Space-based High-Resolution, Multi-temporal Monitoring of Wetland Water Levels: Case Study of WCA1 in the northern Everglades

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Presentation Content

• Wetland InSAR
• STBAS – a new time series technique
  • Algorithm
  • Application to WCA-1
• Results
• Summary
• Acknowledgements
Wetland InSAR

The techniques: InSAR

Interferometric Synthetic Aperture Radar (SAR)

2004/10/24 - 2004/11/17
Synthetic Aperture Radar (SAR)

2010 oil spill in the Gulf of Mexico
(CosmoSkymed2, 2010-07-11)
SAR amplitude data vs optical images

Optical Image (SPIN-2 Data)  Multi-Image SAR (41 Records)

SAR amplitude data are not affected by sun illumination and/or meteo conditions.

Satellite SAR sensors now available can only detect a single frequency (and polarization). Hence they see a grey-scale image.
SAR – phase observable

\[ R = \text{Time delay} \times \text{Light Vel.} \]

\[ = \text{Wavelength} \times (\text{Wave number} + \text{phase}) \]

SAR is most sensitive to phase measurements.
SAR - Phase information

In SAR, the phase of the echoing signal is compared to a reference wave, so the phase of a SAR image is actually the phase difference between the echo and this reference. The phase of the signal backscattered from a radar target is then related to the sensor-target distance. A SAR image is actually a set of pixels characterized by both amplitude and phase values:

Amplitude          Phase
Interferometric SAR - InSAR

Changes in surface location result in detectable phase changes

Two or more data acquisition of the same area from nearby location (< 1000 m)

Fringes – 1 cycle \((2\pi) = \frac{1}{2} \lambda\)
InSAR Applications

- Earthquake deformation
- Land subsidence
- Volcano inflation
- Glacial movement
Water level change measurements

1st acquisition
2nd acquisition

Δt = 24 day (RADARSAT)

Water level change measurement (1st and 2nd acquisitions)
Water level changes

Interferogram

Calibration with stage data

Change maps

Unfortunately, detailed maps of water level changes are not that useful for hydrologists!
InSAR time series

InSAR techniques for monitoring displacement time series of solid-earth surfaces.

Persistent Scatterer InSAR (PSI), • Small BAseline Subset (SBAS) •

These methods work well in urban areas, and in some open areas.-

These applications to wetlands are hardly possible.-

- Because permanent scatterers (PS) targets density is relatively low and the coherence level over wetlands is dominated by temporal baseline rather than by the geometric baseline.
PSI / STBAS

Subset of reliable scatterers •
InSAR time series •
Low pass filter for removing atmospheric noise •
Small Temporal BAseline Subset (STBAS)

Advantages

• The new STBAS technique enables the transition from relative to absolute water levels
• STBAS provides time series for almost all pixels with \(~50\) m resolution.

Rational

• It is based on the SBAS (Small [geometrical] BAaseline Subset) technique.
• Only small temporal baseline subset is used regardless geometrical baseline (less than critical baseline), because coherence in wetlands is mostly affected by temporal baseline.
STBAS algorithm

Step 1: Pair selection
- SAR SLC (1) ➔ InSAR pair (1,2)
- SAR SLC (2) ➔ InSAR pair (2,3)
- SAR SLC (3) ➔ InSAR pair (3,4)
- SAR SLC (N) ➔ InSAR pair (N-1,N)

Step 2: Interferogram generation including unwrapping
- Interferograms

Step 3: Calibration with stage data
- Stage data

Step 4: SVD inversion

Step 5: Tying the relative series to absolute level
- Stage data (reference level)
- Time series of absolute water levels
Applications: Study area

Water Conservation Area 1 - (WCA1) in the Everglades wetlands, South Florida

Surrounded by a series of man-made levees

Provides water storage, flood control and recreational benefits as well as important habitat for wildlife

The overall surface water flow pattern is from north to south
Data

SAR data

29 Radarsat-1 Fine 5 beam mode SAR acquisitions between Jan 29, 2006 and Jan 19, 2008

28 coherent interferograms generated using ROI_PAC-

Topographic removal based on the SRTM-1 DEM and phase - unwrapping included

24 days temporal baselines except two pairs (48 days)-

Stage (water level) data

Daily average stage data monitored by 13 stage stations and - archived at the Everglades Depth Estimation Network (EDEN)

Some stage stations are affected local flow dynamics and can - provide inaccurate stage values (Lin and Gregg, 1998)
Stage 1: pair selection Baselines

Perpendicular baseline with respect to the 1st SAR acquisition.
- Black dash lines (24-day time span)
- Red dash lines (48-day time span)
- The range of perpendicular baselines varies from 64 m to 1367 m.
Stage 2: Interferograms time series

Interferograms time series of the study area.

The fringes show water level changes in radian degree.
STBAS algorithm

Step 1: Pair selection
SAR SLC (1) → InSAR pair (1,2)
SAR SLC (2) → InSAR pair (2,3)
SAR SLC (3) → InSAR pair (3,4)
SAR SLC (4) → InSAR pair (4,5)
SAR SLC (N-1) → InSAR pair (N-1,N)
SAR SLC (N)

Step 2: Interferogram generation including unwrapping
Interferograms

Step 3: Calibration with stage data
Stage data

Step 4: SVD inversion
Time series of relative water levels
Stage data (reference level)
Time series of absolute water levels

Step 5: Tying the relative series to absolute level
STBAS viewer

2π
0 (rad)
4.8
m
4.3
Stage (water level) stations – WCA-1

High temporal resolution
Comparison between InSAR and stage data

InSAR does not work at near hydrologic structures, and canals.
Virtual stations

The virtual stations were defined in order to improve the comparison between InSAR and stage data.
Virtual stations

Stage station location (black squares) - overlying a map showing average coherence over the study area.

The low coherence occurs along the peripheral canals in open water or sparse vegetation areas.

White box squares mark selected virtual stage stations located in higher coherence area near original peripheral stage stations.
Calibration plots for estimating the offsets between InSAR and stage station observations. Most of calibrations show good agreement.
Stage 3: Water level changes

Calibrated water level change time series maps with high spatial resolution (30 m) and 5-10 cm vertical accuracy - Understand flow pattern and estimate physical flow patterns
STBAS algorithm

Step 1: Pair selection
- SAR SLC (1) → InSAR pair (1,2)
- SAR SLC (2) → InSAR pair (2,3)
- SAR SLC (3) → InSAR pair (3,4)
- ... → InSAR pair (N-1,N)

Step 2: Interferogram generation including unwrapping
- Interferograms

Step 3: Calibration with stage data
- Stage data

Step 4: SVD inversion
- Time series of relative water levels
- Stage data (reference level)
- Time series of absolute water levels

Step 5: Tying the relative series to absolute level
- STBAS viewer
Stage 5: Absolute water levels

Calibrated absolute water level time series maps over the study area. Notice the change in scale (4-5 m) with respect to that of water level changes (32 cm in previous water level changes).
Stage 5: Absolute water levels
Uncertainty analysis

The calibration step requires a careful supervision, as the results depend on our choice on which station to use for calibration and which for validation.

Uncertainty analysis between InSAR and stage observations with RMSE was performed.

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<td>10.4</td>
<td>3.3</td>
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</tbody>
</table>
Stage and InSAR

The measured water level time series are in a good agreement with stage data -

The interior stage station in the WCA1 shows better results compared with -

the stage stations located along the levees (6-7 cm RMSE)
Stage and InSAR

The 6.6 cm uncertainty level reflects the sum of two major contributions.

The first contribution is uncertainty of the InSAR measurement in detecting water level change.

The virtual station analysis suggests an uncertainty level of 3-4 cm.

The additional uncertainty of 2-3 cm reflects error propagation due to the conversion from relative to absolute water levels.
Conclusions

• InSAR observations complement high temporal stage measurements
• The new STBAS technique enables the transition from relative to absolute water levels
• STBAS provides time series for almost all pixels with ~50 m resolution.
• Results of the TSBAS analysis can serve as excellent constraints for high spatial resolution flow models.
• STBAS can be applied to other fast deforming surfaces, e.g. glacier flow.
• STBAS can provide a PSI solution for the expected rapid drift of ENVISAT’s ASAR data.
Acknowledgements

**SAR data**
- JAXA – ALOS, JERS-1 L-band data
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  - ENVISAT C-band data (CAT-1)
- DLR – TerraSAR-X

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