Measuring Lateral Ground Movement With Synthetic Aperture Radar Differential Interferometry: Technique and Validation

By

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Abstract

Research under the framework of natural hazards monitoring with Interferometric Synthetic Aperture Radar (InSAR) has gained eminence in the last 10 years with advances in satellite imaging systems. Ground movement is known to be a form of natural hazard, which threatens the integrity of buried infrastructure as either massive instantaneous movement or visually imperceptible, slow incremental movement over a long period. Both types of movement can lead to serious damage. InSAR techniques have been well investigated for measuring ground subsidence, the vertical component of ground movement. If it is incorrectly assumed that the lateral movement component is zero, subsidence movement derived from one satellite look direction will contain errors. The research presented here has resulted in the derivation of a technique by which both vertical and lateral ground movement components can be estimated. Adopting the suggested technique for routine InSAR analysis in certain instances will provide the ability to derive more accurate subsidence estimates compared to the standard single look technique.
Acknowledgements

With a deep sense of gratitude, I wish to express my sincere thanks to my supervisors, Mr. Desmond Power, Dr. Charles Randell and Dr. Eric Gill for their help. It is through immense patience, understanding and encouragement that this work stands complete. I would also especially like to convey my sincere gratitude to Mr. Desmond Power, my thesis supervisor, whose guidance for this work requires no elaboration. His company and assurance at the time of crisis will be remembered. His valuable suggestions as final words during the course of work are greatly appreciated.

I am deeply indebted and grateful to National Research Council of Canada (NSERC) for funding my graduate work (through grants to Dr. Randell and Dr. Gill) and for the facilities at C-CORE that were available during the course of this research. I would like to express my gratitude to the remote sensing team at C-CORE, especially to Dr. James Youden for his suggestions during the course of this work.

Finally, I owe it to my dear family for their support, patience, encouragement and blessing when I am thousands of miles away from them.
# Table of Contents

List of Figures vi
List of Tables xvi
Nomenclature xvii

1 **Introduction** 1

2 **Background Information** 8

2.1 Synthetic Aperture Radar (SAR) 8

2.1.1 SAR Imaging Geometry 10

2.1.2 SAR Raw Image Acquisition 11

2.1.3 SAR Imaging Geometry and Terrain Relief 16

2.1.4 SAR Images 18

2.2 Review of SAR/InSAR Development and Applications 19

2.3 SAR Interferometry 25

2.4 SAR Interferometry Data Acquisition Techniques 27

2.4.1 Across-track Interferometry 27

2.4.2 Along-Track Interferometry 28

2.4.3 Repeat-Pass Interferometry 29

2.5 SAR Interferometric Images 32

2.6 Unwrapping of Interferometric Phases 33

2.7 Fringe Patterns in Interferometric SAR images 34

2.8 Coherence of SAR Images 36

2.9 Sources of Phase Noise in SAR Interferometry 38

2.10 Principles of Extracting Topography from SAR Interferometry 43

2.11 Equations for Deriving Topography from SAR Images 44

2.12 Differential Interferometry 49
2.13 Interpreting Subsidence from Differential Interferogram 51

3 Fusion of Ascending and Descending Pass Interferograms 54
   3.1 Ascending and Descending Pass Geometry 56
   3.2 Ascending and Descending Pass Equations 60
   3.3 Estimating 3-D Ground Movement 66

4 Verification and Results 72
   4.1 Comparison of GPS Measurements Projected onto SAR LOS 78
   4.2 Validation of 2-D Ground Movement 84
   4.3 Simulation with Synthetic Data 90
      4.3.1 Derivation of Synthetic Data 90
      4.3.2 Movement Components Derived from Simulated Data 94
      4.3.3 Simulation of Movement Components Derived from Modified Least Squares Technique 111
   4.4 Validation of 3-D Ground Movement Measurements 118
   4.5 Validation of 3-D Ground Movement Measurements with Constrained Least Squares Solution 126

5 Conclusion and Recommendations for Future Work 131

Bibliography 134

Appendix A 139

Appendix B 156

Appendix C 159
List of Figures

Chapter 1

Figure 1-1: Illustration of InSAR for producing Digital Elevation Map (DEM) and ground displacement map or Slant Range (SR) change. B is the separation of the satellite orbits. 4

Figure 1-2: Damages due to ground movement [5]. 6

Chapter 2

Figure 2-1: 2-Dimensional imaging geometry of real aperture radar (redrawn from [10]) 9

Figure 2-2: SAR imaging geometry illustration of a side looking SAR 11

Figure 2-3: SAR antenna movement along the $x$ - axis, radar pulses to the ground along the $y$ - axis, time instant between position $x = 0$ to $x = x_1$. [10] 12

Figure 2-4: Terrain relief affecting SAR images. Slant range image shows the terrain as perceived by the SAR due to foreshortening, shadowing and layover distortions [16]. 17

Figure 2-5: Image of Greenland (October 2002, ENVISAT) showing terrain relief and its impact on the SAR image [Courtesy C-CORE]. 18

Figure 2-6: SAR imaging system with $I(x, y)e^{j\phi(x, y)}$ a SAR pixel (complex number) 19

Figure 2-7: A simple interferometer geometry illustrated. $\lambda$ is the wavelength, $P_1$ and $P_2$ are the sensor to target distances, $s_1$ and $s_2$ are the sensors and $B$ is the baseline. 26

Figure 2-8: Across-track interferometry. $S_1$ and $S_2$ are the SAR sensors, $r_1$ and $r_2$ are the path lengths, $B$ is the baseline [11]. 28
Figure 2-9: Along-track interferometry. $S_1$ and $S_2$ are the SAR sensors; $r_1$ and $r_2$ are the path lengths; $B$ is the baseline.

Figure 2-10: Repeat-pass interferometry. $S_1$ and $S_2$ are the SAR sensors, $\rho_1$ and $\rho_2$ are path lengths with $\delta\rho$ as the absolute difference, $B$ is the baseline. $H$ is how far the orbit is from ground, $a$ is the ground range, $P$ is the target point on ground and $h$ is the elevation of $P$, $\delta_\rho$ and $\delta_h$ are the components of $B$ [11].

Figure 2-11: SAR master/slave pair with an interferogram. $Z_1(x, y)$ is the master SAR image, $Z_2(x, y)$ is the slave SAR image and $Z_{int}(x, y)$ is the interferogram used to illustrate the concept.

Figure 2-12: Repeat-pass geometry. $S_1$ and $S_2$ are the SAR sensors (antenna), $\rho$ and $\delta\rho$ are the path lengths and variation of the path length and $B$ is the baseline. $H$ is how far the orbit is from the ground, $a$ is the ground range, $P$ is the target point on the ground and $h$ is the elevation of $P$.

Figure 2-13: Ground subsidence from InSAR, where $\nu_d$ is the descending pass look angle.

Chapter 3

Figure 3-1: Sliding from both sides to produce lateral movement. Note: Figure B-4 in Appendix B illustrates the 3-D perspective.

Figure 3-2: Descending and ascending orbits (RADARSAT International, 1996).

Figure 3-3: Coverage area for RADARSAT-1 for both ascending and descending passes. (RADARSAT International, 1996).

Figure 3-4: Plan view of satellite look direction illustrated.

Figure 3-5: Ascending pass. $B$ is the actual movement vector from $P$ to $P'$, $A$ is the component of $B$ from ascending pass, $S$ is subsidence component and $L$ as lateral component.
Figure 3-6: Descending pass. \( \mathbf{B} \) is the actual movement vector from \( P \) to \( P' \), \( \mathbf{D} \) is the measured component of \( \mathbf{B} \) from descending pass, \( \mathbf{S} \) is subsidence component and \( \mathbf{L} \) as lateral component.

Figure 3-7: Relating look angle \( \vartheta \) with respect to circular coordinate \( \theta \).

Figure 3-8: Relating satellite co-ordinate system to geometrical coordinate system. Where \( \varphi_a \) and \( \varphi_d \) are the angles relating to inclination of satellite trajectory with respect to geographical North-South.

Figure 3-9: Dot product table relating spherical coordinate system to Cartesian coordinate system.

Figure 3-10: Bounded region of \( n \) pixels that coherently move together.

Figure 3-11: Ascending and descending pass grid with varying incidence angle. The \( n \) neighborhood identifies region of continuous displacement field used for the least-squares solution.

Chapter 4

Figure 4-1: Pipeline failure due to lateral ground movement (Courtesy of Southern California Gas Company and C-CORE)

Figure 4-2: GPS monument position along the pipeline vector

Figure 4-3: Interferogram obtained from ERS-1/2 after InSAR processing. Each contour line represents 28 mm (i.e. half of the radar wavelength)

Figure 4-4: DEM from ERS-1/2 after InSAR processing.

Figure 4-5: Differential interferogram of 30470 and 30813 Descending pass from RADARSAT-1.

Figure 4-6: Differential interferogram of 30406 and 30749 Ascending pass from RADARSAT-1.

Figure 4-7: Figure on the left is with a planar trend and the figure on the
right is after removing the planar trend.

Figure 4-8: InSAR SRC (cm) versus $\mathbf{G} \cdot \hat{A}$ [Feb-Apr 2001].

Figure 4-9: InSAR SRC (cm) VS $\mathbf{G} \cdot \hat{D}$ [Feb-Apr 2001].

Figure 4-10: InSAR SRC (cm) VS $\mathbf{G} \cdot \hat{A}$ [Averaged Feb-Sept 2001].

Figure 4-11: InSAR SRC (cm) VS $\mathbf{G} \cdot \hat{D}$ [Averaged Feb-Sept 2001].

Figure 4-12: Variation over time in SRC (cm) between Ascending pass and Descending pass

Figure 4-13: InSAR versus GPS subsidence normalized to 24 days from February –April 2001.

Figure 4-14: InSAR versus GPS East-West movement normalized to 24 days from February –April 2001.

Figure 4-15: InSAR versus GPS subsidence normalized to 24 days averaged over 4 DInSAR pairs from February –September 2001.

Figure 4-16: InSAR versus GPS East-West movement normalized to 24 days averaged over 4 DInSAR pair from February –September 2001.

Figure 4-17: The simulated Subsidence Movement.

Figure 4-18: Illustrates the East-West Movement.

Figure 4-19: Illustrates the North-South Movement

Figure 4-20: Slant Range Change data for ascending pass. (Artificially created from individual East-West, North-South and Subsidence data. SRC shown as positive here in the plot.)

Figure 4-21: GPS monument positions obtained by the GPS survey. Note that most of the monument positions inside the dotted ellipse shown as area of movement are mainly on the horizontal (East-West direction).

Figure 4-22: Monuments sampled horizontally as shown by the arrow.
Figure 4-23: Comparison of East-West movement sampled horizontally. 97
Figure 4-24: Comparison of North-South movement sampled horizontally. 97
Figure 4-25: Comparison of Subsidence sampled horizontally. 98
Figure 4-26: North-South ground movement shows discontinuity over a small region on the ground when sampled horizontally. 100
Figure 4-27: Monuments sampled vertically as shown by the arrow. 101
Figure 4-28: Comparison of East-West movement sampled vertically. 101
Figure 4-29: Comparison of North-South movement sampled vertically. 102
Figure 4-30: Comparison of subsidence movement sampled vertically. 102
Figure 4-31: North-South ground movement shows homogeneity over a small region on the ground when sampled vertically. 103
Figure 4-32: East-West ground movement shows discontinuity over a small region on the ground when sampled horizontally. 104
Figure 4-33: Monuments sampled along the image grid. 105
Figure 4-34: Comparison of East-West movement sampled over the entire image. 106
Figure 4-35: Comparison of North-South movement sampled over the entire image. 107
Figure 4-36: Comparison of subsidence movement sampled over the entire image. 107
Figure 4-37: Slant range change data for ascending pass with noise added. (Artificially created from individual East-West, North-South and Subsidence data. SRC shown as positive here.) 108
Figure 4-38: Comparison of East-West [with noise].

Figure 4-39: Comparison of North-South [with noise].
Figure 4-40: Comparison of subsidence [with noise].

Figure 4-41: Comparison of Subsidence as a solution of constrained LSS with simulated data.

Figure 4-42: Comparison of North-South ground movement from constrained LSS solution.

Figure 4-43: Comparison of North-South ground movement from constrained LSS solution.

Figure 4-44: Comparison of North-South ground movement from constrained LSS solution.

Figure 4-45: Correlation between DInSAR & GPS versus Least Mean Square (LMS) window size (n). The y-axis represents the correlation of InSAR estimated subsidence with respect to GPS measurements for all GPS monuments. The x-axis represents increase in the number of pixels for each InSAR versus GPS analysis.

Figure 4-46: InSAR versus GPS Subsidence movement normalized to 24 days from February – April 2001.

Figure 4-47: InSAR versus GPS East-West movement normalized to 24 days from February – April 2001.

Figure 4-48: InSAR versus GPS East-West movement normalized to 24 days from February – April 2001.

Figure 4-49: InSAR versus GPS Subsidence movement normalized to 24 days from February – September 2001.

Figure 4-50: InSAR versus GPS East-West movement normalized to 24 days from February – September 2001.

Figure 4-51: InSAR versus GPS North-South movement normalized to 24 days from February – September 2001.
Figure 4-52: Comparison of East-West ground movement from constrained LSS solution.

Figure 4-53: Comparison of North-South ground movement from constrained LSS solution.

Figure 4-54: Comparison of subsidence ground movement from constrained LSS solution.

Figure 4-55: Comparison of averaged East-West ground movement from [Feb-Sept 2001] with constrained LSS solution

Figure 4-56: Comparison of averaged North-South ground movement from [Feb-Sept 2001] with constrained LSS solution

Figure 4-57: Comparison of averaged subsidence ground movement from [Feb-Sept 2001] with constrained LSS solution

Appendix A

Figure A-1: InSAR SRC (cm) versus $G \cdot \hat{A}$ [Apr-Jun].

Figure A-2: InSAR SRC (cm) versus $G \cdot \hat{D}$ [Apr-Jun].

Figure A-3: InSAR SRC (cm) versus $G \cdot \hat{A}$ [Jun-Sept].

Figure A-4: InSAR SRC (cm) versus $G \cdot \hat{D}$ [Jun-Sept].

Figure A-5: InSAR SRC (cm) versus $G \cdot \hat{A}$ [Sept].

Figure A-6: InSAR SRC (cm) versus $G \cdot \hat{D}$ [Sept].

Figure A-7: InSAR versus GPS East-West normalized to 24 days from Apr-Jun 2001.

Figure A-8: InSAR versus GPS subsidence normalized to 24 days from Apr-Jun 2001.
Figure A-9: InSAR versus GPS East-West normalized to 24 days from Jun- Sept 1st 2001.  

Figure A-10: InSAR versus GPS subsidence normalized to 24 days from Jun- Sept 1st 2001.  

Figure A-11: InSAR versus GPS East-West normalized to 24 days from Sept 1st-Sept 25th 2001  

Figure A-12: InSAR versus GPS subsidence normalized to 24 days from Sept 1st-Sept 25th 2001  

Figure A-13: InSAR versus GPS East-West normalized to 24 days from Apr-Jun 200.  

Figure A-14: InSAR versus GPS North-South normalized to 24 days from Apr-Jun 2001.  

Figure A-15: InSAR versus GPS subsidence normalized to 24 days from Apr-Jun 2001.  

Figure A-16: InSAR versus GPS East-West normalized to 24 days from Jun- Sept 1st 2001.  

Figure A-17: InSAR versus GPS North-South normalized to 24 days from Jun- Sept 1st 2001.  

Figure A-18: InSAR versus GPS subsidence normalized to 24 days from Jun- Sept 1st 2001.  

Figure A-19: InSAR versus GPS East-West normalized to 24 days from Sept 1st-Sept 25th 2001  

Figure A-20: InSAR versus GPS North-South normalized to 24 days from Sept 1st-Sept 25th 2001  

Figure A-21: InSAR versus GPS subsidence normalized to 24 days from Sept 1st-Sept 25th 2001  

Figure A-22: InSAR versus GPS East-West normalized to 24 days from Apr-Jun 2001.  

xiv
Figure A-23: InSAR versus GPS North-South normalized to 24 days from Apr-Jun 2001.

Figure A-24: InSAR versus GPS subsidence normalized to 24 days from Apr-Jun 2001.

Figure A-25: InSAR versus GPS East-West normalized to 24 days from Jun-Sept 1st 2001

Figure A-26: InSAR versus GPS North-South normalized to 24 days from Jun-Sept 1st 2001

Figure A-27: InSAR versus GPS subsidence normalized to 24 days from Jun-Sept 1st 2001

Figure A-28: InSAR versus GPS East-West normalized to 24 days from Sept 1st-Sept 25th 2001

Figure A-29: InSAR versus GPS North-South normalized to 24 days from Sept 1st-Sept 25th 2001

Figure A-30: InSAR versus GPS subsidence normalized to 24 days from Sept 1st-Sept 25th 2001

Figure A-31: InSAR Error Analysis. Estimated relative error in the North-South direction. This plot is based on satellite look direction and look angles projected to map co-ordinates.

Appendix B

Figure B-1: Digital Elevation Model 90° perspective

Figure B-2: Digital Elevation Model 45° perspective

Figure B-3: Digital Elevation Model 20° perspective rotated 180°

Figure B-4: 3-D Subsidence as estimated by InSAR draped over SLC
Appendix C

Figure C-1: Simple SAR raw data processing steps. 163

Figure C-2: Simple InSAR processing steps. 164
List of Tables

Table 1-1: Accuracies of commonly used ground deformation measuring instruments [6]. Note 1 ppm means one part per million or 1 additional millimeter per kilometer of measured line. 3

Table 2-1: List of remote sensing satellites capable of interferometry. 31

Table 4-1: Satellite orbit and data processed for differential interferometry 76
## Nomenclature

### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>Synthetic Aperture Radar</td>
</tr>
<tr>
<td>LOS</td>
<td>Line of Sight</td>
</tr>
<tr>
<td>InSAR</td>
<td>Interferometric SAR</td>
</tr>
<tr>
<td>DInSAR</td>
<td>Differential Interferometric SAR</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>SLC</td>
<td>Single Look Complex</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>Pixel</td>
<td>Picture Element</td>
</tr>
</tbody>
</table>

### Variables

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r$</td>
<td>Distance between the sensor and the target</td>
</tr>
<tr>
<td>$r_0$</td>
<td>Distance between the sensor and the target (the initial position)</td>
</tr>
<tr>
<td>$l_{sa}$</td>
<td>The radar scan range on ground (synthetic aperture)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Wavelength of the system C-Band = 5.6 cm</td>
</tr>
<tr>
<td>$L$</td>
<td>Antenna length</td>
</tr>
<tr>
<td>$v_0$</td>
<td>Constant velocity of the SAR antenna</td>
</tr>
<tr>
<td>$\delta_{az}$</td>
<td>Spatial resolution in the azimuthal direction</td>
</tr>
<tr>
<td>$\phi(x)$</td>
<td>Received echoes resulting after a distance $r$</td>
</tr>
<tr>
<td>$\phi(t)$</td>
<td>Time independent phase term</td>
</tr>
<tr>
<td>$k$</td>
<td>Propagation constant</td>
</tr>
<tr>
<td>$t_{max}$</td>
<td>The illumination time of a point target</td>
</tr>
<tr>
<td>$\theta_{sa}$</td>
<td>The change in look angle due to length $l_{sa}$</td>
</tr>
<tr>
<td>$B_{az}$</td>
<td>Bandwidth of the signal in azimuth</td>
</tr>
<tr>
<td>$Z(x,y)$</td>
<td>SAR pixel</td>
</tr>
<tr>
<td>$I(x,y)$</td>
<td>The intensity of the pixel</td>
</tr>
<tr>
<td>$\alpha_{ra}$</td>
<td>Angular resolution</td>
</tr>
<tr>
<td>$B$</td>
<td>Orbit baseline</td>
</tr>
<tr>
<td>$R_1$</td>
<td>Sensor to target distance</td>
</tr>
<tr>
<td>$R_2$</td>
<td>Sensor to target distance (at another time or separated by baseline)</td>
</tr>
<tr>
<td>$S_1$</td>
<td>Sensor (receive antenna)</td>
</tr>
<tr>
<td>$S_2$</td>
<td>Sensor (transmit antenna)</td>
</tr>
<tr>
<td>$\delta_h$</td>
<td>Horizontal separation from reference path</td>
</tr>
<tr>
<td>$\delta_v$</td>
<td>Vertical separation from reference path</td>
</tr>
</tbody>
</table>
\( Z_{int} \)  
Interferogram pixel

\( \rho \)  
Slant range

\( \Delta \rho \)  
Slant Range Change (SRC)

\( B_h \)  
Horizontal baseline

\( Z_a \)  
Altitude of a point on ground

\( \gamma \)  
Coherence of two SAR Images

\( \gamma_{\text{temporal}} \)  
Temporal decorrelation coefficient

\( \gamma_{\text{spatial}} \)  
Spatial decorrelation coefficient

\( \sigma_e \)  
Error in elevation estimates

\( B_{cr} \)  
Critical baseline

\( \tilde{D} \)  
Descending pass SRC vector

(A pixel from differential interferogram obtained from descending pass)

\( \tilde{A} \)  
Ascending pass SRC Vector

(A pixel from differential interferogram obtained from ascending pass)

\( \tilde{B} \)  
Actual movement of ground

Real ground movement vector representation

\( \theta_d \)  
Satellite look angle descending pass

\( \theta_h \)  
Satellite look angle ascending pass

\( \phi_d \)  
Satellite trajectory inclination of descending pass with geographic
North-South

\( \phi_h \)  
Satellite trajectory inclination of ascending pass with geographic
North-South

\( \Delta Y \)  
Measured East-West movement

\( \Delta X \)  
Measured North-South movement

\( \Delta Z \)  
Measured subsidence movement

\( \rho_d \)  
Slant Range Change SRC descending

\( \rho_h \)  
Slant Range Change (SRC) ascending