A Comparison of Airborne and Ground EM Data at a Calibration Site near the Grand Canyon

大峡谷附近一个校正区 航空和地面瞬变电磁数据的比较

L.J. Davis
贾瑞忠
R.W. Groom
Petros Eikon Inc. 加拿大

Purpose of Calibration Site
校准区的目的

Airborne TEM :
航空瞬变电磁法:

- **used extensively for locating conductors in mineral exploration**
- **广泛用于矿产资源勘查中, 寻找低 电阻异常**

- **can it be used for more quantitative interpretation and thus in a wider range of applications?**
- **是否可以定量解释，从而在更广泛的应用范围内使用吗？**

Quantitatively consistent with:

定量分析, 航空数据是否与

1) Ground TEM ？地面瞬变电磁数据

2) Geological information ? 地质资料

相符?

Calibration Study
校准过程

To compare data and structural results from
为了比较数据和构造资料, 它们来自于校准区内:

1) 2007 - Airborne surveys 航空勘测: MEGATEM, GEOTEM, VTEM

2) 2008 - ground TEM surveys 地面瞬变电磁勘测: extensive PROTEM (Geonics), small GDP-32 (Zonge)

3) 2008 - ground FEM systems地面频率域设备: VLF-R (2 frequencies), MaxMin (2 separations, 5 frequencies)

4) 2008 - drill logs, 钻探记录

over the calibration site.

Data thanks to Uranium One USA
数据由一个美国Uranium One 公司提供

Site　校准区位置

[from Google Earth]

- North of the Grand Canyon (Arizona Strip)

大峡谷北(亚利桑那地带)

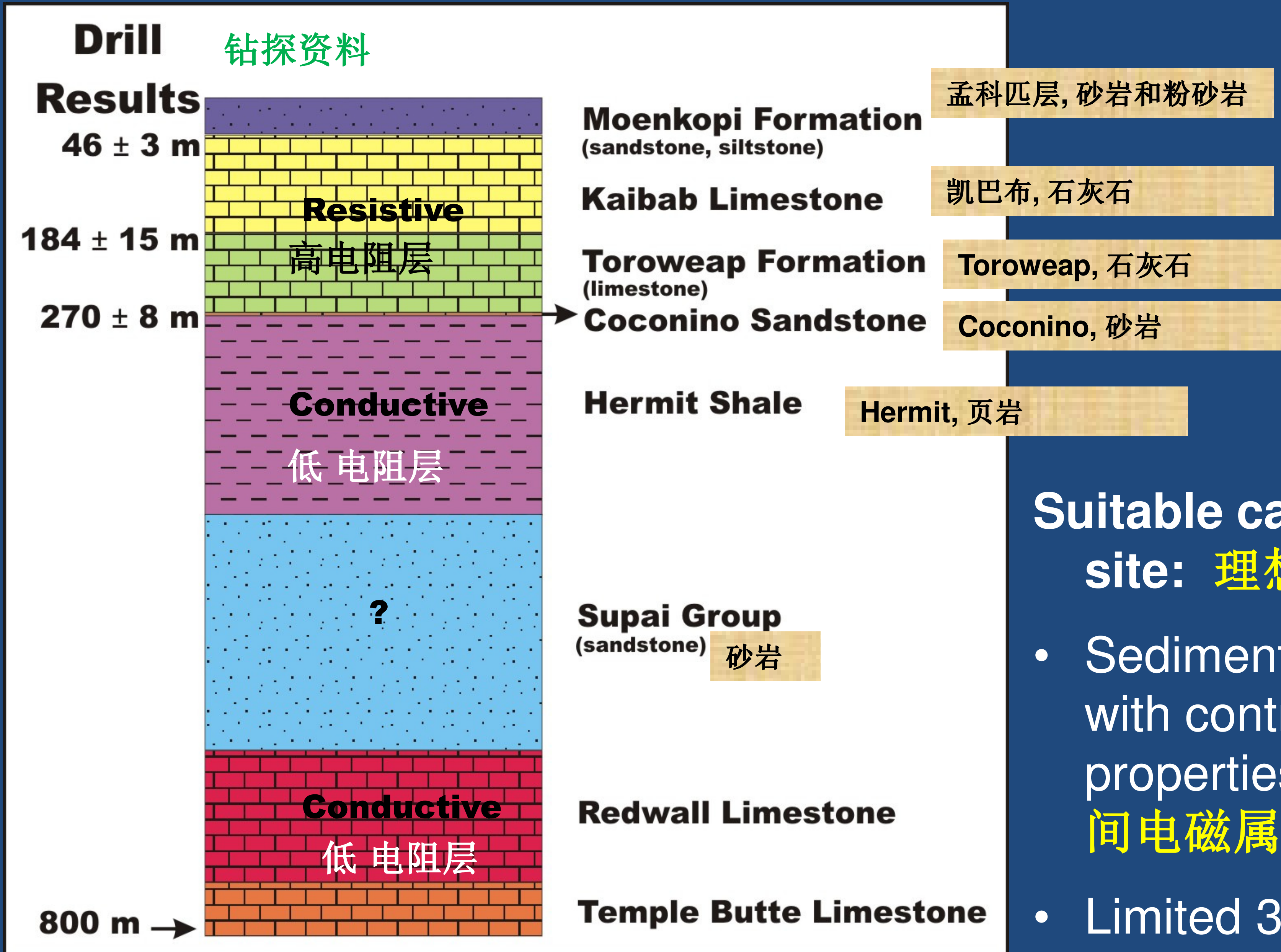
- 2005-2008: *active exploration for breccia pipe uranium deposits*

大量进行着角砾岩筒铀矿探测工作

Host environment:
a thick sequence of sedimentary rocks

背景地质：
较厚的沉积岩序列

Geology 地质层分布



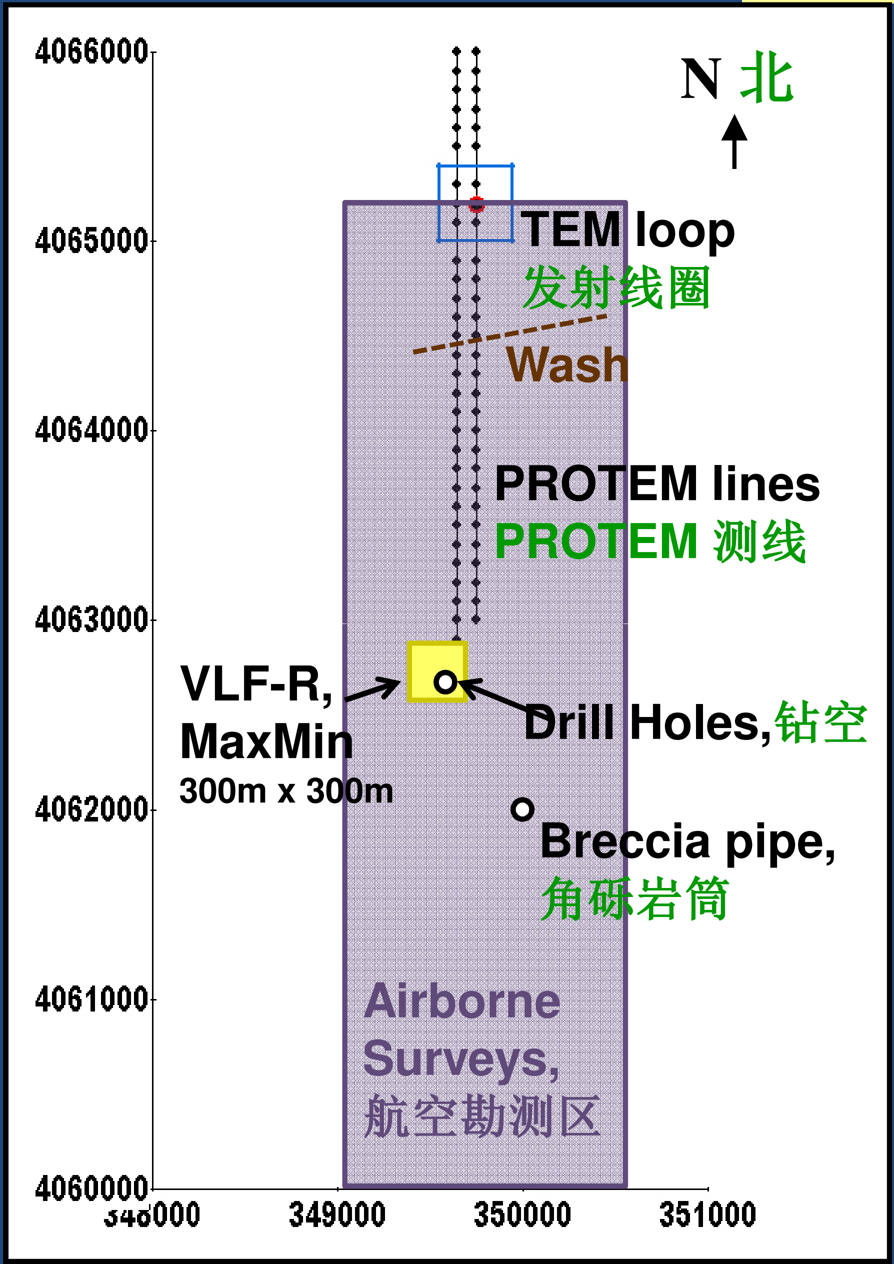
Suitable calibration site: 理想的校准区

- Sedimentary layers with contrasting EM properties 沉积层之间电磁属性差别明显
- Limited 3D structure

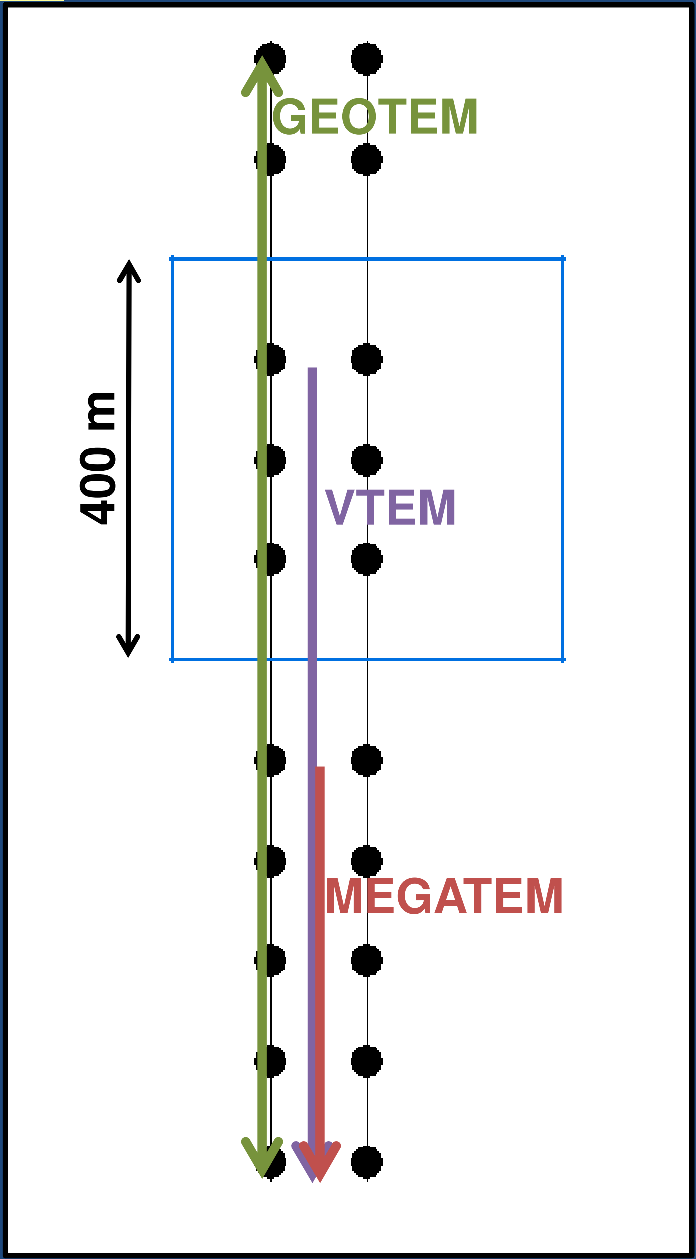
有限的三维结构

Survey Location

勘测区



所研究的测线

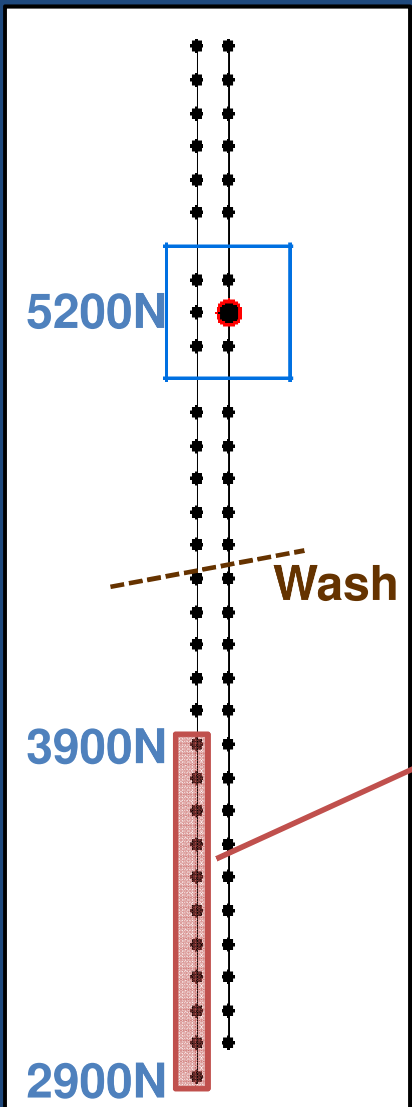


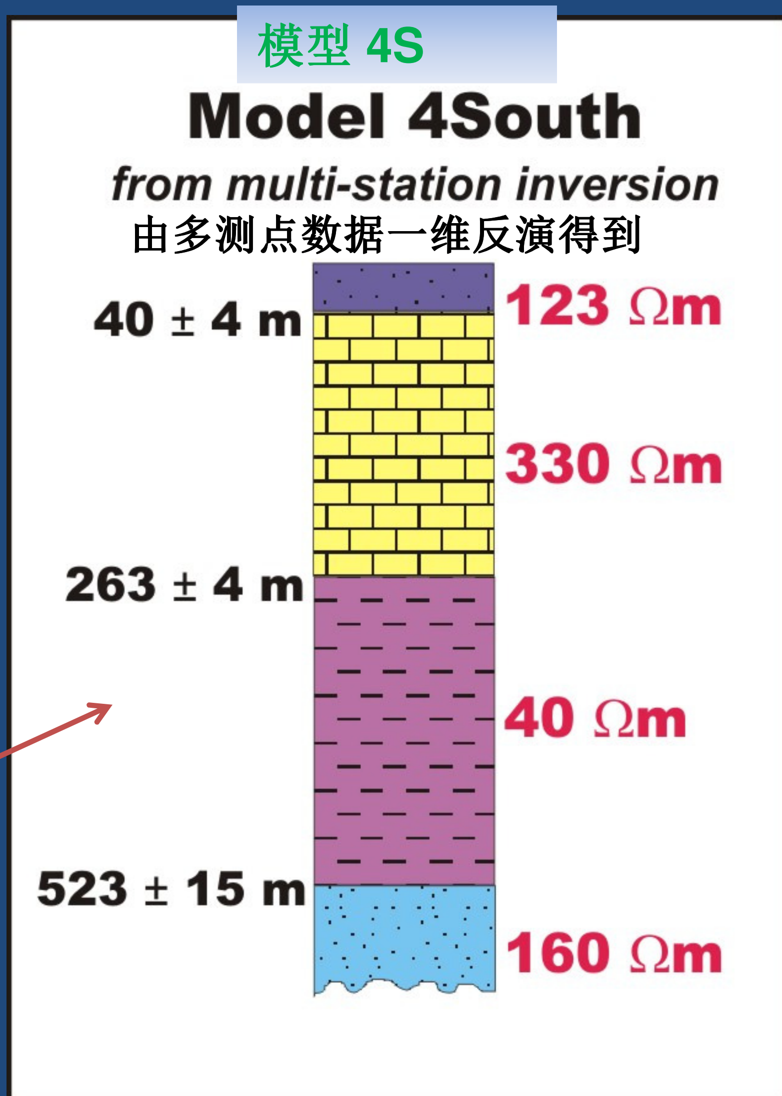
Calibration Area: 1.5 km x 5 km
校准区面积: 1.5 公里x5公里

Line Spacing: approx 100m
线距: 大约 100 米

Ground TEM: Model

地面瞬变电磁法: 模型





Ground Model 4South
from multi-station 1D inversion
using 11 wide-offset stations
(2900N-3900N).
地面模型 4S
由多测点数据一维反演得到，使用离发射线圈较远的11个站（2900N-3900N）

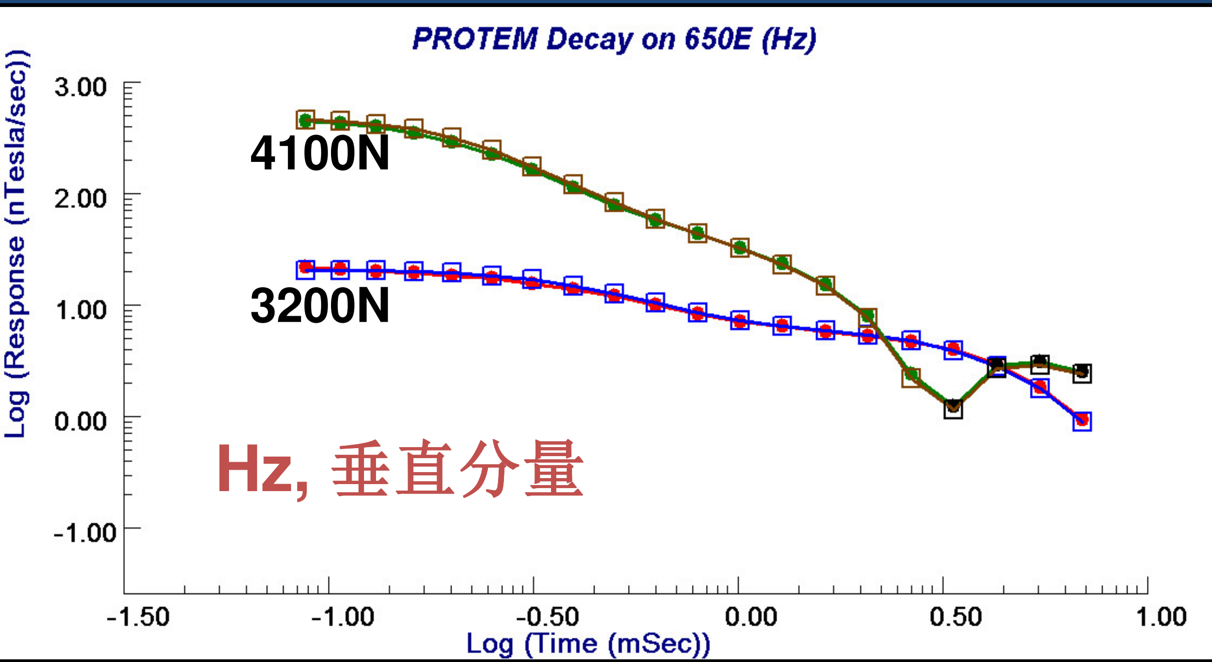
Model 4South fits Hx, Hz
across entire survey indicating
limited lateral variation.
在整个测区内，模型4South拟合x分量及z分量，表明横向变化有限。

Inloop and Short Offset Data
Provide less depth resolution
位于发射线圈内的及离发射线圈较近的数据对深层的分辨精度不高

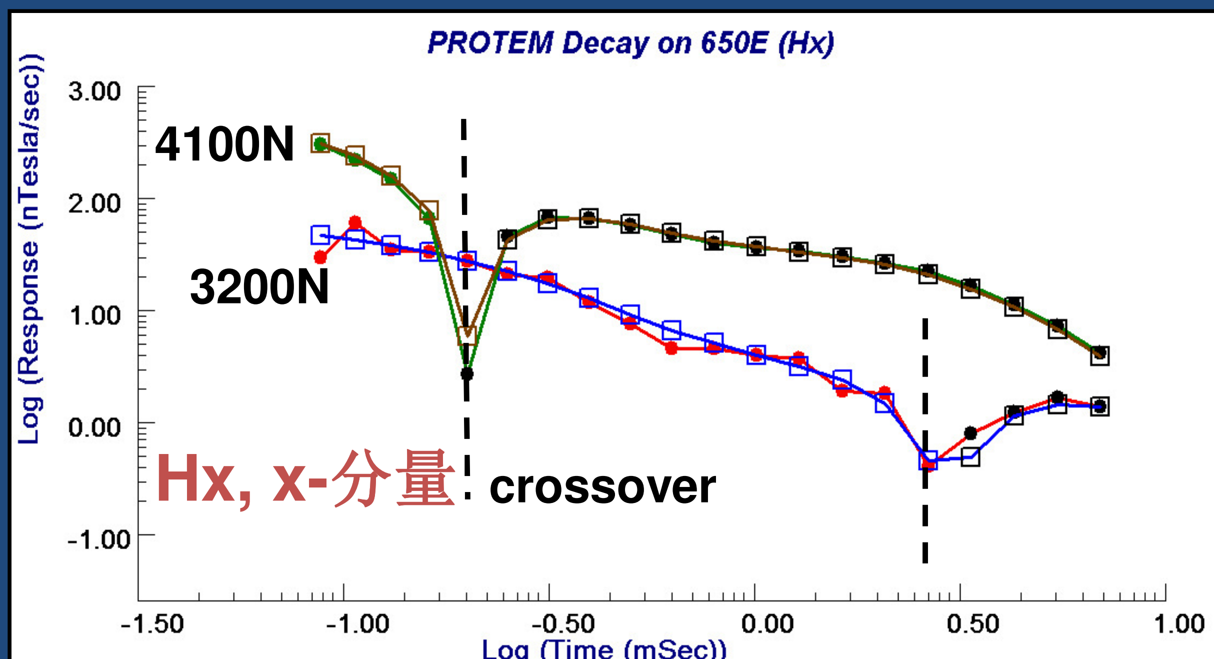
Modeling and inversion were performed using EMIGMA V8.6 *(PetrosEikon, 2009)*
建模和反演使用的软件: EMIGMA V8.6

Ground TEM: Model to Data

地面瞬变电磁法: 模型及数据

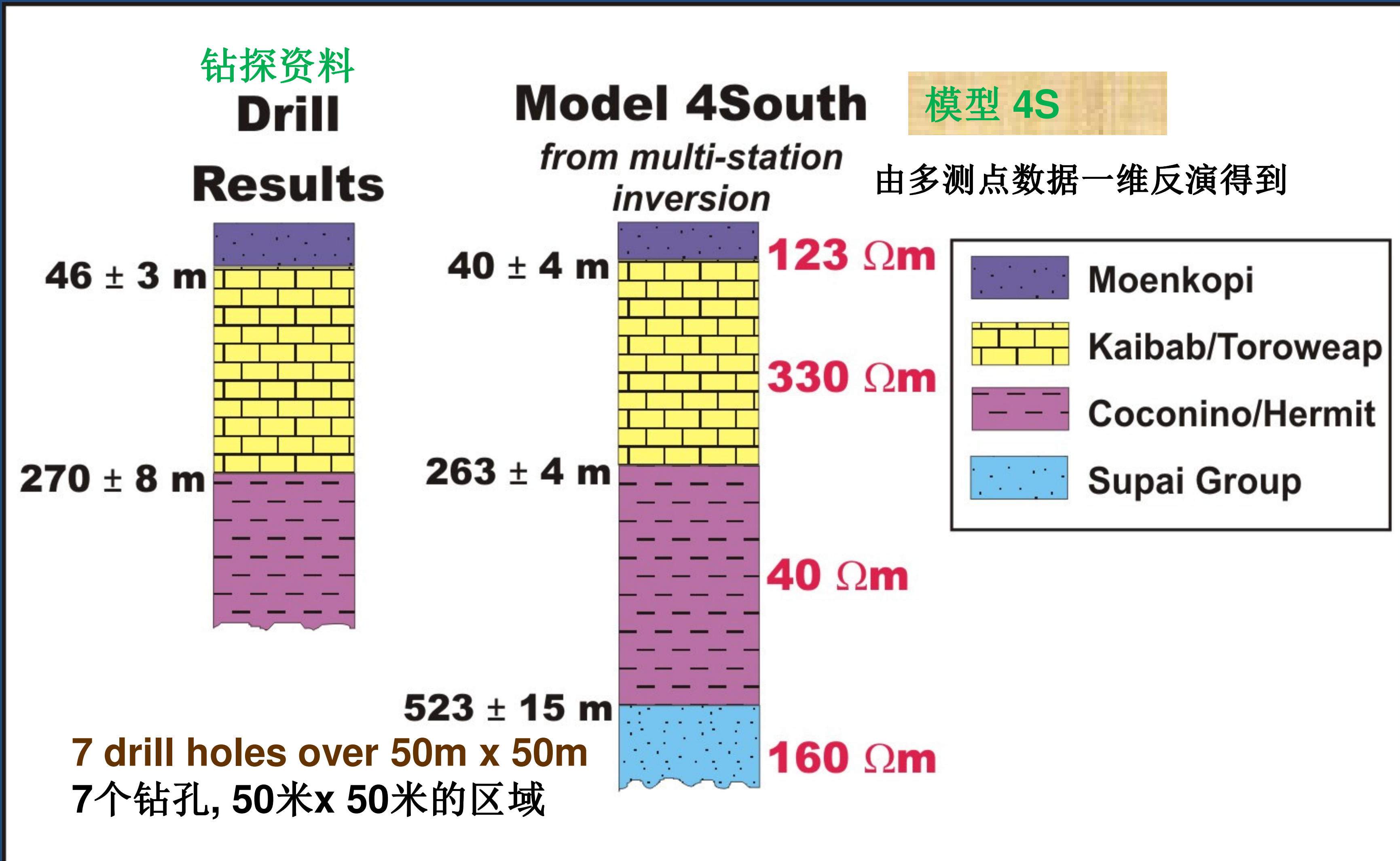


- Measured – 3200N 实测数据
- Model 4South – 3200N 模拟数据
- Measured – 4100N 实测数据
- Model 4South – 4100N 模拟数据



Comparison of Model with Geology

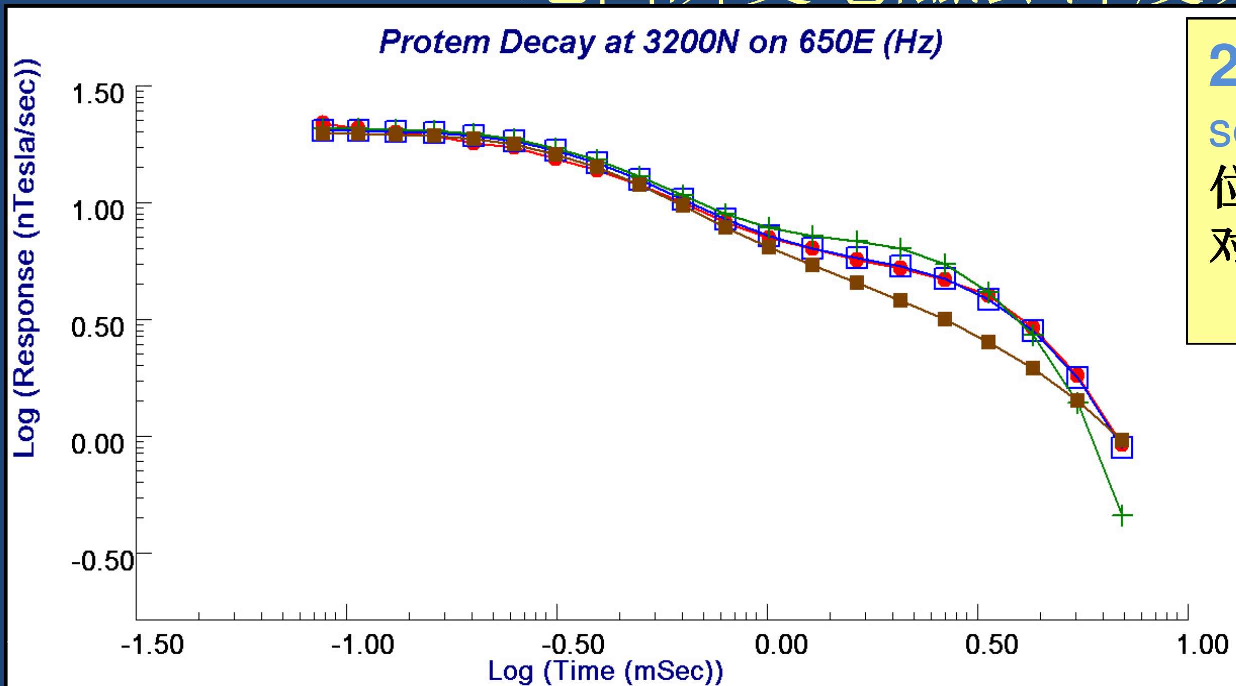
反演模型与地质资料的比较



- Drill results just south of ground survey confirm Model 4South
- Moenkopi resistivity (123 Ωm) of Model 4South close to resistivity determined from VLF-R and MaxMin data (thickness uncertain)
- 地面勘测区南部钻探资料认证模型4S
模型4S 中Moenkopi电阻率（123 Ωm ）接近由VLF- R和MaxMin数据得到的电阻率（厚度不明）

Ground TEM: Depth Resolution

地面瞬变电磁法:深度分辨精度



2 km south of Loop Center

sensitive to Supai Group

位于发射线圈中心2公里以南的测点对苏佩组较为敏感

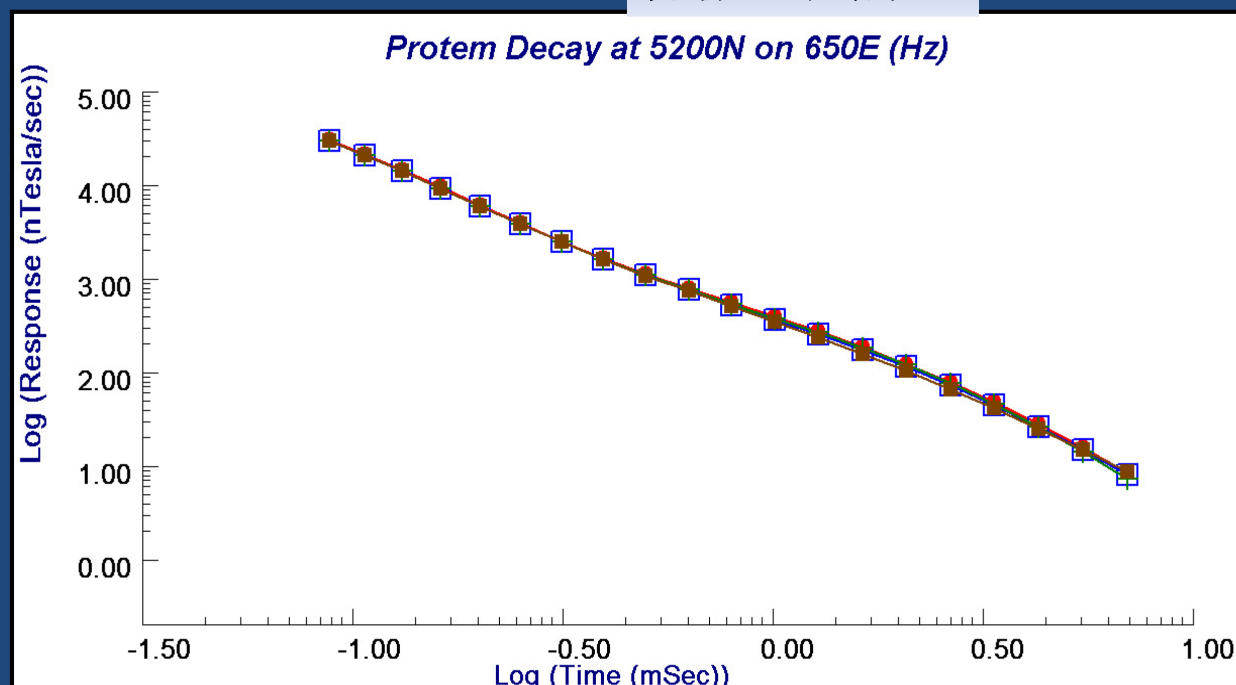
- **Measured** 实测
- **Model 4South** 模型 4S
- **No Supai Group** 无 Supai
- **Resistive Supai Group** 苏佩 电阻层

Center of Loop

Limited sensitivity to Supai Group

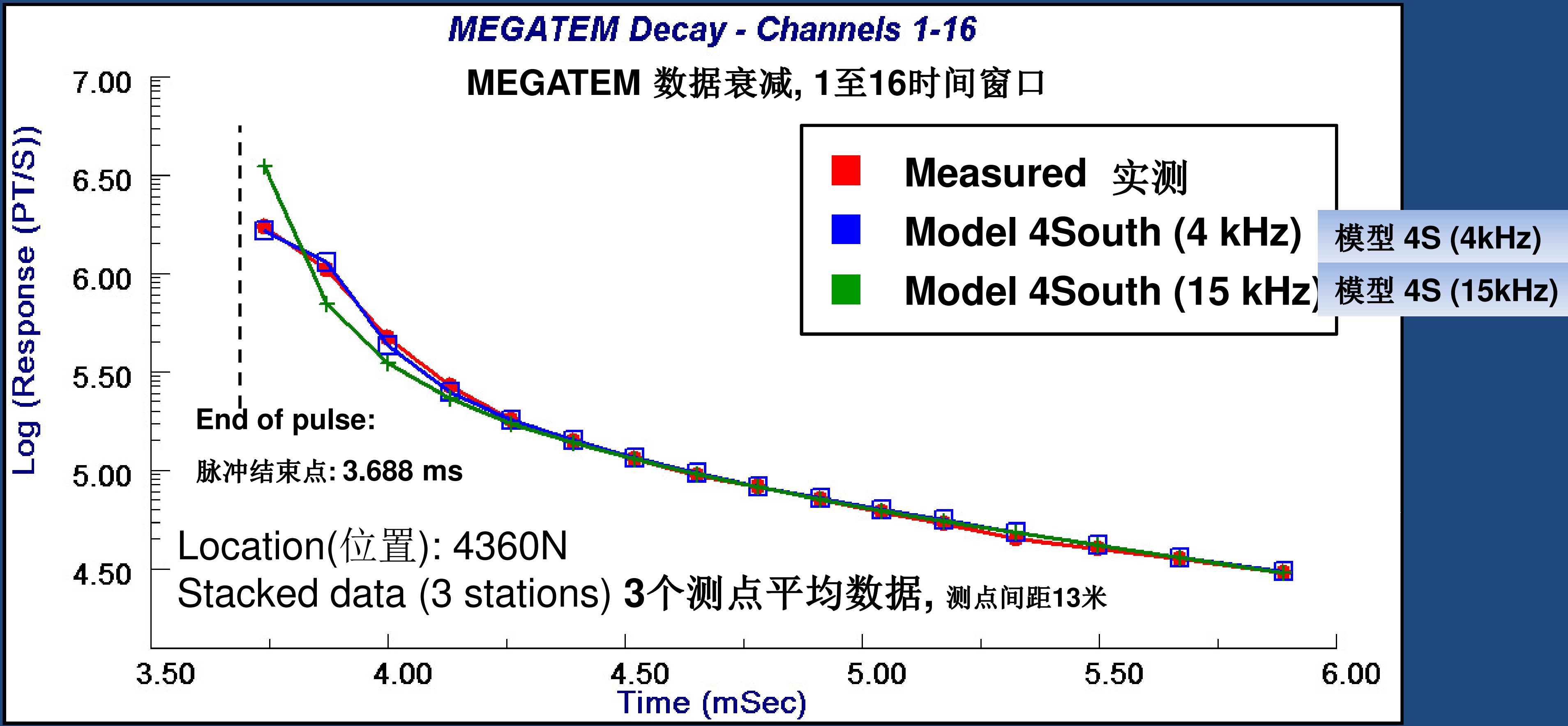
All 3 models fit equally well

位于发射线圈中心的测点
苏佩组并不敏感
3模型都拟合数据



MEGATEM: Fit to Ground Model

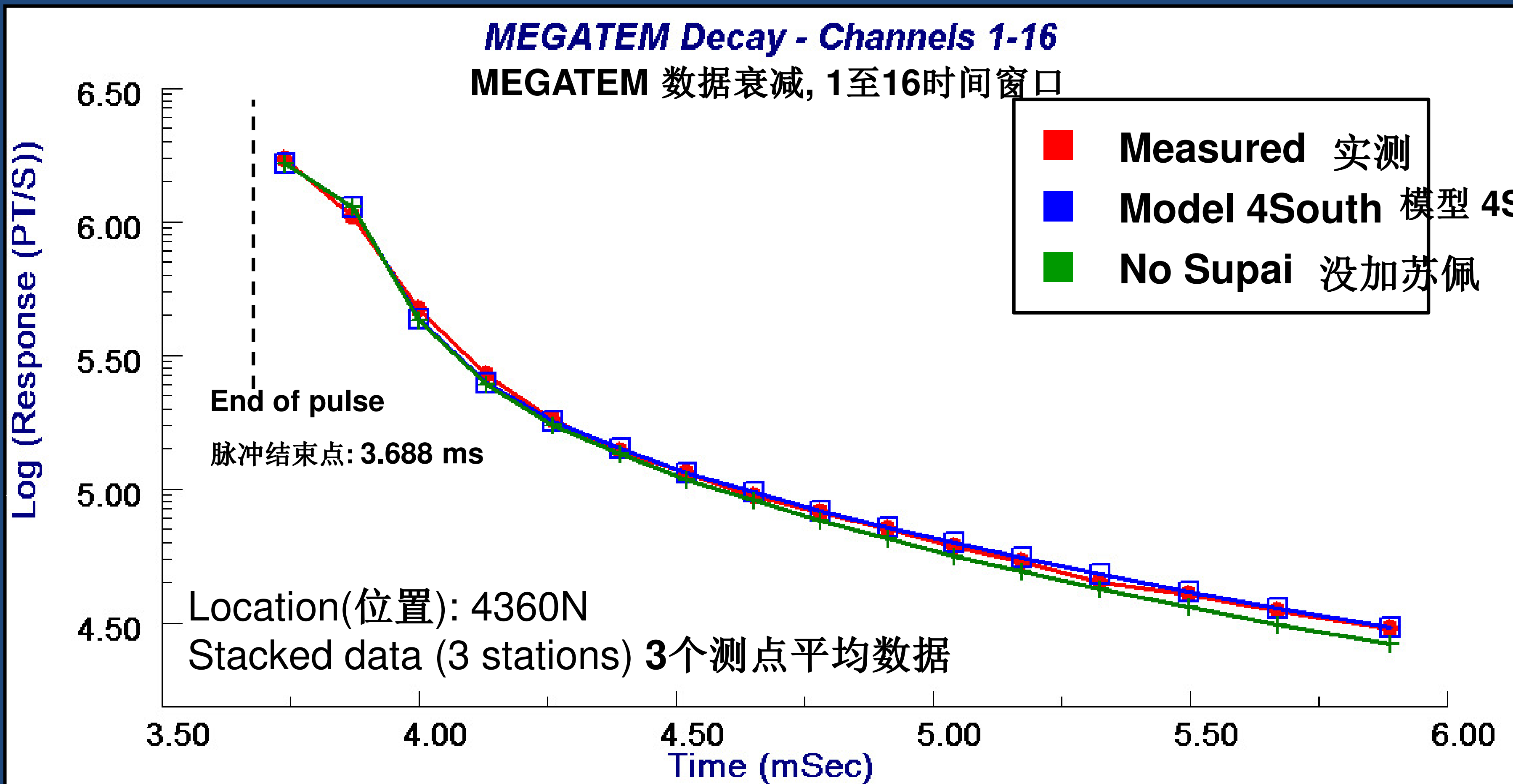
MEGATEM：与地面模型拟合



- Data rewindowed to have 20 off-time channels to increase shallow resolution
- Waveform files were used to study pulse width, dipole moment, window positions, Tx-Rx separation and system bandwidth. Accurate modeling requires precise knowledge of settings.
- Model 4South fits the MEGATEM data just south of the wash if an upper bandwidth frequency of 4 kHz is used.
- 为改善浅层分辨率重新定位窗口后得到20个断电时间窗口
  波形文件被用来查证脉冲宽度，偶极矩，窗口位置，发射器与接收器间距和设备带宽。准确建模需要确切了解仪器设备的设置。
  如果使用上限带宽为4 kHz频率, 模型 4S 拟合MEGATEM数据.

MEGATEM: Depth Resolution

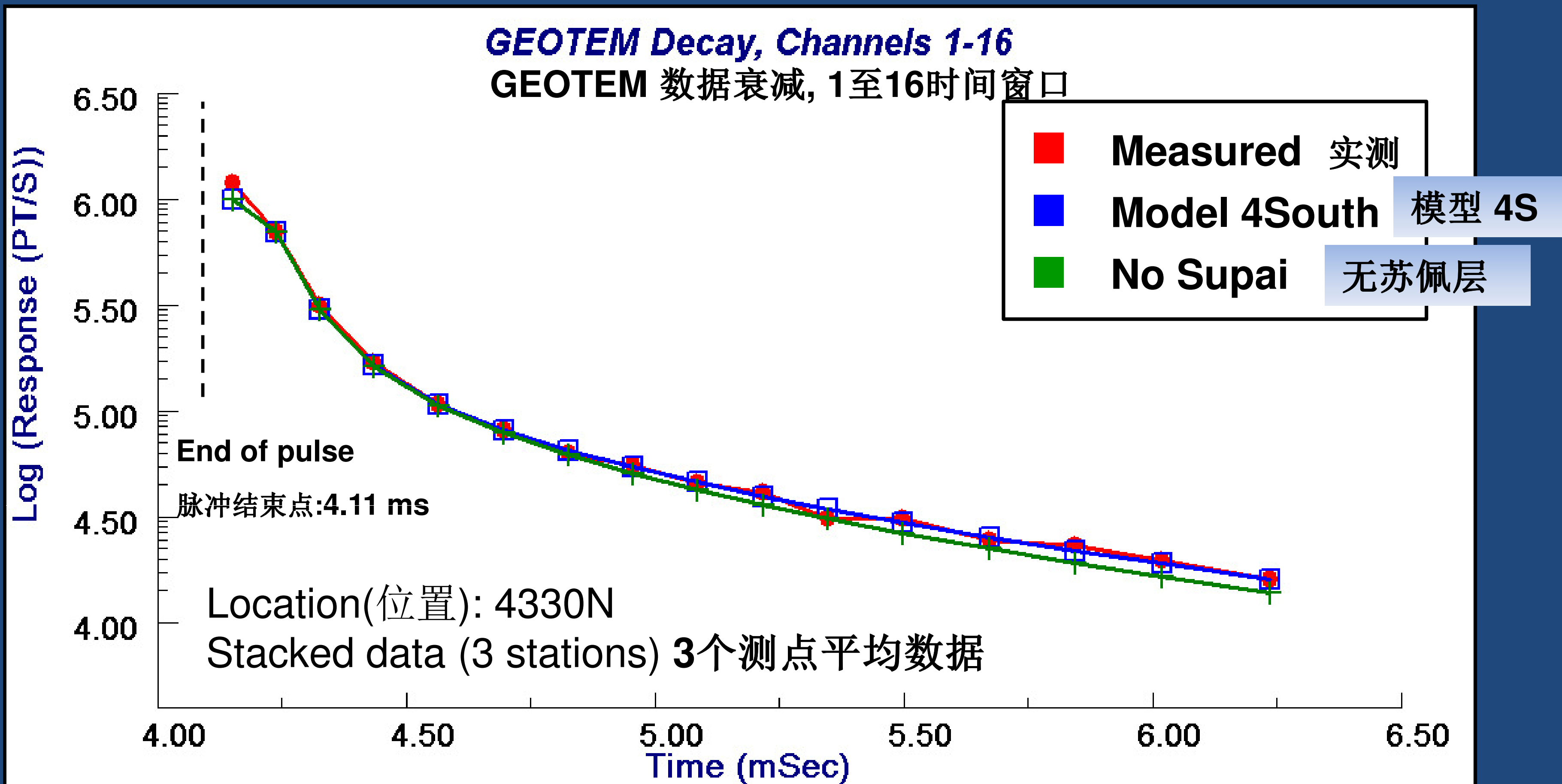
MEGATEM：深度分辨精度



Removing the fourth layer (Supai Group) has a small but definite effect on the response at mid to late times.
Note: This 4th layer has a significant effect on the ground response at wide offsets. MEGATEM offset is 128m only.
删除第四层（苏佩组）对中期到晚期时间窗口有一定的影响, 但影响不大。
注：第四层对地面数据影响显著，地面测量发射器与接收器间距较大。航空测量MEGATEM,发射器与接收器间距仅是128M。

GEOTEM: Fit of Ground Model

GEOTEM：与地面模型的拟合



Model 4South fits the GEOTEM reasonably well just south of the wash, provided an upper bandwidth frequency of 6 kHz is used. Again the Supai Group is required to fit late time.

模型 4S拟合GEOTEM数据，使用上限带宽6千赫的频率。苏佩层必须用来满足晚期时间窗口数据。

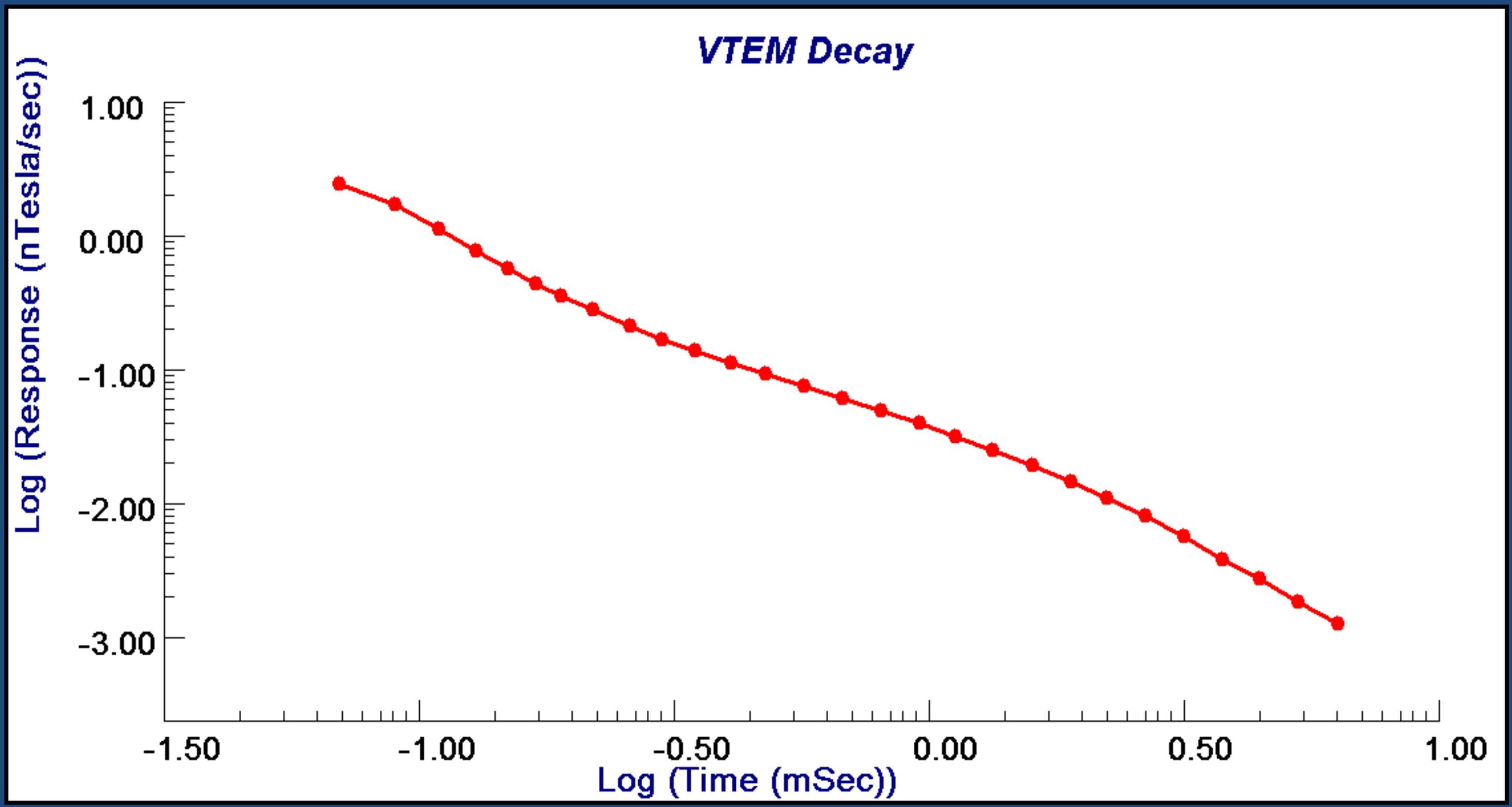
VTEM

时间窗口	MEGATEM	VTEM
Time Channels	20	28
Δz	128 m	0 m
Δx	46 m	0 m
Alt. of bird 接收器离地面高度	70 m	35 m

Potential advantages of VTEM system for resolving shallow structure:

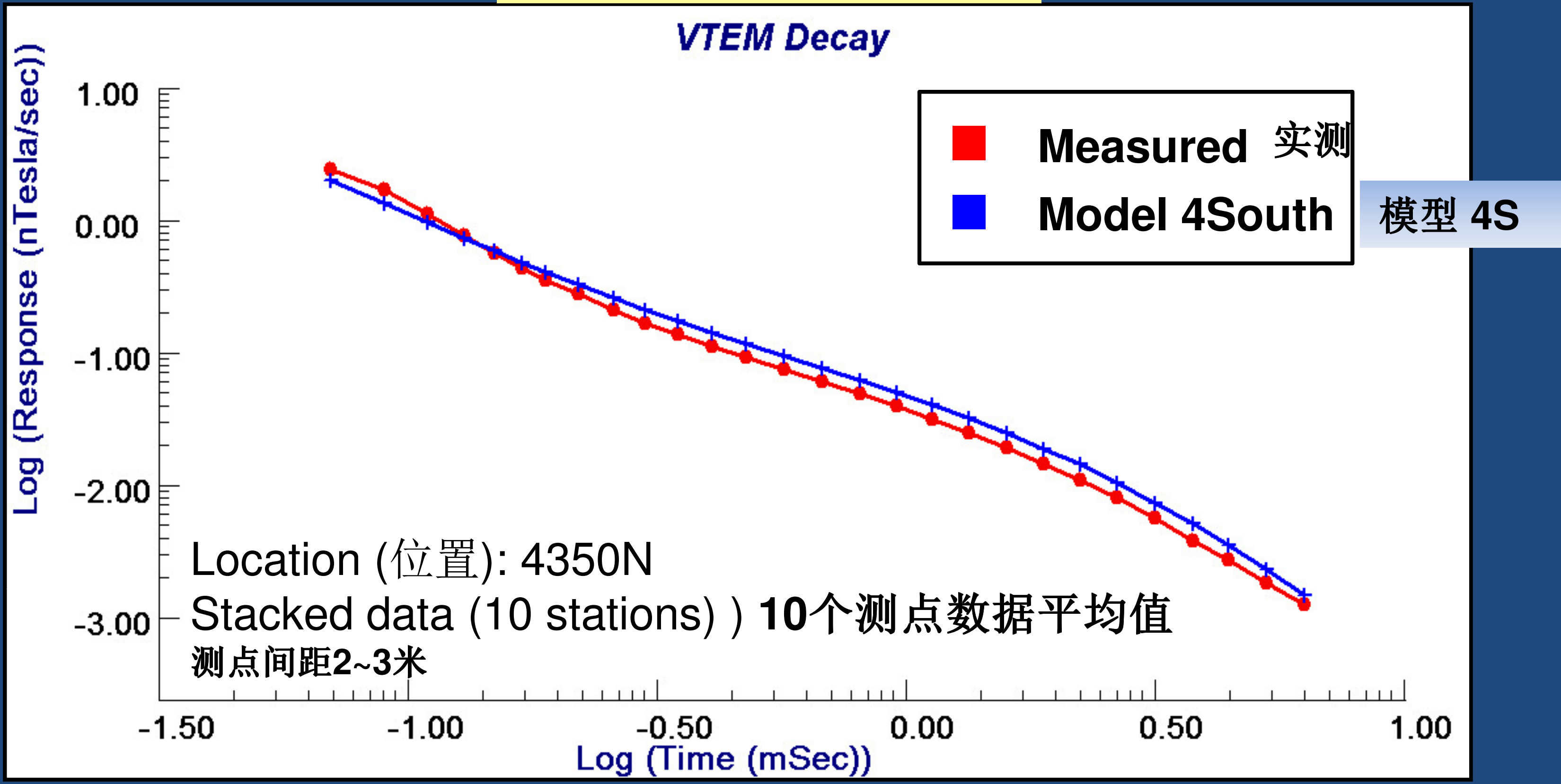
- Clean decays
- More time channels (28)
- Closer to ground

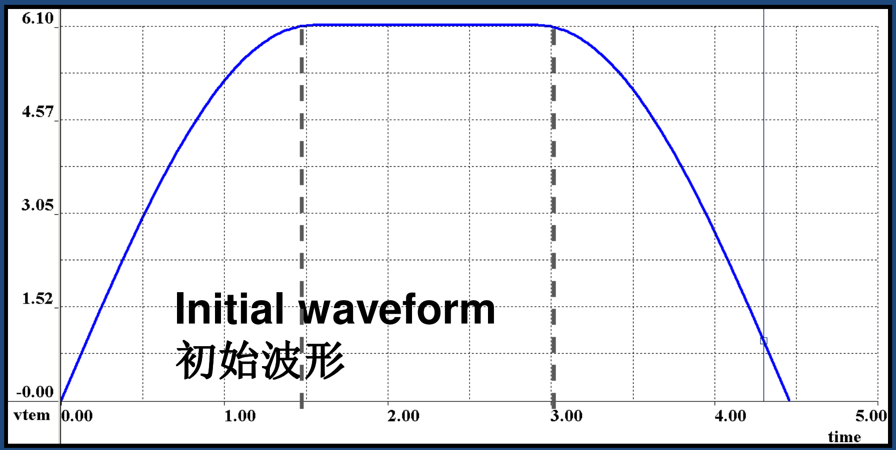
解释浅层结构, VTEM系统的潜在优势为:
衰变显著
较多的时间窗口（28）
更接近地面



VTEM: Initial Waveform

VTEM:初始波形

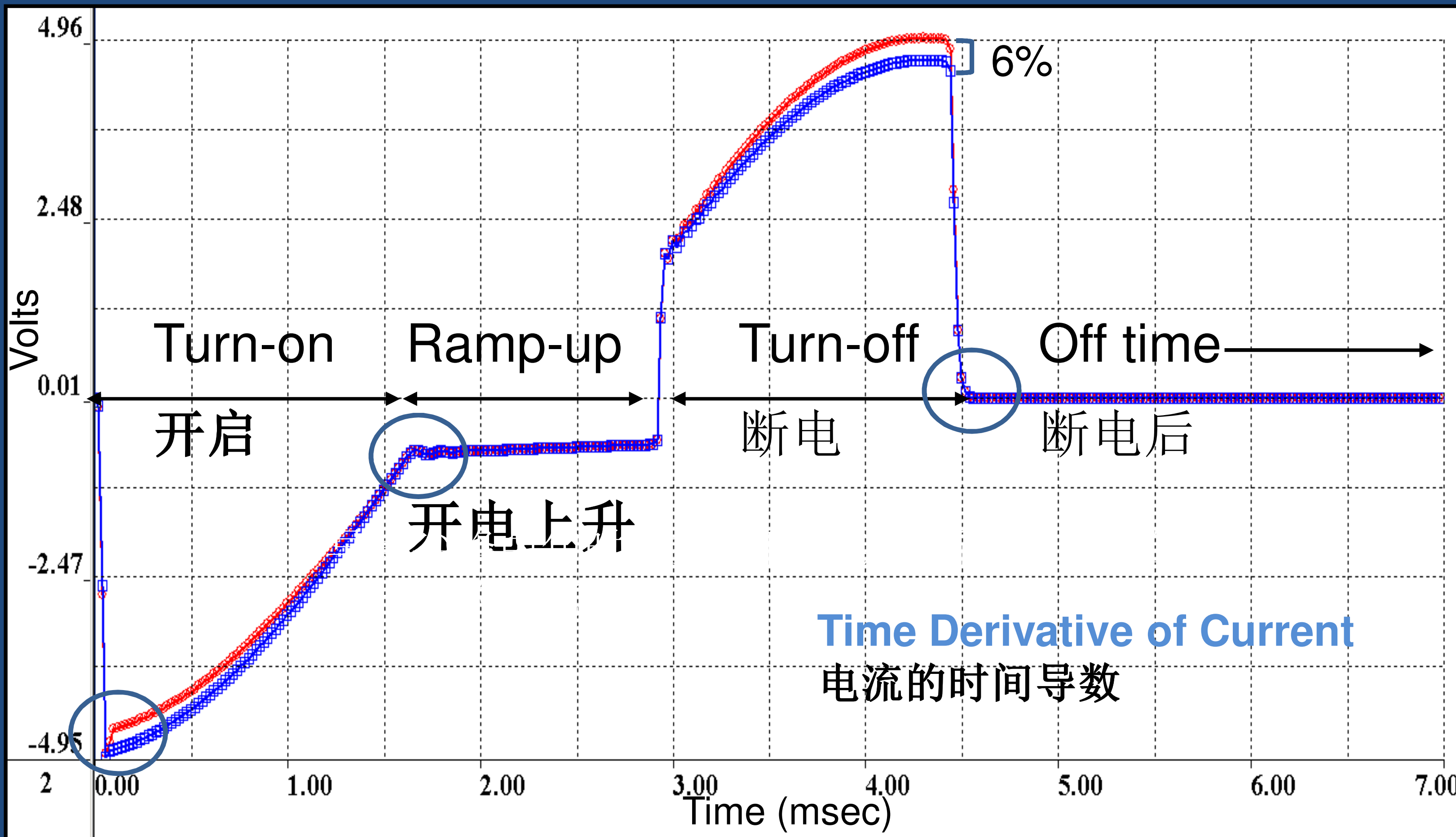


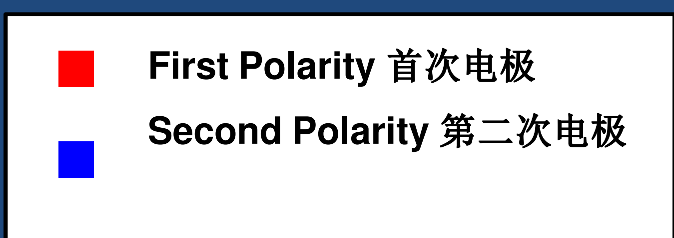


- Initial waveform for simulation: ¼ sine wave turn-on and turn-off
- Frequency = 1/(4*turnoff); turn-off time from waveform file
- Model 4South does not fit the data
- Too large at mid to late times, too small at early times
- 初步的模拟波形：¼正弦波开启和断电
  频率= 1 /（4*断电滞留时间; 断电滞留时间从波形文件得到
  模型 4S 不拟合合数据中晚期窗口数据过大，早期窗口数据太小

VTEM: Waveform File

VTEM：波形文件

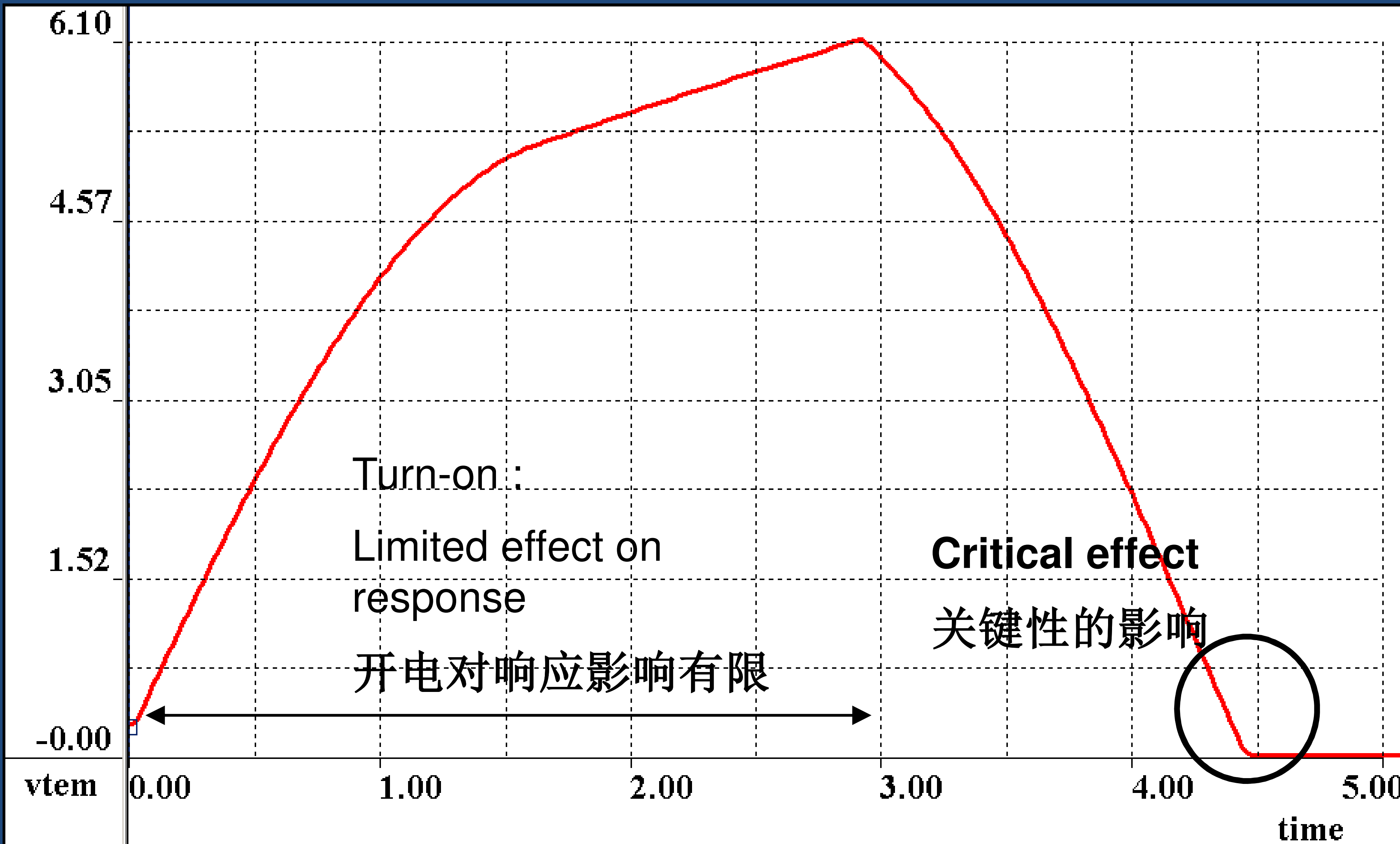




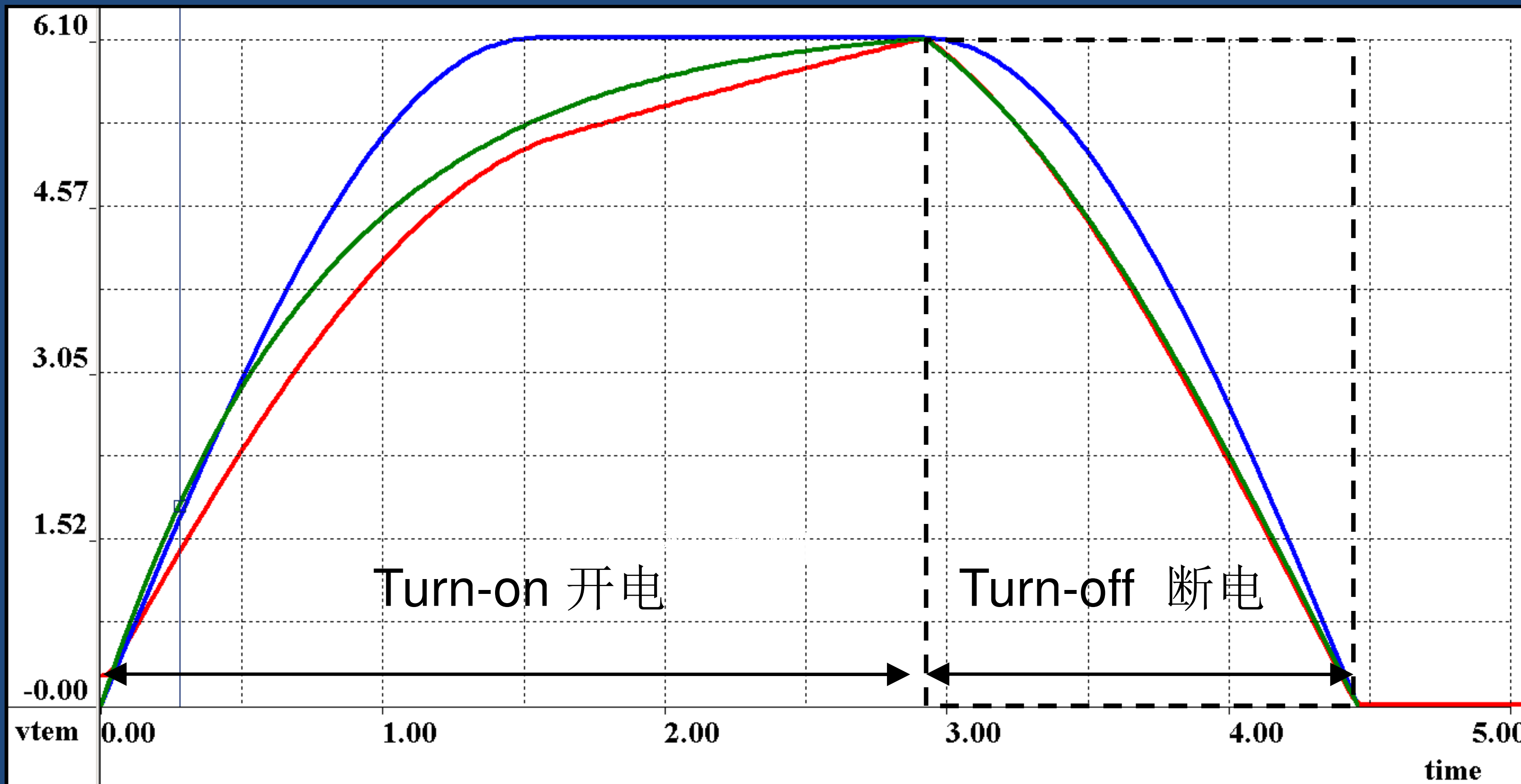
The system uses a bi-polar waveform, stacking measurements from both polarities.
该系统采用了两次电极的波形，综合两次的测量。
Bandwidth of early time spike not consistent with the bandwidth of the mid on-time ringing and early off-time response.早期尖峰的带宽与中期开电振荡和早期断电响应的带宽不一致。

VTEM: Integrated Waveform

VTEM：积分后得到的波形



VTEM: Integrated Waveform
VTEM：积分波形



Integrated Waveform 积分波形

Initial Waveform: Quarter sine turn-on and turn-off

初始波形: ¼正弦波开启和断电

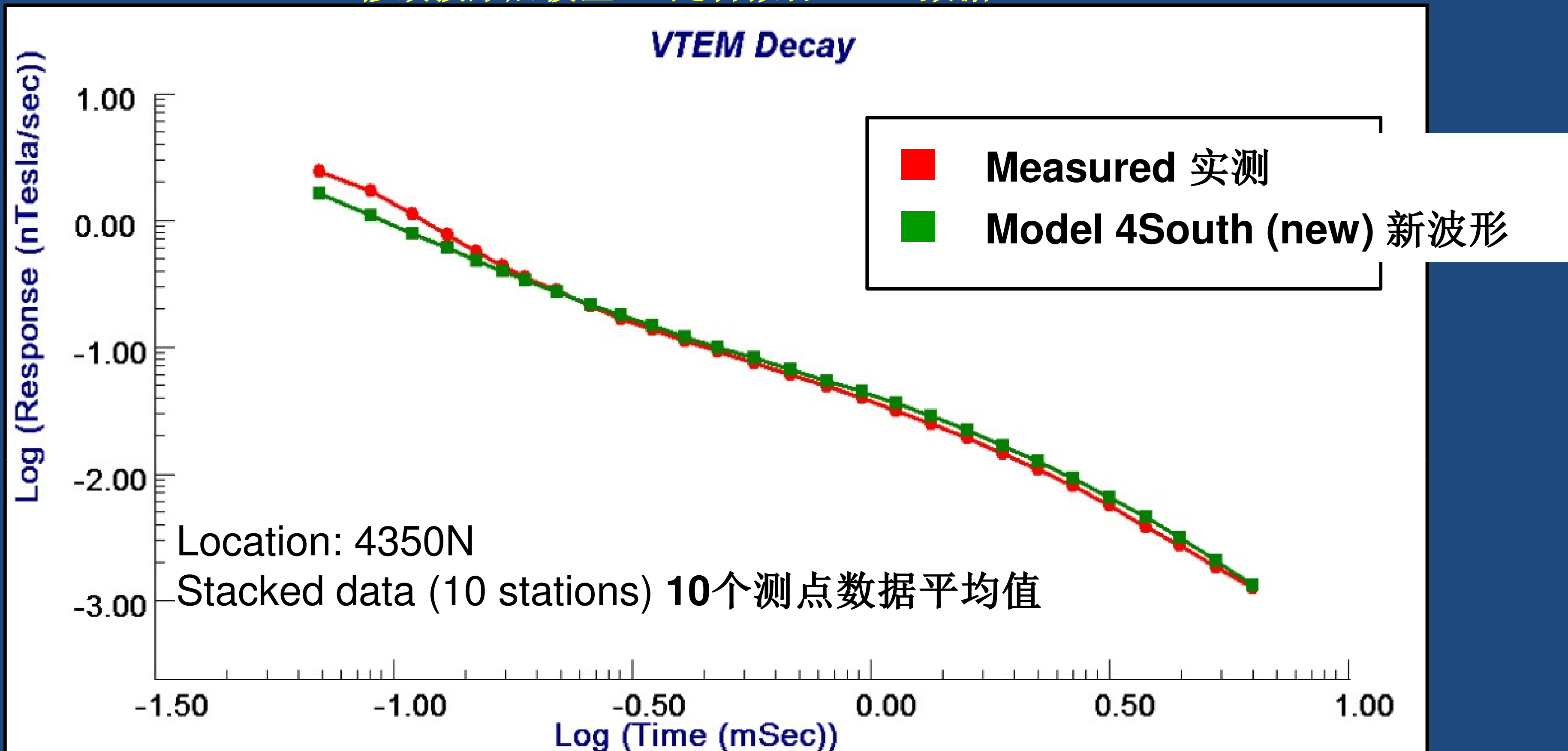
Modified waveform : turn-on : $f(t) = A\,(1-e^{-t/\tau})$

turn-off : 77% of ¼ a quarter sine

修正波形:开电: $f(t) = A\,(1-e^{-t/\tau})$,断电: 77% 的 ¼正弦波形

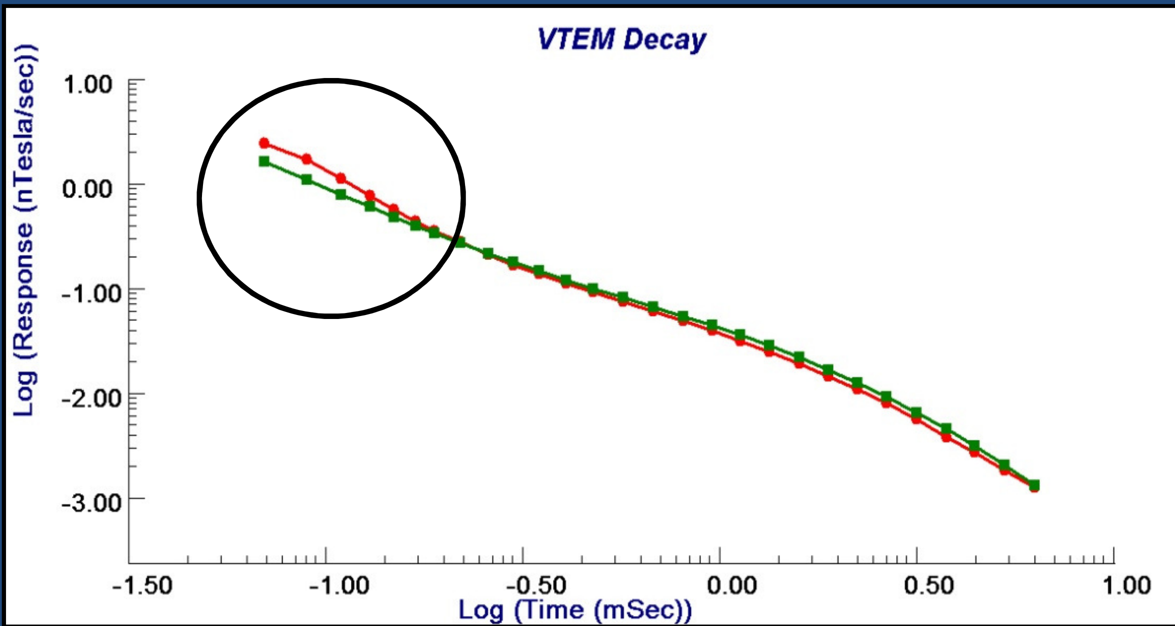
VTEM: New Waveform

Will Model 4South fit the VTEM data with the modified waveform?
修改波形后模型4S 是否拟合VTEM数据？



- With new waveform representation, Model 4South still a poor fit, especially at early times
- 修正波形后，模型4S仍然不能很好地拟合数据，尤其是在早期时间窗口

VTEM



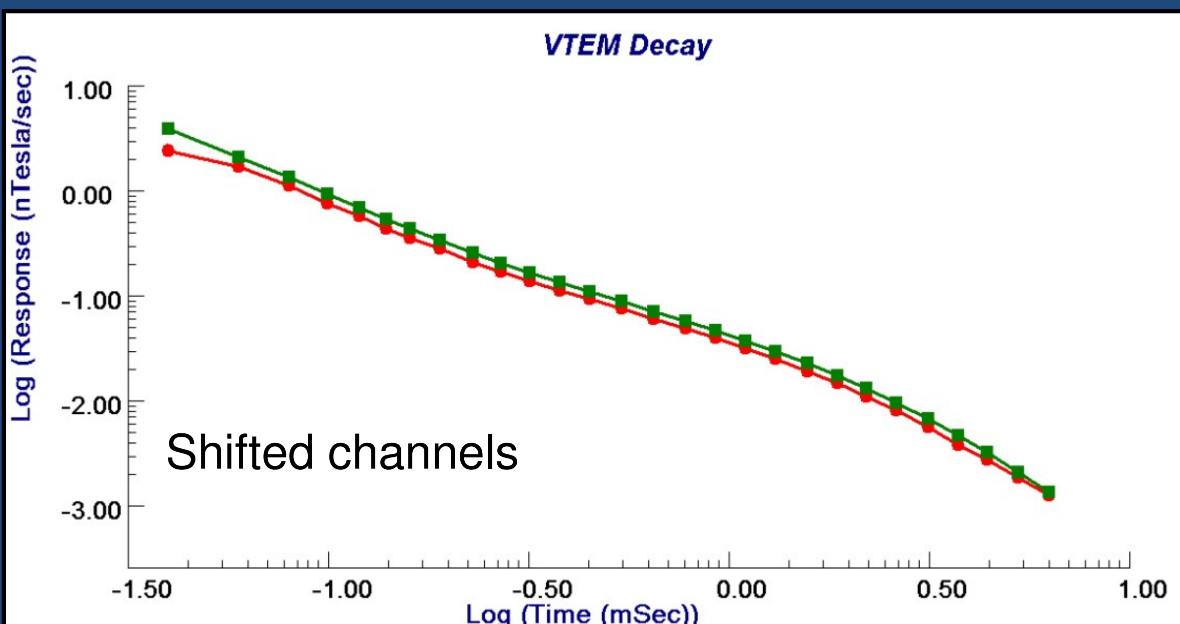
Early-time misfit:

早期时间误差:

- Time channel positions ?
- 时间窗口定位?

Measured 实测

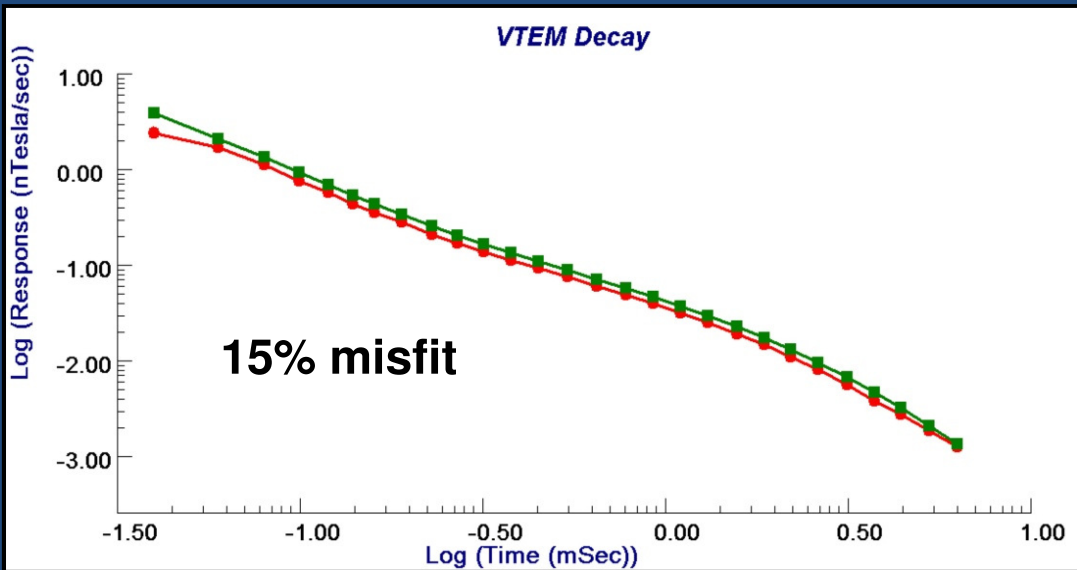
Model 4South (new) 模型 4S

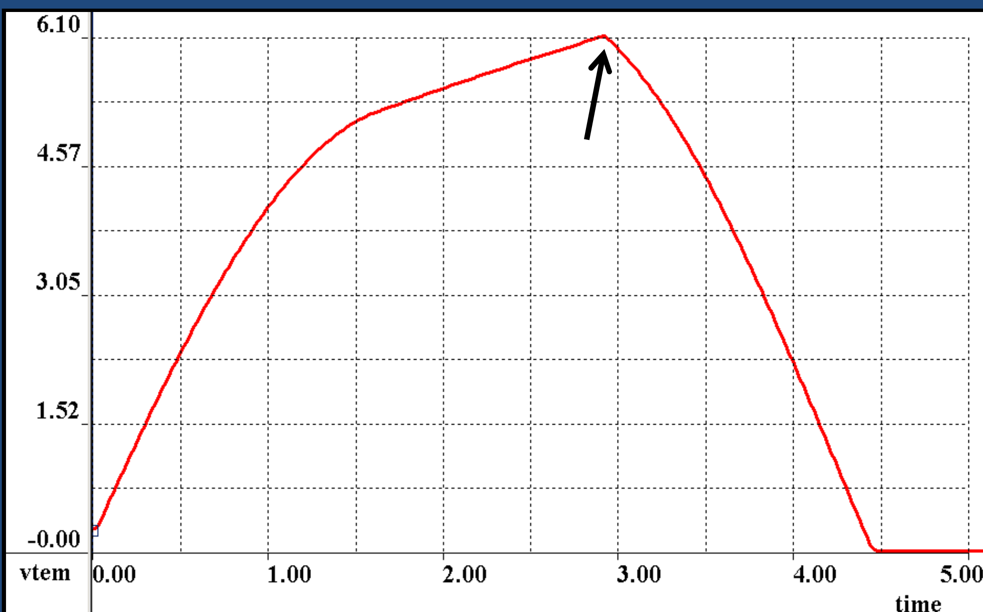


Time channels shifted 30 μs earlier: 15% misfit across Channels 2-28

时间窗口向前移动30毫秒
早期窗口2-28 数据误差15%，

VTEM





- How are the data reduced by dipole moment?
- Where in the cycle is the current determined for normalization?
- How are the differences in the two polarities accounted for?
- 如何消除偶极矩的影素？
  用来归一的电流在周期何处？
  两次电极的差异原因何在？

VTEM may provide better shallow discrimination than fixed-wing airborne systems. However, we cannot use it quantitatively without more knowledge of system parameters.

VTEM可能比固定翼飞机机载系统提供更好的浅层分辩精度。但是，但定量分析需确切地知道系统参数。

Conclusions
结论

Accurate modeling of the airborne response depends on precise knowledge of system parameters. These include pulse width, exact window locations, waveform details, and impulse response of the receiver coils.

•MEGATEM and GEOTEM calibrate with the ground data provided upper bandwidths of 4 kHz and 6 kHz are used.

•VTEM may calibrate with other data but more information on system settings is required, such as how the data are reduced by dipole moment and possible errors in the positions of the time channels.

•This information would assist us in accurately modeling the VTEM response.

•航空数据的准确建模处理取决于系统参数的确切确了解。这些参数包括脉冲宽度，确切的窗口位置，波形细节，并接收线圈的脉冲响应。

若使用上限为4 kHz和6 kHz的带宽。MEGATEM和GEOTEM数据可与地面数据校准提供,

VTEM可与其他数据校准，但需要系统设置的详细信息，如偶极矩因素是如何消除的, 及可能出现的时间窗口的定位误差。

这些信息将有助于对VTEM数据的准确建模。

We would like to thank Uranium One USA for the data, and acknowledge Petra Web, Ron Haycock, and Roger Holland for their assistance with this work.

For a complete report email: laura@petroseikon.com

感谢美国*Uranium One*公司提供数据，并感谢*Petra Web, Ron Haycock, and Roger Holland*协助这项工作。

若索取更完整的报告,请致电子邮件：laura@petroseikon.com