Application of multi-temporal, multiple-satellite SAR data for land cover characterization and mapping of water-level changes over swamp forests at southeastern Louisiana

Oh-ig Kwoun¹ & Zhong Lu²

(1) SAIC, contractor to U.S. Geological Survey, Sioux Falls, South Dakota.

Acknowledgement: ESA CAT-1 2853
Outline

• Background
• Multi-temporal SAR Data Analysis
  – Land Cover Characterization
  – Water-level Change Detection
  – L-band ALOS imagery
• Conclusion
Southeastern Louisiana

• Louisiana contains one of the largest expanses of coastal wetlands in the contiguous US.

• The balance of Louisiana’s coastal systems has been upset by a combination of natural processes and human activities.
  – About 20% of the coastal lowlands (mostly wetlands) have eroded in the past 100 years.
  – Major pathways of hurricane in the Gulf of Mexico.

• Precise estimate of water storage over wetlands is important to improve hydrological modeling predictions and enhance the assessment of future flood events over wetlands.
Coastal Wetland Characterization

• Goals:
  Identify SAR characteristics associated with different vegetation classes
  – Urban
  – Agriculture
  – Bottomland forest
  – Swamp forest
  – Freshwater marsh
  – Intermediate marsh
  – Brackish marsh
  – Saline marsh
Existing Land-cover / Land-use map
Sampling sites
Seasonally Averaged $\sigma^0$ of Vegetation Classes

Leaf-ON: May ~ September
Leaf-OFF: October ~ April
SAR Backscatter Coefficients and NDVI

- Seasonal changes of vegetation cover can also be detected by optical sensors.
  - Normalized Difference Vegetation Index (NDVI)
    - Directly related to the photosynthetic capacity and hence energy absorption of plant canopies
    - Useful for the estimation of the leaf-area-index, biomass, chlorophyll concentration in leaves, plant productivity, etc.
- We focus on leaf-off seasons as NDVI changes are subtle during leaf-on seasons.
Radarsat dB (leaf-off season) vs. AVHRR NDVI

- Bottomland forest, $\sigma^2$ (dB):
  - $R^2=0.90$
  - $y = -0.056x + 1.41$

- Swamp forest, $\sigma^2$ (dB):
  - $R^2=0.78$
  - $y = -0.035x - 0.24$

- Intermediate marshes, $\sigma^2$ (dB):
  - $R^2=0.55$
  - $y = 0.035x - 16.10$

- Freshwater marshes, $\sigma^2$ (dB):
  - $R^2=0.78$
  - $y = 0.051x - 18.03$

- Brackish marshes, $\sigma^2$ (dB):
  - $R^2=0.30$
  - $y = 0.035x - 18.85$

- Saline marshes, $\sigma^2$ (dB):
  - $R^2=0.66$
  - $y = 0.038x - 14.41$
C-band InSAR Coherence Comparison

Water

Agriculture

Bottomland Forest

Swamp Forest

ERS

RADARSAT-1

Coherence vs. Temporal baseline (days)
C-band InSAR Coherence Comparison

ERS

RADARSAT-1

Freshwater Marsh

Intermediate Marsh

Brackish Marsh

Saline Marsh

Temporal baseline (days)
<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Inference on backscattering mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottomland forests</td>
<td>Mostly surface and volume scattering</td>
</tr>
<tr>
<td>Swamp forests</td>
<td>Dominantly double-bounce backscattering</td>
</tr>
<tr>
<td>Freshwater marshes</td>
<td>Mostly volume scattering</td>
</tr>
<tr>
<td>Intermediate marshes</td>
<td>Mostly volume scattering</td>
</tr>
<tr>
<td>Brackish marshes</td>
<td>Surface (and volume) scattering; probably specular scattering during leaf-off seasons</td>
</tr>
<tr>
<td>Saline marshes</td>
<td>Mostly double-bounce and volume backscatterings</td>
</tr>
</tbody>
</table>
Mapping water-level changes with InSAR

- L-band InSAR images can maintain coherence over swamp forests
- Demonstrated by both SIR-C and JERS-1 images
- Can C-band radar see water-level changes?

Alsdorf et al., Nature, 2001
Double-bounced signal and water-level change detection

\[ h = \frac{\Delta \phi}{4\pi} \cdot \lambda \cdot \sin \theta \]

- \( h \): water level change
- \( \Delta \phi \): interferometric phase change
- \( \lambda \): radar wave length
- \( \theta \): incidence angle

Diagram:
- Two images labeled image 1 and image 2
- A tree
- An arrow indicating the direction of \( h \)
InSAR Images of Swamp Forests
Examples of Interferograms: ERS

ERS-1/-2: Leaf-OFF seasons

ERS-1/-2: Leaf-ON seasons

(a) 1996-01-20 ~ 1996-01-21 water
(b) 1998-03-01 ~ 1998-04-05
(c) 1995-11-12 ~ 1996-01-21
(d) 1993-01-07 ~ 1998-01-25

- bottomland forest
- freshwater marsh
- intermediate marsh
- brackish marsh
- saline marsh

(e) 10 km
(f) 1996-05-04 ~ 1996-05-05
(g) 1992-07-16 ~ 1992-08-20
(h) 1997-05-25 ~ 1998-08-23

water-level change

0 3 cm
Examples of Interferograms: RADARSAT

Leaf-OFF
- Bottomland forest
- Freshwater marsh
- Intermediate marsh
- Brackish marsh
- Saline marsh

Leaf-OFF: 2002-10-18 ~ 2002-11-11

Leaf-ON: 2002-08-07 ~ 2002-08-31

Leaf-ON: 2003-01-22 ~ 2004-01-16

Leaf-ON: 2003-08-02 ~ 2004-09-12

Water-level change: 0 ~ 3 cm
Swamp forests near coastal New Orleans

L. Verret

Lower Texas

Thibodaux

Swamp Forests

Sugar Cane Fields

Lake

Canal

~20 m
Water-level change imaged by C-band InSAR

Lu et al., 2005
Feasibility of Measuring Water-level From C-band InSAR

• C-band ERS-1/-2, and RADARSAT-1 SAR images can maintain adequate coherence over swamp forests composed of moderately dense trees;

• Swamp forests with a medium-low canopy closure permit double-bounce returns for C-band radar;

• InSAR phase measurements are discontinued by levees, canals, bayous, roads, and other barriers.

• Converting InSAR-derived water-level changes into absolute volumetric changes requires calibration points within swamp forests.

• For InSAR to become an effective tool for monitoring dynamic water-level changes beneath wetlands, a SAR system with shorter imaging repeat times is required.
ALOS imagery: 2/10-3/28, 2007

Marshes

Bottom-land forests
ALOS vs Radarsat imagery

Radarsat-1: 3/4-28, 2004

ALOS: 02/27-4/14, 2007
InSAR Images vs Gage Measurements

- Both C-band and L-band InSAR images suggest that water level changes over the study site can be dynamic and spatially heterogeneous, and cannot be represented by readings from sparsely distributed gauge stations.
- InSAR phase measurements are disconnected by structures and other barriers and require absolute water level measurements from gauge stations or other sources to convert InSAR phase values to absolute water level changes.
- Gages in the river (C & D) do not show good correlation with InSAR-derived water-level measurements at nearby pixels over swamp forests.
- Therefore, modeling surface water based on existing gages may not be accurate.
Volumetric Rendering of Surface Water-level Changes

- Within Atchafalaya Basin Floodway between 05/22/2003 and 06/15/2003
- Calibrated with respect to the water-level measurement at Cross Bayou (E)

Total number of SAR image pixels covering the region: 296469 pixels
Area: 842 km²
Water-level change at the Cross Bayou gage: +0.2847 m
Adjustment of volumetric change: 0.23457 km³
Total volumetric change: 2.07 km³
Conclusions

- SAR backscatter can be used for coastal wetlands classification
  - Multi-year season-averaged backscatter observations provide more robust results

- C-band InSAR can estimate water-level changes beneath moderately dense swamp forests.

- L-band InSAR provides a robust measurement of water-level changes.

- Both C-band and L-band InSAR images suggest that water level changes can be dynamic and spatially heterogeneous, and cannot be represented by readings from sparsely distributed gauge stations.

- InSAR phase measurements are disconnected by structures and other barriers and require absolute water level measurements from gauge stations or other sources to convert InSAR phase values to absolute water level changes.

- A minimum of one absolute water-level change measurement over a “wetland system” is required to estimate the “true” volumetric water storage.
Thank you
Implications on Wetlands Landcover Classification

- For landcover classification
  - Single SAR image is not sufficient for coastal wetlands classification; multi-year seasonally averaged $\sigma^o$s are necessary.
  - Season-averaged $\sigma^o$s may be sufficient to detect swamp forests and brackish marshes
  - Freshwater and intermediate marshes may not be readily distinguishable from each other using ERS and RADARSAT data only.
  - Classification between bottomland forests and saline marshes can be done by geographic proximity to ocean or using multi-year season-averaged $\sigma^o$s; saline marshes have distinctive low $\sigma^o$s of ERS during leaf-on season.
  - NDVI can be useful to distinguish between forests and marshes
Both C-band and L-band InSAR images suggest that water level changes over the study site can be dynamic and spatially heterogeneous, and cannot be represented by readings from sparsely distributed gauge stations.

InSAR phase measurements are disconnected by structures and other barriers and require absolute water level measurements from gauge stations or other sources to convert InSAR phase values to absolute water level changes.

Therefore, modeling surface water based on existing gages may not be accurate.
InSAR Images & Atmospheric Contaminations

- Significant atmospheric delay
- Negligible atmospheric delay
Average Deformation Rate During 1992~1998
Estimated by **Persistent Scatterer InSAR Technique**