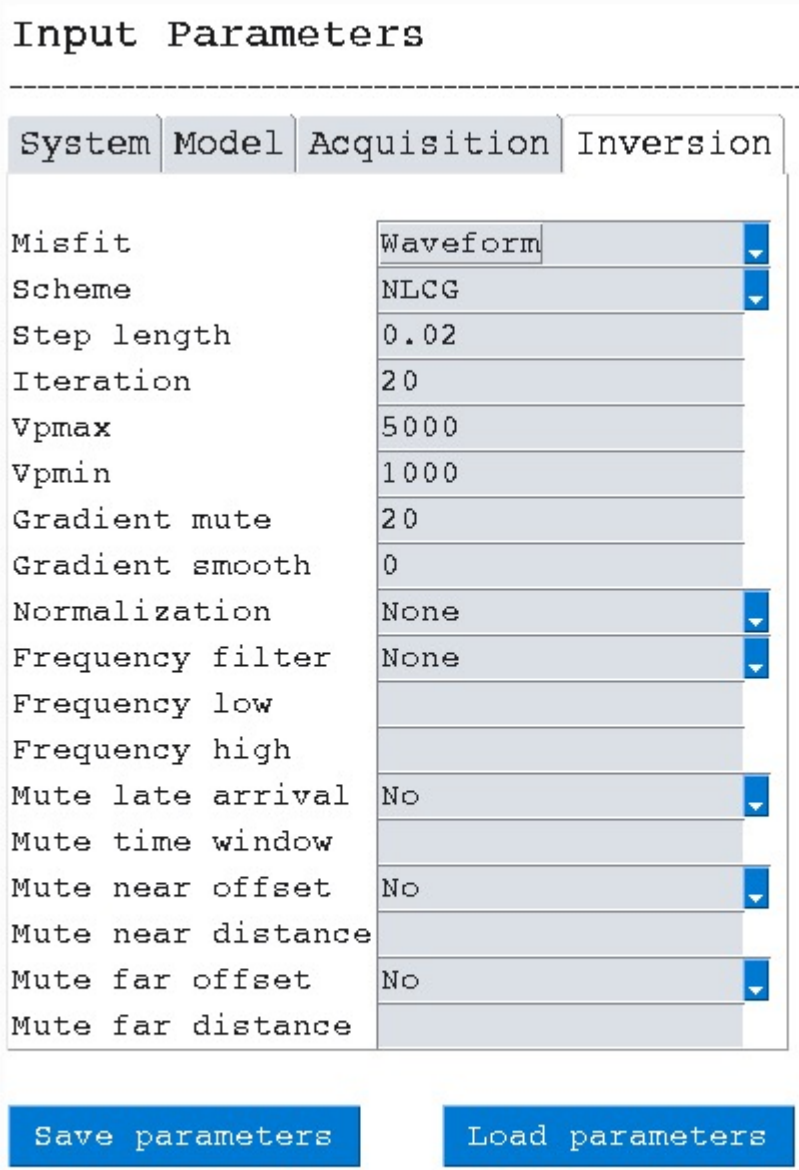
Receiver file, see examples for detailed format

Source file, see examples for detailed format

Acqusition type: land or marine
Source wavelet: Ricker or from file
If Ricker, set the dominant frequency

If from file, set the file path, txt files

SWIT参数设定与运行： Inversion



各个参数含义

Set misfit function: Waveform, Traveltime, etc.

Set optimization scheme: NLCG or L-BFGS **(NLCG is recommended)**

Set step length, i.e., 0.01 or 0.02 (with respect to Vp model), **small step length is recommended**

Set number of iteration

Maximum Vp (in m/s)

Minimum Vp (in m/s)

Set gradient mute. **In marine case, it's the water layer size; in land case, set as ~10 (in grid)**

Set gradient smoothing size, i.e., 10 (in grid)

Set whether to normalize the data. If so, set which type

Set whether to filter the data. If so, set which type

Set the low frequency bound (in Hz)

Set the high frequency bound (in Hz)

Set whether to mute late arrivals based on the automatically picked first break

Set the time window after the first break, i.e., 1.0 (in s)

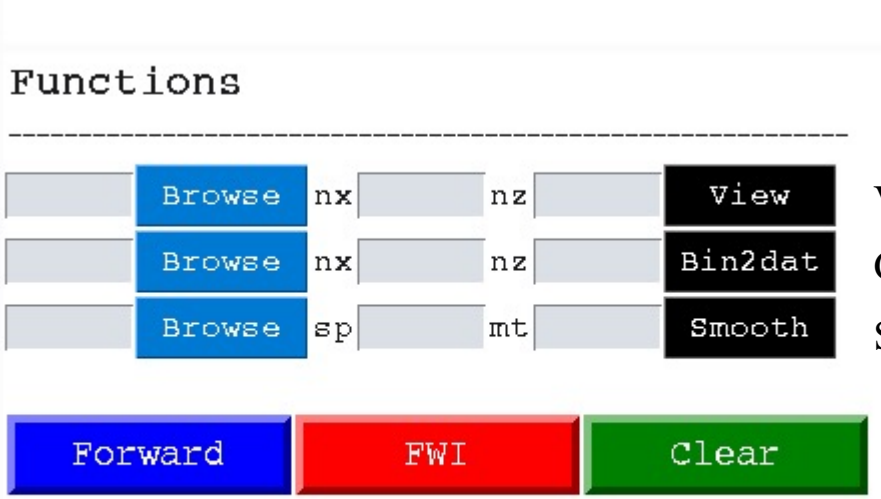
Set whether to mute traces of near offset

Set the distance to mute near offset distance (in m)

Set whether to mute far offset

Set the distance to mute traces of far offset distance (in m)

SWIT参数设定与运行：功能窗板



各个参数含义

View a txt file (donot require nx & nz) or binary file (**require nx & nz**)

Convert a binary file to a txt file (**require nx & nz**)

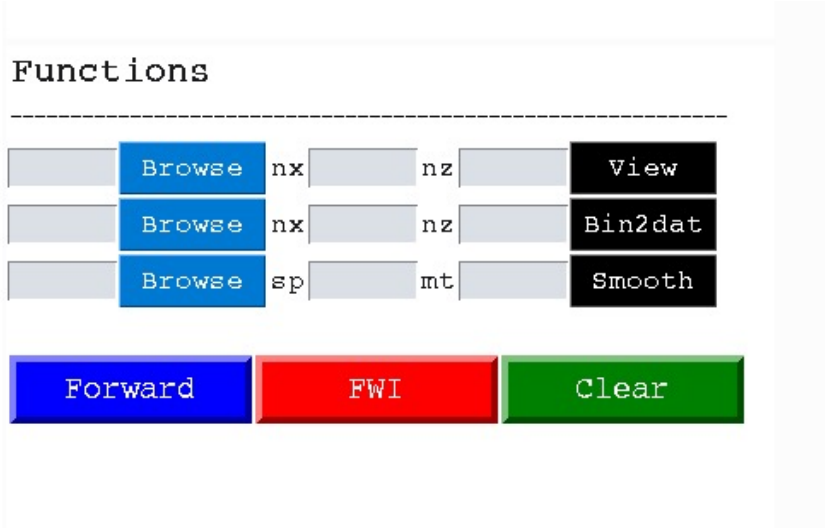
Smooth a txt file. **sp:** the smoothing radius; **mt:** the top mute for any water layer

Forward 根据提供的**Vp true**模型进行波场正演模拟，产生合成波形数据存储在/data/obs/xxx.su

FWI 根据提供的**Vp initial** 和**SU data**进行反演

Clear 清除历史输出记录

SWIT参数设定与运行



- **合成模型FWI：**

  Step 1: 设置好所有参数 **(需提供Vp true和Vp init)**;

  Step 2: 运行**Forward** 计算真实的合成数据;

  Step 3: 运行**FWI**反演刚计算出的合成数据.

- **实际数据FWI：**

  Step 1: 设置好所有参数 **(需提供Vp init和SU data)**;

  Step 2: 运行**FWI**反演提供的实际数据.

注：在提供的SU数据中：

- 震源和检波器的设置需和Acquisition中的设置保持一致；
- Nt和Dt需和Model中设置保持一致；
- 目前不支持变观测系统. 对于滚动采集的数据，可填充zero traces以使所有震源使用的检波器保持一致；
- 坏道处可以填充 zero traces，所有zero traces均不参与残差计算和梯度计算.

SWIT参数设定与运行 （通过Python Script）

参数的含义与设定和GUI操作一致，且在提供的**Python scripts**里均有详细注释（example 文件夹下）

```python
# import modules
import numpy as np
import base
from inversion import inversion, source_inversion
from plot import plot_geometry, plot_model2D, plot_stf, plot_trace
from preprocess import process_workflow
from solver import forward, source_wavelet
from tools import saveparjson, smooth2d


### system setup
homepath   = '/data/haipeng/SWIT-1.0/examples/land-case1-marmousi/'   # working path
mpiproc    = 41                                                       # mpi process for fd2dmpi
figaspect  = 1.0                                                      # Figure aspect

### model setup
nx,  nz      = [481,  121]                                            # Grid number along x and z directions
pml, fs      = [50,  True]                                            # Grid number for PML layers (use a large one)
dx,  dt,  nt = [25, 0.002, 4001]                                      # Grid size, time interval, and time step

# velocity and density
vp_true = np.zeros((nx, nz))
vp_init = np.zeros((nx, nz))
rho_true = np.zeros((nx, nz))
rho_init = np.zeros((nx, nz))

vp_true = np.loadtxt(homepath + 'model/Marmousi_481_121_25m_True.dat')
```

通过命令行提交SWIT任务：

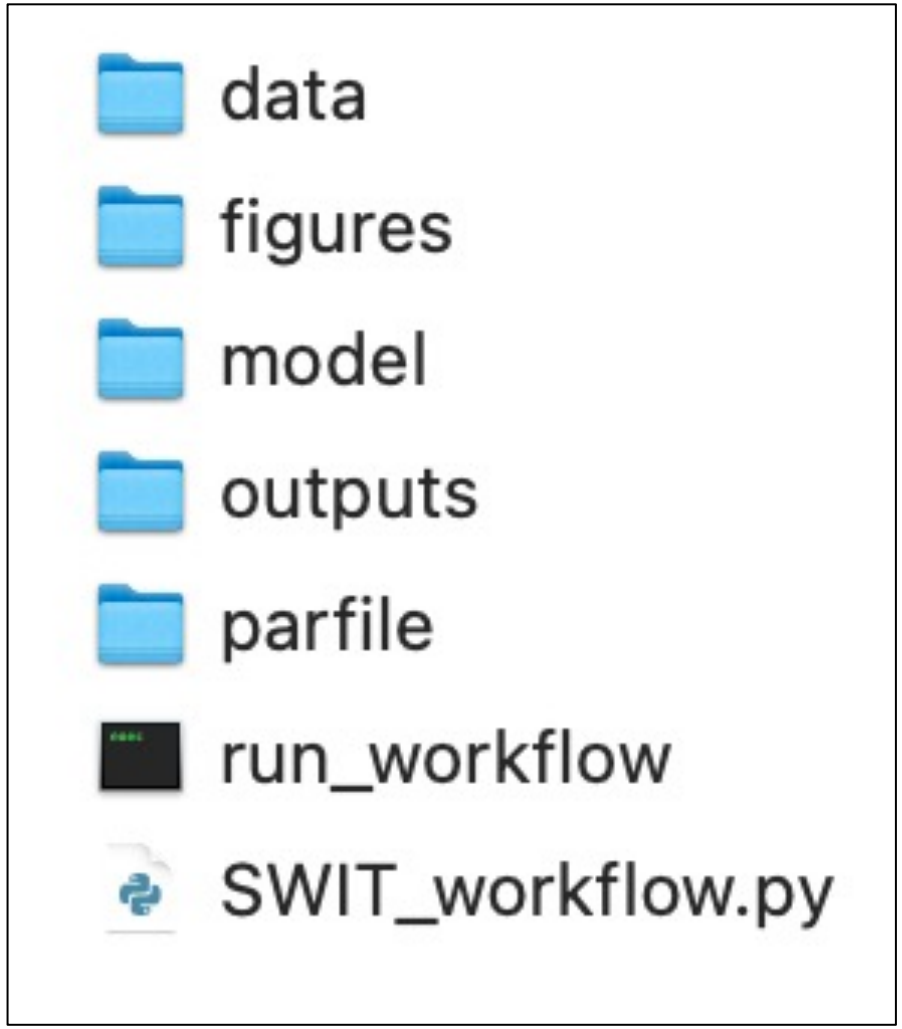
（注意要先激活Anaconda环境）

python -W ignore SWIT_workflow.py

也可以将Python script在Jupyter Notebook里运行，这里便不再提供详细的Notebook

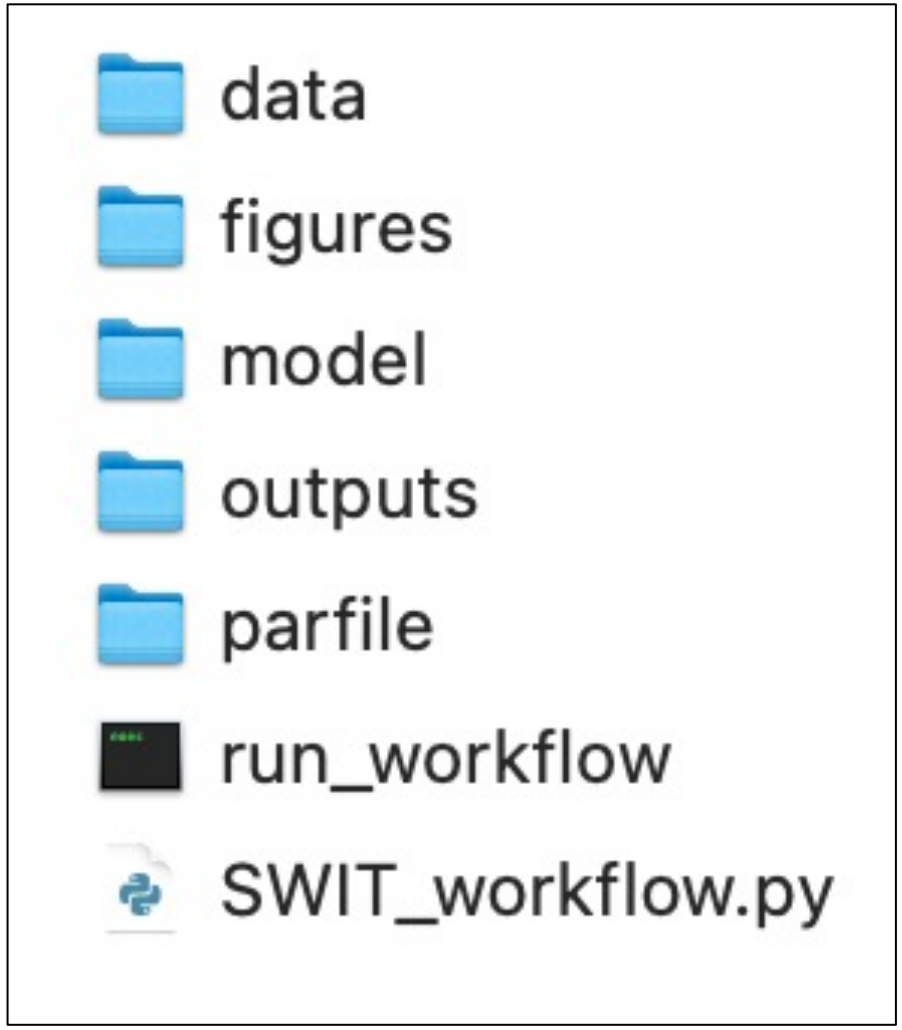
SWIT参数设定与运行

主要文件



SWIT参数设定与运行

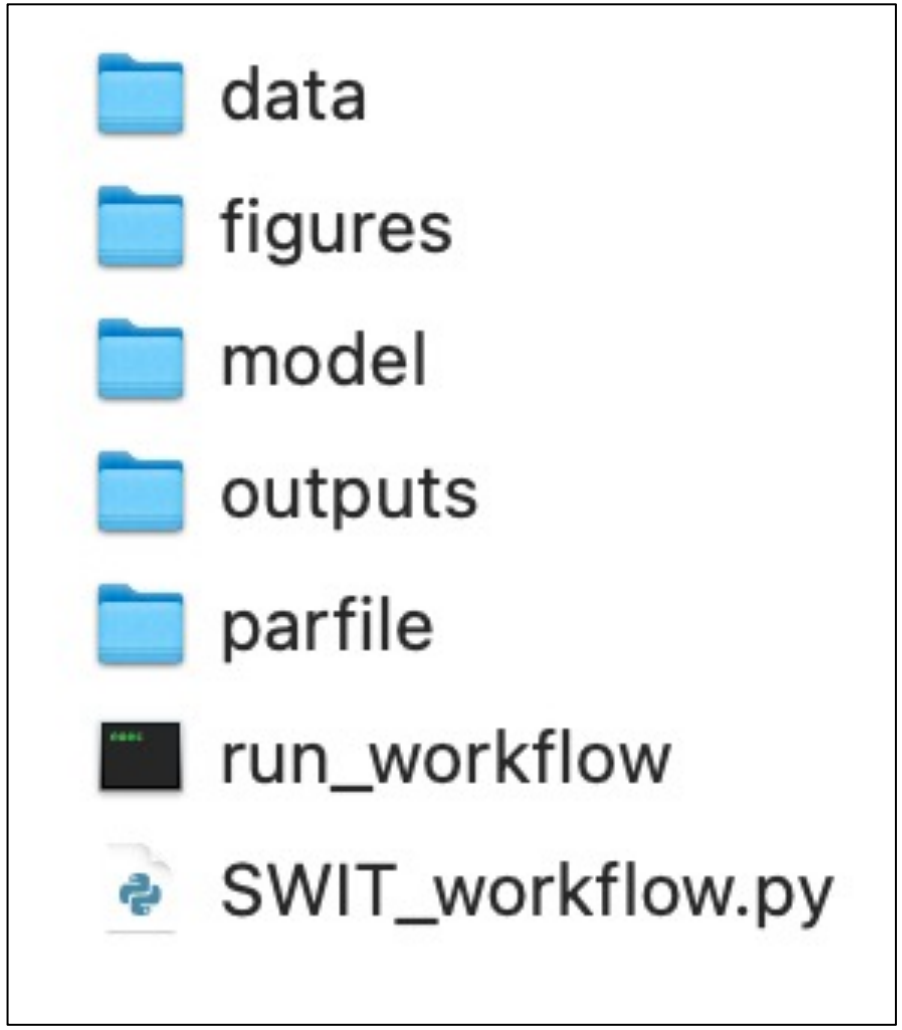
主要文件



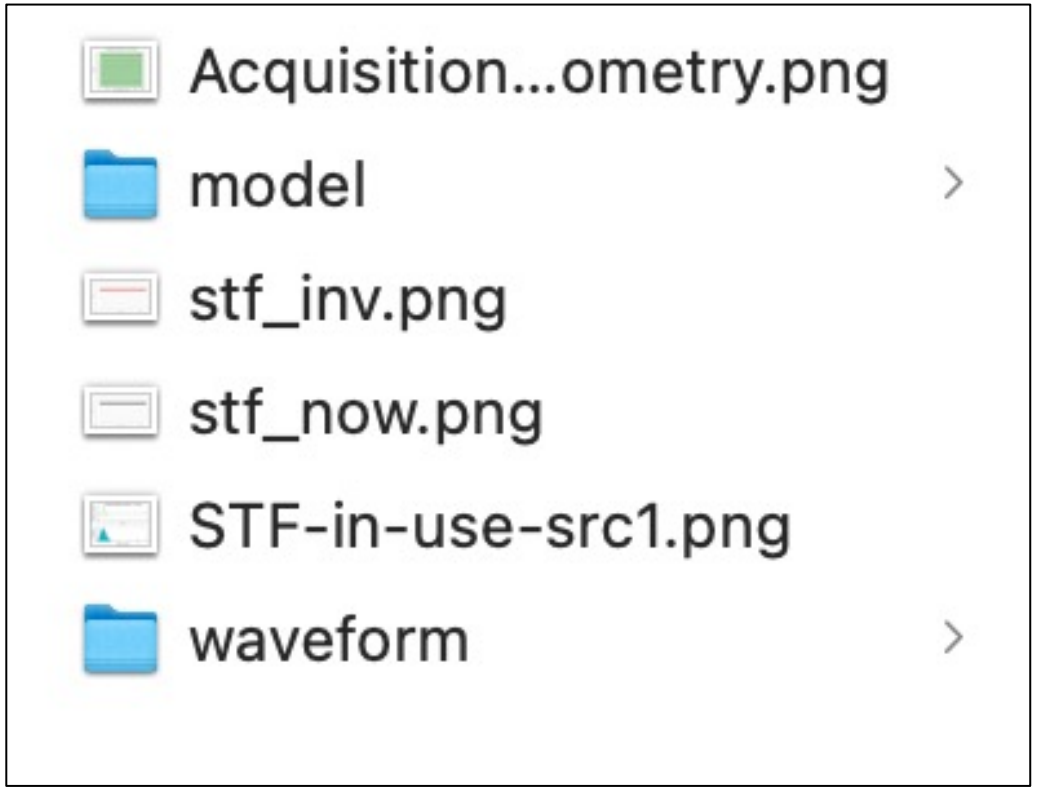
波形/波场数据

SWIT参数设定与运行

主要文件

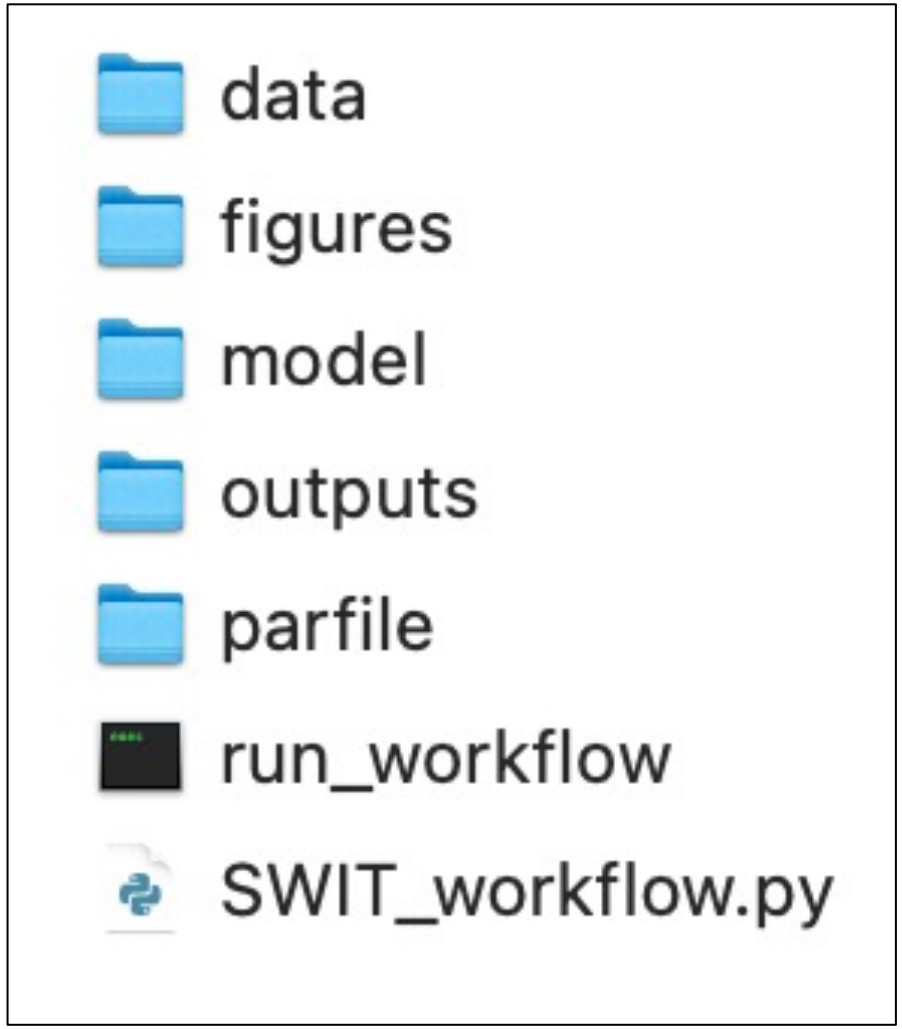


绘图结果： acquisition, model (velocity, gradient, illumination), wavelet, waveform



SWIT参数设定与运行

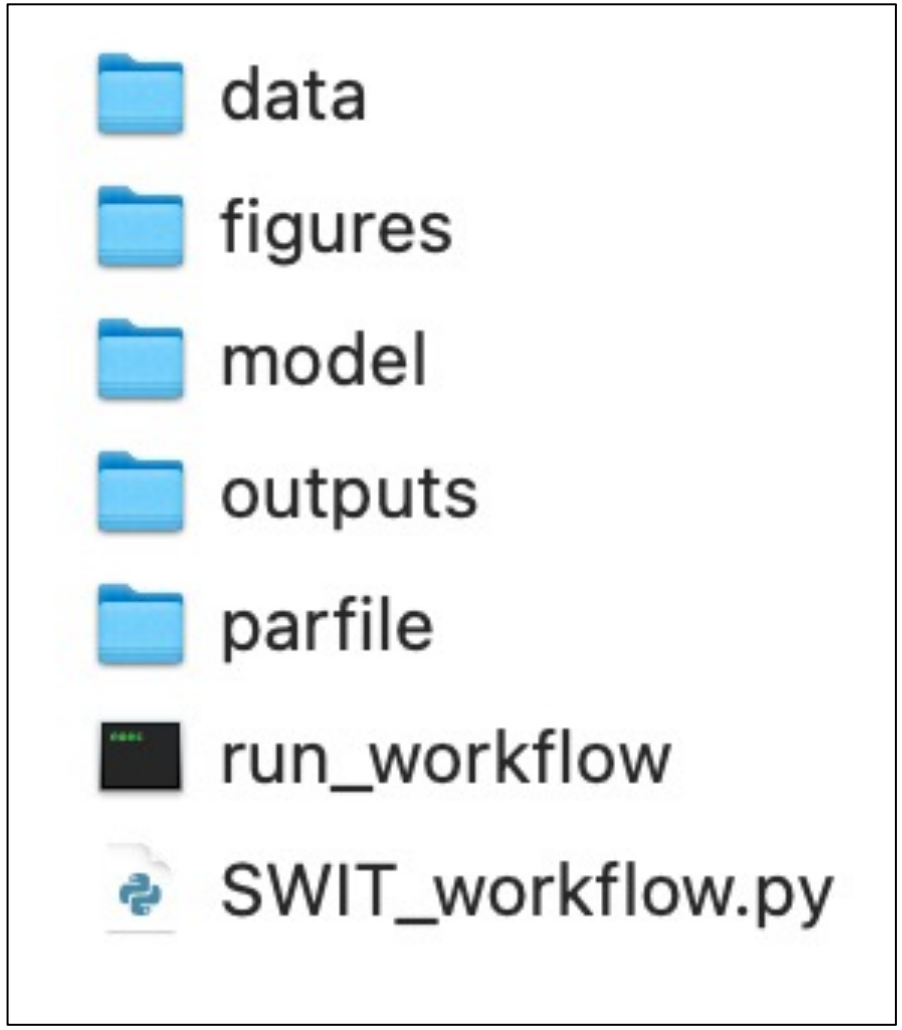
主要文件



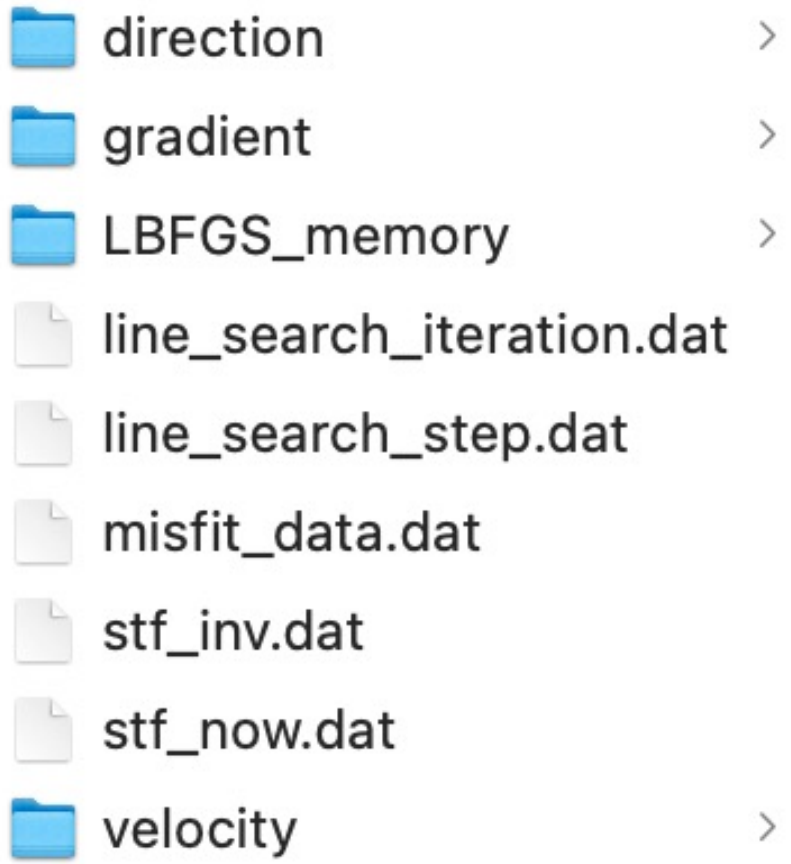
提供的真实/初始速度模型位置

SWIT参数设定与运行

主要文件

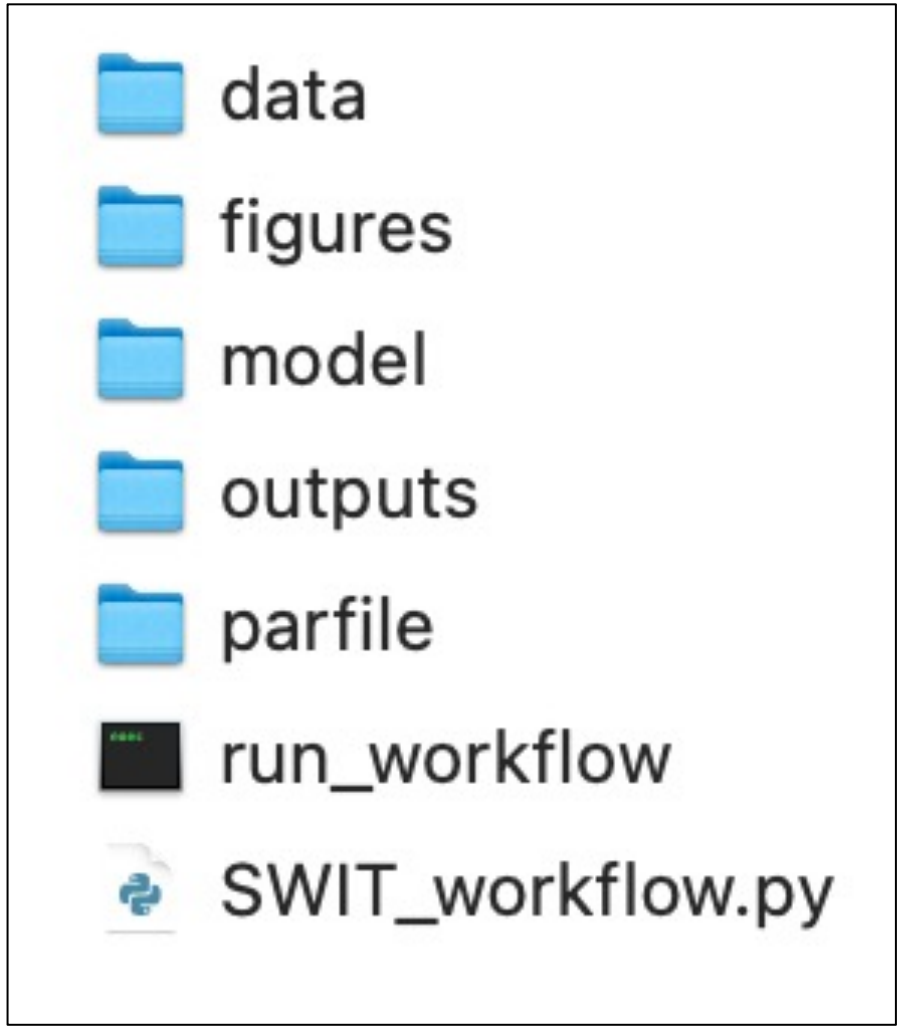


反演结果： direction, gradient, line length, misfit, velocity, etc.



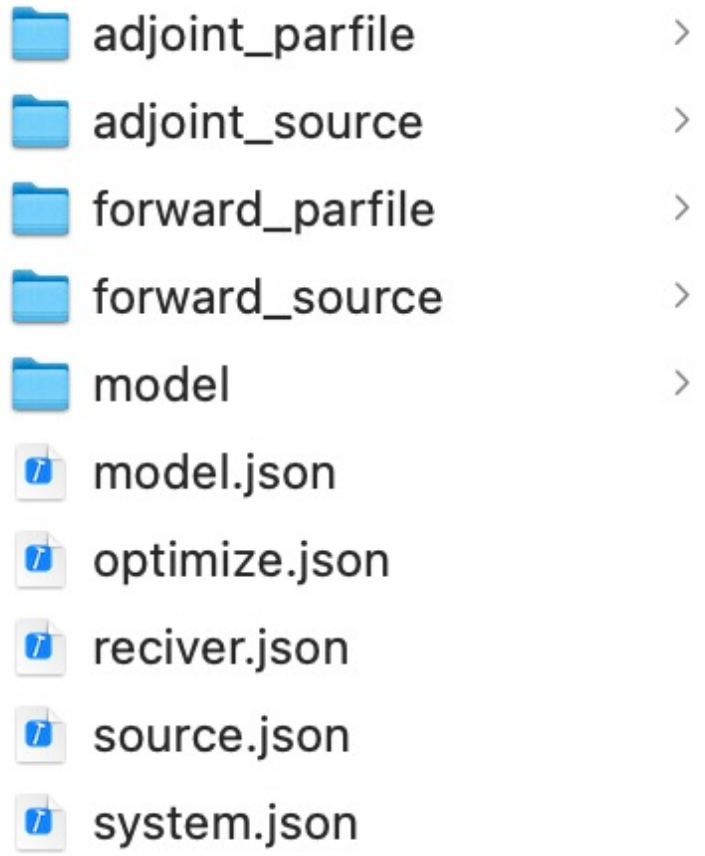
SWIT参数设定与运行

主要文件



计算中使用的参数文件

参数文件将存为json文件供后期查看



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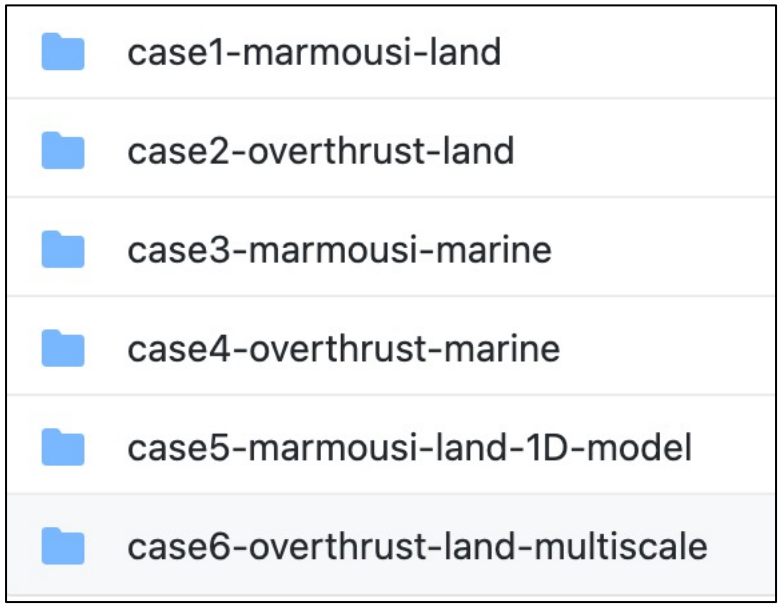
SWIT模型测试

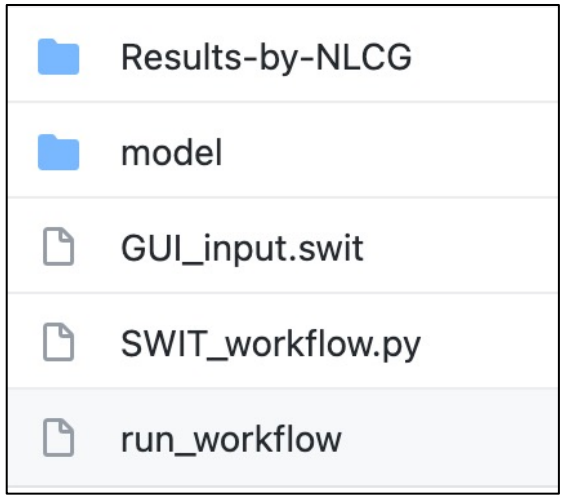
SWIT主页：https://github.com/Haipeng-ustc/SWIT-1.0

Example文件中提供了多个FWI测试案例（keep updating）

No.	Acquisition	Model	Misfit	Features	Optimization	Size
1	Land	Marmousi	Waveform	-	NLCG	481x121, 25 m
2	Land	Overthrust	Waveform	-	NLCG	401x101, 25 m
3	Marine	Marmousi	Waveform	-	NLCG	481x141, 25 m
4	Marine	Overthrust	Waveform	-	NLCG	401x121, 25 m
5	Land	Marmousi	Traveltime & Waveform	1D initial model	NLCG	401x121, 25 m
6	Land	Overthrust	Waveform	Multi-scale Inversion	NLCG	401x101, 25 m



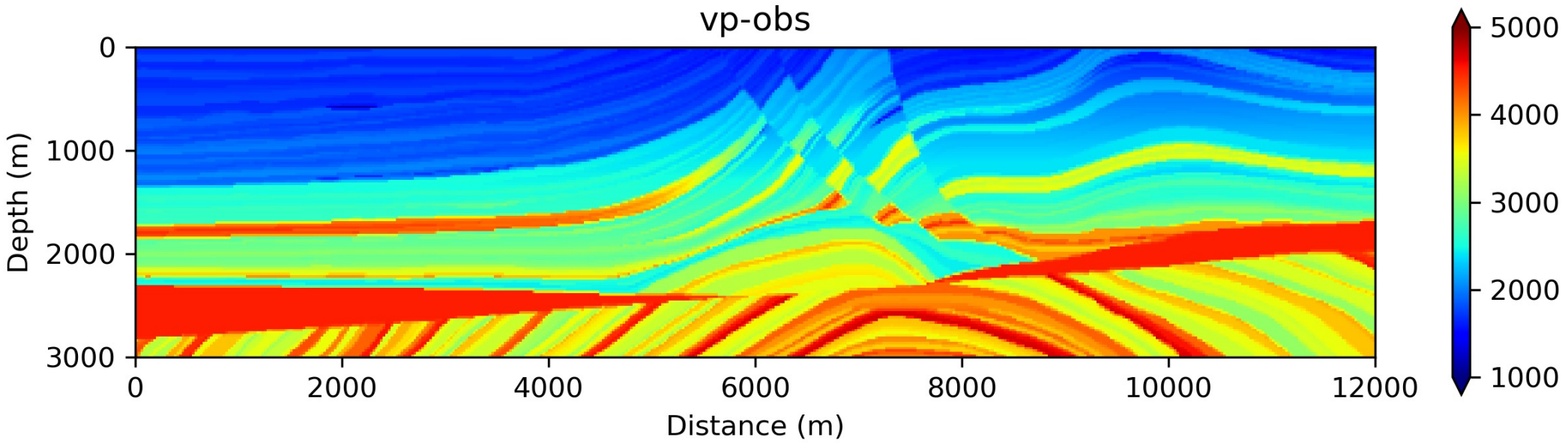
每个例子中均提供了如下内容



- 参考反演结果
- 真实模型
- GUI的参数文件（注意所有的PATH均需重新修改）
- Python script （注意所有的PATH均需重新修改）
- Bash script

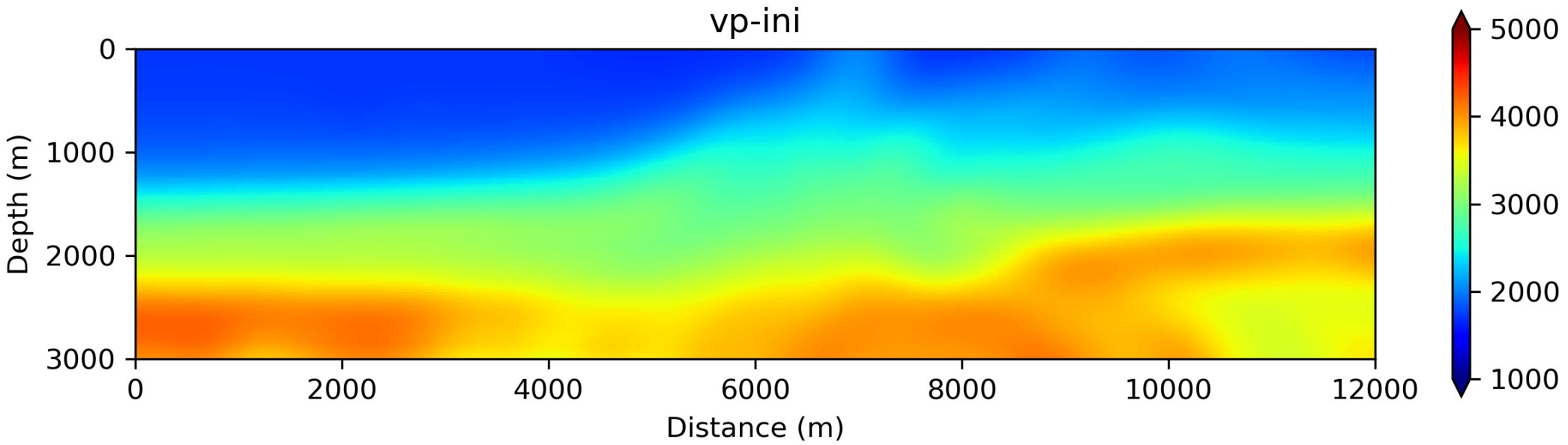
SWIT模型测试-Marmousi

真实速度模型



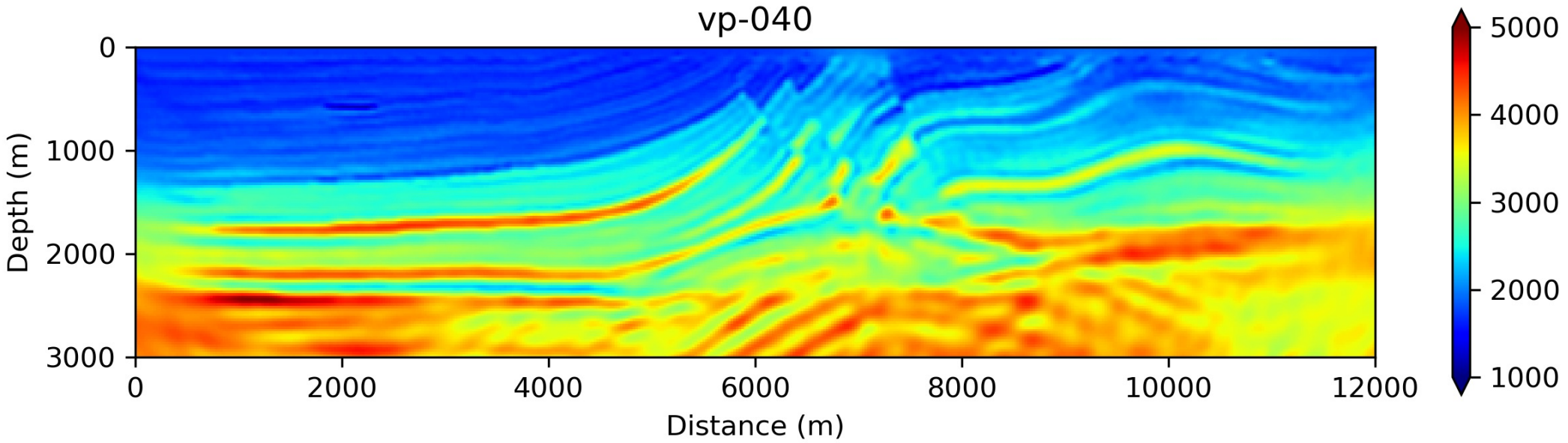
SWIT模型测试-Marmousi

初始速度模型



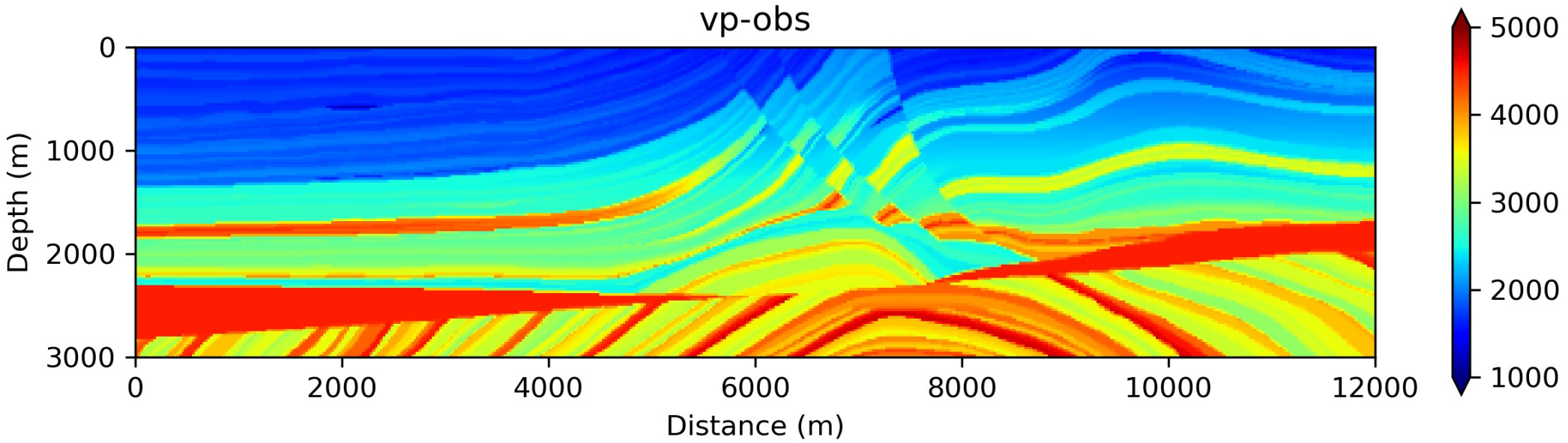
SWIT模型测试-Marmousi

反演速度模型 (40 次迭代)



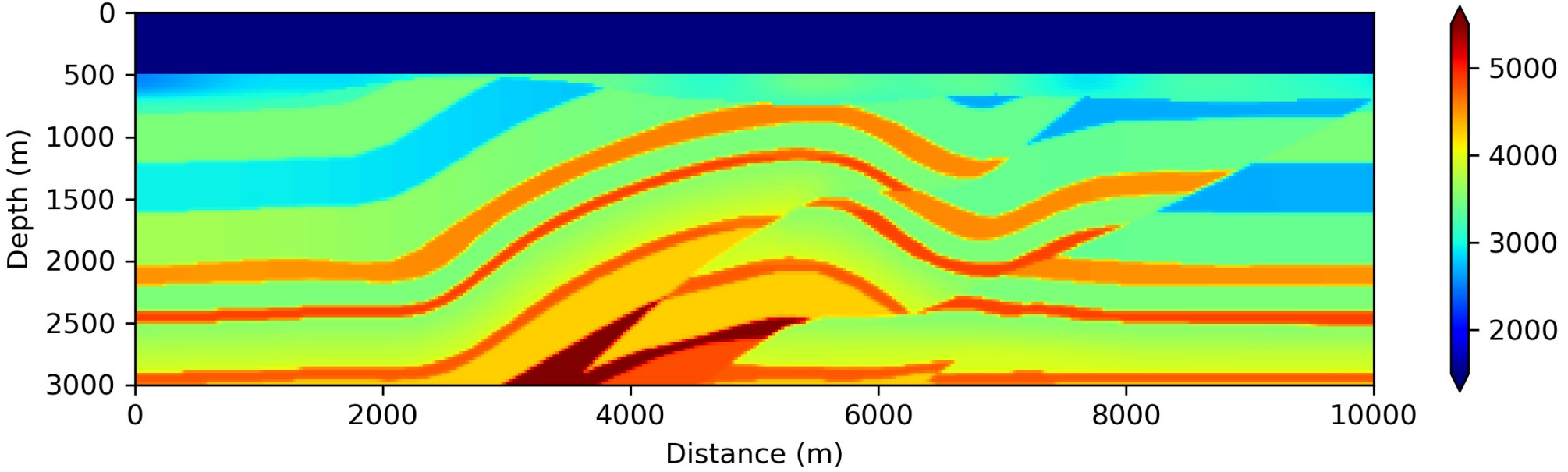
SWIT模型测试-Marmousi

真实速度模型



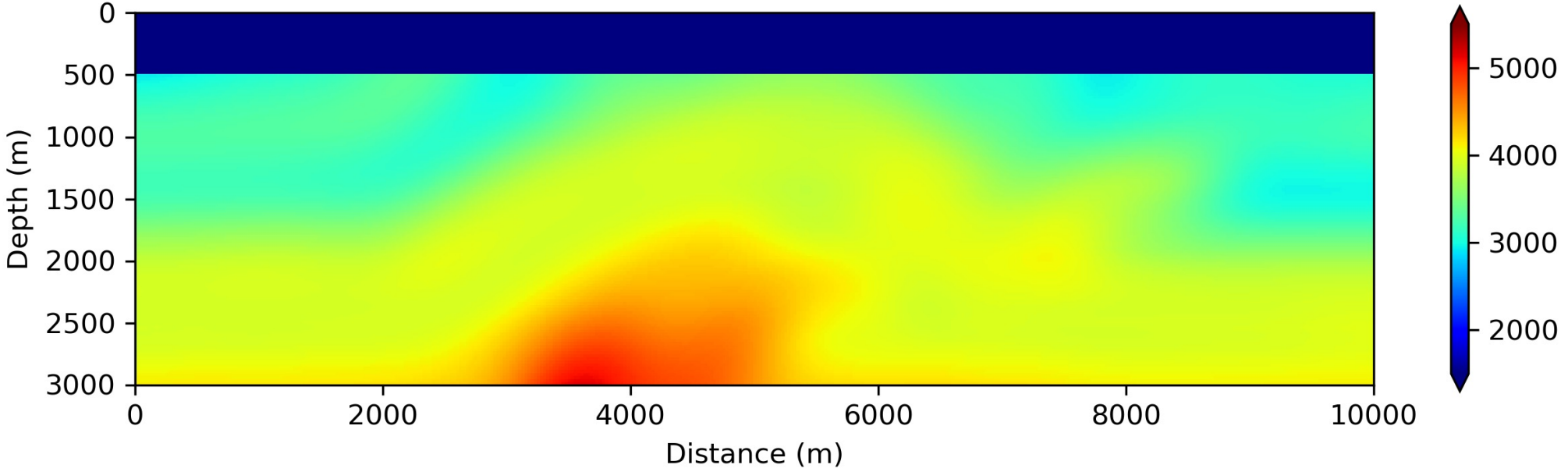
SWIT模型测试- SEG/EAGE Overthrust

真实速度模型



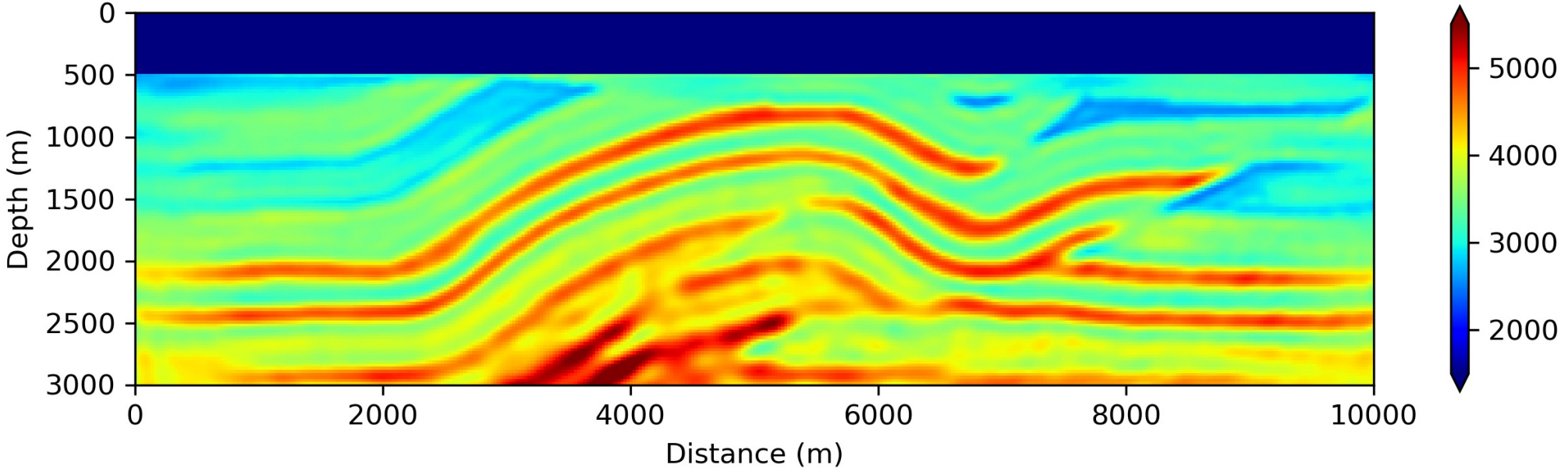
SWIT模型测试- SEG/EAGE Overthrust

初始速度模型



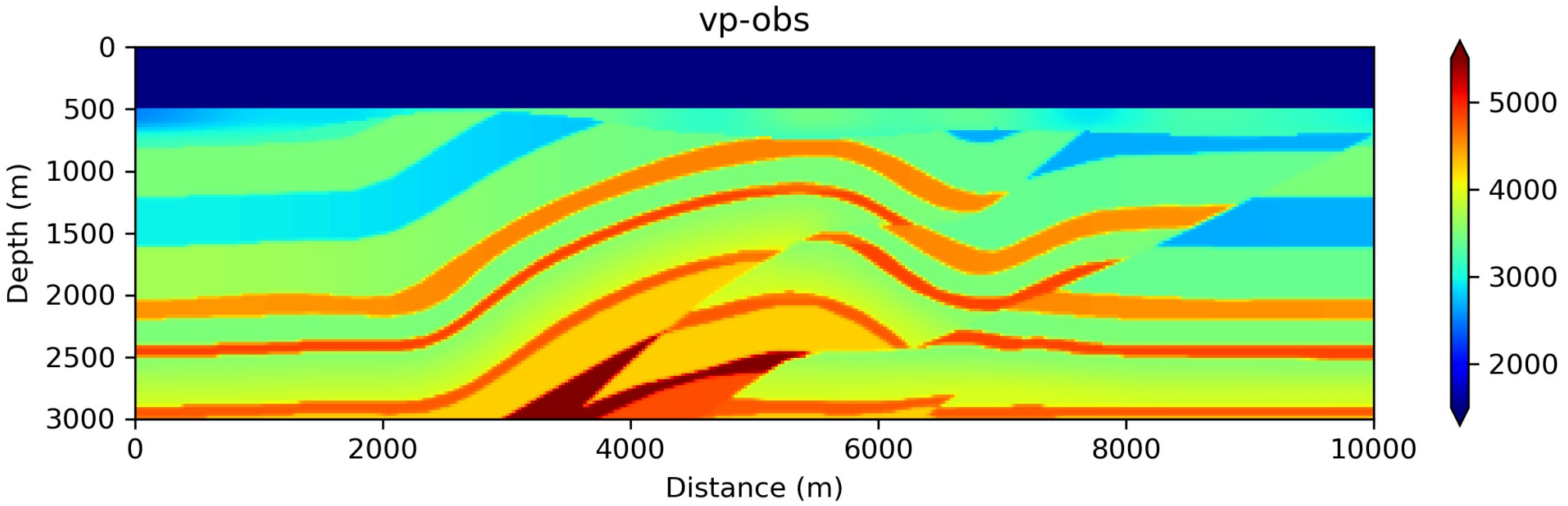
SWIT模型测试- SEG/EAGE Overthrust

反演速度模型 (40 次迭代)



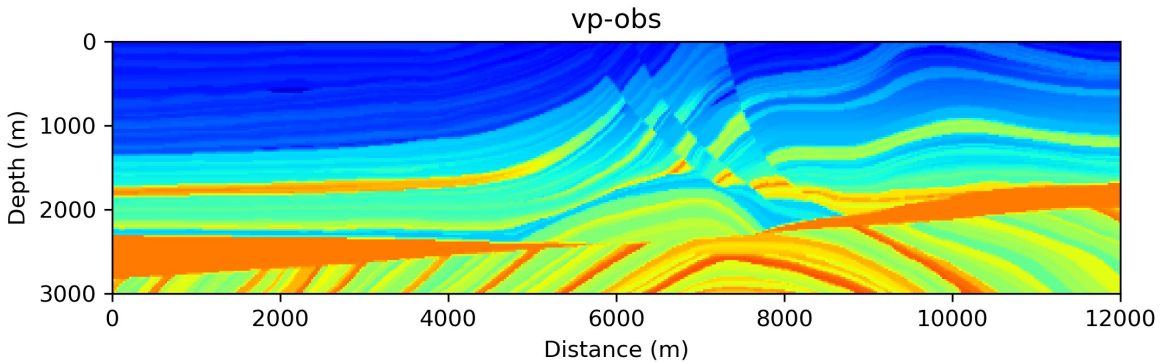
SWIT模型测试- SEG/EAGE Overthrust

真实速度模型

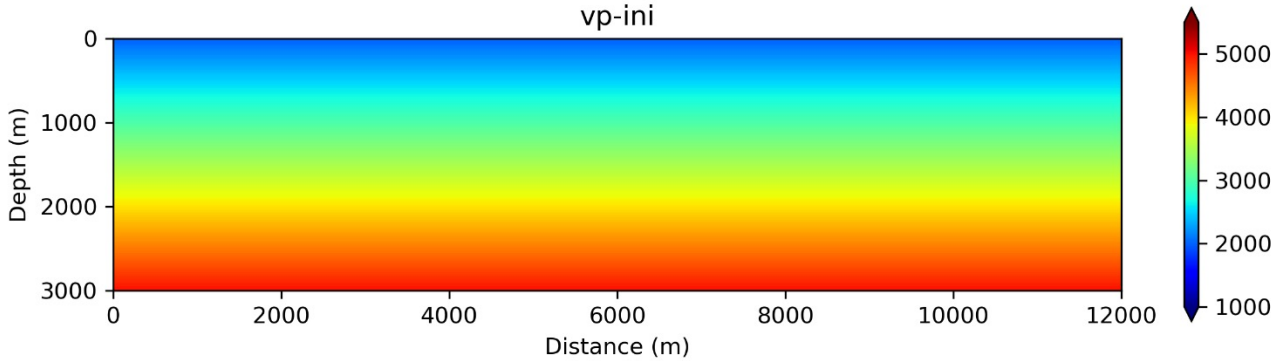


SWIT模型测试-1D初始模型

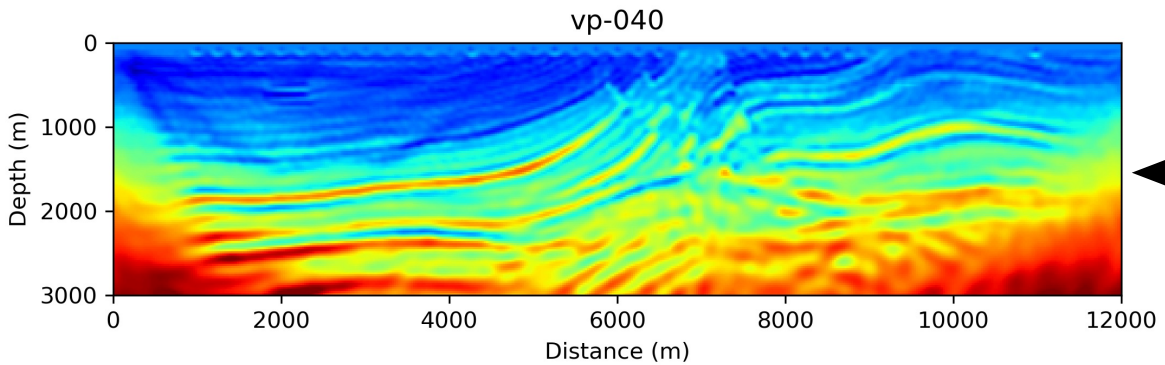
真实模型



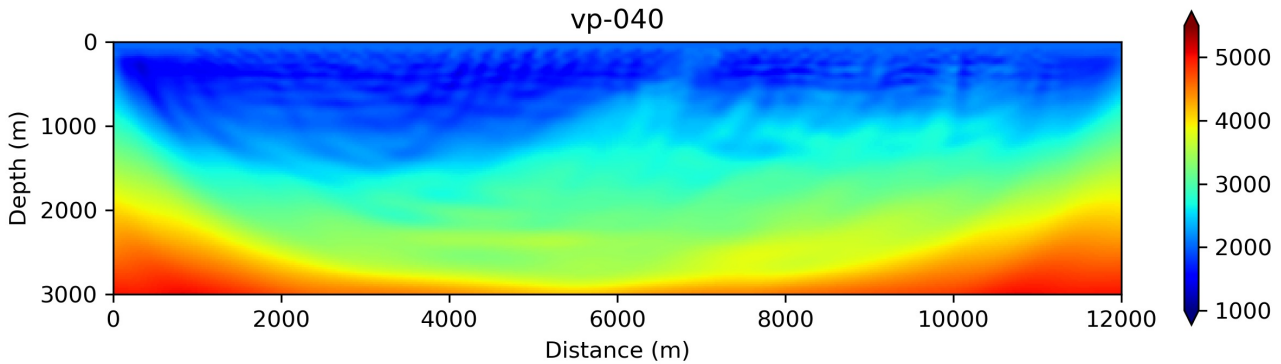
1D初始模型



Waveform-FWI

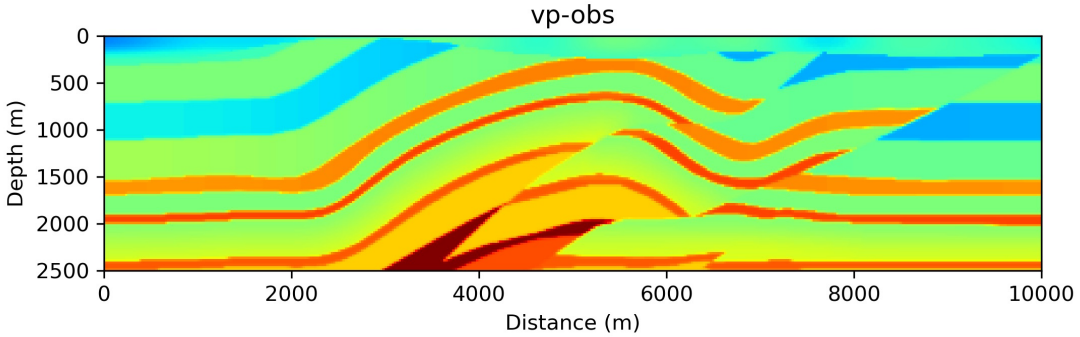


Traveltime-FWI

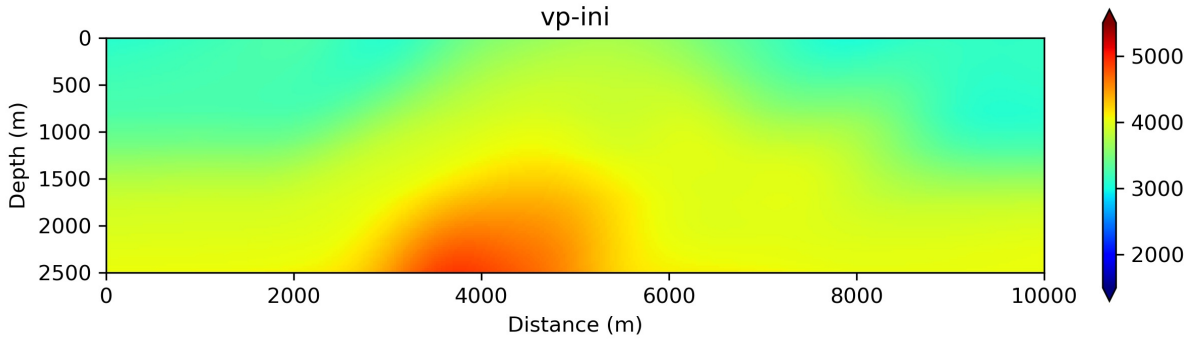


SWIT模型测试-多尺度分频带反演

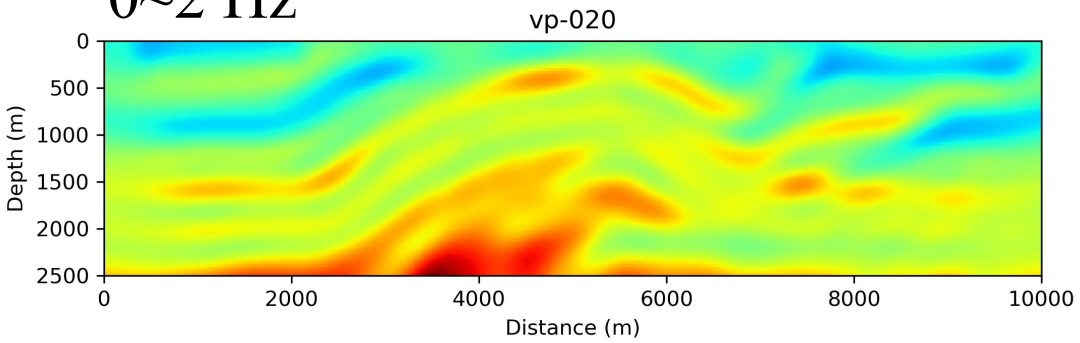
真实模型



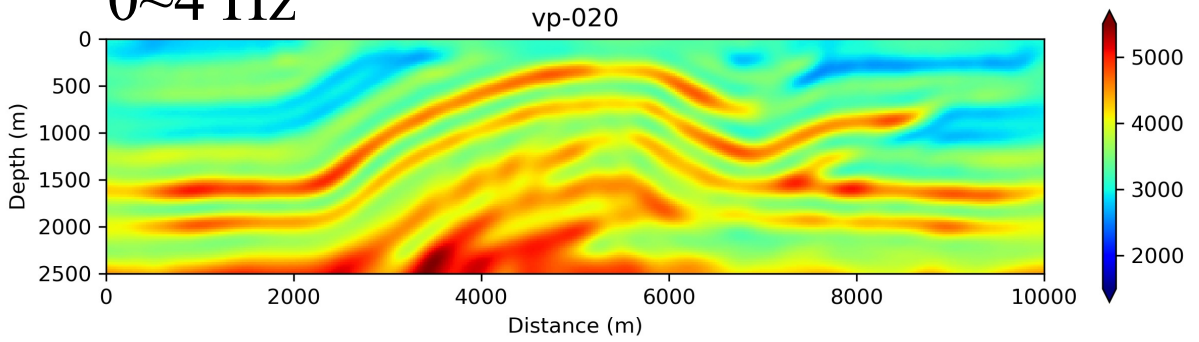
初始模型



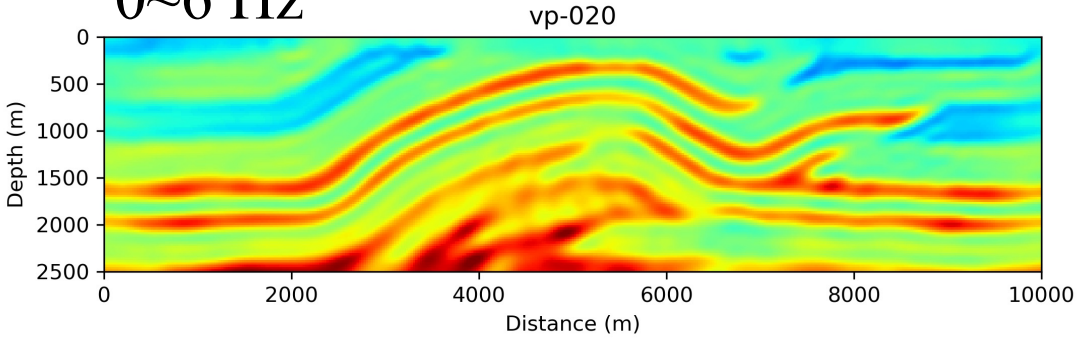
0~2 Hz



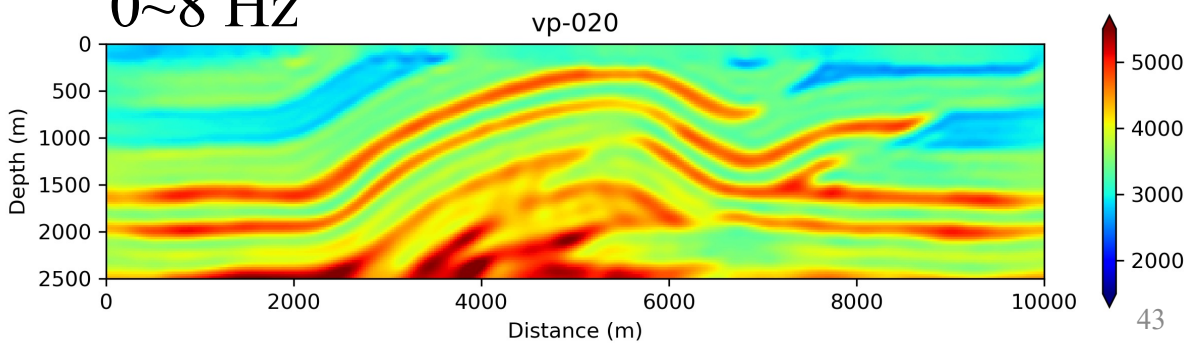
0~4 Hz



0~6 Hz



0~8 Hz



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我们十分感谢

- **Computational Toolkit** by Prof. Schuster
- **SeisFlows** by Dr. Ryan Modrak
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- 常凯博士、陈则强、邓宝帮助测试程序（中国科学技术大学）

References:

1. Li, H., Li, J., Liu, B., Huang, X. (2021). Application of full-waveform tomography on deep seismic profiling dataset for tectonic fault characterization. *International Meeting for Applied Geoscience & Energy*.

2. Schuster, G. T. (2017). Seismic inversion. *Society of Exploration Geophysicists*.

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谢谢大家

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