APPLICATION OF SYNTHETIC APERTURE RADAR METHODS FOR MORPHOLOGICAL ANALYSIS OF THE SALAR DE UYUNI DISTAL FLUVIAL SYSTEM

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ABSTRACT

Knowledge of the present-day activity of river channels in distal fluvial systems strongly contributes to the reconstruction of past branching and avulsion processes. Established remote sensing techniques can be applied to monitor the formation of flooding planes (crevasse splays) and channel activity. In this research variations in the amplitude in Synthetic Aperture Radar images are interpreted as soil moisture changes. Interferometric SAR showed minor phase changes during dry season and loss of coherence after peak run-off. After peak discharge during the dry season in 2009 reactivation of multiple avulsed river paths and crevasse channels was detected. These results show that analysis of SAR images can contribute to the monitoring of fluvial systems. It is expected that these initial results will be confirmed by field data and analysis of alternative remote sensing data sources.

***Index Terms*—** SAR, InSAR, channel morphology, endorheic basin, Salar de Uyuni

1. INTRODUCTION

Distal fluvial systems in a low-gradient, semi-arid, endorheic setting are poorly understood currently. In particular, the origin of the branching river channel morphology at the river terminus is a hot topic of debate: Is it the result of a distributary pattern of simultaneously active channels or is the morphology the result of one or many river channels [1, 2, 3]? In order to answer this question a reconstruction of the depositional history of a fluvial system should be made, which considers: (1) the avulsion history, and (2) the development of crevasse splays and terminal lobes. Mapping of previous and present-day active channels, crevasse splays, and terminal lobes will aid the reconstruction of the depositional history. In addition, the correlation between the areal extent of crevasse splays and channel width and depth provides information about the downstream changes in crevasse sheet size and intensity. Crevasse splays originate during peak run-off when the channels are not able to contain the stream and massive flood-out brings water and sediment onto the floodplain which borders the river.

This work shows the application of Synthetic Aperture Radar (SAR) remote sensing for studying the distal fluvial system south of Uyuni city in the Bolivian Altiplano Basin. The main goal is to map changes after rainy seasons and single rainfall events. Two SAR analysis techniques with each their own application are used: amplitude analysis (changes of soil characteristics) and interferometry (deformation). The main challenges of this particular application of SAR remote sensing are the spatial resolution of the data and its availability. Furthermore, the high precipitation rates during rain season as well as large single rainfall events in the dry season decrease the correlation between certain image pairs. Therefore, the image pairs should be selected carefully.

2. REGION OF INTEREST

The Salar de Uyuni is the world's largest salt lake, located in the Bolivian Altiplano Basin at an altitude of 3653 m. Geological markers indicate that the present lake water level is much lower than in history. This results in a very flat landscape near the present lake margin. These low slopes shape the terminal parts of the feeding rivers which are characterised by many branching channels with decreasing depth and width towards the terminal lobes. The Bolivia Altiplano Basin experiences heavy rain seasons and very dry summers. The precipitation during peak run-off cannot be contained in the river channels resulting in reactivation of old channels, channel cut-offs and flooding events creating so-called crevasse splays. The chronology of the branching of these channels and their activity is the key question in this field.

This work focusses on the Colorado river system to the South-East of Salar de Uyuni indicated in green in Fig. 1. Precipitation data from neighbouring stations show that the main rain season takes place from December to April. The image combinations selected to analyse surface changes will be chosen according to the precipitation information.

3. SYNTHETIC APERTURE RADAR

Within the field of radar remote sensing, Synthetic Aperture Radar (SAR) sensors acquire imaging radar data. SAR sensors mounted on spaceborne platforms orbit the Earth in a sunsychronous polar repeat orbit transmitting radar pulses to the area of interest. Time information and the returned echoes are the main ingredients of a raw SAR image. Synthetic aperture is the distance travelled by the SAR antenna while the target is illuminated.

Radar remote sensing can be split up into two parts: 'SAR amplitude analysis' and 'Interferometric SAR analysis' (InSAR) . The first technique analyses single SAR amplitude images for change detection and classification. The latter uses both the amplitude and phase information to form a so-called interferogram for deformation monitoring.

Amplitude analysis: After resampling the stack of SAR images onto the same grid and calibration of the images, their amplitude can be visualised in an RGB color composite image. This method can be used for change detection and only works if the scatterer characteristics of the soil changes (because of e.g. flooding, snow or vegetation cover).

Interferometric SAR: By means of Interferometric SAR (InSAR) the deformation can be measured between 2 acquisitions. In radar interferometry complex multiplication of two images acquired from the same location but on different times is performed. After a correction for topography, the residual signal is deformation. However, there are more contributions that interfere with the signal, such as DEM and orbit errors, tropospheric delay and noise. This noise can be introduced by decorrelation either in space or time or just by thermal noise from the SAR sensor itself. The measure for how well the complex signal of two images is correlated is called coherence. The coherence will be low if the soil characteristics change between 2 acquisitions. Additionally, low coherence can be caused by geometric decorrelation. In our area of interest, however, the geometric decorrelation is negligible due to the low slopes of the terrain. Consequently, coherence is used as an indication of local changes of soil characteristics.

4. DATA AVAILABILITY

This study uses the SAR data acquired from track 282 in descending mode by the ERS SAR and Envisat ASAR sensors (both C-band, corresponding to a wavelength of 3 cm). Both data sets are briefly discussed below.

ERS 1/2 SAR: 17 images acquired between 1995 and 2002 are available. The difficulty with processing ERS data is the large baselines: B_{temp}, $B_{\perp}$ and $B_{f_{DC}}$ (the temporal, perpendicular and doppler baselines). Due to the failure of one of the gyroscopes at the ERS2 satellite in 2001, the satellite operates in 0-gyromode and no control of the doppler centroid is possible. This impedes the application of time series InSAR on the full data stack.

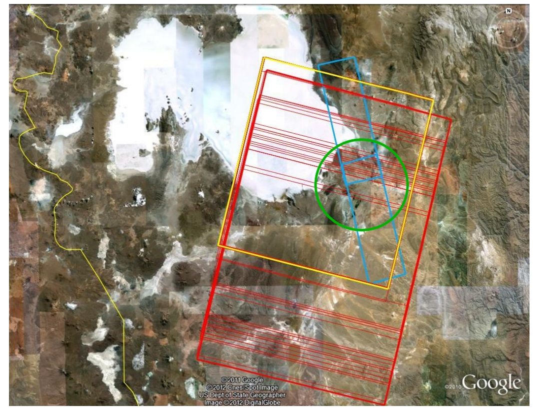

Fig. 1. Overview of the selected data covering the fluvial system of interest. Yellow: ERS SAR, Red: Envisat ASAR, Green: area of interest, its diameter is 50 km. Image courtesy of Google Earth.

Envisat ASAR: 25 Envisat ASAR images acquired between 2003 and 2010 are considered. Due to the varying sensing times of the Envisat ASAR instrument most of the data is not usable for studying the downstream part of the fluvial system. The available images do not have the same so-called 'sensing start time'. For most of the images the ASAR instrument starts acquiring data slightly too late and hence covering only the southwestern part of the area of interest. Only 10 images cover the entire area of interest.

5. RESULTS AND DISCUSSION

We apply the two methods discussed in Section 3 to study the crevasse splay growth and channel activation after rain seasons.

For the first part of the study we selected two ERS SAR images that are acquired in different rain seasons and create an RGB color composite from the amplitude images as explained in Section 3. The images are first calibrated and speckle filtering is applied. The result is shown in Fig. 2.

For the second part of this study we selected 3 ASAR images acquired in the 2009 dry season. Dates of acquisition are: 20090426, 20090531, and 20090913. Fig. 4 and Fig. 5 show two cascading interferograms containing the line of sight (LOS) deformation obtained by traditional interferometry and their corresponding coherence. The coherence in Fig. 5 is lower than in Fig. 4, indicating that the dielectric constant of the soil changed. Most decorrelated (dark) pixels in

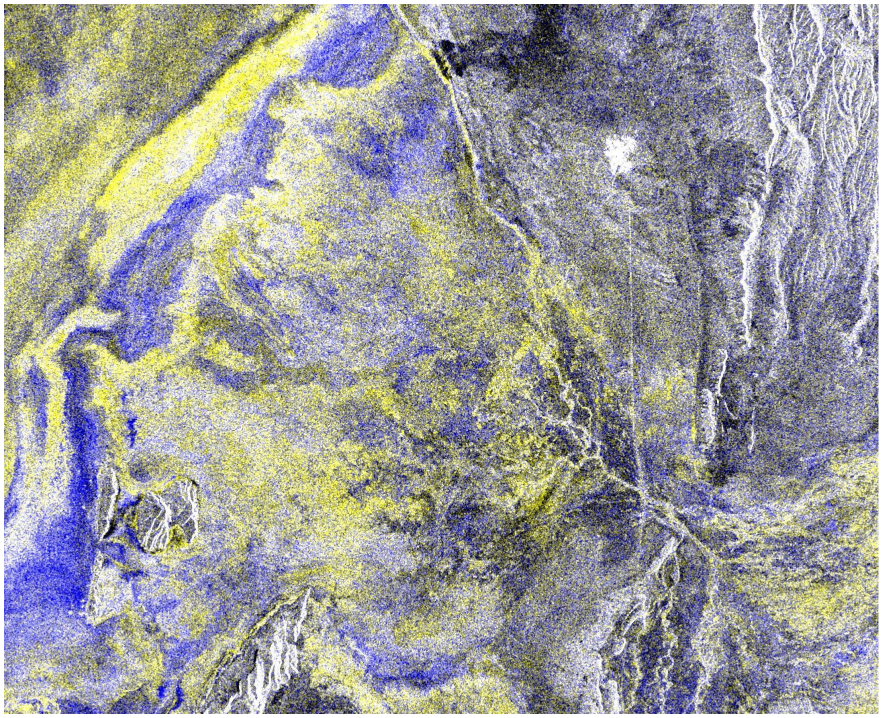

Fig. 2. Inter-rain season RGB color composite: 19981011-20001119 (SAR). Yellow: high amplitude in 1998; Blue: high amplitude in 2000; White: high amplitude in both images; Black: low amplitude in both images. Area: 40 x 40 km.

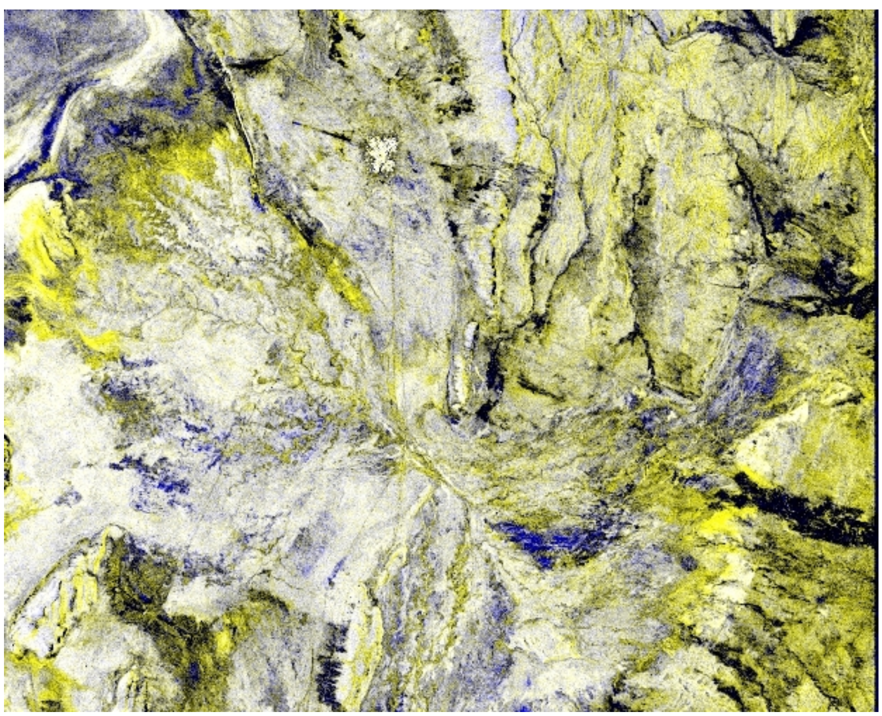

Fig. 3. RGB color composite of the coherence images of the 20090426-20090531 and 20090531-20090913 interferograms (ASAR). White: high coherence in both periods; Black: low coherence in both periods; Yellow: coherence lost in the second period; Blue: coherence increase in second period. Area: 45 x 50 km.

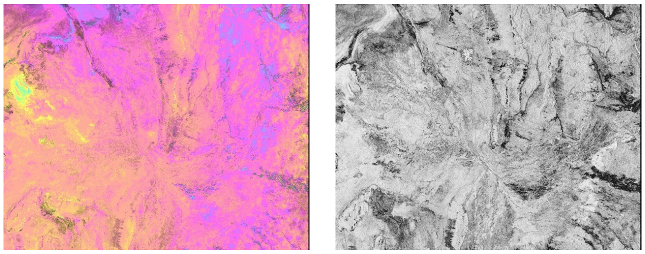

Fig. 4. First part of the 2009 dry period: 20090426-20090531. Left: wrapped interferogram; right: coherence (White: large coherence; Black: low coherence).
$B_{\perp} = -50.4$ m, Area: 45 x 50 km.

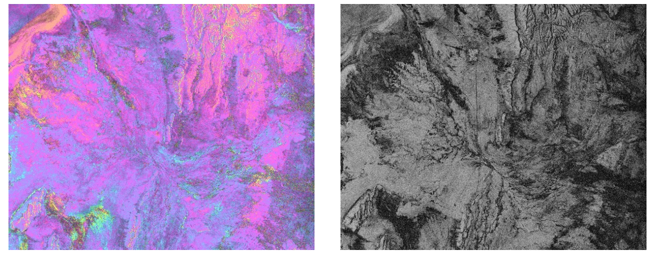

Fig. 5. Second part of the 2009 dry period: 20090531-20090913. Left: wrapped interferogram; right: coherence (White: large coherence; Black: low coherence).
$B_{\perp} = -334.6$ m. Area: 45 x 50 km.

the basin correspond to channels, indicating that on 20090913 the channels were filled with water. This is confirmed when we create an RGB color composite of the coherence images of the two interferograms (see Fig. 3). This figure shows the areas that lost coherence in the second interferogram in yellow. Note that these yellow areas are located mainly around the channels, indicating that at 20090913 these channels were active.

6. CONCLUSIONS AND FUTURE WORK

This work shows the potential of the application of radar remote sensing analysis techniques to detect changes in the soil characteristics after peak run-off. These changes can be linked to channel activation and flooding events in so-called crevasse splays.

Concerning the radar remote sensing techniques, the amplitude analysis has the highest potential to identify crevasse splays. Changes in the amplitude are observed and can be linked to crevasse splay formation and water level in the channels. The application of InSAR and more in particular time series InSAR is less suitable due to the high temporal decorrelation caused by high differences in soil moisture. Interferograms spanning dry seasons do have a high coherence but the soil compaction is too low to be measured accurately. The change of coherence, on the other hand, is a valuable tool to identify channel activity after single precipitation events in a dry season. From Fig. 3 and from ground check in the field we conclude that during peak discharge existing topographical depressions of avulsed river paths and crevasse channels were reactivated.

Future work includes further interpretation of the RGB images created from the amplitude images. Furthermore, the analysis of L-band ALOS PALSAR fully polarised data which has a higher resolution is ongoing. The availability of the four polarisations (sending and receiving the radar pulses in both horizontal and vertical polarisation) is expected to give more insight in the soil characteristics. Additionally the results will be merged with optical multi-spectral data and validated by geological surveys.

7. REFERENCES

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