• What is GMTSAR?

• Precise orbits and accurate timing simplifies software and enables seamless mosaicing.

• Geometric validation of ERS, Envisat, and ALOS.

• InSAR phase comparisons: ISCE, Stanford, ROI_PAC, GMTSAR.
An InSAR processing system based on GMT

David Sandwell - Scripps Institution of Oceanography
Rob Mellors - San Diego State University
Xiaopeng Tong - Scripps Institution of Oceanography
Meng Wei - Scripps Institution of Oceanography
Paul Wessel - University of Hawaii
Looking for volunteers to develop scripts

GMTSAR is an open source (GNU General Public License) InSAR processing system designed for users familiar with Generic Mapping Tools (GMT). The code is written in C and will compile on any computer where GMT and NETCDF are installed. The system has three main components:

1. a preprocessor for each satellite data type (e.g., ERS, Envisat, and ALOS) to convert the native format and orbital information into a generic format
2. an InSAR processor to focus and align stacks of images, map topography into phase, and form the complex interferogram
3. a postprocessor, mostly based on GMT, to filter the interferogram and construct interferometric products of phase, coherence, phase gradient, and line-of-sight displacement in both radar and geographic coordinates.

GMT is used to display all the products as postscript files and KML images for Google Earth. A set of C-shell scripts has been developed for standard 2-pass processing as well as image alignment for stacking and time series. ScanSAR processing is also possible but requires a knowledgeable user. Users are welcome to contribute to this effort. In particular, contributions using other scripting languages such as Perl and Python are desired.

ACKNOWLEDGEMENTS This research was supported by ConocoPhillips, Scripps Institution of Oceanography, and San Diego State University.
One-stop shop for InSAR:

- Software
- Documentation
- Orbits (ERS and Envisat)
- Example data sets
- GNU public license, no passwords, no registration, no restrictions
GMTC SAR Processing Modes

2-pass processing
- no ground control
- seamless abutment of frames along track

Stacking for time series
- one master and many slaves
- primary, secondary, tertiary, image alignment

ScanSAR Interferometry
- possible but not easy
- code needs refinement
2-pass processing with no ground control

p2p_ALOS.csh IMG-HH-ALPSRP207600640-H1.0__A IMG-HH-ALPSRP227730640-H1.0__A config.alos.txt

QuickTime™ and a decompressor are needed to see this picture.
2-Pass Processing Example

Feb 27, 2010, M8.8, Maule Chile Earthquake ALOS SAR data

Each frame is processed independently on a different CPU and recombined later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

[Tong et al., 2010]
2-pass processing
  no ground control
  seamless abutment of frames along track

**stacking for time series**
  one master and many slaves
  primary, secondary, tertiary, image alignment

ScanSAR Interferometry
  possible but not easy
  code needs refinement
stacking for time series

- known phase from DEM
- master SLC
- slave(s) SLC

dimensions: 720.0x540.0
stacking for time series
Stacking Example
LOS interseismic velocity from ALOS and GPS

Used to estimate seismic moment accumulation rate and thus earthquake potential.

(Seamless integration of 880 interferograms using GMT. kml file is available at ftp://topex.ucsd.edu/pub/SAF_models/insar/ALOS_ASC_masked.kmz)

Creeping section of SAF has low seismic potential
GMTSAR Processing Modes

2-pass processing
  no ground control
  seamless abutment of frames along track

stacking for time series
  one master and many slaves
  primary, secondary, tertiary, image alignment

ScanSAR Interferometry
  possible but not easy
  code needs refinement
ScanSAR Example - ALOS WB1

- SW4 look angle matches FBS/FBD 34.3°
- SW4 PRF matches FBS/FBD 34.3°
- of course ScanSAR and StripSAR will have 100% burst overlap
- Pinon corner reflectors appear in SW2

<table>
<thead>
<tr>
<th></th>
<th>SW1</th>
<th>SW2</th>
<th>SW3</th>
<th>SW4</th>
<th>SW5</th>
</tr>
</thead>
<tbody>
<tr>
<td>near range (m)</td>
<td>730097</td>
<td>770120</td>
<td>806544</td>
<td>848515</td>
<td>878195</td>
</tr>
<tr>
<td>PRF (Hz)</td>
<td>1692</td>
<td>2370</td>
<td>1715</td>
<td>2160</td>
<td>1916</td>
</tr>
<tr>
<td>nburst</td>
<td>247</td>
<td>356</td>
<td>274</td>
<td>355</td>
<td>327</td>
</tr>
<tr>
<td>Δt (s)</td>
<td>0.146</td>
<td>0.150</td>
<td>0.160</td>
<td>0.164</td>
<td>0.171</td>
</tr>
<tr>
<td>nsamples</td>
<td>4976</td>
<td>4720</td>
<td>5376</td>
<td>4432</td>
<td>4688</td>
</tr>
<tr>
<td>off nadir (deg)</td>
<td>20.1</td>
<td>26.1</td>
<td>30.6</td>
<td>34.1</td>
<td>36.5</td>
</tr>
</tbody>
</table>

(Ortiz and Zebker, 2007)
Pinon Flat Geodetic Observatory - Radar reflectors
2.4 m corner reflectors
D1, D2 installed 1996
A1 installed Nov, 2005
Precise orbit for image focusing and geolocation

\[ R(s) = R_o + \dot{R}_o (s - s_o) + \frac{\ddot{R}_o}{2} (s - s_o)^2 + \ldots \]

phase history of point reflector

\[ C(s) = \exp \left\{ i \frac{4\pi}{\lambda} R(s) \right\} \]

parabolic approximation to range history

Least-squares fit of range history for each point in DEM provides both the accurate position in range azimuth \([R_o, s_o]\) space and the Doppler centroid and rate parameters needed to focus the image. This analysis only needs to be applied to the master image.
Precise orbit for image focussing and geolocation - ALOS

<table>
<thead>
<tr>
<th></th>
<th>FBS</th>
<th>FBD</th>
<th>WB1</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>13</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>ground-range</td>
<td>-11.5±5.5 m</td>
<td>-14.9±5.8 m</td>
<td>-5.6±8.4 m</td>
</tr>
<tr>
<td>azimuth</td>
<td>1.3±3.7 m</td>
<td>2.4±4.2 m</td>
<td>-9.55±18.3 m</td>
</tr>
</tbody>
</table>
Precise orbit for image focusing and geolocation - ERS, Envisat

ERS 36 acquisitions

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>range</td>
<td>-17.2 m</td>
<td>2.8 m</td>
</tr>
<tr>
<td>azimuth</td>
<td>14.8 m</td>
<td>10.4 m</td>
</tr>
</tbody>
</table>

Envisat 10 acquisitions

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>range</td>
<td>80.6 m</td>
<td>1.9 m</td>
</tr>
<tr>
<td>azimuth</td>
<td>3.6 m</td>
<td>8.8 m</td>
</tr>
</tbody>
</table>
ScanSAR Example - ALOS

Wenchuan Earthquake, M7.9, May 12, 2008,

ALOS Scan-Scan, $B_{\text{perp}} = 850$ m

JAXA controlled burst overlap in this case. Thank You!

(Tong et al., JGR, 2010)
seamless abutment of 10 swaths processes independently with no adjustments
seamless abutment of 10 swaths processes independently with **no adjustments**
Summary

Precise orbits are critical for 4 areas of InSAR processing

1. Proper focus requires accurate estimates of Doppler centroid and Doppler rate.
2. Transformation from geographic to radar coordinates without ground control.
3. Accurate initial estimates for image alignment.
4. InSAR baseline estimation - no trend removal.
• What is GMTSAR?
• Precise orbits and accurate timing simplifies software.
• Geometric validation of ERS, Envisat, and ALOS.
• InSAR phase comparisons: ISCE, Stanford, ROI_PAC, GMTSAR.
Next generation InSAR processor Workshop

Scripps Institution of Oceanography
La Jolla, CA
March 17-18, 2011

David Sandwell, SIO
Paul A. Rosen, JPL
Howard Zebker, SU
Goals

1) Review community software for InSAR processing
2) Compare and validate processing algorithms and geometry
3) Generate explicit feedback and suggested improvements
4) Compare algorithmic performance among codes on real satellite data
5) Develop community plans for use cases and calibration/validation approaches
6) Define/Refine meta-data and data products
7) Discuss mechanisms for developer contributions
Test datasets

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Location</th>
<th>Baseline (km)</th>
<th>Interval (yrs)</th>
<th>CR</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS</td>
<td>Baja</td>
<td>1</td>
<td>0.5</td>
<td></td>
<td>Includes M 7.2 Earthquake</td>
</tr>
<tr>
<td>ALOS</td>
<td>Pinon</td>
<td>~0</td>
<td>3</td>
<td>Y</td>
<td>Temporal decorrelation</td>
</tr>
<tr>
<td>ALOS</td>
<td>Pinon</td>
<td>2</td>
<td>0.1</td>
<td>Y</td>
<td>Large topo effects</td>
</tr>
<tr>
<td>ALOS</td>
<td>Hawaii</td>
<td>1</td>
<td>0.1</td>
<td></td>
<td>HH channel of Polarimetric data</td>
</tr>
<tr>
<td>C-band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Envisat</td>
<td>Baja</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td>Includes M 7.2 Earthquake</td>
</tr>
<tr>
<td>Envisat</td>
<td>Pinon</td>
<td>~0</td>
<td>6</td>
<td>Y</td>
<td>Temporal decorrelation</td>
</tr>
<tr>
<td>Envisat</td>
<td>Pinon</td>
<td>0.7</td>
<td>0.1</td>
<td>Y</td>
<td>Large topo effects</td>
</tr>
<tr>
<td>Envisat</td>
<td>SF (asc)</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
<td>Large topo effects</td>
</tr>
<tr>
<td>Envisat</td>
<td>SF (des)</td>
<td>0.2</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERS</td>
<td>Hector Mine</td>
<td>~0</td>
<td>0.1</td>
<td></td>
<td>Includes M 7.2 Earthquake</td>
</tr>
<tr>
<td>ERS</td>
<td>Pinon</td>
<td>~0</td>
<td>13</td>
<td>Y</td>
<td>Temporal decorrelation</td>
</tr>
<tr>
<td>ERS</td>
<td>Pinon</td>
<td>0.3</td>
<td>0.003</td>
<td>Y</td>
<td>Large topo effects</td>
</tr>
</tbody>
</table>

All test data sets are available by ftp seasat.ucsd.edu. Ask dsandwell@ucsd.edu for username and password.
Benchmarks

1. SAR focusing
2. InSAR phase
3. Geolocation
4. Coherence (not finished by the time of workshop)
"Comparison matrix"

Full workshop report and “comparison matrix” available at ftp://topex.ucsd.edu/pub/sandwell/insar_workshop_report.zip
Identified problems

- Building/Installation can be difficult
- New packages have total dependence on precise orbits; it is important to have the ability to control the software in the fashion of ROI_PAC
- License issues; the new processors were meant to be open source, but really aren’t (except for GMTSAR)
- Coherence estimation among the packages was apparently not consistent. GMTSAR appeared to differ by a large amount
Recommendations

- Complete comparison matrix; include commercial codes (community users)
- Resolve the licensing issues for ISCE so that the community can begin using it more freely (Rosen)
- The next level of testing is with stacks and time series. Participants wanted a set or sets of data that could be used for this testing (Sandwell)
- Create 18 point target response data sets in order to rigorously test the phase fidelity and geometric accuracy of each processor (Hensley)
- Separate preprocessors from ISCE code
Conclusions

David Sandwell, UCSD/SIO
CEOS Cal/Val Workshop,
November 8, 2011

• GMTSAR is a mature InSAR package that will soon become part of the standard GMT distribution so GMT users will have an InSAR package on their computer.

• Precise orbits are used in 4 areas of InSAR processing and eliminate the need for ground control.

• Geometric validation of ERS, Envisat, and ALOS shows accuracies of 10-20 m.

• InSAR phase comparisons from 4 packages (ISCE, Stanford, ROI_PAC, GMTSAR) are remarkably similar suggesting the processing methods are mature.
EXTRA SLIDES
Each frame processed independently on a different CPU and recombined later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

Snaphu phase unwrapping has a consistent zero level of $\pm 2\pi N$ so unwrapped phase can be recombined.

Feb 27, 2010, M8.8, Maule Chile Earthquake
ALOS SAR data
Each frame processed independently on a different CPU and recombined later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

Snaphu phase unwrapping has a consistent zero level of +/- $2\pi N$ so unwrapped phase can be recombined.

Feb 27, 2010, M8.8, Maule Chile Earthquake ALOS SAR data
Each frame processed independently on a different CPU and recombined later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

Snaphu phase unwrapping has a consistent zero level of $\pm 2\pi N$ so unwrapped phase can be recombined.

Feb 27, 2010, M8.8, Maule Chile Earthquake
ALOS SAR data
Each frame processed independently on a different CPU and recombed later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

Snaphu phase unwrapping has a consistent zero level of \( \pm 2\pi \) so unwrapped phase can be recombed.

Feb 27, 2010, M8.8, Maule Chile Eathquake ALOS SAR data
Each frame processed independently on a different CPU and recombined later in radar or lon-lat coordinates.

This requires a consistent geometry and no geometric adjustments.

Snaphu phase unwrapping has a consistent zero level of $\pm 2\pi N$ so unwrapped phase can be recombined.

Feb 27, 2010, M8.8, Maule Chile Earthquake ALOS SAR data
Los Angeles - ScanSAR and FBD
Los Angeles
PALSAR
FBD-FBD

$\Delta T = 46 \text{ days}$
JUL 3, 2007
AUG 18, 2007

$B_{\text{perp}} = 10 \text{ m}$
(topophase not removed)

mean coherence
$= 0.67$
Los Angeles
PALSAR
FBD-ScanSAR

$\Delta T = 184$ days
DEC 31, 2006
JUL 3, 2007

$B_{\text{perp}} = 121$ m
(topophase not removed)

mean coherence
$= 0.48$
Los Angeles
PALSAR
FBD-ScanSAR

$\Delta T = 184$ days
DEC 31, 2006
JUL 3, 2007

$B_{perp} = 121$ m
(topophase not removed)

mean coherence
$= 0.24$

Note that the FBD raw data is not zeroed in the zero areas of the ScanSAR
Los Angeles
PALSAR
ScanSAR-ScanSAR

$\Delta T = 92 \text{ days}$
DEC 31, 2006
APR 1, 2007

$B_{\text{perp}} = 445 \text{ m}$
(topophase not removed)

Burst alignment decreases because the reference and repeat images have different PRF.
Need > 0.2 burst overlap to recover phase form ScanSAR to ScanSAR interferometry.