School of Earth & Environment
UNIVERSITY OF LEEDS

InSAR observations of post-rifting deformation around the Dabbahu rift segment, Afar, Ethiopia

Ian Hamling[1,2], Tim Wright[2], Laura Bennati[3], Eric Calais[3], Elias Lewi[4], Carolina Pagli[2]

1. GNS Science; 2. University of Leeds;

3. Purdue University; 4. Addis Ababa University.

School of Earth & Environment
UNIVERSITY OF LEEDS

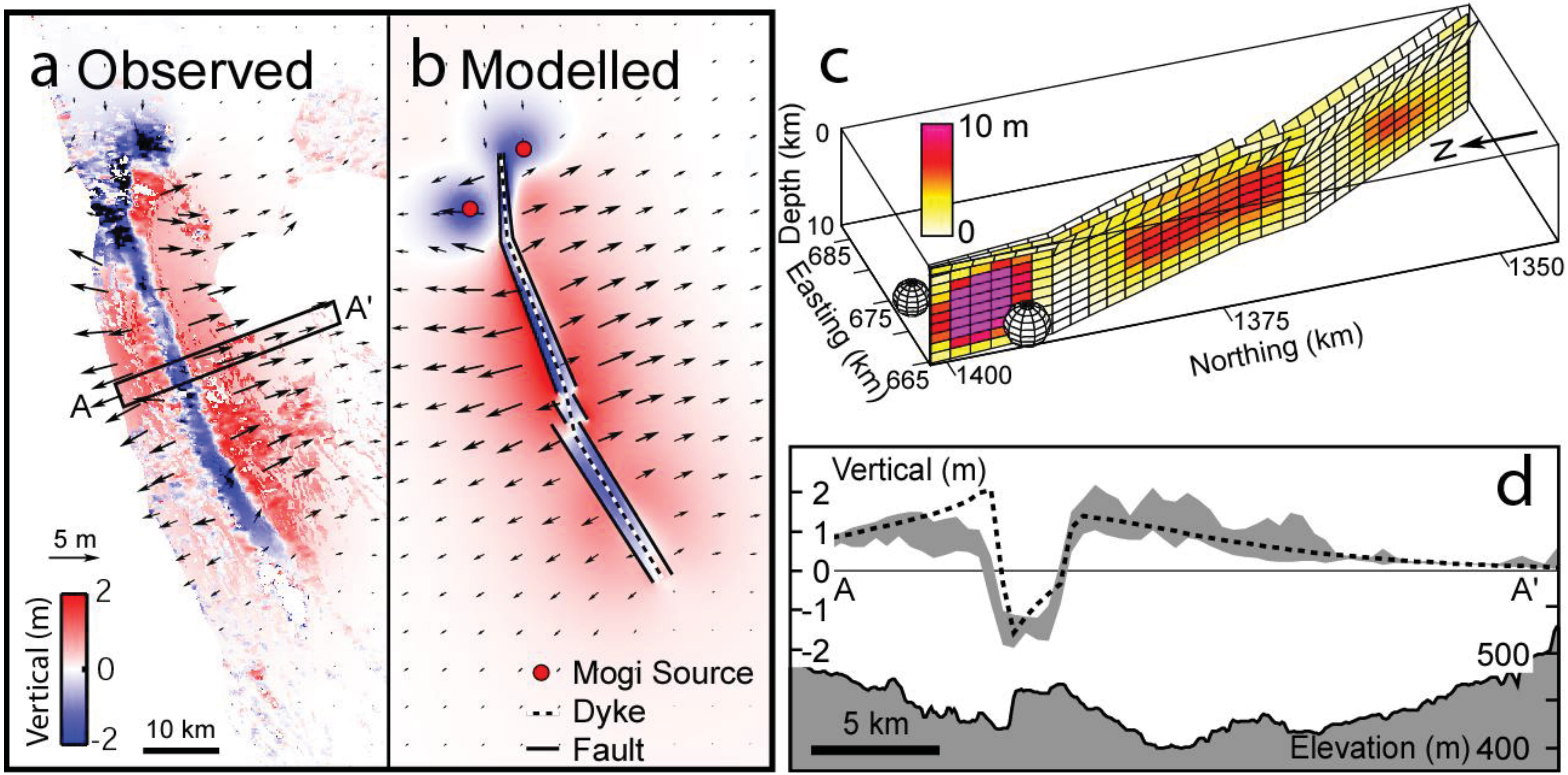
InSAR observations of post-rifting deformation around the Dabbahu rift segment, Afar, Ethiopia

Ian Hamling[1,2], Tim Wright[2], Laura Bennati[3], Eric Calais[3], Elias Lewi[4], Carolina Pagli[2]

1. GNS Science; 2. University of Leeds;

3. Purdue University; 4. Addis Ababa University.

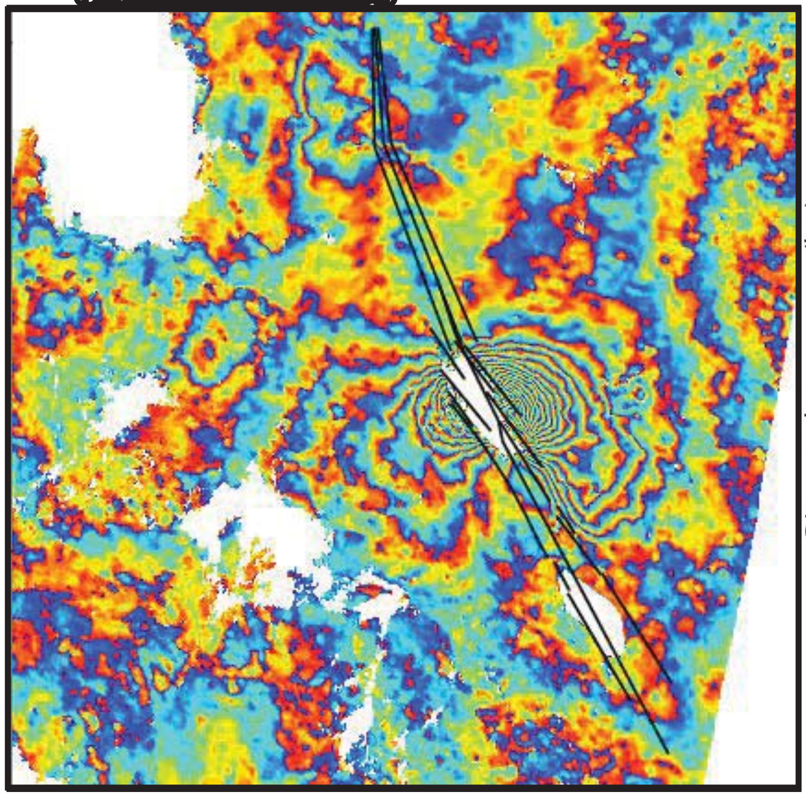
Key Question: How do we model visco-elastic relaxation when magma is moving?

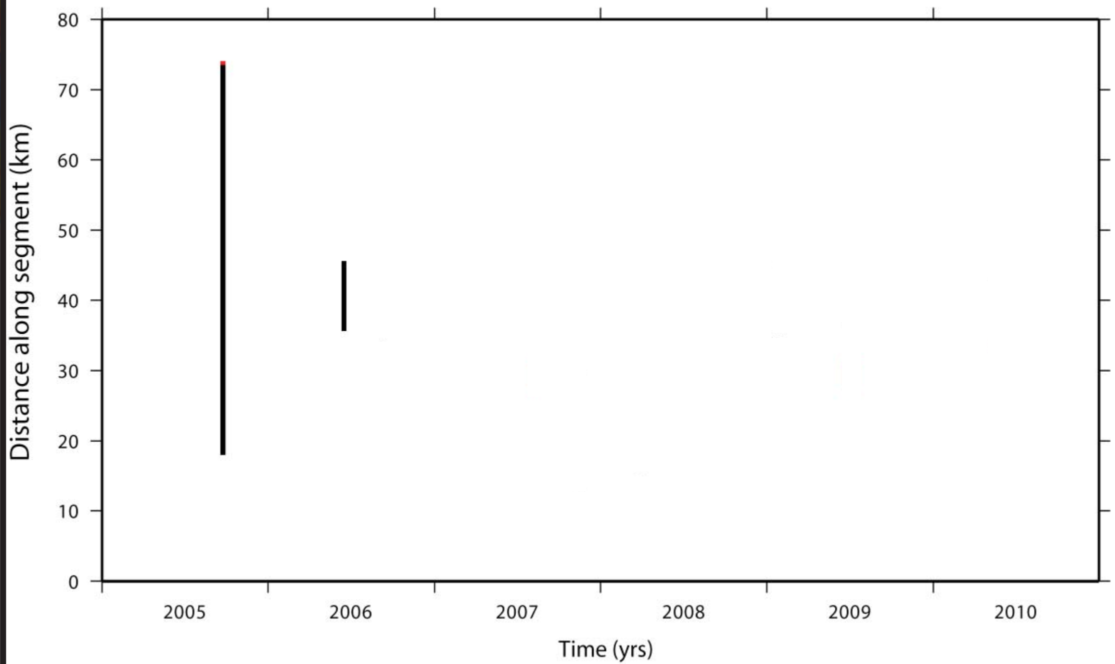


Wright et al., Nature 2006

- **2.5 km^3 magma intruded along 60 km dyke, which was up to ~10 m thick**
- **Equivalent moment release to M~7.2 earthquake [Landers M~7.3; Hector Mine M~7.1]**

2006 – 2010 dyke sequence





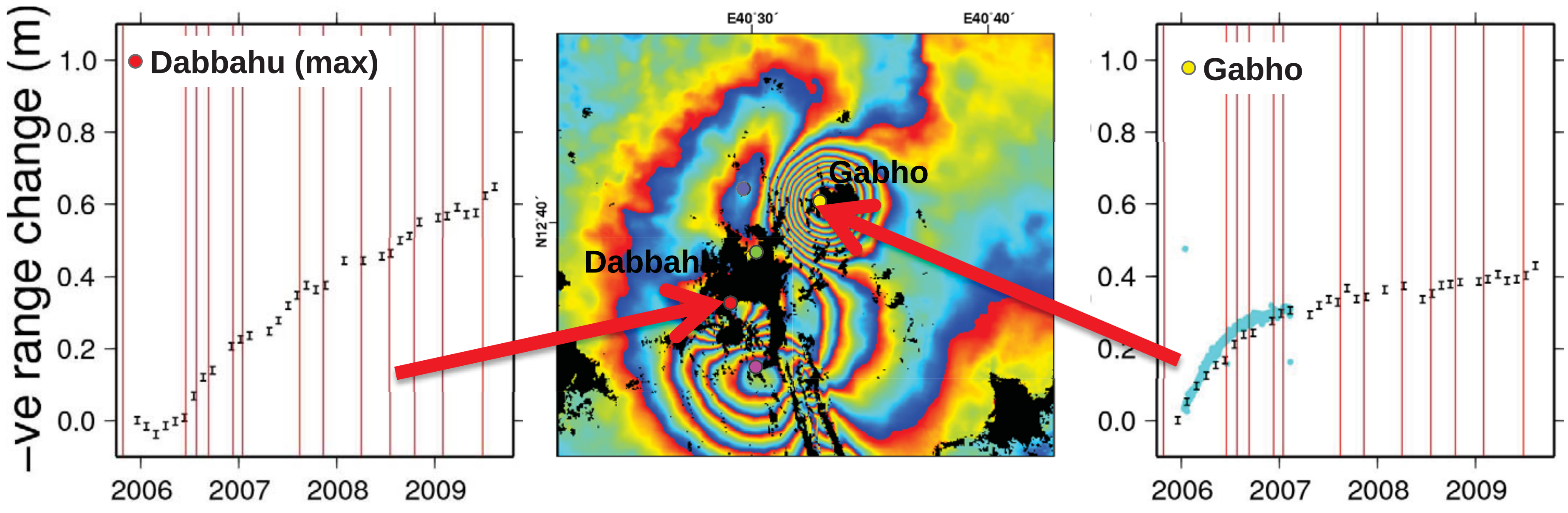
Dyking event

Dyking event with eruption

- **More details on dyke intrusion sequence in:**

Hamling et al., GJI 2009; Keir et al., Geology 2009; Hamling et al., Nature Geosci. 2010; Ebinger et al., AREPS 2010

Deformation at magmatic centres



Visco-elastic relaxation

- Analogy with Iceland, viscosity estimates for hot upper mantle beneath rift:

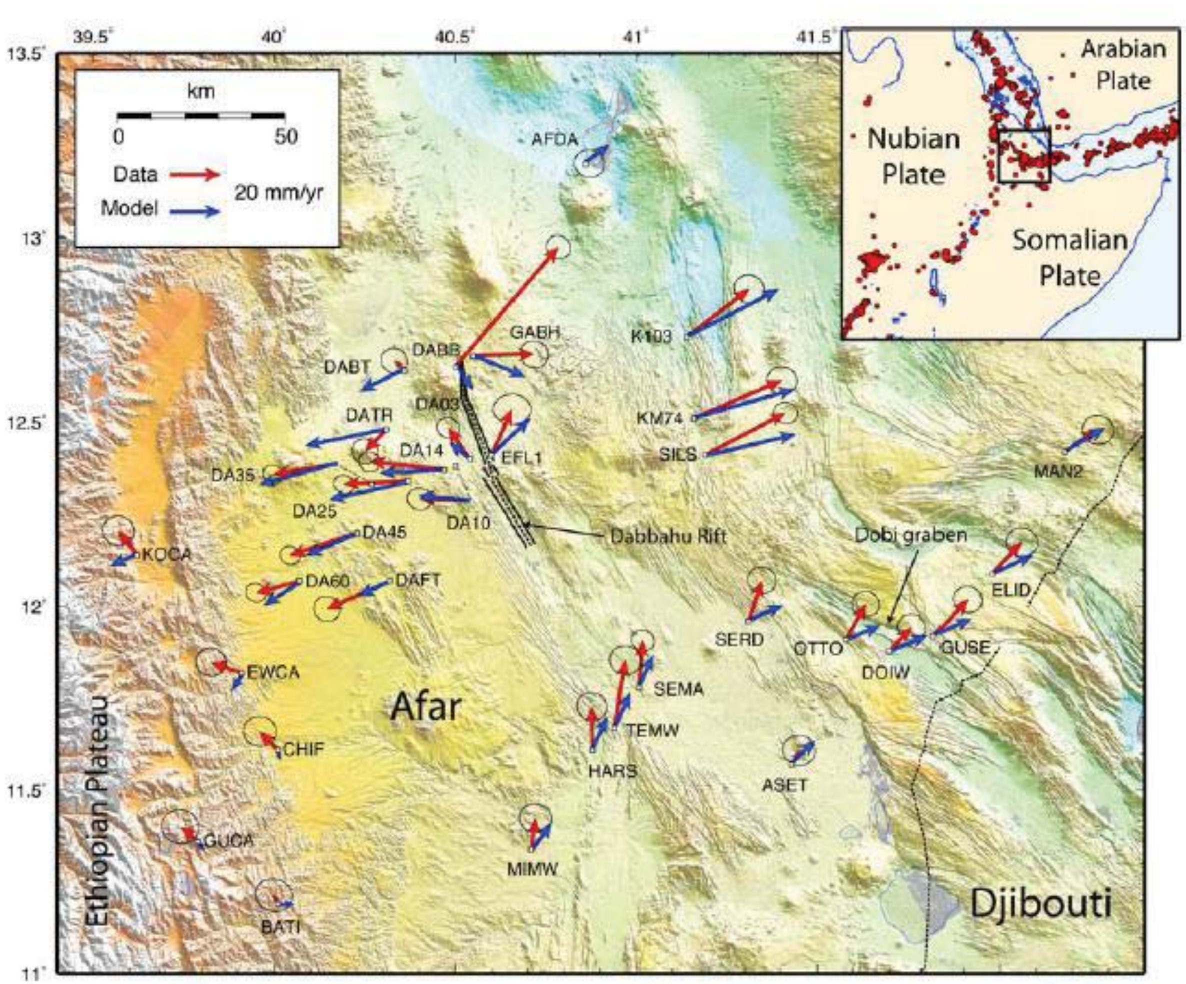
GIA ⇨ $\eta < 10^{19}$ Pa s (Sigmundsson, 1991)

Krafla ⇨ $\eta \sim 1 \times 10^{18}$ Pa s (Hofton & Foulger, 1996)

$\eta \sim 3 \times 10^{18}$ Pa s (Pollitz & Sacks, 1996)

- Expect relaxation times ~1-10 years.

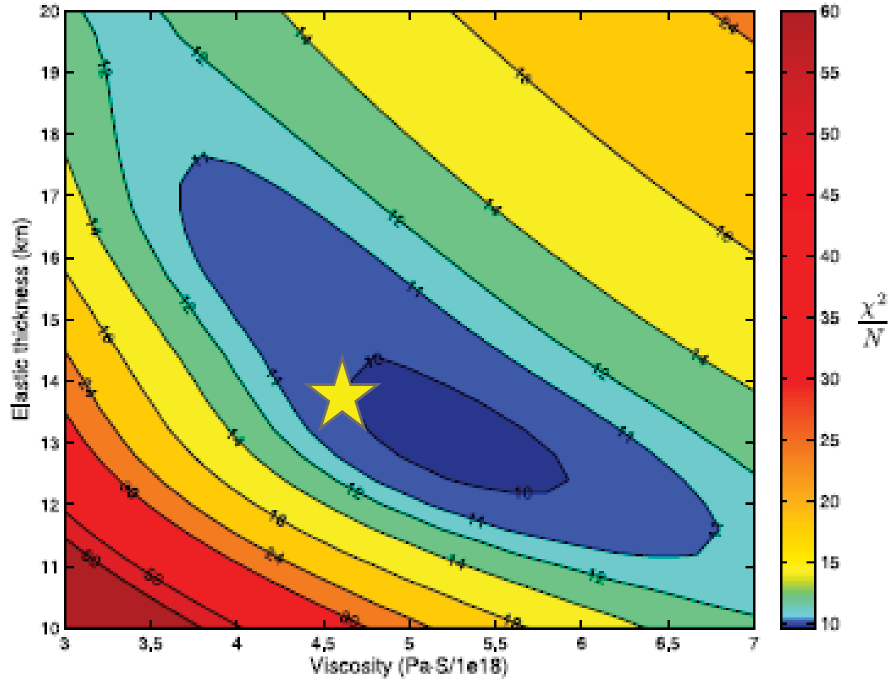
Modelled as entirely visco-elastic...



Nooner et al., GRL 2009:

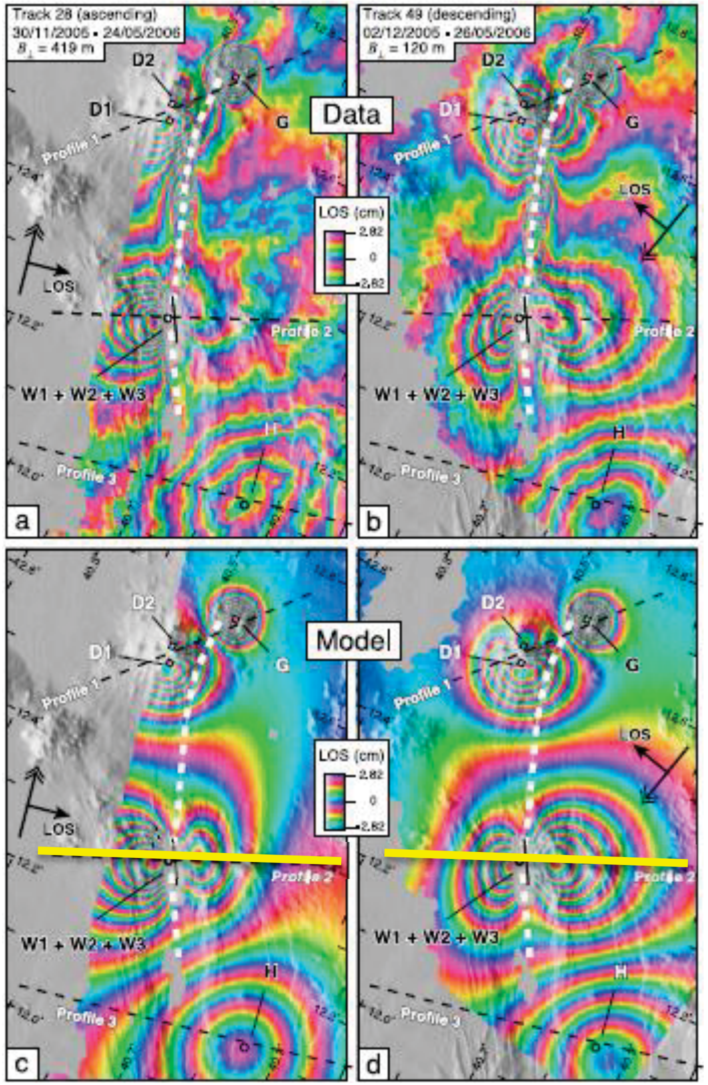
Viscosity 5.2 x 10^{18} Pa s

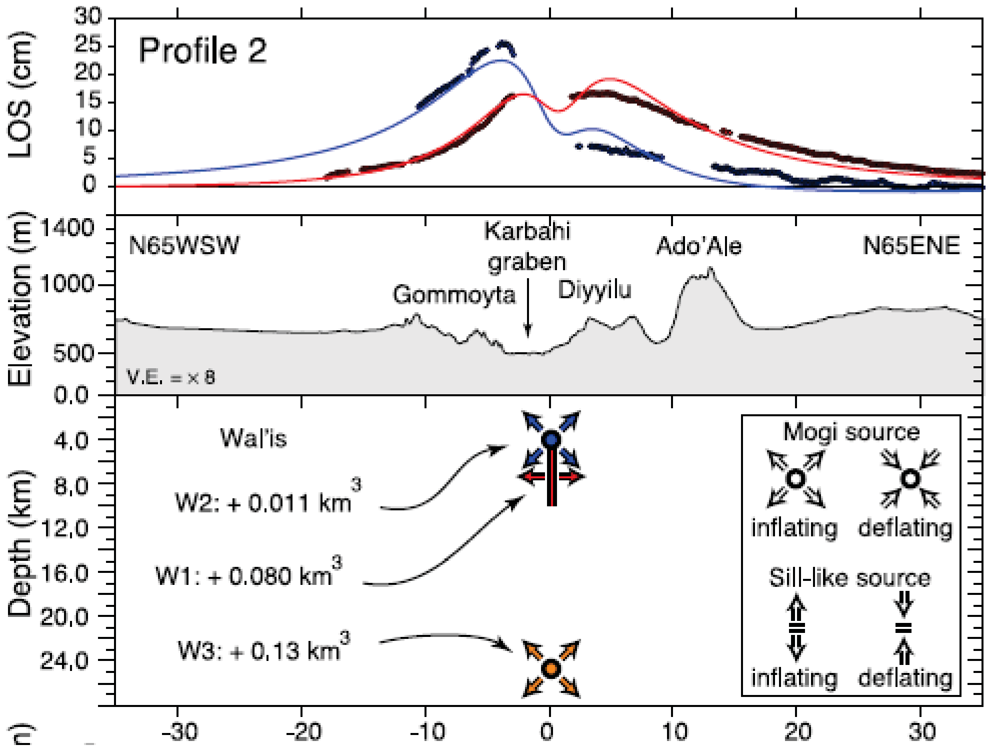
Lid thickness 13.2 km



...and entirely magmatic

Grandin et al. JGR 2010

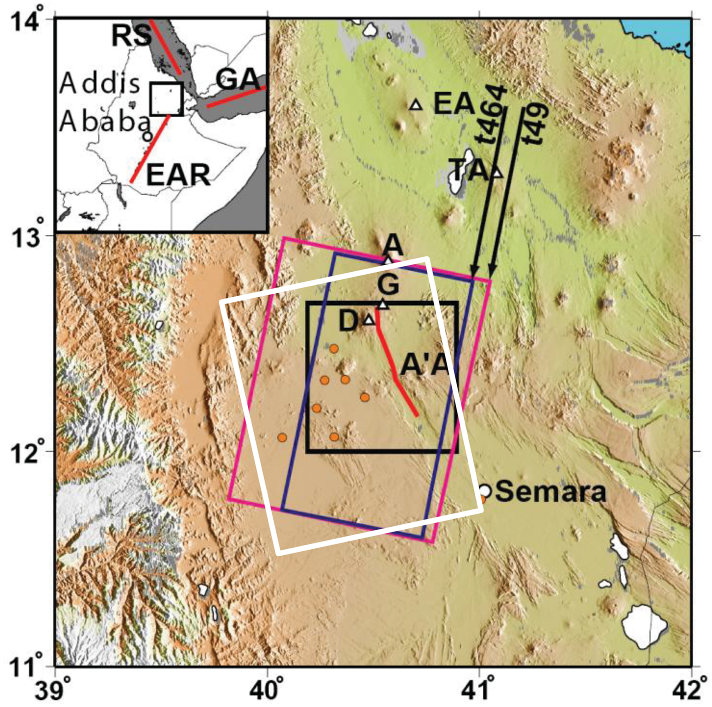




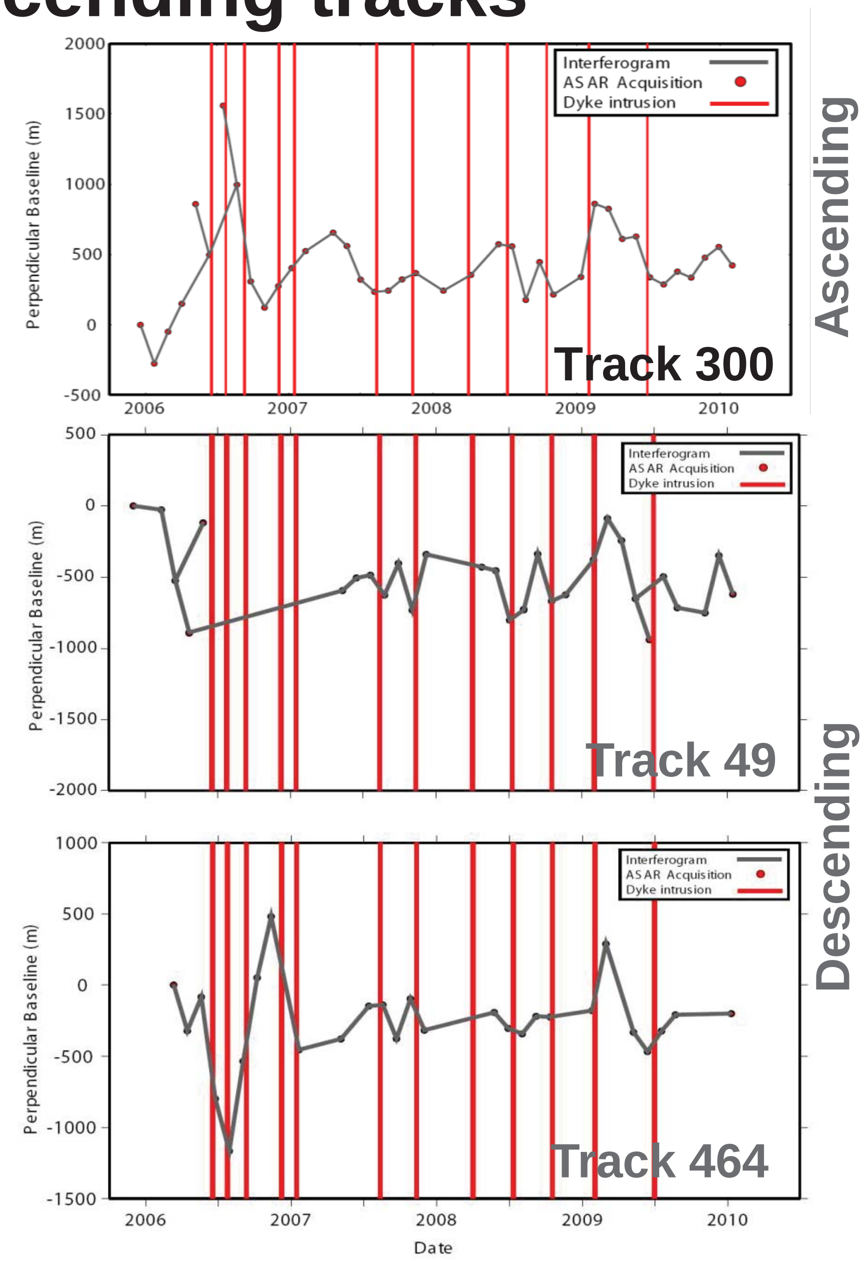
We assume that visco-elastic relaxation is happening and attempt to separate its contribution from magmatic deformation

1. Find best-fit visco-elastic model
2. Model residual using magmatic sources
3. Remove magmatic deformation from original data, and re-estimate visco-elastic parameters
4. Repeat steps 2,3 until solution converges

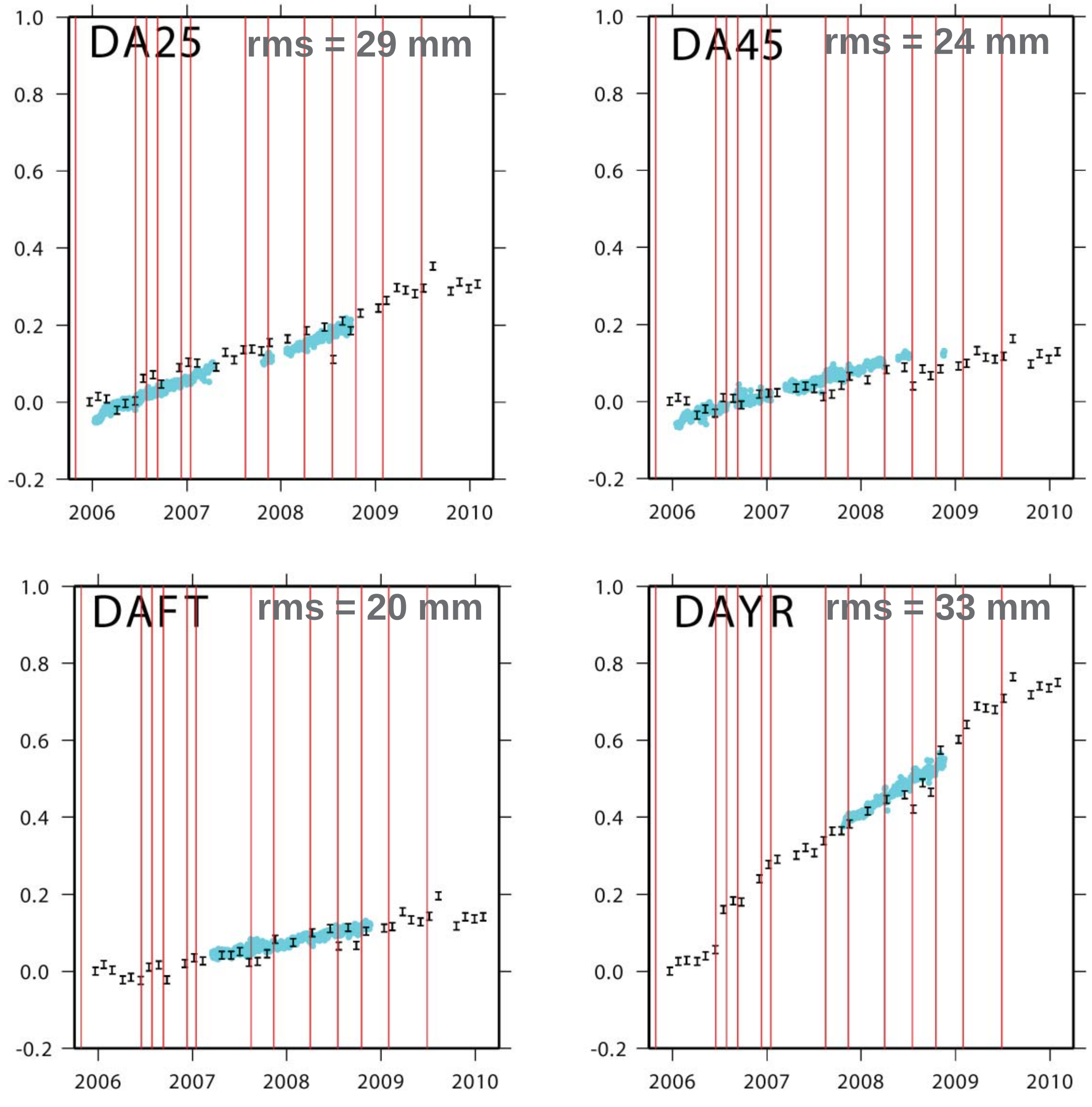
But first... the data: InSAR time series on 1 Ascending and 2 Descending tracks



First solve for simple time series on each track using least squares approach.

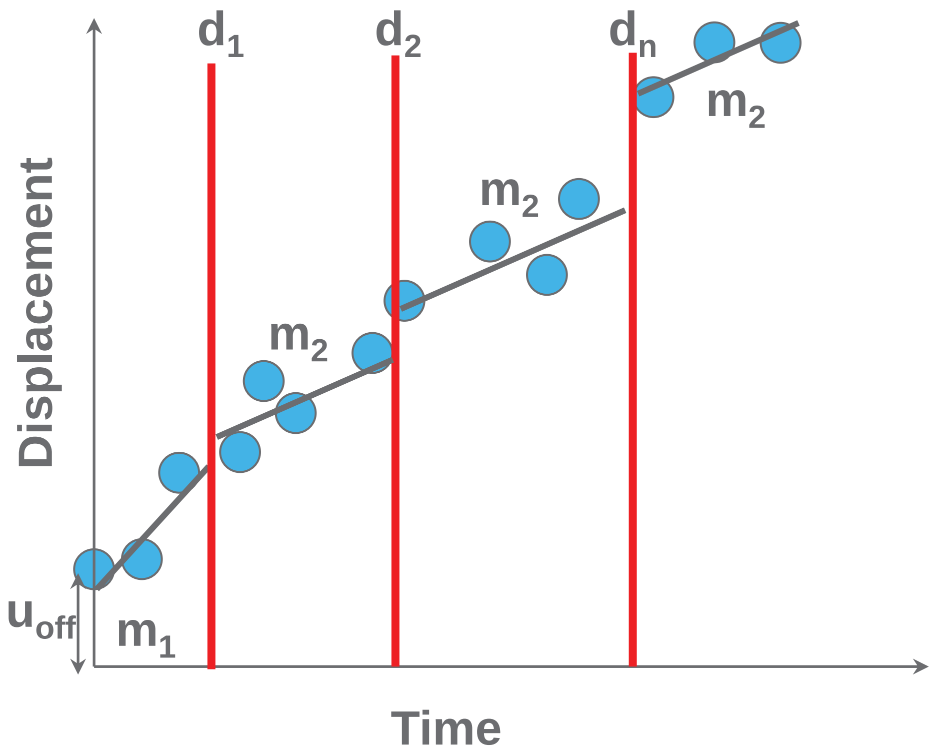


Comparison with GPS for track 300

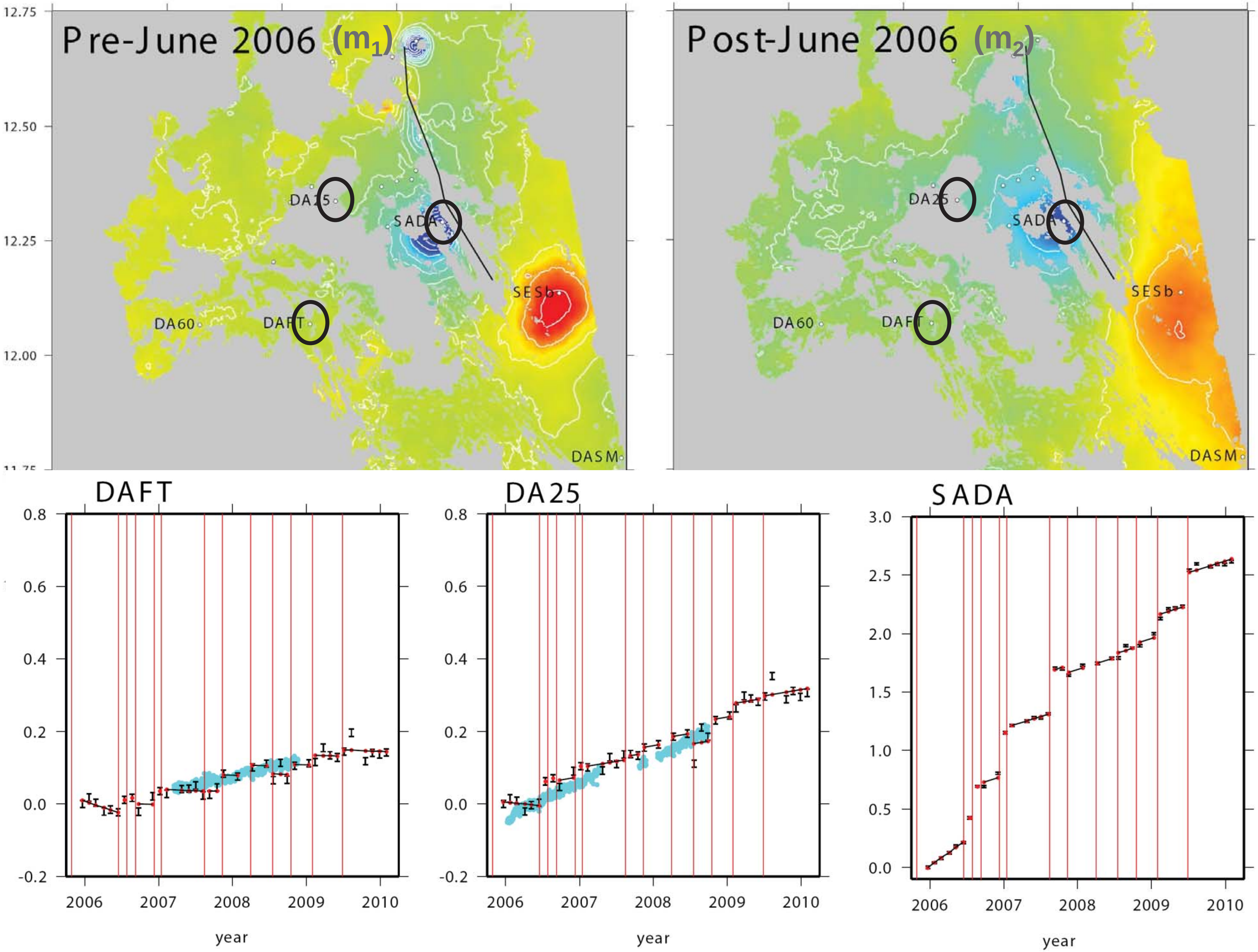


- In general, when projected into satellites line of site, GPS and InSAR displacements are consistent.
- Similar results for descending tracks

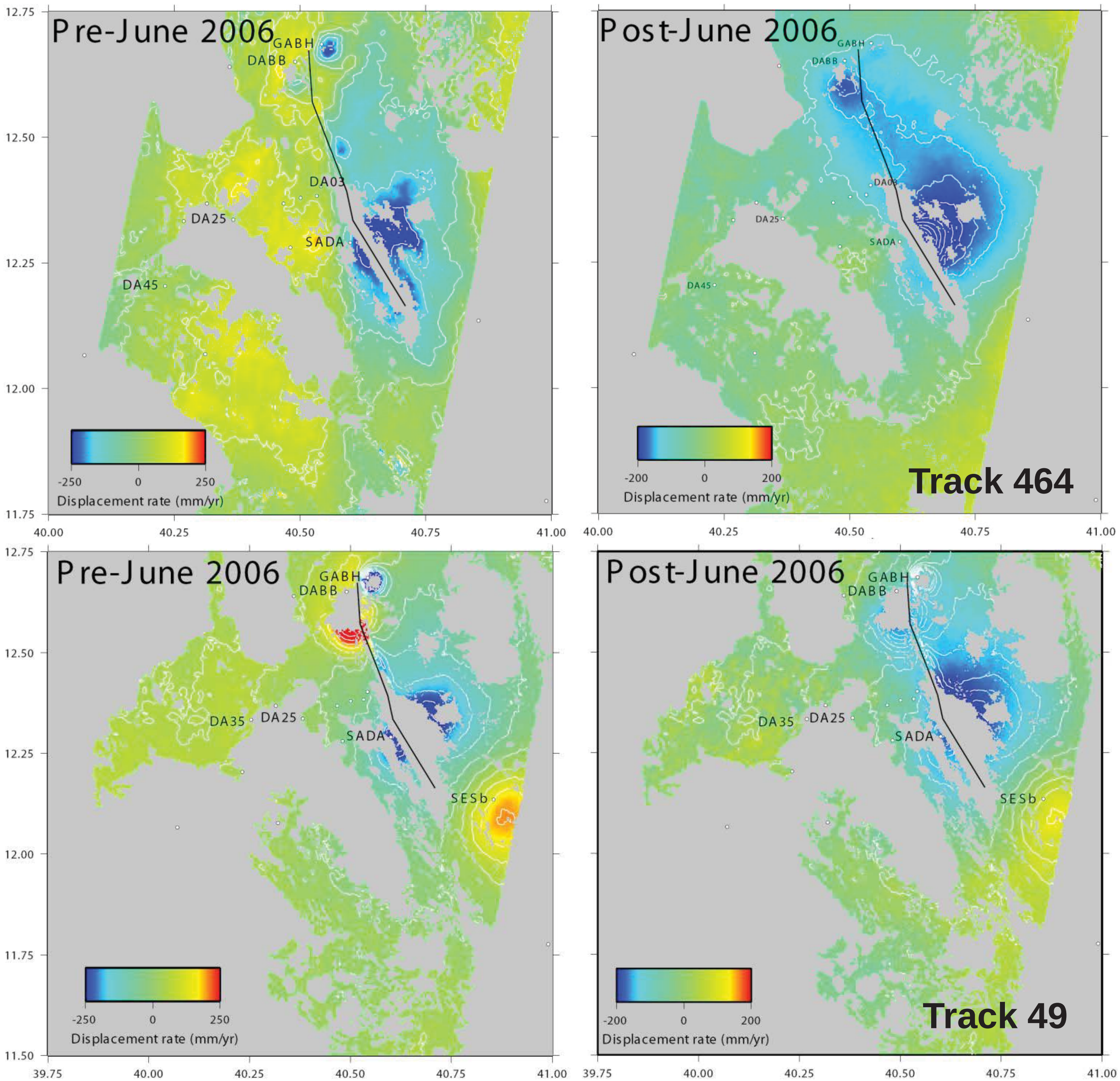
Separating steady deformation from sudden dyke intrusions



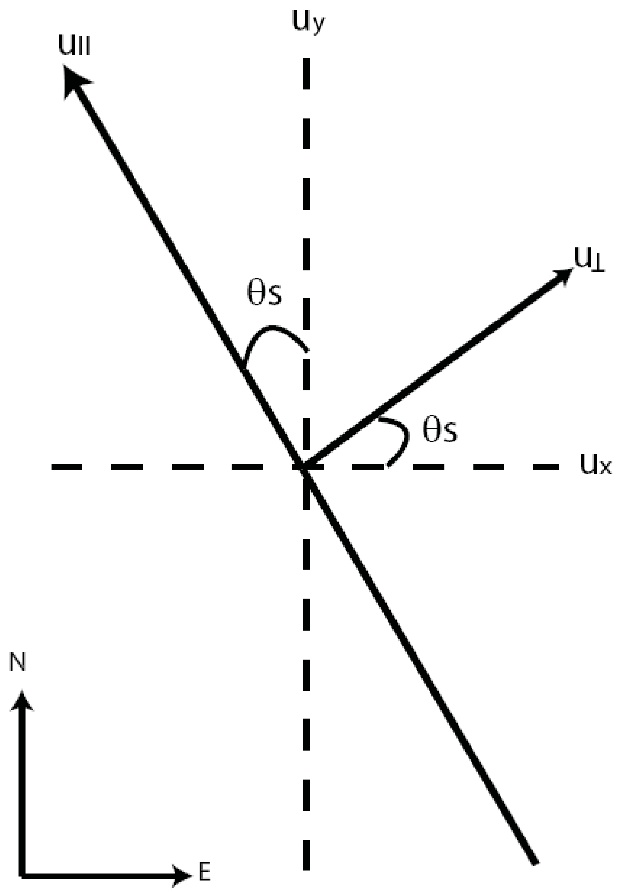
- We isolate steady background deformation by solving for linear displacement rates (m_1, m_2), with jumps (d_1, d_2,...d_n) at the known times of each dyke intrusion.
- Again, a simple least squares problem.



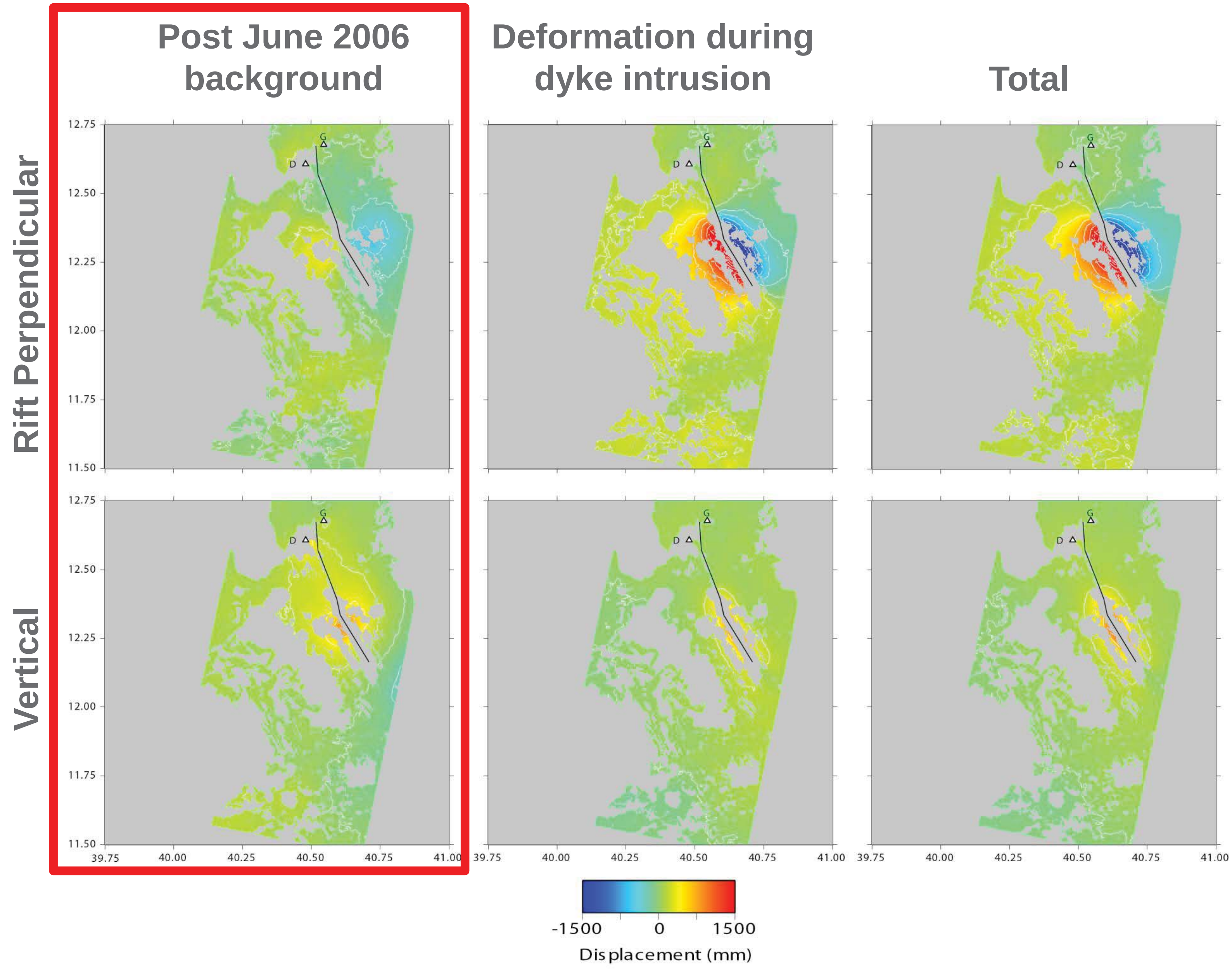
Pre-June 2006 (m1)
Post-June 2006 (m2)
12.75
12.50
12.25
12.00
DA25
SADA
SESb
DA60
DAFT
DASM
DAFT
DA25
SADA
0.8
0.6
0.4
0.2
0.0
-0.2
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2006
2007
2008
2009
2010
year


Pre-June 2006
Post-June 2006
GABH
DABB
DA03
DA25
SADA
DA45
DA35
SESb
-250
0
250
-200
0
200
Displacement rate (mm/yr)
Track 464
Track 49
12.75
12.50
12.25
12.00
11.75
11.50
39.75
40.00
40.25
40.50
40.75
41.00

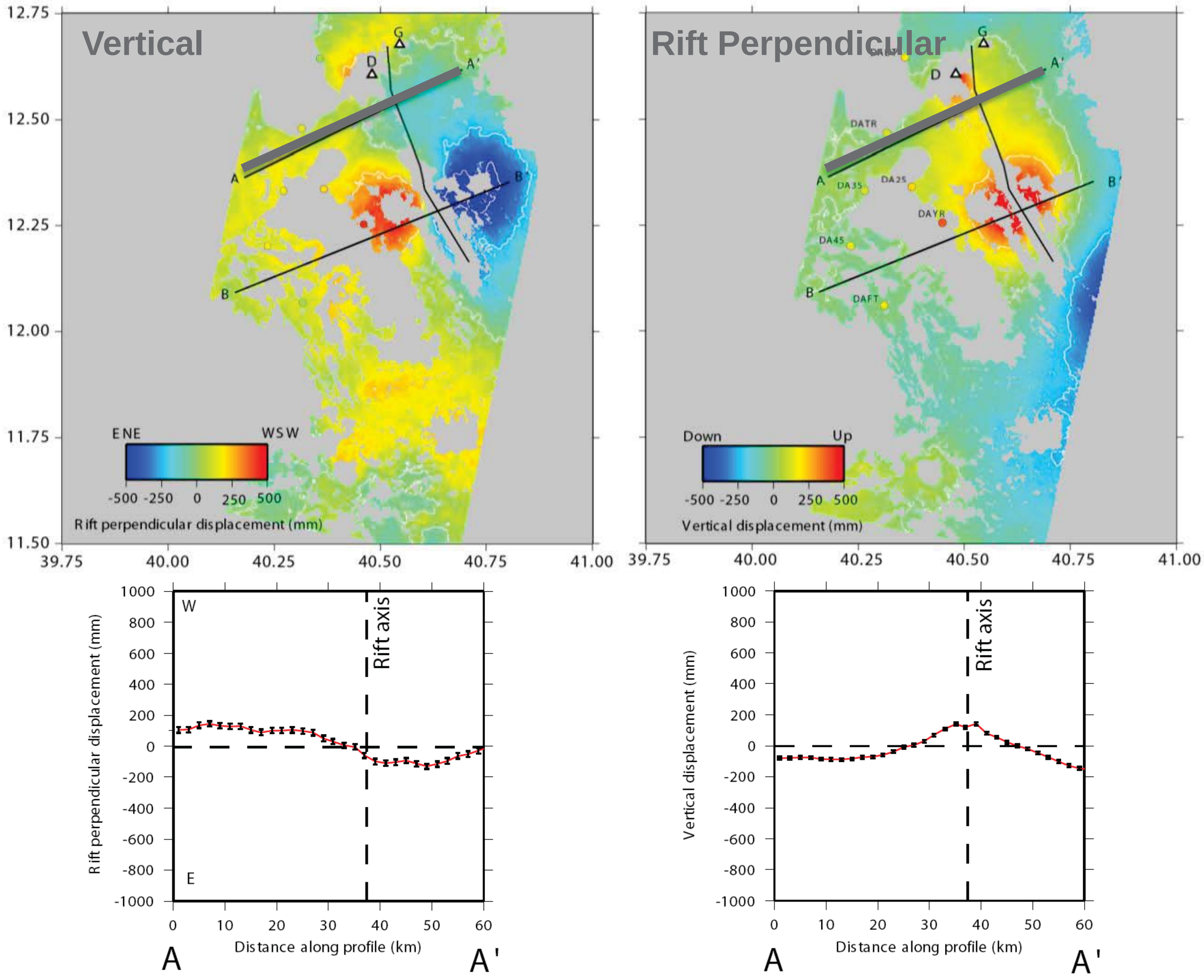
Retrieving the vertical and horizontal components



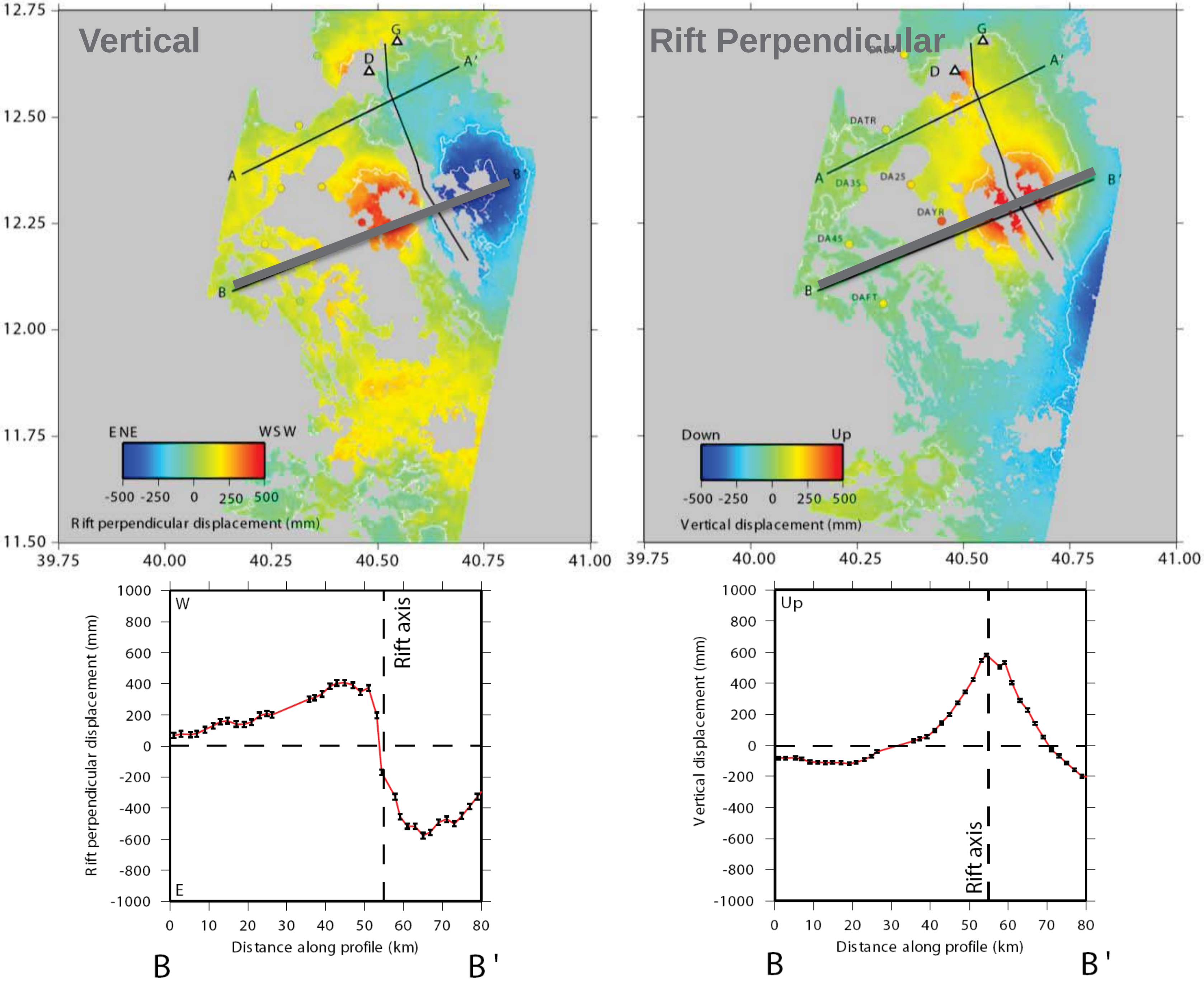
- Assuming that all of the motion is in the vertical and perpendicular to the rift we can transform LOS deformation into these components



Post June 2006 background
Deformation during dyke intrusion
Total
Rift Perpendicular
Vertical
12.75
12.50
12.25
12.00
11.75
11.50
39.75
40.00
40.25
40.50
40.75
41.00
G
D
-1500
0
1500
Displacement (mm)

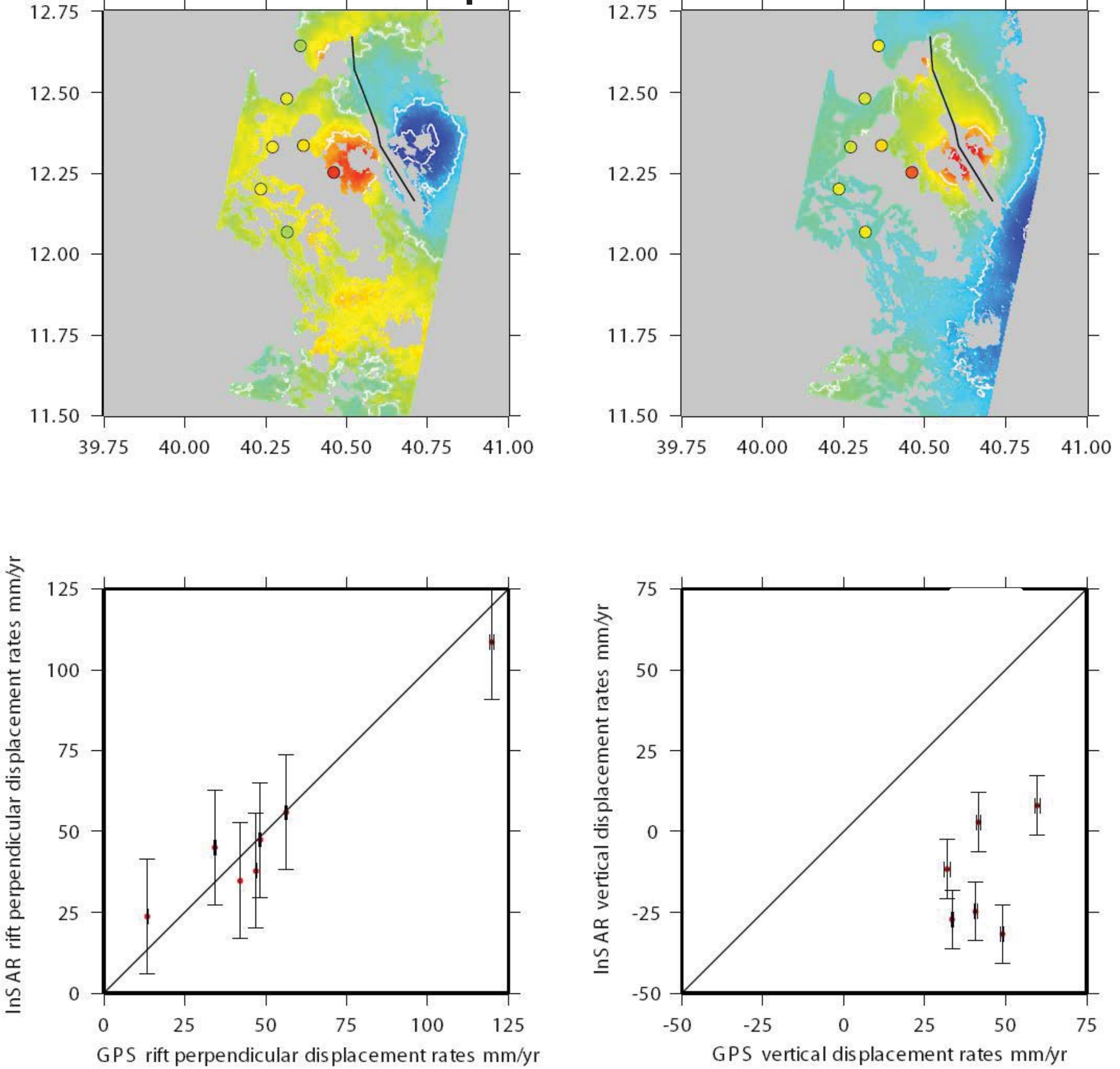


Vertical
Rift Perpendicular
12.75
12.50
12.25
12.00
11.75
11.50
39.75
40.00
40.25
40.50
40.75
41.00
G
D
A
A'
B
B'
DATR
DA3S
DA2S
DAYR
DA4S
DAFT
ENE
WSW
-500 -250 0 250 500
Rift perpendicular displacement (mm)
Down
Up
-500 -250 0 250 500
Vertical displacement (mm)
W
E
Rift axis
Rift perpendicular displacement (mm)
Vertical displacement (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0 10 20 30 40 50 60
Distance along profile (km)
A
A'

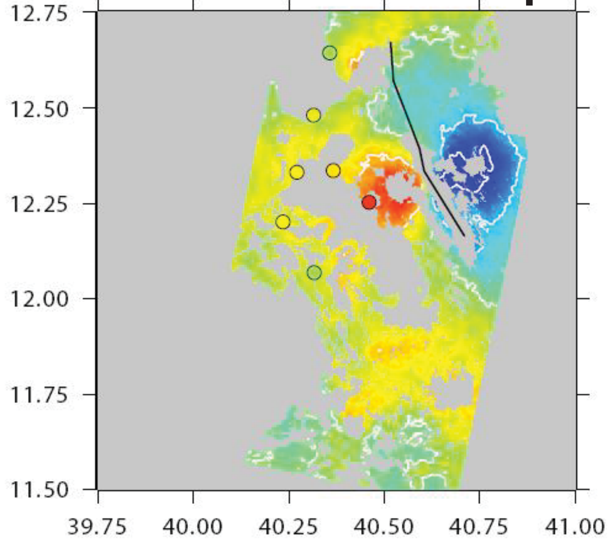


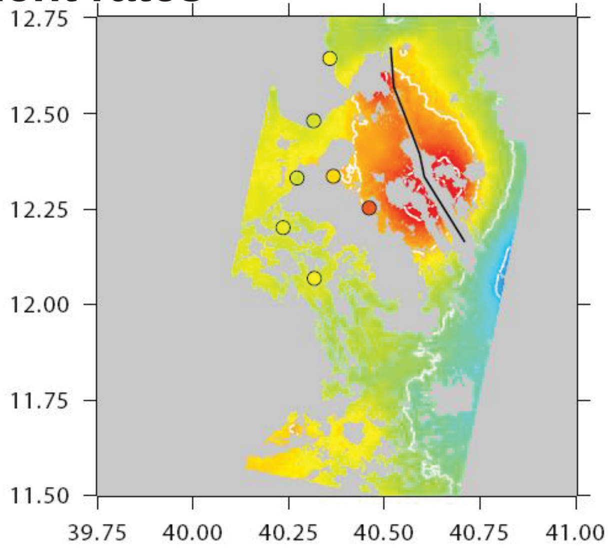
Vertical
Rift Perpendicular
12.75
12.50
12.25
12.00
11.75
11.50
39.75
40.00
40.25
40.50
40.75
41.00
G
D
A
A'
B
B'
DATR
DA35
DA25
DAYR
DA45
DAFT
ENE
WSW
-500 -250 0 250 500
Rift perpendicular displacement (mm)
Down
Up
-500 -250 0 250 500
Vertical displacement (mm)
W
E
Up
Rift axis
Rift perpendicular displacement (mm)
Vertical displacement (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0 10 20 30 40 50 60 70 80
Distance along profile (km)
B
B'

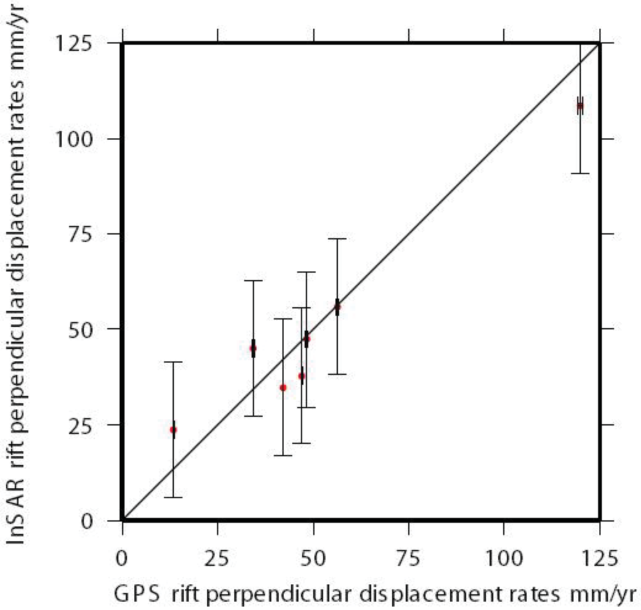
Comparison between GPS and InSAR displacement rates



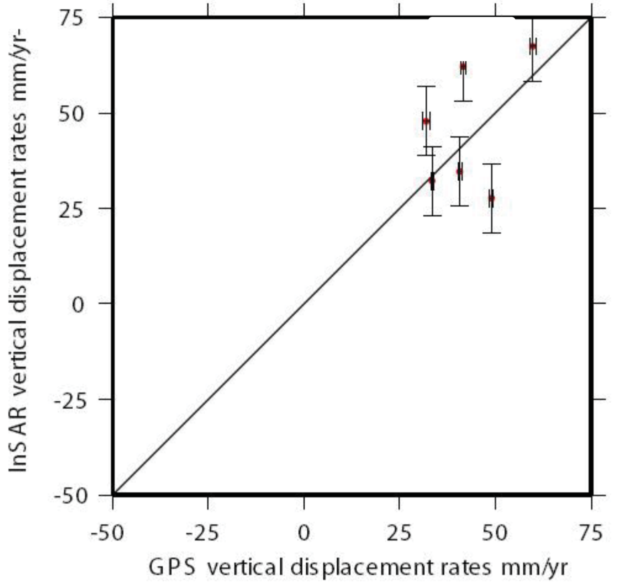
Comparison between GPS and InSAR displacement rates







InSAR adjusted by applying a static shift

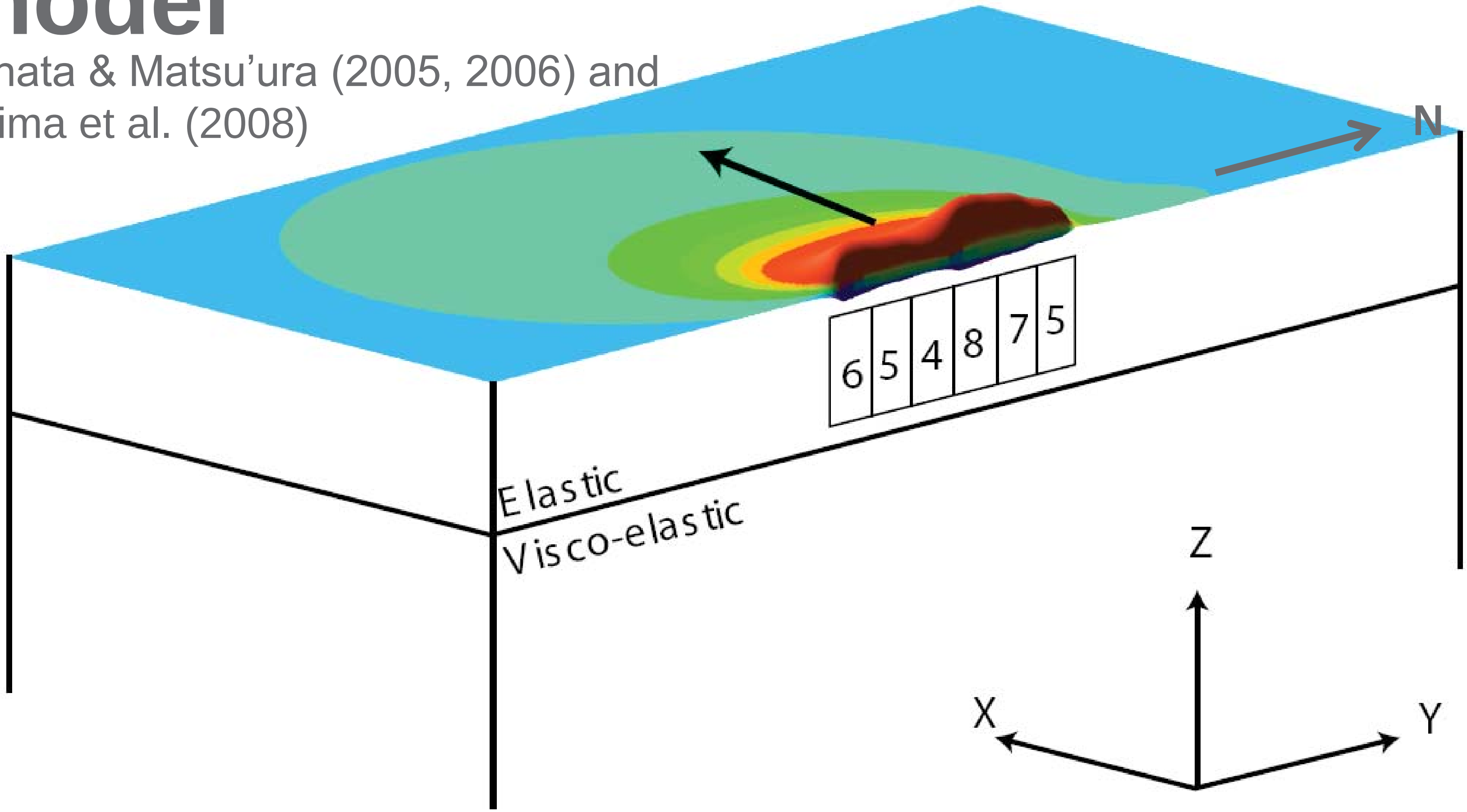


Reminder of strategy

1. Find best-fit visco-elastic model
2. Model residual using magmatic sources
3. Remove magmatic deformation from original data, and re-estimate visco-elastic parameters
4. Repeat steps 2,3 until solution converges

1. Find best fit visco-elastic model

Fukahata & Matsu’ura (2005, 2006) and
Hashima et al. (2008)

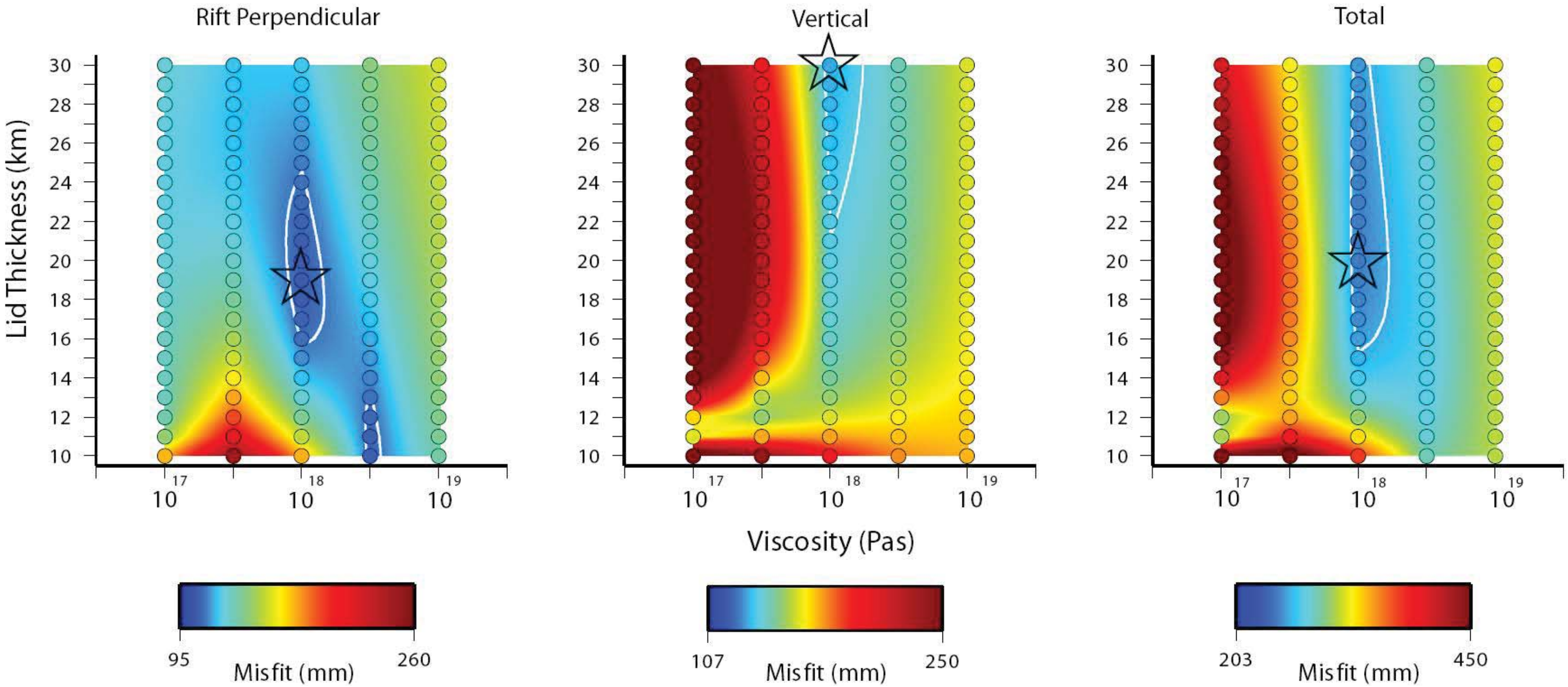


Layer	V_p (m/s)	V_s (m/s)	Density (kg/m^3)
1	5.35	2.95	2600
2	7.1	3.7	3000

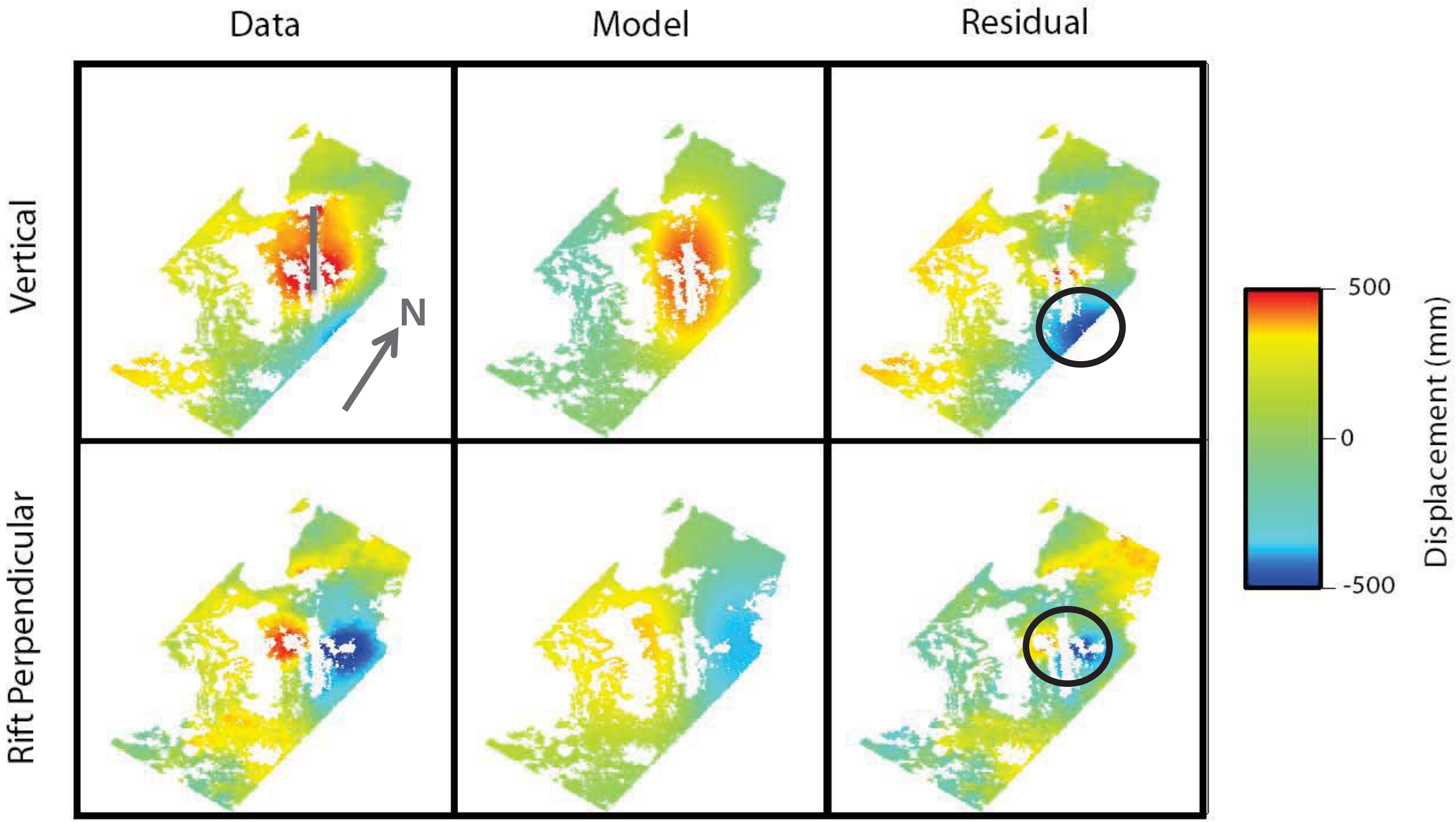
Simulate the September 2005 intrusion with 6, 10 km-long patches with the amount of opening shown.

1. Find best fit visco-elastic model

Best fit model with 20 km thick lid and viscosity of 10^{18} Pa s.

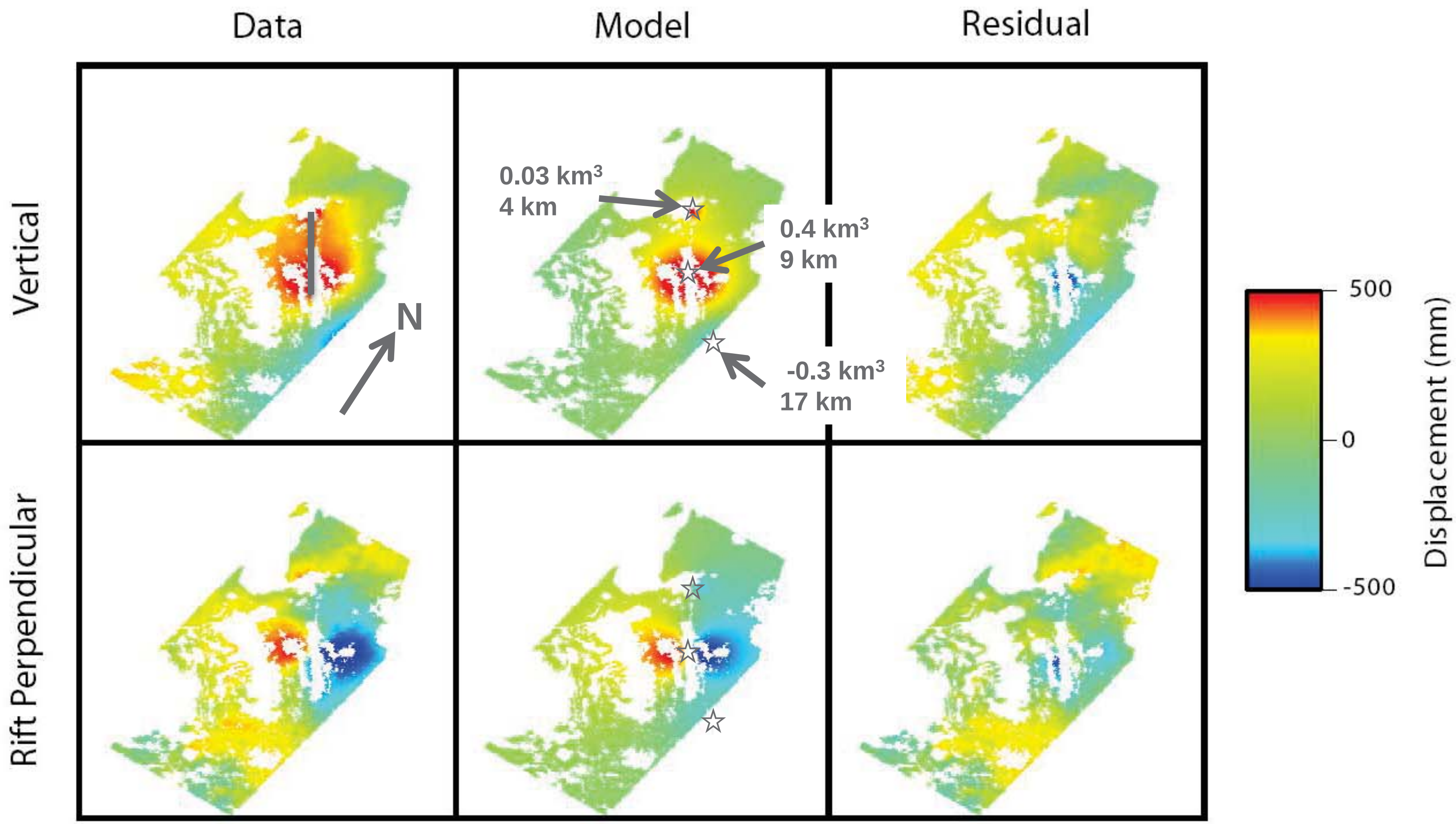


1. Find best fit visco-elastic model

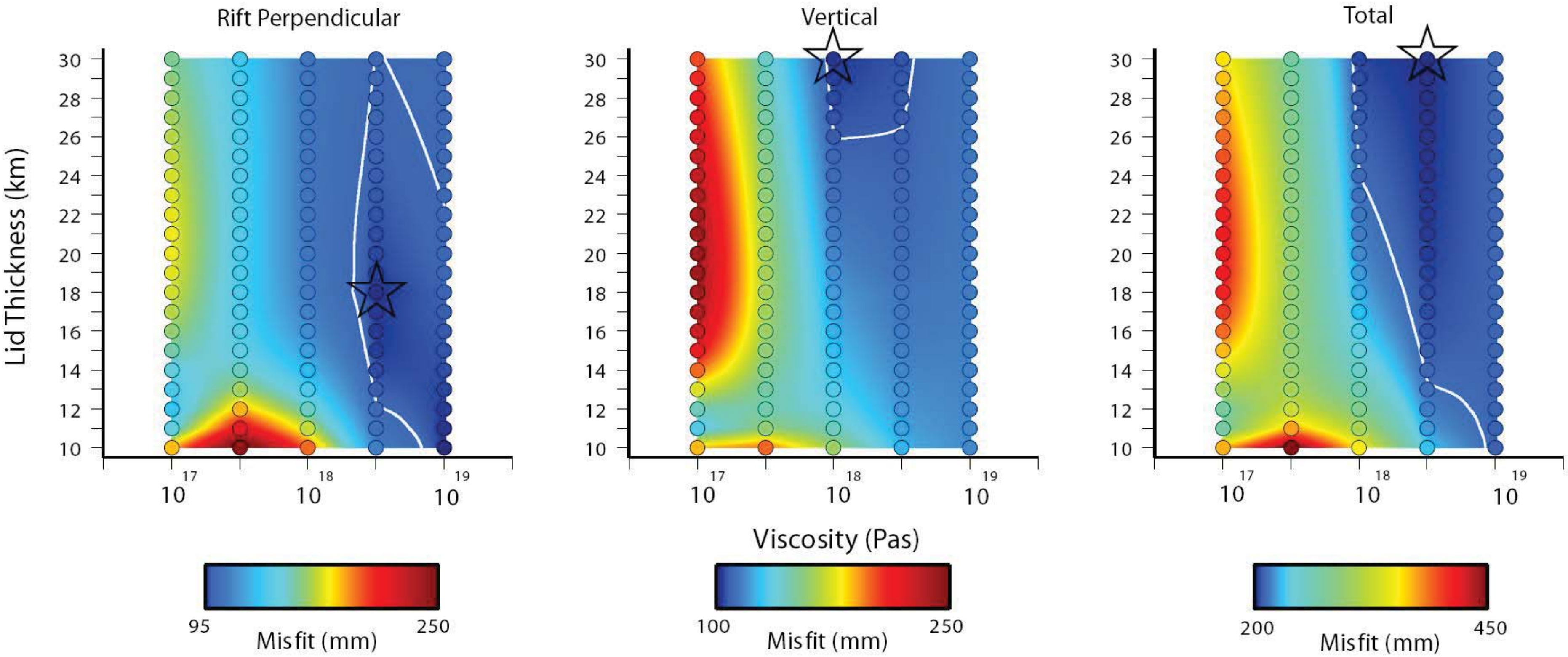


Large residuals around Ado'Ale and to the south east of the segment.

2. Model residual using magmatic sources



3. Remove magmatic deformation from original data, and re-estimate visco-elastic parameters

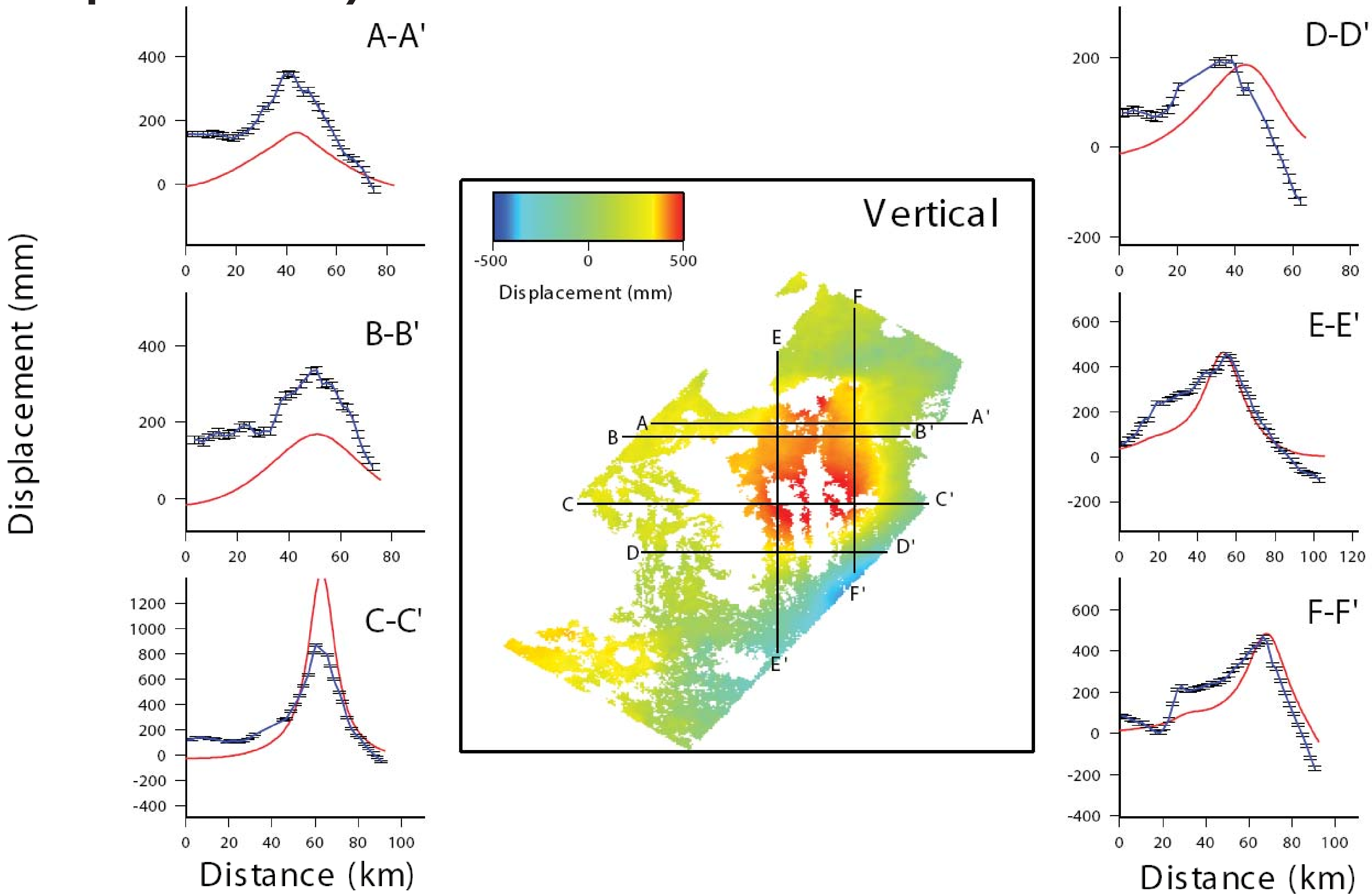


Lid thickness > 15 km;

Viscosity ~$10^{18.5}$ Pa s.

- Problem matching the vertical displacements with this simple model

4. Final model (iterations did not change parameters)



Conclusions

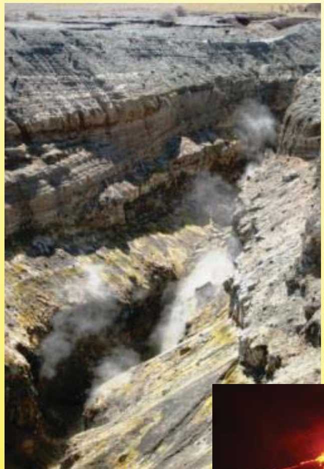
- Deformation in Dabbahu cannot be explained by viscoelasticity alone
- But models of ongoing deformation that do not consider visco-elasticity are probably unreasonable.
- Two step approach allows us to separate magmatic and v-e contributions
- Suggests viscosity of ~ $10^{18.5}$ beneath an elastic lid > 15 km thick.
- More work required on understanding long-wavelength vertical deformation.

Magmatic Rifting & Active Volcanism Conference

Addis Ababa, Ethiopia

11-13th January, 2012

Afar Rift Consortium



Plenary Sessions

- Active Magmatic Rifting
- Mid-Ocean Ridge Processes
- Rifted Continental Margins
- The East African Rift
- Natural Hazards
- Rifting and Climate
- Mantle-Lithosphere Interactions and the Causes of Break Up
- Resources from Magmatic Rift (Geothermal, Petroleum etc)

Field Trips

- Introduction to the East African Rift (3 days)
- Afar including the Erta Ale lava lake (6 days)
- Transect through a continental margin, including the historic sites of Axum, Gonar and Lalibela (6 days)

website: **http://see.leeds.ac.uk/afar/conference.html**

email**: addis2012@see.leeds.ac.uk**

??? km
elastic crust