**Figure S-1.** Interferograms imaging the dike intrusions of November 2007 (d7, left) and October 2008 (d10, right). These two events are the most distant from the inferred central magma reservoir lying at 12.30°N (Figure 1). A small subsidence signal at the same location as sources W2 and W3 (black circle) is caused by co-diking deflation of the suspected magma source [Hamling et al., 2009; Grandin et al., 2010].
**Figure S-2.** InSAR data set used in this paper, for ascending tracks 28 and 300. Horizontal segments represent the time spanned by each interferogram. The black segments correspond to interferograms that image inter-diking deformation only. Grey segments represent interferograms that include deformation produced by at least one rifting event. The perpendicular baseline is indicated to the right of each segment. The dates of each SAR acquisition are shown at the bottom. The thick vertical line gives the date of the main 2005 rifting event. Thin dashed lines are for smaller subsequent rifting events.
Figure S-3. Same as Figure S-2 for descending tracks 464 and 49.
Figure S-4. Example of the result of the downsampling scheme used for elastic inversion of InSAR data. The original interferogram (left) contains hundreds of thousands of data points. Downsampling is performed by averaging InSAR measurement over successively small square areas, with the size of each square depending on the distance from inferred active geological structures (center). Surface projections of sources of transient deformation discussed in this study are shown by white squares. The surface projection of the September 2005 dike model by Grandin et al. [2009] is shown by a black line. The resulting set of measurements contains less than 1000 points (right). Generally, downsampled data points are not located exactly at the center of the squares shown in the figure, but rather at the isobarycenter of the data points that were averaged in each square region. The interferogram used in this example is from track 49 (descending), and spans the period from 02/12/2005 to 10/02/2006. The areas imaged by the different ENVISAT tracks used in this study are shown on the left.
Figure S-5. Result of preliminary inversion of InSAR data for intervals a, b and c. Left: data. Middle: model. Right: residue. Top rows: ascending and descending tracks. Profiles: cross-sections in the area of deformation at the center of the Manda Hararo rift (location indicated by black line in upper panels). Bottom: dates of images used in the inversion. Double headed arrows show direction of satellite trajectory, with the approximate value of incidence angle indicated.
Figure S-6. Same as Figure S-5 for intervals d, e, and f.
Figure S-7. RMS misfit between downsampled InSAR data and predicted LOS deformation as a function of depth and volume of sources D1 (shallow Dabbahu), D2 (deep Dabbahu), G (Gabho) and H (Hereru) in the periods that allow them to be best constrained. Contours are shown every 0.025 cm. See Figure S-5 and Table S-1 for definition of sources and time intervals. Only depth and volume of the specified source are allowed to change during each parameter exploration, and other parameters are fixed to best-fitting model deduced from non-linear inversion. Effect of changing source geometry (sill-like point-source or Mogi-source) does not change significantly the RMS misfit, while yielding different depth and volume for the best-fitting model.
Figure S-8. Intensity of smoothing imposed in the inversion versus RMS misfit of the solution. A non-negativity constraint was applied on $m$ (blue diamonds), but, for high degrees of smoothing, the non-negativity constraint was released to enhance the computational efficiency (red circles). The asymptote on the upper right corresponds to a steady-state solution on each interval separating two dike intrusions. The asymptote on the lower left represents the minimum RMS misfit that can be achieved with a completely unconstrained inversion.
Figure S-9. Standard deviations of each downsampled interferogram (red lines) and residue after inversion (blue lines) for the preferred smoothing (Figure S-8). The length of each segment represents the time spanned by the interferogram (see also Tables S-2 and S-3).
Figure S-10. RMS misfit *versus* characteristic time $\tau$ for the model of exponentially decaying activity of source W1 (see Appendix C for details). The RMS misfit between predicted activity rate of W1 and inflation rate deduced from inversion of InSAR data is calculated on each time interval as a function of $\tau$ is indicated by the colour lines (unconstrained intervals following dikes d1, d2 and d4 are not shown). A minimum RMS is found for $\tau_{\text{best}} \sim 250$ days (black dashed line).
Table 1. Geometric features of the dislocation elements (D1, D2, G and W1) and Mogi sources (W2, W3 and H) used in the elastic time-series inversion.

<table>
<thead>
<tr>
<th>Element</th>
<th>Longitude(^a) (°N)</th>
<th>Latitude(^a) (°N)</th>
<th>Depth(^a) (km)</th>
<th>Width(^b) (km)</th>
<th>Length (km)</th>
<th>Strike (°N)</th>
<th>Dip (°N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>40.477</td>
<td>12.575</td>
<td>8.8</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>D2</td>
<td>40.469</td>
<td>12.600</td>
<td>4.9</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>G</td>
<td>40.540</td>
<td>12.681</td>
<td>3.8</td>
<td>1.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W1</td>
<td>40.629</td>
<td>12.306</td>
<td>4.0</td>
<td>6.0</td>
<td>8.0</td>
<td>150.0</td>
<td>90.0</td>
</tr>
<tr>
<td>W2</td>
<td>40.614</td>
<td>12.302</td>
<td>4.0</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
</tr>
<tr>
<td>W3</td>
<td>40.614</td>
<td>12.302</td>
<td>25.0</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
</tr>
<tr>
<td>H</td>
<td>40.850</td>
<td>12.099</td>
<td>17.0</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
<td>n/d</td>
</tr>
</tbody>
</table>

\(^a\) location of the middle of the top of the dislocation.
\(^b\) width of dislocation along dip.
n/d: not defined.
Table S-1. Dates of acquisitions of master (T*A) and slave (T*B) SAR images used in the preliminary inversion of InSAR data for time intervals a to f (Figures S-5 and S-6), and average inflation rate for the three inflation modes at Wal’is (see Table 1 for details of the geometry of sources W1, W2 and W3).

<table>
<thead>
<tr>
<th>Interval</th>
<th>Ascending track</th>
<th>T_{A}^{\text{Asc}}</th>
<th>T_{B}^{\text{Asc}}</th>
<th>Descending track</th>
<th>T_{A}^{\text{Desc}}</th>
<th>T_{B}^{\text{Desc}}</th>
<th>W1 ($\times 10^{-2}$ km$^3$/month)</th>
<th>W2 ($\times 10^{-2}$ km$^3$/month)</th>
<th>W3 ($\times 10^{-2}$ km$^3$/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>28</td>
<td>2005-11-30</td>
<td>2006-02-08</td>
<td>49</td>
<td>2005-12-01</td>
<td>2006-02-10</td>
<td>1.5</td>
<td>0.13</td>
<td>3.3</td>
</tr>
<tr>
<td>b</td>
<td>300</td>
<td>2006-02-27</td>
<td>2006-06-12</td>
<td>49</td>
<td>2006-02-10</td>
<td>2006-05-26</td>
<td>1.2</td>
<td>0.26</td>
<td>2.1</td>
</tr>
<tr>
<td>c</td>
<td>28</td>
<td>2007-01-24</td>
<td>2007-05-09</td>
<td>464</td>
<td>2007-01-20</td>
<td>2007-05-05</td>
<td>0.6</td>
<td>0.14</td>
<td>3.1</td>
</tr>
<tr>
<td>d</td>
<td>28</td>
<td>2008-08-06</td>
<td>2008-10-15</td>
<td>464</td>
<td>2008-08-02</td>
<td>2008-10-11</td>
<td>0.7</td>
<td>0.17</td>
<td>0.2</td>
</tr>
<tr>
<td>e</td>
<td>300</td>
<td>2008-11-03</td>
<td>2009-01-12</td>
<td>49</td>
<td>2008-11-21</td>
<td>2009-01-30</td>
<td>0.6</td>
<td>0.26</td>
<td>3.5</td>
</tr>
<tr>
<td>f</td>
<td>300</td>
<td>2009-02-16</td>
<td>2009-06-01</td>
<td>464</td>
<td>2009-02-28</td>
<td>2009-06-13</td>
<td>0.5</td>
<td>0.20</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Table S-2. Standard deviation of input data and residues for the time-series inversion.

<table>
<thead>
<tr>
<th>Interferogram</th>
<th>Number of points</th>
<th>Standard deviation of data vector</th>
<th>Standard deviation of residue vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>20051130-20060208</td>
<td>505</td>
<td>4.960</td>
<td>1.411</td>
</tr>
<tr>
<td>20060208-20060315</td>
<td>508</td>
<td>1.842</td>
<td>1.053</td>
</tr>
<tr>
<td>20051026-20060419</td>
<td>508</td>
<td>12.422</td>
<td>3.476</td>
</tr>
<tr>
<td>20060315-20060524</td>
<td>508</td>
<td>3.530</td>
<td>0.915</td>
</tr>
<tr>
<td>20051219-20060123</td>
<td>533</td>
<td>1.882</td>
<td>0.734</td>
</tr>
<tr>
<td>20051219-20060227</td>
<td>534</td>
<td>2.857</td>
<td>0.897</td>
</tr>
<tr>
<td>20060123-20060227</td>
<td>534</td>
<td>2.026</td>
<td>0.686</td>
</tr>
<tr>
<td>20051219-20060403</td>
<td>529</td>
<td>5.139</td>
<td>1.234</td>
</tr>
<tr>
<td>20060227-20060403</td>
<td>533</td>
<td>3.036</td>
<td>0.985</td>
</tr>
<tr>
<td>20060403-20060612</td>
<td>512</td>
<td>1.980</td>
<td>1.425</td>
</tr>
<tr>
<td>20060508-20060612</td>
<td>532</td>
<td>1.569</td>
<td>1.086</td>
</tr>
<tr>
<td>20060311-20060415</td>
<td>488</td>
<td>2.564</td>
<td>0.727</td>
</tr>
<tr>
<td>20060311-20060520</td>
<td>490</td>
<td>4.656</td>
<td>1.173</td>
</tr>
<tr>
<td>20060415-20060520</td>
<td>493</td>
<td>2.449</td>
<td>1.002</td>
</tr>
<tr>
<td>20051201-20060210</td>
<td>563</td>
<td>2.837</td>
<td>0.940</td>
</tr>
<tr>
<td>20060210-20060317</td>
<td>488</td>
<td>2.807</td>
<td>1.171</td>
</tr>
<tr>
<td>20051028-20060421</td>
<td>536</td>
<td>8.788</td>
<td>2.742</td>
</tr>
<tr>
<td>20060317-20060421</td>
<td>505</td>
<td>1.950</td>
<td>1.330</td>
</tr>
<tr>
<td>20060210-20060526</td>
<td>528</td>
<td>5.112</td>
<td>0.867</td>
</tr>
<tr>
<td>20060317-20060526</td>
<td>484</td>
<td>3.415</td>
<td>0.923</td>
</tr>
<tr>
<td>Total interval d0-d1</td>
<td>10288</td>
<td>4.252</td>
<td>1.402</td>
</tr>
<tr>
<td>200607.29-20060902</td>
<td>480</td>
<td>1.018</td>
<td>0.752</td>
</tr>
<tr>
<td>Total interval d2-d3</td>
<td>480</td>
<td>1.018</td>
<td>0.752</td>
</tr>
<tr>
<td>20060925-20061030</td>
<td>508</td>
<td>2.132</td>
<td>0.874</td>
</tr>
<tr>
<td>20060925-20061204</td>
<td>533</td>
<td>3.310</td>
<td>0.772</td>
</tr>
<tr>
<td>20061030-20061204</td>
<td>509</td>
<td>1.224</td>
<td>0.699</td>
</tr>
<tr>
<td>20061007-20061111</td>
<td>506</td>
<td>2.830</td>
<td>0.848</td>
</tr>
<tr>
<td>Total interval d3-d4</td>
<td>2056</td>
<td>2.505</td>
<td>0.801</td>
</tr>
<tr>
<td>20070124-20070509</td>
<td>499</td>
<td>4.187</td>
<td>1.111</td>
</tr>
<tr>
<td>20070124-20070613</td>
<td>497</td>
<td>4.441</td>
<td>0.836</td>
</tr>
<tr>
<td>20070509-20070613</td>
<td>509</td>
<td>2.176</td>
<td>0.864</td>
</tr>
<tr>
<td>20070124-20070718</td>
<td>491</td>
<td>5.673</td>
<td>1.110</td>
</tr>
<tr>
<td>20070613-20070718</td>
<td>490</td>
<td>1.485</td>
<td>0.742</td>
</tr>
<tr>
<td>20070718-20070528</td>
<td>533</td>
<td>1.713</td>
<td>0.696</td>
</tr>
<tr>
<td>20070212-20070528</td>
<td>530</td>
<td>3.058</td>
<td>0.784</td>
</tr>
<tr>
<td>20070423-20070528</td>
<td>533</td>
<td>2.333</td>
<td>0.901</td>
</tr>
<tr>
<td>20070212-20070702</td>
<td>516</td>
<td>5.290</td>
<td>0.857</td>
</tr>
<tr>
<td>20070528-20070702</td>
<td>533</td>
<td>0.902</td>
<td>0.568</td>
</tr>
<tr>
<td>20070702-20070806</td>
<td>526</td>
<td>2.230</td>
<td>0.875</td>
</tr>
<tr>
<td>20070120-20070505</td>
<td>477</td>
<td>4.057</td>
<td>1.138</td>
</tr>
<tr>
<td>20070505-20070714</td>
<td>477</td>
<td>4.288</td>
<td>0.906</td>
</tr>
<tr>
<td>20070511-20070615</td>
<td>562</td>
<td>1.160</td>
<td>0.694</td>
</tr>
<tr>
<td>20070615-20070720</td>
<td>529</td>
<td>1.032</td>
<td>0.581</td>
</tr>
<tr>
<td>Total interval d4-d6</td>
<td>7202</td>
<td>3.971</td>
<td>0.856</td>
</tr>
<tr>
<td>20070822-20071031</td>
<td>493</td>
<td>3.196</td>
<td>1.624</td>
</tr>
<tr>
<td>20070910-20071015</td>
<td>532</td>
<td>1.635</td>
<td>1.096</td>
</tr>
<tr>
<td>20070818-20070922</td>
<td>476</td>
<td>1.661</td>
<td>1.119</td>
</tr>
<tr>
<td>20070818-20071027</td>
<td>477</td>
<td>2.176</td>
<td>0.864</td>
</tr>
<tr>
<td>20070922-20071027</td>
<td>485</td>
<td>1.147</td>
<td>0.791</td>
</tr>
<tr>
<td>20070824-20070928</td>
<td>528</td>
<td>4.444</td>
<td>1.581</td>
</tr>
<tr>
<td>20070824-20071102</td>
<td>529</td>
<td>1.992</td>
<td>0.863</td>
</tr>
<tr>
<td>Total interval d6-d7</td>
<td>3520</td>
<td>2.122</td>
<td>1.194</td>
</tr>
</tbody>
</table>
Table S-3. Standard deviation of input data and residues for the time-series inversion (continued).

<table>
<thead>
<tr>
<th>Interferogram</th>
<th>Number of points</th>
<th>Standard deviation of data vector</th>
<th>Standard deviation of residue vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>20080109-20080213</td>
<td>498</td>
<td>1.336</td>
<td>0.398</td>
</tr>
<tr>
<td>20071119-20080128</td>
<td>534</td>
<td>2.434</td>
<td>0.680</td>
</tr>
<tr>
<td>20071207-20080215</td>
<td>535</td>
<td>2.965</td>
<td>0.512</td>
</tr>
<tr>
<td>Total interval d7-d8</td>
<td>1567</td>
<td>1.813</td>
<td>0.545</td>
</tr>
<tr>
<td>20080423-20080528</td>
<td>505</td>
<td>3.372</td>
<td>1.041</td>
</tr>
<tr>
<td>20080423-20080507</td>
<td>497</td>
<td>3.626</td>
<td>0.946</td>
</tr>
<tr>
<td>20080428-20080507</td>
<td>495</td>
<td>5.416</td>
<td>0.677</td>
</tr>
<tr>
<td>20080407-20080616</td>
<td>531</td>
<td>2.366</td>
<td>0.839</td>
</tr>
<tr>
<td>20080524-20080628</td>
<td>486</td>
<td>1.171</td>
<td>0.682</td>
</tr>
<tr>
<td>20080425-20080530</td>
<td>536</td>
<td>1.591</td>
<td>0.722</td>
</tr>
<tr>
<td>20080530-20080704</td>
<td>535</td>
<td>0.976</td>
<td>0.667</td>
</tr>
<tr>
<td>Total interval d8-d9</td>
<td>3585</td>
<td>2.832</td>
<td>0.808</td>
</tr>
<tr>
<td>20080806-20080910</td>
<td>492</td>
<td>1.015</td>
<td>0.825</td>
</tr>
<tr>
<td>20080806-20081015</td>
<td>486</td>
<td>1.532</td>
<td>0.975</td>
</tr>
<tr>
<td>20080810-20081015</td>
<td>487</td>
<td>1.431</td>
<td>0.948</td>
</tr>
<tr>
<td>20080721-20080929</td>
<td>529</td>
<td>5.438</td>
<td>1.944</td>
</tr>
<tr>
<td>20080825-20080929</td>
<td>532</td>
<td>1.640</td>
<td>0.987</td>
</tr>
<tr>
<td>20080802-20080906</td>
<td>479</td>
<td>1.739</td>
<td>1.769</td>
</tr>
<tr>
<td>20080802-20081011</td>
<td>476</td>
<td>2.654</td>
<td>1.096</td>
</tr>
<tr>
<td>20080906-20081011</td>
<td>477</td>
<td>1.246</td>
<td>0.675</td>
</tr>
<tr>
<td>Total interval d9-d10</td>
<td>4484</td>
<td>2.163</td>
<td>1.064</td>
</tr>
<tr>
<td>20081119-20081224</td>
<td>490</td>
<td>3.350</td>
<td>0.751</td>
</tr>
<tr>
<td>20081119-20090128</td>
<td>487</td>
<td>4.946</td>
<td>0.713</td>
</tr>
<tr>
<td>20081224-20090128</td>
<td>484</td>
<td>1.899</td>
<td>0.595</td>
</tr>
<tr>
<td>20081103-20081208</td>
<td>521</td>
<td>1.588</td>
<td>0.694</td>
</tr>
<tr>
<td>20081103-20090112</td>
<td>521</td>
<td>3.286</td>
<td>0.545</td>
</tr>
<tr>
<td>20081208-20090112</td>
<td>530</td>
<td>3.565</td>
<td>0.548</td>
</tr>
<tr>
<td>20081221-20081226</td>
<td>533</td>
<td>0.993</td>
<td>0.438</td>
</tr>
<tr>
<td>20081121-20090130</td>
<td>528</td>
<td>3.204</td>
<td>0.637</td>
</tr>
<tr>
<td>Total interval d10-d11</td>
<td>4640</td>
<td>2.291</td>
<td>0.604</td>
</tr>
<tr>
<td>20090304-20090408</td>
<td>499</td>
<td>1.169</td>
<td>0.643</td>
</tr>
<tr>
<td>20090304-20090513</td>
<td>500</td>
<td>2.198</td>
<td>0.875</td>
</tr>
<tr>
<td>20090404-20090513</td>
<td>500</td>
<td>1.758</td>
<td>0.862</td>
</tr>
<tr>
<td>20090304-20090617</td>
<td>497</td>
<td>6.686</td>
<td>1.533</td>
</tr>
<tr>
<td>20090408-20090617</td>
<td>500</td>
<td>6.323</td>
<td>1.313</td>
</tr>
<tr>
<td>20090513-20090617</td>
<td>499</td>
<td>5.121</td>
<td>1.493</td>
</tr>
<tr>
<td>20090216-20090323</td>
<td>531</td>
<td>1.351</td>
<td>0.722</td>
</tr>
<tr>
<td>20090216-20090427</td>
<td>532</td>
<td>2.289</td>
<td>0.649</td>
</tr>
<tr>
<td>20090323-20090427</td>
<td>531</td>
<td>1.249</td>
<td>0.521</td>
</tr>
<tr>
<td>20090216-20090427</td>
<td>532</td>
<td>2.880</td>
<td>0.737</td>
</tr>
<tr>
<td>20090323-20090601</td>
<td>533</td>
<td>1.760</td>
<td>0.459</td>
</tr>
<tr>
<td>20090427-20090601</td>
<td>532</td>
<td>0.840</td>
<td>0.337</td>
</tr>
<tr>
<td>20090228-20090509</td>
<td>481</td>
<td>5.187</td>
<td>1.206</td>
</tr>
<tr>
<td>20090228-20090613</td>
<td>478</td>
<td>4.111</td>
<td>1.070</td>
</tr>
<tr>
<td>20090509-20090613</td>
<td>483</td>
<td>2.001</td>
<td>0.997</td>
</tr>
<tr>
<td>20090306-20090410</td>
<td>533</td>
<td>1.333</td>
<td>1.141</td>
</tr>
<tr>
<td>20090306-20090515</td>
<td>536</td>
<td>2.162</td>
<td>0.850</td>
</tr>
<tr>
<td>20090410-20090515</td>
<td>533</td>
<td>2.176</td>
<td>1.153</td>
</tr>
<tr>
<td>20090306-20090619</td>
<td>536</td>
<td>1.951</td>
<td>1.070</td>
</tr>
<tr>
<td>20090410-20090619</td>
<td>522</td>
<td>1.896</td>
<td>1.088</td>
</tr>
<tr>
<td>20090515-20090619</td>
<td>535</td>
<td>1.296</td>
<td>1.145</td>
</tr>
<tr>
<td>Total interval d11-d12</td>
<td>10825</td>
<td>2.827</td>
<td>0.993</td>
</tr>
<tr>
<td>Total all intervals</td>
<td>49145</td>
<td>3.339</td>
<td>1.036</td>
</tr>
</tbody>
</table>