VDOT Virginia Department of Transportation

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SEARCH REQUEST

PREPARED FOR:
Edward Hoppe, Ph.D., P.E.
VCTIR Senior Research Scientist
Edward.Hoppe@VDOT.Virginia.gov
(434) 293-1960

PREPARED BY:
Bethanie Glover
VDOT Research Library
Bethanie.Glover@VDOT.Virginia.gov
(434) 293-1959

Ken Winter, MLIS
VDOT Research Library
Ken.Winter@VDOT.Virginia.gov
(434) 962-8979

Interferometric Synthetic Aperture Radar (InSAR) Technology and Its Applications: A Literature Search

OBJECTIVE: The objective of this search was to update a search conducted on 1-25-13 for peer reviewed and other credible literature related to the use Synthetic Aperture Radar (SAR), which can be used to detect and monitor sinkholes, landslides, bridge displacements and other subsidence-related effects to transportation infrastructure. This particular bibliography is a subset of a larger one entitled, "Synthetic Aperture Radar Technology and Its Applications," focusing on citations that included InSAR only. This bibliography excludes citations focused exclusively on seismic processes, mining, ocean or river currents, ship wakes or navigation, ice streams floes or glacier detection, flood hazards/control, volcanic activity, levees, analysis of vegetation/biomass, oil spill remediation, navigation, or nondestructive testing of building materials.

SEARCH STRATEGY: Key search terms included all forms and variants of the following: satellite, space, synthetic aperture radar, Interferometric Synthetic Aperture Radar, Interferometric Sar, InSAR, IFSAR, Differential Synthetic Aperture Radar, DinSAR, Polarimetric SAR Interferometry, Pol-InSAR, interferometry, landslides, slopes, sinkholes, highway, traffic, transportation, bridges, structures, and infrastructure.

DATABASES SEARCHED: The following subscription and freely accessible databases were searched: ASCE, Civil Engineering Abstracts, TRID, Abstracts in New Technology & Engineering, Aerospace Database, Abstracts in New Technology & Engineering, Environmental Engineering Abstracts, Mechanical & Transportation Engineering Abstracts, ProQuest Deep Indexing: Engineering, GeoRef, ProQuest Dissertations & Theses (PQDT), WorldCat, NITS, Research in Progress, Research Needs Metasearch, and TERI Database (AASHTO).

CITATION ORDER: Relevant search results from all databases were compiled and duplicate citations were removed. The remaining citations were placed into one of the following three categories: Primary Reading, Additional Reading, and Research in Progress/Completed.

SEARCH REQUESTS

Search Requests are comprehensive literature searches. Resources cited include state DOT reports, peer-reviewed articles from TRB and other key publishers, and other timely and reliable sources. If available, links to full-text online documents are included. Due to copyright law and practical considerations, items cited may not be freely accessible online, however, they may be held in the library's print collections and online subscriptions. In most cases items that are not held can be borrowed through the library's Interlibrary Loans service. VDOT employees can request documents by contacting us at Library.Circulation@VDOT.Virginia.gov or (434) 293-1902.

RESEARCH SYNTHESIS BIBLIOGRAPHY

The VDOT Research Library also offers a service combining a literature search with analysis and synthesis. The RSB is designed to provide a customized search for information on a critical topic that is authoritative, confidential, objective and nonpartisan. The RSB includes an exhaustive literature search (using both subscription and freely accessible sources), excerpts from key documents, interviews and contact information of known subject experts and other analysis/synthesis. RSBs usually take 4-6 weeks to compile. VDOT employees can request an RSB by contacting Ken Winter, Ken.Winter@VDOT.Virginia.gov or (434) 962-8979.

CONTENTS:

PRIMARY READING: The following citations should be reviewed first. Citations are listed in alphabetical order by title, not in order of relevance, with key terms highlighted for context. *(Return to Contents…)*

INSAR PRINCIPLES: GUIDELINES FOR SAR INTERFEROMETRY PROCESSING AND INTERPRETATION.
CITATION: Fletcher, K. European Space Agency, European Space Research and Technology Centre, Noordwijk, The Netherlands: ESA Publications Division, ESTEC, 2007, various pagings.
ABSTRACT: Not available.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov or http://www.esa.int/esapub/tm/tm19/TM-19_ptA.pdf, http://www.esa.int/esapub/tm/tm19/TM-19_ptB.pdf and http://www.esa.int/esapub/tm/tm19/TM-19_ptC.pdf

THE SAR GUIDEBOOK: EXAMPLES BASED ON SARSCAPE®.
CITATION: Sarmap. Switzerland, CREASO GmbH, 2007, 265p.
ABSTRACT: The aim of this tutorial is to introduce beginners to land applications based on spaceborne Synthetic aperture radar (SAR). It is intended to give users a basic understanding of SAR technology, the main steps involved in the processing of SAR data, and the type of information that may be obtained from SAR images. Note that this tutorial is based on an introductory course developed by sarmap in collaboration with the UNESCO BILKO group and financed by the European Space Agency. With respect to the original one, it has been extended (to Polarimetry and Polarimetric SAR interferometry) and adapted to introduce the use of SARscape®.
ACCESS: https://www.exelisvis.com/portals/0/pdfs/envi/SAR_Guidebook.pdf

EDUCATIONAL RESOURCES FOR RADAR REMOTE SENSING.
CITATION: GlobeSAR Program. Canada Centre for Remote sensing, Natural Resources Canada, Ottawa, Ontario, 955p.
ABSTRACT: Welcome to the GlobeSAR-2 Radar Remote sensing Training package, a comprehensive and unique set of radar remote sensing training materials. Our goal is to make these materials available for use by universities and for general educational purposes around the world. To reach a wider audience, the material has been produced in four languages; English, French, Spanish, and Portuguese. This CD-ROM was produced as part of GlobeSAR-2 Program to support the development of radar training capabilities in universities and agencies in South and Central America. It incorporates training slides developed by scientists at the Canada Centre for Remote sensing for international technical co-operation programs, including GlobeSAR and ProRadar. Significant contributions have also been made by radar specialists from different disciplines and by scientists and user agencies in many countries, particularly in South and Central America. The slides have been divided into four main sections: basic, intermediate, advanced, and applications. Each section includes theory and image examples, with associated explanations. The intent of this package is to provide a 'toolkit' of instructional materials that may be customized to suit the needs of each instructor and audience. It is expected that users will pick-and-choose the material most appropriate to the background and technical level of the audience. The material was developed primarily for audiences interested in the geoscience applications of radar imagery, but the 'Advanced Radar Techniques' section will be of relevance to the engineering and signal processing disciplines.
ACCESS: http://www.ida.liu.se/~746A27/Literature/Radar%20Remote%20Sensing.pdf

DETECTION OF GEOPHYSICAL FEATURES IN INSAR POINT CLOUD DATA SETS USING SPATIOTEMPORAL MODELS.
CITATION: Vaccari, A., Stuecheli, M., Hoppe, E., et. al. International Journal of Remote Sensing, Vol. 34, No. 22, 2013, 8215-8234.
ABSTRACT: In this paper we introduce an approach for detecting evolving geophysical features within InSAR-derived point cloud data sets. This approach is based on the availability of models describing both the spatial and temporal behaviour of the geophysical features of interest. The model parameters are used to generate a multidimensional space that is then scanned with user-defined resolution. For each point in the parameter space, a spatiotemporal template is reconstructed from the original model. This template is then used to scan the point cloud data set for regions matching the spatiotemporal behaviour. We also introduce a proportional measure where the residual for each point in the data set is compared to both the data and the template to provide a scale invariant measure of the behavioural matching. The matching is evaluated for every point in the parameter over a region of influence determined by the parameters. The resulting multi-dimensional space is then collapsed onto geographical coordinates to produce an overlay map identifying regions whose spatiotemporal behaviour matches the feature of interest. We tailored our approach to the detection of subsidence behaviour, indicative of the development of sinkholes, modelled as Gaussian with amplitude linearly increasing with time.We verified the validity of our model using both synthetic and actual InSAR data sets. The latter was obtained by processing imagery of a region near Wink, Texas containing ground truth

sinkhole data. We applied this framework to a 40x40km2 area of interest located in western Virginia and performed ground validation on a subset of the identified regions. The results show good agreement between the locations detected by our algorithm and the evidences of subsidence observed during the ground validation campaign.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov OR http://viva-lab.ece.virginia.edu/foswiki/pub/InSAR/WebHome/SpatiotemporalMatchingIJRS_Rev2.pdf

ADVANCED INSAR TECHNOLOGY (SQUEESAR™) FOR MONITORING MOVEMENT OF LANDSLIDES.
CITATION: Morgan, J., Falorni, G., Bohane, A., et. al. TRE Canada Inc., Yeh and Associates, Inc., US Department of Transportation, Federal Highway Administration, Central Federal Lands Highway Division, 2011, 93p.
ABSTRACT: Landslides are destructive natural hazards that can impact highway infrastructure within federal lands. InSAR technology can be used to monitor landslide movement, which has been demonstrated in previous projects sponsored by the FHWA. However, these demonstrations have been mainly limited to traditional InSAR methods. The SqueeSAR™ algorithm uses distinct properties of the signal from radar satellites, to detect millimeter-scale changes in the Earth's surface from natural and man-made features on the ground, representing a significant breakthrough in InSAR technology. This approach represents a significant advancement in the field of InSAR and has been successful in providing a more accurate overview of surface movement at other landslide sites under suitable conditions. Given the continued interest by the FHWA in the use of InSAR for natural hazard monitoring, the objective of this project was to test the use of the SqueeSAR™ algorithm for measuring landslide movement. Two sites previously analyzed using more traditional InSAR approaches were revisited with the SqueeSAR™ algorithm; the Amphitheatre Point Landslide (36.5426N, 118.7840W) in California and the Cimarron Landslide (38.3561N, 107.5823W) in Colorado. While the accuracy and density of measurement points identified in surrounding areas was quite high, the coverage of identified targets was limited within the two areas of interest. These limitations were the result of considerable environmental challenges at both sites. The Amphitheatre Point Landslide was located in a densely forested area of steep and variable topography, while the Cimarron Landslide site was also characterized by significant vegetation coverage. Despite the lack of results at the two landslides of interest, the effectiveness of the SqueeSAR™ approach was still demonstrated by identifying and measuring ground movement for a series of landslides near a reservoir north of the Cimarron Landslide site. The SqueeSAR™ technique is an algorithm for processing radar data that is based on a multi-interferogram approach and is the intellectual property of Tele-Rilevamento Europa - T.R.E. s.r.l.
ACCESS:
http://www.ctiponline.org/publications/view_file.ashx?fileID=208&ei=d6aKVe6eEIOCsAXg7IGQCQ&usg=AFQjCNEtfMiyiG6RJqdnUsZem0FYUxCHlw

REMOTE SENSING AND DECISION SUPPORT FOR TRANSPORTATION.
CITATION: ABJ50 Information and Technology. 2009.
ABSTRACT: In the last decade, satellite, airborne, and other forms of remote sensing have increasingly been applied by transportation agencies to meet a variety of business needs. With this growth in the use of remote sensing technologies in the transportation sector, the USDOT Research and Innovate Technologies Administration (RITA) has funded several university led consortium to research use of commercial remote sensing and spatial information for applications ranging from environmental analysis, traffic flow analysis, infrastructure assessment, port logistics, border crossings, and more. States, too, such as the Michigan Department of Transportation, have sponsored applied research on the use of remote sensing for asset management, environmental assessment, and other applications. Together, the work that has been done by transportation agencies and the research funded by USDOT, states, and others has resulted in significant advances in knowledge and numerous lessons for practitioners. Beyond the most obvious environmental applications, however, this knowledge and these lessons have not been made widely available to the broader transportation community. Thus, as more state DOTs and local agencies consider or pursue the use of remote sensing techniques, they do so without the benefit of accumulated knowledge and lessons on how to apply these techniques and use and manage the large data sets produced by these techniques. To remedy this shortcoming in technology transfer, a review of the current state-of-the-art is proposed. To be most useful to practitioners, the proposed study should include several components. First, it should include a thorough literature review that documents published methods and use of remote sensing to solve specific problems in the transportation field. Second, it should present the current state of technology and document how, where, and when remote-sensing technology is most effectively applied. This review should cover both electro-optical- and RADAR-based systems, as well as satellite, airborne, and ground-based platforms. Third, it should demonstrate how remotely sensed data can be integrated with other tools (such as GIS, decision support systems, etc.). Fourth, it should present detailed recent case studies of how transportation agencies and other entities have used remote sensing to further their analytic capabilities across several domains, such as asset management, traffic and logistic studies, and environmental analysis. Fifth, it should include a

workshop to reach out to domain experts, users, and other stakeholders on the study results, and to obtain additional input on study direction and findings. The results of the workshop should be published to ensure widespread communication of results to interested parties, as should the literature review, case studies, and the rest of the study.
ACCESS: http://rns.trb.org/dproject.asp?n=20457

ACCURACY ASSESSMENT OF INSAR DERIVED INPUT MAPS FOR LANDSLIDE SUSCEPTIBILITY ANALYSIS: A CASE STUDY FROM THE SWISS ALPS.
CITATION: Lalan P. Singh, C. J. Westen, PK Champati Ray, et al. , Landslides, 2005. Springer- Germany. Vol. 2, No. 3, Pg. 221-228.
ABSTRACT: In recent years SAR interferometry has become a widely used technique for measuring altitude and displacement of the surface of the earth. Both these capabilities are highly relevant for landslide susceptibility studies. Although there are many problems that make the use of SAR interferometry less suitable for landslide inventory mapping, it's use in landslide monitoring and in the generation of input maps for landslide susceptibility assessment looks very promising. The present work attempts to evaluate the usefulness and limitations of this technique based on a case study in the Swiss Alps. Input maps were generated from ERS repeat pass data using SAR interferometry. A land cover map has been generated by image classification of multi-temporal SAR intensity images. An InSAR DEM was generated and a number of maps were derived from it, such as slope-, aspect, altitude- and slope form classes. These maps were used to generate landslide and rockfall susceptibility maps, which give fairly well acceptable results. However, a comparison of the InSAR DEM with the conventional Swisstopo DEM, indicated significant errors in the absolute height and slope angles derived from InSAR, especially along the ridges and in the valleys. These errors are caused by low coherence mostly due to layover and shadow effects. Visual comparison of stereo images created from hillshading maps and corresponding DEMs demonstrate that a considerable amount of topographic details have been lost in the InSAR-derived DEM. It is concluded that InSAR derived input maps are not ideal for landslide susceptibility assessment, but could be used if more accurate data is lacking.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

THE ANALYSIS OF CONDITIONS FOR INSAR IN THE FIELD OF DEFORMATION MONITORING.
CITATION: Xin Tian and Ming-Sheng Liao. , Diqiu Wuli Xuebao, 2013. Kexue Chubanshe,. Vol. 56, No. 3, 812-823.
ABSTRACT: For InSAR application in deformation monitoring field, we discuss the traditional interferometry basis of D-InSAR and its constraint conditions are summarized in this paper. According to sensors with different system parameters, we focus on spatial decorrelation and deformation gradient as the main clue to quantitatively analyze how these factors impact the deformation extraction and limit the use of interferometry. The study achieves the following: (1) Analyze the range of critical slope for each sensor and the blind areas monitored by SAR are estimated. (2) Volume scattering component must be considered while using coherence decomposition technique in vegetation area and the model is modified. (3) Illuminate the difference between deformation gradient and phase gradient and their function is proposed. Meanwhile, the angle of incidence is introduced to the function of deformation gradient. (4) On this basis, we use a series of representative data to validate the conclusion. This study further extends conditions for InSAR measurements, which also has important reference value and application significance for understanding the interferometry mechanism, establishing improved InSAR numerical model and helping researchers to determine the most appropriate data by different deformation characteristics.
ACCESS: http://manu16.magtech.com.cn/geophy/EN/abstract/abstract9328.shtml

APPLICATION AND RELIABILITY OF TECHNIQUES FOR LANDSLIDE SITE INVESTIGATION, MONITORING AND EARLY WARNING: OUTCOMES FROM A QUESTIONNAIRE STUDY.
CITATION: I. Baron and R. Supper. , Natural Hazards and Earth System Sciences, 2013. European Geosciences Union, France. Vol. 13, No. 12, 3157-3168.
ABSTRACT: The presented questionnaire study summarizes an evaluation of approaches, techniques and parameters of slope-instability investigation and monitoring of their occurrence, reliability and the applicability of the monitoring techniques for early warning. The study is based on information collected from 86 monitored landslides in 14 European and Asian countries. Based on the responses, lidar ALS (airborne laser scanners), geophysical logging, aerial photographs, resistivity surveying, GB InSAR (ground-based synthetic aperture radar interferometer) and the refraction seismic were considered the most reliable methods for investigation of structure and character of landslides. Especially lidar ALS and geophysical logging were ranked high despite their application at relatively few landslides. Precipitation amount, pore-water pressure and displacement monitored by wire extensometers, dGPS and total stations, followed by air temperature and EM-emissions monitoring and displacement monitored by the TM 71 crack gauge were considered the most

promising parameters for early warning.
ACCESS: http://www.nat-hazards-earth-syst-sci.net/13/3157/2013/nhess-13-3157-2013.html

APPLICATION OF INSAR MEASUREMENTS AND MECHANICAL MODELING FOR NATURAL HAZARD ASSESSMENT AND MITIGATION ALONG THE DEAD SEA TRANSFORM.
CITATION: G. Baer, M. Abelson, Y. Finzi, et al. , Appearing in: Geophysical Research Abstracts, Geophysical Research Abstracts,
ABSTRACT: InSAR measurements along the Dead Sea Transform (DST) are used to assess and mitigate natural hazards originating from both seismic and non-seismic processes. We are currently focusing on three major topics: (1) the deformation cycle of the November 1995 Gulf of Elat (Aqaba) earthquake, (2) interseismic slip along the DST and secondary faults, and (3) infrastructure collapse. Ascending and descending track interferograms of the November 22, 1995, Mw=7.2 Gulf of Elat Earthquake were inverted for fault geometry and slip distribution. Using these fault parameters, we calculated the induced stress changes associated with the earthquake and found that major aftershocks and aseismic slip along nearby Gulf-parallel faults were associated with positive Coulomb stress changes. Evidence for accelerated vertical deformation several months prior to the earthquake were observed along the Arava Valley segment north of the main rupture. Continuous vertical deformation in the step zones between these fault segments suggests aseismic creep at a rate of about 30% of the GPS-determined loading rate. This implies an increased expected recurrence time for characteristic major earthquakes along this segment by as much as 40%. Over the last decade, hundreds of collapse-sinkholes formed along the Dead Sea (DS) coastlines of Israel and Jordan, causing severe damage to the regional infrastructure. The sinkholes cluster along discrete lineaments which, in some places, coincide with the boundaries of gradual land subsidence features detected by InSAR. Based on similarity in orientation distribution with structural features and earthquake mechanisms, these lineaments were suggested to trace young, possibly active, fault systems, concealed within the fill. This process forms an immediate hazard to the DS coast tourist centers and to the ongoing damming activity of the Dead Sea Works for new salt evaporation ponds. The subsidence zones and their linear boundaries are already incorporated into sinkhole hazard maps used for regional planning. The Carmel Fault, which splays off the DST further to the north, has been considered as potentially active, threatening the city of Haifa and the nearby petrochemical industry. Recent PSInSAR measurements (processed by TRE Milano) show no relative detectable motion across the fault. This observation is consistent with new seismic and paleoseismic evidence which show lack of seismic energy production along this fault segment, thus questioning its definition as an active fault. The Haifa PSInSAR measurements also show subsidence at rates as high as 7 mm/yr in several locations away from the fault trace, causing significant damage to public buildings. The PSInSAR results will be incorporated in land use maps of the region.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

APPLICATION OF REMOTE SENSING TECHNIQUES TO DETERMINE THE KINEMATICS OF THE BULL LAKE CREEK LANDSLIDE, WIND RIVER MOUNTAINS, WYOMING.
CITATION: Bjorn Held. , ProQuest Dissertations and Theses, 2011. University of Missouri - Columbia. United States -- Missouri.
ABSTRACT: Landslides are one of many natural hazards that impact human settlements. On average, each year landslides account for billions of dollars of property damage and claim thousands of lives around the world. Landslides are prevalent throughout the United States, and require constant monitoring and remediation. This abundance is a result of a combination of weak stratigraphic layers, extensive faulting and tilting, and a climate that allows for large amounts of snow melt to be input into the water table. It is therefore important to gain a better understanding of how and when landslides occur, not only to minimize damage in areas with currently active landslides but also to identify landslide prone areas in order to avoid developing infrastructure near them. In order to accomplish these goals it is important to understand the mechanics of mass movements and the variables that affect their activity. The goal of this thesis research was to determine seasonal kinematics of the Bull Lake Creek Landslide (BLCS) in the Wind River Mountains of Wyoming. Satellite-based L-band Interferometric synthetic aperture radar (InSAR) data was utilized to monitor short-term movement of BLCS and was correlated to meteorological and stream discharge data provided by USGS gauging and weather stations in the Bull Lake Creek Valley. Cumulative displacements recorded by InSAR analysis were greater than 300cm over a 3 year time span, with maximum amounts of movement occurring during the months of May and June corresponding with peaks in stream discharge. For longer-term variations, aerial photos over a 50 year time span were observed. Results from the aerial photo analysis show massive cliff failure events (~5 million m 3 of material) occur and that catastrophic mobilization of the slide occurs on decadal time scales with displacement of large (>20m) clasts up to ~2km, and destruction and entrainment of mature growth trees (60cm dia.). Since other slides located in the Wind River Mountains share a similar structure as that of BLCS, it can be inferred that they may also fail catastrophically. Therefore, a re-assessment of the hazard that they pose to human infrastructure (such as Bull Lake

Reservoir) may be in order.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

APPLICATION OF PSI TECHNIQUE IN DEFORMATION MONITORING.
CITATION: Yun-Ju Nie, Guo-Xiang Liu, Jin-Feng Shi, et al. , Science of Surveying and Mapping, 2013. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 38, No. 2, 80-83, 97.
ABSTRACT: The accurate identification of PSs is one of the key issues in Persistent Scatterer (PS) Synthetic aperture radar Inter-ferometry (InSAR) modeling and deformation extraction. The paper presented an improved algorithm for PS detection. Based on the time series of SAR amplitude data, the PS candidates (PSC) were firstly selected using both amplitude thresholding and amplitude dispersion index thresholding. The true PSs were then screened out from the PSC set by an iterative process based on phase stability analysis. The deformation values of the true PSs were finally estimated. Experimental results demonstrated that the proposed algorithm could significantly improve the accuracy and reliability of deformation measurements derived with PSI.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

APPLICATIONS OF GPS AND INSAR IN MONITORING OF LANDSLIDE STUDIES.
CITATION: Qing-Song Fan, Cui-Lian Tang, Yu Chen, et al. , Cehui Kexue / Science of Surveying and Mapping, 2006. Chinese Academy of Surveying and Mapping, China, Vol. 31, No. 5, Pg. 60-62.
ABSTRACT: The powerful tool of Interferometric synthetic aperture radar (InSAR) is drawing more and more attention in the field of landslide studies. The paper presents the characteristics and advantages of InSAR in landslide monitoring. The integration of InSAR and GPS in investigation of landslide can simultaneously improve both temporal resolution and spatial resolution. And it has become an effective way to investigate and manage landslide hazards. This paper demonstrates the theory and method of GPS-InSAR integration, and discusses its broad prospects in landslide monitoring.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

BAYOU CORNE, LOUISIANA, SINKHOLE: PRECURSORY DEFORMATION MEASURED BY RADAR INTERFEROMETRY.
CITATION: Cathleen E. Jones and Ronald G. Blom. , Geology, 2014. Vol. 42, No. 2, 111-114.
ABSTRACT: Catastrophic sinkholes are formed through the collapse of natural or human-made subterranean caverns, and are common in areas with evaporite and carbonate rock. Despite their danger, advance warning of these events is rare. We report a measurement of precursory surface deformation of as much as 260 mm, derived with Interferometric synthetic aperture radar (InSAR) and evident over a month before surface collapse, at the site of the Bayou Corne, Louisiana (USA) sinkhole that formed in August 2012. Data collected by the airborne Uninhabited Aerial Vehicle SAR (UAVSAR) instrument were used for the study. Analysis of data acquired from two flight tracks with near-opposing imaging geometries reveal a deformation pattern consistent with compressive loading at the surface due to loss of support from a subterranean cavity collapse related to Texas Brine Oxy Geismar Well #3. The precursor deformation was nearly entirely horizontal, i.e., oriented along the surface, and manifested as movement of surface material toward the location where the sinkhole later formed. The sinkhole formed in the area with the largest gradient in surface strain, but did not cover the full extent of the precursory deformation detected with radar. This work suggests that InSAR data collected operationally for hazard monitoring could, in some cases, identify sinkhole development before surface collapse, and decrease subsequent danger to people and property.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

CHARACTERIZATION OF GEOLOGICAL HAZARDS USING A GLOBALLY OBSERVING SPACEBORNE SAR.
CITATION: E. Chaussard and F. Amelung. , Photogramm.Eng.Remote sensing, 2013. Vol. 79, No. 11, 982-986.
ABSTRACT: Geological hazards threaten millions of people living in vulnerable areas worldwide. Monitoring of inch hazards can help decision-makers take measures to reduce the associated risks. Ground deformation characterization using satellite-based Interferometric synthetic aperture radar (InSAR). which measures ground displacement in the radar line-of-sight (LOS) direction between passes of a satellite over the same area, can play an important role for hazard assessment and the mitigation of disasters, For example, the arrival of a new magma batch beneath a volcano can be detected by observations of edifice inflation, which can help identify volcanoes that are likely to erupt in the near future (Lu et al., 2007: Segall, 2013). Similarly, land subsidence, which threatens the integrity of buildings and infrastructures and increases the risk of flooding in coastal regions or near rivers, can be precisely mapped with InSAR (Raucoules et al., 2007). Spaceborne monitoring of other geological hazards (not discussed in this paper) includes slow creep and strain accumulation along major faults and catastrophic landslides generally preceded by long-term slow

motion.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

COLLAPSE-SINKHOLES AND RADAR INTERFEROMETRY REVEAL NEOTECTONICS CONCEALED WITHIN THE DEAD SEA BASIN.
CITATION: M. Abelson, G. Baer, V. Shtivelman, et al. , Geophys.Res.Lett., 2003. American Geophysical Union, Vol. 30, No. 10,
ABSTRACT: The Dead Sea (DS) pull-apart basin is one of the more seismically active segments of the DS Transform plate boundary. In the last decade, hundreds of collapse-sinkholes have been formed along the DS coastlines in Israel and Jordan, causing severe damage to the regional infrastructure. The formation of these sinkholes is attributed to the dissolution of a buried salt layer by fresh groundwater due to the drop of the DS and the associated groundwater levels. Here we show that the sinkhole distribution, combined with gradual land subsidence measured by radar interferometry (InSAR) track young fault systems suspected as active, concealed within the fill of the DS rift. This notion is supported by (1) sinkholes clustering along discrete lineaments with a striking trend similarity to that of the exposed rift-margin faults; (2) prominent discontinuities in seismic reflection profiles offsetting young sediments (several kyrs old) below sinkhole lines, and (3) straight boundaries of gradual subsidence features that coincide with or parallel sinkhole lines. Combined, the sinkhole lineaments and the InSAR measurements reveal a zigzag pattern of buried faults within the DS rift fill.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

COUPLING OF GPS/GNSS AND RADAR INTERFEROMETRIC DATA FOR A 3D SURFACE DISPLACEMENT MONITORING OF LANDSLIDES.
CITATION: Marko Komac, Rachel Holley, Pooja Mahapatra, et al. , Landslides, 2015. Springer Science+Business Media, Netherlands. Vol. 12, No. 2, 241-257.
ABSTRACT: Persistent scatterer interferometry (PSI) is capable of millimetric measurements of ground deformation phenomena occurring at radar signal reflectors (persistent scatterers, PS) that are phase coherent over a period of time. However, there are also limitations to PSI; significant phase decorrelation can occur between subsequent interferometric radar (InSAR) acquisitions in vegetated and low-density PS areas. Here, artificial amplitude- and phase-stable radar scatterers may have to be introduced. I2GPS was a Galileo project (02/2010-09/2011) that aimed to develop a novel device consisting of a compact active transponder (CAT) with an integrated global positioning system (GPS) antenna to ensure millimetric co-registration and a coherent cross-reference. The advantages are: (1) all advantages of CATs such as small size, light weight, unobtrusiveness and usability with multiple satellites and tracks; (2) absolute calibration for PSI data; (3) high sampling rate of GPS enables detection of abrupt ground motion in 3D; and (4) vertical components of the local velocity field can be derived from single-track InSAR line-of-sight displacements. A field trial was set to test the approach at a potential landslide site in Potoska planina, Slovenia to evaluate the applicability for operational monitoring of natural hazards. Preliminary results from the trial highlight some of the key considerations for operational deployments in the field. Ground motion measurements also allowed an assessment of landslide hazard at the site and demonstrated the synergies between InSAR and GPS measurements for landslide applications. InSAR and GPS measurements were compared to assess the consistency between the methods from the slope mass movement detection aspect.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

DEFORMATION MONITORING OF SLOW-MOVING LANDSLIDE WITH L- AND C-BAND SAR INTERFEROMETRY.
CITATION: Xuguo Shi, Lu Zhang, Mingsheng Liao, et al. , Remote sensing Letters, 2014. Taylor & Francis Group Ltd., United Kingdom. Vol. 5, No. 11, 951-960.
ABSTRACT: SAR interferometry (InSAR) is an effective tool for wide-area earth surface deformation detection and mapping. In this letter, Persistent Scatterers InSAR method was employed to derive the deformation histories of Huangtupo and Zhaoshuling landslides located in Badong County of the Three Gorges area. One Environmental Satellite C-band Advanced Synthetic aperture radar (ASAR) data stack acquired from descending orbit and two Advanced Land Observation Satellite Phased Array type L-band Synthetic aperture radar (PALSAR) data stacks collected from two adjacent ascending orbits were used. Different deformation trends were observed from the descending and ascending data stacks. Disagreements were found on Huangtupo and Zhaoshuling landslides between measurements of ASAR data and PALSAR data, which might be primarily attributed to different viewing geometries. Meanwhile, due to smaller decorrelation effects for longer wavelength, L-band PALSAR data can be used to detect more point-like targets than C-band ASAR data, which makes it more suitable for monitoring landslides in vegetated areas such as the Three Gorges. Preliminary temporal correlation analyses between deformation measurements and water level fluctuation as well as rainfall were performed to explore the driving mechanism for landslide motion within the Three Gorges

Reservoir area.
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DELIVERING GEOHAZARD AND GEOTECHNICAL DATA; FROM THE SATELLITE TO THE FIELD.
CITATION: Andrea Vaccari, Brian S. Bruckno, Edward Hoppe, et al. , Abstracts with Programs - Geological Society of America, 2014. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 46, No. 2, 74.
ABSTRACT: As part of the USDOT-funded research program RITA-RS-11-H-UVA, "Sinkhole Detection and Bridge/Landslide Monitoring for Transportation Infrastructure by Automated Analysis of Interferometric synthetic aperture radar [InSAR] Images," the authors completed the a pilot study in which they developed a computational approach aimed at the early detection and evaluation of potential geohazards within a point cloud dataset obtained from processed InSAR data. The technique was applied to the detection of sinkholes within an active 40X40 km data frame located in the Valley and Ridge Province in Virginia. The analysis, based on the detection of a specific spatio-temporal model describing incipient sinkhole behavior, was used to scan a 10 million point dataset for regions where the spatio-temporal behavior matched the model, providing as output a geo-referenced map indicating the quality of match. This map was then converted to a risk map where fastest growing features were identified as riskier. To favor visualization and integration with commonly used GIS platform, results were exported in KML (Google Earth) and SHP (ArcGIS) formats. The authors believe this approach can be implemented as a map-production workflow where routine monitoring of satellite data is pushed within a GIS-integrated analysis pipeline to be analyzed by a set of plugins designed to monitor/detect potentially hazardous features, and the results exported as Google Earth (KML) files or ArcGIS layers to provide immediate visualization and delivery. Other geospatial data layers, such as geology, karst, soils maps, or fault zones, can be delivered on the same platforms, thus offering greater efficiency and geospatial data integration in planning, inspection, and incident response. Disclaimer: The views, opinions, findings and conclusions reflected in this paper are the responsibility of the authors only and do not represent the official policy or position of the US DOT/RITA, or any State or other entity.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

DETECTION AND ANALYSIS ON SUBSIDENCE OF SHANGHAI WITH HIGH RESOLUTION PSI TECHNIQUE.
CITATION: Yun-Ju Nie, Guo-Xiang Liu, Jin-Feng Shi, et al. , Science of Surveying and Mapping, 2013. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 38, No. 3, 73-76.
ABSTRACT: The subsidence in Shanghai was detected using the Persistent Scatterer (PS) Interferometric synthetic aperture radar (InSAR) technique with high resolution (HR) imagery, which was based on an improved algorithm for PS detection. The causes of subsidence were also analyzed. This investigation aimed to explore and provide an effective technology for monitoring subsidence in urban areas and on engineering structures. The experiments of PS detection, PSI modeling, deformation extraction and analysis were performed with data sources of 18 HR X-band (wavelength of 3.1 cm) SAR images (covering 54 x 31 km(2)), which were collected by the radar sensor onboard the German satellite TerraSAR-X (TSX) from April 2008 to January 2010. The experimental results demonstrated that the PS points detected by the improved method were accurate and reliable. The PSs' density and coverage could be increased dramatically due to the unique characteristics of the HR TSX SAR imagery in distinguishing the hard objects. The accuracy and reliability of the deformation measurements derived by PSI could be improved significantly. The maximum relative subsidence rate in the study area was as high as 30 mm/yr and the averaged subsidence rate was 11.52 mm/yr.
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DETECTION OF PAST SLOPE ACTIVITY IN A DESERT AREA USING MULTI-TEMPORAL DINSAR WITH ALOS PALSAR DATA.
CITATION: Alfredo Rocca, Paolo Mazzanti, Daniele Perissin, et al. , Italian Journal of Engineering Geology and Environment, 2014. University of Rome "La Sapienza", Valmontone Rome Italy. Vol. 1, np.
ABSTRACT: Coastal slope involved in the construction of a road in the Sultanate of Oman was affected during the period 2011-2012 by instability processes. Lithological and geomorphological evidence suggested a general conformation of the slope that is very prone to gravitational instability processes. Because satellite SAR interferometry (InSAR) is the only technique that is able to provide quantitative information about past ground displacements, it has been chosen to investigate the past evolution of the slope. Nine archived SAR images acquired by the ALOS PALSAR have been analysed using a hybrid approach based on the classical differential interferometry (DinSAR) and Quasi-Persistent Scatterers (QPS) techniques. Some ground deformation processes have been detected and measured on three portions of the slope. One of them has been localised within the area affected by the recent landslide phenomenon. Thanks to this approach the deformation processes have been defined in time and the related displacements have been quantitatively

estimated.
ACCESS: http://www.nhazca.it/pdf/ijege-14_01-rocca-et-alii.pdf

DEVELOPMENT OF A MULTISCALE MONITORING AND HEALTH ASSESSMENT FRAMEWORK FOR EFFECTIVE MANAGEMENT OF LEVEE INFRASTRUCTURE.
CITATION: M. Zeghal, T. Abdoun, M. Exton, et al. , Geo-Congress 2013, 2014. American Society of Civil Engineers. 1605-1614.
Note: 23; M1: 3; doi:10.1061/9780784412787.161.
ABSTRACT: This paper presents an overview of a framework to assess the structural integrity and health of earthen levees. The framework is being developed through a project supported by NIST (National Institute of Standards and Technology) and relies on remote sensing and field monitoring data of levees during environmental loading conditions and natural processes of degradation. The monitoring data consists of levee displacements obtained using satellite-based Interferometric synthetic aperture radar (InSAR), Global Position System (GPS) receivers, and Shape-Acceleration Pore Pressure (SAPP) Arrays. These measurements are used in an integrated fashion to localize internal zones of degradation within levees and quantify the corresponding level of weakening. The framework is demonstrated using test data of small scale centrifuge levee models.
ACCESS: http://dx.doi.org.vdot.idm.oclc.org/10.1061/9780784412787.161

DINSAR ANALYSIS OF ALOS PALSAR IMAGES FOR THE ASSESSMENT OF VERY SLOW LANDSLIDES: THE TENA VALLEY CASE STUDY.
CITATION: Juan Carlos Garcia-Davalillo, Gerardo Herrera, Davide Notti, et al. , Landslides, 2014. Springer Science+Business Media, Netherlands. Vol. 11, No. 2, 225-246.
ABSTRACT: In this work we analyse the performance of advanced land observing satellite (ALOS) phased array type L-band syntetic aperture radar (PALSAR) images for mapping and monitoring of very slow landslides using conventional differential interferometry in the Tena Valley (Central Pyrenees, Spain). These results are compared with those retrieved in previous works where multi-band advanced differential Interferometric synthetic aperture radar (DinSAR) analysis was performed for the same area using PSI techniques. The study area is largely underlain by slates (ca. 80 %) where large deep-seated very slow earth flows are dominant. The results reveal that DinSAR analysis is able to measure displacements of landslides with a greater spatial coverage than PSI analysis, but for a lower amount of them (nine against 51). Overall, the combination of the DinSAR and multi-band PSI analysis permitted to map and monitor 68 % of the landslides in Tena Valley. From this amount, 63 landslides are considered as active. The main advantage of DinSAR with respect to PSI analysis is the capability to detect faster movements (up to 145 cmyear super(-1)) derived from the 46 days interferograms. That is the case of Sextas and La Selva landslides where an acceleration of the moving mass was measured after intense rainfall periods producing major damages to linear infrastructures. The combination of measured displacement from ALOS interferograms, with the observed damages on the A-136 road, was useful to assess the potential damage that could cause these slow movements. In general, it is demonstrated that even though PSI analysis provides a better performance in terms of landslide mapping, L-band DinSAR analysis provides an added value for landslide hazard assessment through radar remote sensing. For this reason it is necessary to encourage the launch of new satellite missions similar to ALOS PALSAR that could operate with shorter revisiting time periods.
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DINSAR MEASUREMENTS OF GROUND DEFORMATION BY SINKHOLES, MINING SUBSIDENCE, AND LANDSLIDES, EBRO RIVER, SPAIN.
CITATION: Carmen Castaneda, Francisco Gutierrez, Michele Manunta, et al. , Earth Surf.Process.Landforms, 2009. John Wiley and Sons Ltd. United Kingdom. Vol. 34, No. 11, Pg. 1562-1574.
ABSTRACT: Differential Interferometric synthetic aperture radar (DInSAR) has been applied to detect and measure ground deformation in a stretch of the Ebro River valley (Spain) excavated in salt-bearing evaporites. The capability of the Small Baseline Subset (SBAS) DInSAR technique to detect ground displacement is analyzed comparing the DInSAR results with the available geomorphological information. The deformation map derived from 27 European Remote sensing (ERS) satellite images covering more than five years provides sub-centimeter displacement measurements in zones coinciding with known active sinkholes and landslides. Moreover the map provides the first account of mining subsidence in the area. The measured deformation rates reach 1&middot68 cm/y for the sinkholes, 0&middot80 cm/y for the landslides and 1&middot45 cm/y for the area affected by mining subsidence. The SBAS DInSAR technique provided deformation measurements in a small proportion (5-10%) of the known active sinkholes and landslides. This limitation is mainly due to the lack of coherence in agricultural areas, the spatial resolution of the deformation map (pixel size of 90 m), and the parallelism between the ERS satellite line of sight and the linear escarpment on which most of the landslides occur. Despite this, the Interferometric technique provides valuable data that complement traditional geomorphological studies including the quantification of the deformation phenomena,

the identification of mining subsidence otherwise only recognizable by geodetic methods, and the detection of creep deformation which might correspond to premonitory indicators of catastrophic sinkholes and landslides capable of causing the loss of lives. Detailed DInSAR studies combined with field data would be required to improve the analysis of each deformation area.
ACCESS: http://dx.doi.org/10.1002/esp.1848

D-INSAR-BASED LANDSLIDE LOCATION AND MONITORING AT WUDONGDE HYDROPOWER RESERVOIR IN CHINA.
CITATION: Guijie Wang, Mowen Xie, Xiaoqing Chai, et al. , Environmental Earth Sciences, 2013. Springer Science+Business Media, Netherlands. Vol. 69, No. 8, 2763-2777.
ABSTRACT: Differential synthetic aperture radar interferometry (D-InSAR) has become a useful technique for monitoring ground movement. The technique enables the analysis of very small ground movements in continuous, large areas and has the advantages of high accuracy, high resolution, all-weather adaptability, low cost, and inaccessible area coverage. Thus, D-InSAR has been widely used in the investigation of geologic hazards, such as subsidence, landslide, earthquake, and volcanic activity. In this paper, D-InSAR is used to locate and monitor landslide movement in the wide area of Wudongde Hydropower Reservoir in Jinsha River, China. Five SAR acquisitions are obtained by using the phased array-type L-band synthetic aperture radar sensor of the Advanced Land Observing Satellite. Detailed moving displacement maps in two time periods are derived by using the D-InSAR technique, and potentially moving landslide areas, as well as landslide hazard areas, are then located. The L1R-6 landslide, which is in active state, is investigated in detail. The deforming tendency obtained via D-InSAR is consistent with that obtained via global positioning system (GPS) monitoring. Error analysis of the D-InSAR results is also conducted. Finally, the grid function interpolation method of error reduction, which combines D-InSAR and GPS, is proposed to reduce the single-point error in D-InSAR monitoring and is further verified by the considerable improvement in the accuracy of L1R-6 landslide monitoring.
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DIRECT MEASUREMENTS OF LAND SURFACE DEFORMATION BASED ON PS-INSAR IN LANZHOU, CHINA.
CITATION: Ya Ting Xue, Xing Min Meng, Guan Chen, et al. , Applied Mechanics and Materials, 2015. Trans Tech Publications Ltd., Switzerland. Vol. 744-746, No. Advances in Civil Engineering and Transportation IV, 1684-1688.
ABSTRACT: Surface deformation is a slow and irreversible change. It is impacted by topographic, geologic and human activities. To investigate the spatial distribution of surface deformation in Lanzhou, we used PS-InSAR technique. PS-InSAR is a remote sensing method that can be used to detect surface deformation: an indicator of potential hazards. By capturing these deformations over a period of time, we can get valuable information about impending geohazards, such as landslides. This study focused on using this technique to investigate the distribution and cause of surface deformation in the region around Lanzhou, the capital of Gansu Province, China.
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AN EVALUATION OF COMMERCIALLY AVAILABLE REMOTE SENSORS FOR ASSESSING HIGHWAY BRIDGE CONDITION.
CITATION: T. Ahlborn M, R. Shuchman, L. Sutter L, et al. , 2010. Pg. 73p.
ABSTRACT: This report focuses on evaluating twelve forms of remote sensing that are potentially valuable to assessing bridge condition. The techniques are: ground penetrating radar (GPR), spectra, 3-D optics (including photogrammetry), electro-optical satellite and airborne imagery, optical interferometry, LiDAR, thermal infrared, acoustics, digital image correlation (DIC), radar (including backscatter and speckle), Interferometric synthetic aperture radar (InSAR), and high-resolution "StreetView-style" digital photography. Using a rating methodology developed specifically for assessing the applicability of these remote sensing technologies, each technique was rated for accuracy, commercial availability, cost of measurement, pre-collection preparation, complexity of analysis and interpretation, ease of data collection, stand-off distance, and traffic disruption. Key findings from the evaluation are that 3-D optics and â€œStreetView-styleâ€□ photography appear to have the greatest potential for assessing surface condition of the deck and structural elements, while radar technologies, including GPR and higher frequency radar, as well as thermal/infrared imaging demonstrate promise for subsurface challenges. Global behavior can likely be best monitored through electro-optical satellite and airborne imagery, optical interferometry, and LiDAR.
ACCESS: http://www.mtri.org/bridgecondition/doc/RITA_BCRS_Commercial_Sensor_Evaluation.pdf

EXPERIMENT RESEARCH OF D-INSAR TECHNIQUE ON IDENTIFYING LANDSLIDE MOVING IN A WIDE AREA.

CITATION: G-J Wang, M-W Xie, C. Qiu, et al. , Journal of University of Science and Technology Beijing, 2011. University of Science and Technology Beijing. Vol. 33, No. 2, Pg. 131-141.
ABSTRACT: Based on three-frame synthetic aperture radar (SAR) data derived from ALOS satellite sensor PALSAR, a three-pass differential SAR interferometry (D-InSAR) technique was used to analyze landslide activities in the Wudongde Hydropower Reservoir area at lower Jinsha River, and high accuracy ground displacement values were acquired by this method. The classification of these ground displacement values by sliding velocity and displacement clearly illustrated the ground activity deformation states of various zones in the studied area were clearly obtained, determined some potential moving landslides and active landslides and identified the dangerous zones of landslides. For an active landslide numbered No. L1R-6, the deformation detected by D-InSAR analysis shows an accordance tendency with the one by global positioning system (GPS) monitoring. In the end, single-point errors which existed in the result of D-InSAR technique were analyzed and a grid function error interpolation method of D-InSAR and GPS was proposed to improve the monitoring accuracy of D-InSAR technique.
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FRONTIERS OF RADAR REMOTE SENSING.
CITATION: Zhong Lu and Lei Zhang. , Photogramm.Eng.Remote sensing, 2014. Vol. 80, No. 1, 5-13.
ABSTRACT: Radar provides an all-weather, day-and-night imaging capability for mapping the Earth's surface. Through Interferometric synthetic aperture radar (InSAR) technique, radar imagery can be used to map Earth surface characteristics and measure land surface deformation at an unprecedented precision and spatial resolution. This article introduces the basics of radar and InSAR imaging, summarizes the revolution of InSAR technology on monitoring natural hazards and characterizing natural resources, and highlights emerging InSAR technologies in coming years.
ACCESS:
http://www.smu.edu/~/media/Site/Dedman/Academics/Departments/EarthSciences/PDF/Lu/107_Lu_Zhang_InSAR_frontiers_PERS_2014.ashx?la=en

GEODETIC MONITORING OF SURFACE DEFORMATION ALONG THE WESTERN DEAD SEA SHORES AND IN SINKHOLE SITES, USING GPS AND INSAR MEASUREMENTS.
CITATION: U. Schattner, S. Wdowinski, D. Wachs, et al. , Annual Meeting - Israel Geological Society, 2001. Israel Geological Society, Jerusalem. Jerusalem, Israel (ISR). Vol. 2001, Pg. 105.
ABSTRACT: Not available.
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GPS AND REMOTE SENSING STUDY OF SLOPE MOVEMENT IN THE BERKELEY HILLS, CA.
CITATION: J. Cohen-Waeber, N. Sitar and R. Bürgmann. , Geo-Congress 2013, 2014. American Society of Civil Engineers. 319-322.
Note: 23; M1: 3; doi:10.1061/9780784412787.031.
ABSTRACT: Recent advances in geodetic technologies allow for analysis of spatial and temporal deformation of landslides that was previously not possible. Technologies such as continuous GPS and Interferometric synthetic aperture radar (InSAR) need to be incorporated in the current state of practice for landslide characterization. This landslide risk assessment project aims to characterize slope movement at Lawrence Berkeley National Laboratory (LBNL) and in the Berkeley Hills as a result of static and dynamic forces, first using a comprehensive network of continuously streaming GPS stations that measure active ground surface displacement with sub-centimeter precision and accuracy. The intent is to combine the GPS observations with InSAR time series analyses to help develop a method for the determination and evaluation of landslide hazards remotely. Since the implementation of our GPS observation program in January 2012, landslide related surface displacements have been recorded as an effect of precipitation.
ACCESS: http://dx.doi.org.vdot.idm.oclc.org/10.1061/9780784412787.031

HISTORICAL ANALYSIS OF TUNNEL APPROACH DISPLACEMENTS USING SATELLITE REMOTE SENSING.
CITATION: Hoppe, E., Kweon, Y., Bruckno, B., et. al. Transportation Research Board, Transportation Research Board 94th Annual Meeting, 2015, 16p.
ABSTRACT: This study investigated historical displacements of the tunnel boat sections at the approaches to the Monitor-Merrimac Memorial Bridge-Tunnel in Virginia as a potential reason for ongoing seawater infiltration. The analysis was based on archived data collected from December 2001 to March 2010 by the Radarsat-1 Earth orbiting radar satellite. Millimeter precision in displacement measurements was achieved over an area of approximately 100 km², including the bridge-tunnel and adjacent regions of Suffolk and Newport News. Data consisting of 42 radar acquisitions were processed using the differential technique of Interferometric Synthetic aperture radar (InSAR). Additional statistical analysis was conducted on the specific

points of interest. The results of the historical analysis of satellite radar remote sensing data indicated no significant displacements of the tunnel boat sections during the period of study. The annual displacement rate precision of the tunnel boat sections was estimated to be within ±1 mm/year at the 95th percentile confidence interval. Thus, it is unlikely that the settlement of man-made islands was a reason for the ongoing water infiltration.
ACCESS: http://trid.trb.org/view/2015/C/1338934

INSAR APPLICATIONS FOR HIGHWAY TRANSPORTATION PROJECTS.
CITATION: Desmond Power, James Youden, Jerry English, et al. , 2006. Pg. 101p.
ABSTRACT: Satellite Synthetic aperture radar (SAR) technology, in combination with interferometry (InSAR), has the ability to measure topography or ground movement to sub-centimeter accuracy. Many factors affect the ability to apply InSAR for the detection of slope movement. If these factors are considered, InSAR can often be successfully used to monitor slope movement. The Federal Lands Highway Program (FLH) of the Federal Highway Administration (FHWA) has initiated the project described within this report to evaluate the utility of InSAR technology to monitor slide movements that impact road networks. The project objective was to establish and demonstrate reliable, cost effective procedures to measure ground movement using InSAR in support of federal highways projects. This report describes the effectiveness of InSAR in monitoring ground movement, and recommends guidelines for the coordinated use of InSAR with other FLH data collections, including photogrammetry, field surveys, boreholes and slope inclinometers. InSAR has the unique ability to measure both present and prior (based on the data archives accumulated over the last 12 years) ground movement and consequently, the present study involved collection and analysis of InSAR data from both the past and present at three sites. The first site, the Prosser slide in Benton County WA, provided a site with excellent InSAR coherence and gradual creeping movement that demonstrated the limits of InSAR movement measurement. The combination of a set of InSAR movement maps over a two-year period produced movement on the order of several centimeters that qualitatively correlated well with site observations and slope inclinometer measurements. The second slope, the Cimarron slide in Owl Creek CO, exhibited moderate coherence and highly visible InSAR movement signatures were produced over periods of only several months. The third site, in Mesa Verde National Park near Cortez, CO, is a region of significant topographic relief, which made the use of satellite-based InSAR a challenge.
ACCESS: http://www.cflhd.gov/programs/techdevelopment/geotech/InSAR/

INSAR DEFORMATION MONITORING: GENERALS HIGHWAY, SEQUOIA NATIONAL PARK.
CITATION: Sato, S.; Kampes, B.; Van Der Koij, M.; Place, A. MDA Geospatial Services Inc., Ottawa, Ontario, Canada.; Federal Highway Administration, Lakewood, CO. Central Federal Lands Division, 2009, 46p.
ABSTRACT: Ground movement was monitored using Interferometric Synthetic aperture radar (InSAR) coupled with on-site corner reflector technology for an area where the General's Highway in the Sequoia National Park, California crossed over an unstable slope. As part of proposed roadway improvements for this section, one corner reflector was placed on a known stable rock outcrop, and two corner reflectors were placed in known unstable locations on the slope above and below the roadway. This study found some minimal InSAR deformation at the corner reflector locations over a four month period of 1.7 to 2.5 mm vertical movement, and 2.3 to 3.4 mm on the flow line.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=PB2010106093

INSAR EVALUATION OF LANDSLIDES AND ALTERNATIVE TRANSPORTATION ROUTES.
CITATION: Roger Surdahl, Scott A. Anderson and Brian Young. , Geotechnical Engineering for Transportation Projects, 2010. American Society of Civil Engineers. Vol. 126, Pg. 2038-2047.
ABSTRACT: Interferometric Synthetic aperture radar (InSAR) was used to monitor ground movement in Badlands National Park. InSAR is an innovative method that can be used to detect, map and measure movement without the need of survey targets or ground-based instruments. Using current and historic data sets, InSAR was applied in observing landslides that impact the Park's access road, and in evaluating possible alternate alignments. Although traditional geotechnical instruments have monitored the road for years, the total area assessed using InSAR is larger than could practically be studied by these instruments. The results are on an interactive website and show that nearby landslides are not interrelated, the boundaries of a large, slow moving landslide agree with data from instruments and observations, and the amount of movement occurring along the existing alignment may be typical for the area. Availability of historic data, unexplainable ground movement and low coherence were some difficulties encountered.
ACCESS: http://dx.doi.org/10.1061/40744(154)199

INTEGRATING GEOMORPHOLOGICAL MAPPING, INSAR, GPR AND TRENCHING FOR THE IDENTIFICATION AND INVESTIGATION OF BURIED SINKHOLES IN THE MANTLED EVAPORITE KARST OF THE EBRO VALLEY (NE SPAIN).

CITATION: Francisco Gutierrez, Jorge Pedro Galve, Pedro Lucha, et al. , Geophysical Research Abstracts, 2010. Copernicus GmbH on behalf of the European Geosciences Union (EGU), Katlenburg-Lindau. Katlenburg-Lindau, Germany (DEU). Vol. 12, Pg. EGU2010-1757.
ABSTRACT: Not available.
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INTEGRATING GEOMORPHOLOGICAL MAPPING, TRENCHING, INSAR AND GPR FOR THE IDENTIFICATION AND CHARACTERIZATION OF SINKHOLES; A REVIEW AND APPLICATION IN THE MANTLED EVAPORITE KARST OF THE EBRO VALLEY (NE SPAIN).
CITATION: Francisco Gutierrez, Jorge Pedro Galve, Pedro Lucha, et al. , Geomorphology, 2011. Elsevier, Amsterdam. Amsterdam, Netherlands (NLD). Vol. 134, No. 1-2, Pg. 144-156.
ABSTRACT: This contribution illustrates the advantages of integrating conventional geomorphological methods with InSAR, ground penetrating radar and trenching for sinkhole mapping and characterization in a mantled evaporite karst area, where a significant proportion of the karstic depressions have been obliterated by artificial fills. The main practical aim of the investigation was to elucidate whether buried sinkholes overlap the areas planned for the construction of buildings and services, in order to apply a preventive planning strategy. Old aerial photographs and detailed topographic maps were the most useful sources of information for the identification of sinkholes and helped to obtain information on their chronology, either a minimum age or bracketing dates. The InSAR technique provided subsidence rate values ranging from 4.4 to 17.3 mm/yr consistent with the spatial distribution of the mapped sinkholes. This quantitative deformation data helped corroborating independently the existence of active buried sinkholes and improving the delineation of their limits. The GPR profiles contributed to the precise location of sinkhole edges, provided information on the geometry of buried sinkholes and deformation structures and helped to site trenches and to rule out the existence of sinkholes in particular areas. The main input derived from the trenches includes: (1) Confirming or ruling out anomalies of the GPR profiles attributable to subsidence. (2) Precise location of the edge of some filled sinkholes. (3) Information on subsidence mechanisms recorded by various deformation structures and cumulative subsidence magnitude. (4) Calculating minimum long-term subsidence rates using radiocarbon dates obtained from deformed sinkhole deposits. (5) Unequivocal evidence of active subsidence in areas assigned for the construction of buildings.
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INTEGRATION BETWEEN GROUND BASED AND SATELLITE SAR DATA IN LANDSLIDE MAPPING: THE SAN FRATELLO CASE STUDY.
CITATION: Federica Bardi, William Frodella, Andrea Ciampalini, et al. , Geomorphology, 2014. , Netherlands. Vol. 223, 45-60.
ABSTRACT: The potential use of the integration of PSI (Persistent Scatterer Interferometry) and GB-InSAR (Ground-based Synthetic aperture radar Interferometry) for landslide hazard mitigation was evaluated for mapping and monitoring activities of the San Fratello landslide (Sicily, Italy). Intense and exceptional rainfall events are the main factors that triggered several slope movements in the study area, which is susceptible to landslides, because of its steep slopes and silty-clayey sedimentary cover. In the last three centuries, the town of San Fratello was affected by three large landslides, developed in different periods: the oldest one occurred in 1754, damaging the northeastern sector of the town; in 1922 a large landslide completely destroyed a wide area in the western hillside of the town. In this paper, the attention is focussed on the most recent landslide that occurred on 14 February 2010: in this case, the phenomenon produced the failure of a large sector of the eastern hillside, causing severe damages to buildings and infrastructures. In particular, several slow-moving rotational and translational slides occurred in the area, making it suitable to monitor ground instability through different InSAR techniques. PS-InSAR(TM) (permanent scatterers SAR interferometry) techniques, using ERS-1/ERS-2, ENVISAT, RADARSAT-1, and COSMO-SkyMed SAR images, were applied to analyze ground displacements during pre- and post-event phases. Moreover, during the post-event phase in March 2010, a GB-InSAR system, able to acquire data continuously every 14min, was installed collecting ground displacement maps for a period of about three years, until March 2013. Through the integration of space-borne and ground-based data sets, ground deformation velocity maps were obtained, providing a more accurate delimitation of the February 2010 landslide boundary, with respect to the carried out traditional geomorphological field survey. The integration of GB-InSAR and PSI techniques proved to be very effective in landslide mapping in the San Fratello test site, representing a valid scientific support for local authorities and decision makers during the post-emergency management.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

INTEGRATION OF GPS WITH INSAR TO MONITORING OF THE JIAJU LANDSLIDE IN SICHUAN, CHINA.
CITATION: Yueping Yin, Wamo Zheng, Yuping Liu, et al. , Landslides, 2010. Springer- Germany. Vol. 7, No. 3,

Pg. 359-365.
ABSTRACT: In 2006, a cooperation project between China Geological Survey and the Geological Survey of Canada started the monitoring of the landslide along the deep-cut valley in the western Sichuan using integrated GPS and InSAR observation at the Jiaju landslide. Both GPS and InSAR techniques provided complementary measurements with the GPS providing horizontal movement and InSAR providing vertical motion. Meanwhile, InSAR images demonstrate also an effective tool to recognize new landslides in complex steep mountain region. The GPS observations provide continuous monitoring data while InSAR data provide monthly measurements. The differential InSAR results show a deformation information that divided the Jiaju landslide to two areas, the north and south parts. The north part is sliding greater than the southern part in spatial domain. The sliding was faster in 2008 than that in 2006 in time domain, suggesting a gradual increased acceleration over time. The GPS displacement data during the past 2 years show the northern part slid horizontally 55-207 mm/a and vertically -23 mm/a, while the southern part slid horizontally 12-34 mm/a; and the vertical displacement mainly moved downward 0.05 to 12 mm/a. On average, the observations from December of 2006 to January of 2008 indicate that the northern part is sliding at 41.6 mm/a horizontally and 43.9 mm/a vertically, while the southern part is sliding at 16.1 mm/a horizontally and 17.5 mm/a vertically. The data acquired through the GPS and InSAR are generally comparable. Geological survey revealed some secondary landslides, cracks, and fissures within the deformation of the Jiaju landslide that could be induced by following factors: surface water drainage, river erosion, and slope cutting and overloading.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

JOINT PIXELS INSAR FOR HEALTH ASSESSMENT OF LEVEES IN NEW ORLEANS.
CITATION: Lv, X., Yazici, B., Bennett, V., et. al. Go-Congress 2013, 2013, 10p.
ABSTRACT: The integrity and reliability of levees, earthen dams and flood-control infrastructure are essential components of homeland safety. The development of a potentially affordable satellite-based interferometric synthetic aperture radar (InSAR) technique for use in a new health assessment framework to monitor, manage and ensure the safety of levees and other systems of flood-control infrastructure is presented in this paper. To estimate the yearly rate of deformation of both the concrete and grass-covered levee structures with sub-wavelength accuracy, a new InSAR technique referred to as joint pixels InSAR (JPInSAR) is proposed. The corresponding results of applying JPInSAR to TerraSAR-X Stripmap data from February 2009 to October 2011 for widespread settlement monitoring in the New Orleans area are presented herein. The presented data processing chain significantly increases the number of pixels where the deformation-rate can be estimated as compared to the number of pixels that can be processed by the classical persistent scatterer technique. Local measurements from GPS and ShapeAccelArrays (SAAs), which were installed in June 2012, will be integrated with the satellite-based InSAR measurements into a global-local network to monitor the response of flood-control levees.
ACCESS: http://dx.doi.org/10.1061/9780784412787.028

JOINT PIXELS INSAR FOR HEALTH ASSESSMENT OF LEVEES IN NEW ORLEANS.
CITATION: X. Lv, B. Yazici, V. Bennett, et al. , Geo-Congress 2013, 2013. American Society of Civil Engineers. 279-288.
Note: 23; M1: 3; doi:10.1061/9780784412787.028.
ABSTRACT: The integrity and reliability of levees, earthen dams and flood-control infrastructure are essential components of homeland safety. The development of a potentially affordable satellite-based Interferometric synthetic aperture radar (InSAR) technique for use in a new health assessment framework to monitor, manage and ensure the safety of levees and other systems of flood-control infrastructure is presented in this paper. To estimate the yearly rate of deformation of both the concrete and grass-covered levee structures with sub-wavelength accuracy, a new InSAR technique referred to as joint pixels InSAR (JPInSAR) is proposed. The corresponding results of applying JPInSAR to TerraSAR-X Stripmap data from February 2009 to October 2011 for widespread settlement monitoring in the New Orleans area are presented herein. The presented data processing chain significantly increases the number of pixels where the deformation-rate can be estimated as compared to the number of pixels that can be processed by the classical persistent scatterer technique. Local measurements from GPS and ShapeAccelArrays (SAAs), which were installed in June 2012, will be integrated with the satellite-based InSAR measurements into a global-local network to monitor the response of flood-control levees.
ACCESS: http://dx.doi.org.vdot.idm.oclc.org/10.1061/9780784412787.028

LANDSLIDE DEFORMATION MONITORING WITH ALOS/PALSAR IMAGERY: A D-INSAR GEOMORPHOLOGICAL INTERPRETATION METHOD.
CITATION: Romy Schlogel, Cecile Doubre, Jean-Philippe Malet, et al. , Geomorphology, 2015. , Netherlands. Vol. 231, 314-330.
ABSTRACT: The objective of this work is to propose a geomorphologically-guided method for the

interpretation of L-band ALOS/PALSAR interferograms created by Differential Interferometric synthetic aperture radar (D-InSAR). The interferograms are used to estimate the deformation pattern of two rapid and large landslides (Poche, La Valette; South East France). The wrapped and unwrapped phase values are interpreted for different movement types (rotational, translational, and complex sliding) and two ranges of surface displacement rates. Kinematic sub-units are detected for both landslides, and zones affected by enlargement or retrogression are identified. The InSAR-derived displacement rates are consistent with ground-based measurements and with remote estimates of the displacement from C-band and X-band satellite SAR sensors. The results demonstrate the potential of L-band ALOS/PALSAR imagery for the monitoring of active landslides with important changes in the soil surface state and covered by vegetation.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

LANDSLIDE MONITORING BY GROUND-BASED RADAR INTERFEROMETRY: A FIELD TEST IN VALDARNO (ITALY).
CITATION: M. Pieraccinp, N. Casagli, G. Luzi, et al. , Int.J.Remote Sens., 2003. Taylor & Francis Ltd , UK, Vol. 24, No. 6, Pg. 1385-1391.
ABSTRACT: A ground-based Interferometric synthetic aperture radar (InSAR) was installed to monitor a landslide in Valdarno (Italy). The aim was to field-test an innovative remote sensing instrument able to provide distributed information over sliding slopes with a rate of several images a day. Radar images and interferometric displacement maps projected on the Digital Elevation Model (DEM) of the test site are reported.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

LANDSLIDE OBSERVATION AND VOLUME ESTIMATION IN CENTRAL GEORGIA BASED ON L-BAND INSAR.
CITATION: E. Nikolaeva, T. R. Walter, M. Shirzaei, et al. , Natural Hazards and Earth System Sciences, 2014. European Geosciences Union. France. Vol. 14, No. 3, 675-688.
ABSTRACT: The republic of Georgia is a mountainous and tectonically active area that is vulnerable to landslides. Because landslides are one of the most devastating natural hazards, their detection and monitoring is of great importance. In this study we report on a previously unknown landslide in central Georgia near the town of Sachkhere. We used a set of Advanced Land Observation Satellite (ALOS) Phased Array type L-band Synthetic aperture radar (PALSAR) data to generate displacement maps using Interferometric synthetic aperture radar (InSAR). We detected a sliding zone of dimensions 2 km north-south by 0.6 km east-west that threatens four villages. We estimated surface displacement of up to similar to 30 cm/yr over the sliding body in the satellite line-of-sight (LOS) direction, with the largest displacement occurring after a local tectonic earthquake. We mapped the morphology of the landslide mass by aerial photography and field surveying. We found a complex set of interacting processes, including surface fracturing, shear and normal faults at both the headwall and the sides of the landslide, local landslide velocity changes, earthquake-induced velocity peaks, and loss in toe support due to mining activity. Important implications that are applicable elsewhere can be drawn from this study of coupled processes. We used inverse dislocation modelling to find a possible dislocation plane resembling the landslide basal decollement, and we used that plane to calculate the volume of the landslide. The results suggest a decollement at similar to 120 m depth, dipping at similar to 10 degree sub-parallel to the surface, which is indicative of a translational-type landslide.
ACCESS: http://www.nat-hazards-earth-syst-sci.net/14/675/2014/nhess-14-675-2014.html

THE LOWEST PLACE ON EARTH IS SUBSIDING; AN INSAR (INTERFEROMETRIC SYNTHETIC APERTURE RADAR) PERSPECTIVE.
CITATION: Gidon Baer, Uri Schattner, Daniel Wachs, et al. , Geological Society of America Bulletin, 2002. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 114, No. 1, Pg. 12-23.
ABSTRACT: Since the early 1990s, sinkholes and wide, shallow subsidence features (WSSFs) have become major problems along the Dead Sea shores in Israel and Jordan. Sinkholes are readily observed in the field, but their locations and timing are unpredictable. WSSFs are often difficult to observe in the field. However, once identified, they delineate zones of instability and increasing hazard. In this study we identify, characterize, and measure rates of subsidence along the Dead Sea shores by the Interferometric synthetic aperture radar (InSAR) technique. We analyze 16 SAR scenes acquired during the years 1992 to 1999 by the European Remote sensing ERS-1 and ERS- 2 satellites. The interferograms span periods of between 2 and 71 months. WSSFs are observed in the Lisan Peninsula and along the Dead Sea shores, in a variety of appearances, including circular and elongate coastal depressions (a few hundred meters to a few kilometers in length), depressions in ancient alluvial fans, and depressions along salt-diapir margins. Phase differences measured in our interferograms correspond to subsidence rates generally in the range of 0-20 mm/yr within

the studied period, with exceptional high rates that exceed 60 mm/yr in two specific regions. During the study period, the level of the Dead Sea and of the associated ground water has dropped by approximately 6 m. This water-level drop within an aquifer overlying fine-grained, marly layers, would be expected to have caused aquifer-system consolidation, resulting in gradual subsidence. Comparison of our InSAR observations with calculations of the expected consolidation shows that in areas where marl layers are known to compose part of the upper 30 m of the profile, estimated consolidation settlements are of the order of the measured subsidence. Our observations also show that in certain locations, subsidence appears to be structurally controlled by faults, seaward landslides, and salt domes. Gradual subsidence is unlikely to be directly related to the sinkholes, excluding the use of the WSSFs features as predictable precursors to sinkhole formation.
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MONITORING DEFORMATION AT THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA USING C-BAND AND X-BAND INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: Vasco, D., Rutqvist, J., Feretti, A., et. al. Department of Energy General, Lawrence Berkeley National Lab., CA, Department of Energy, Washington, DC, 2013, 22p.
ABSTRACT: We resolve deformation at The Geysers geothermal held using two distinct sets of interferometric synthetic aperture radar (InSAR) data. The first set of observations utilize archived European Space Agency C-band synthetic aperture radar data from 1992 through 1999 to image the long-term and large- scale subsidence at The Geysers. The peak range velocity of approximately 50 mm/year agrees with previous estimates from leveling and global positioning system observations. Data from a second set of measurements, acquired by TerraSAR-X satellites, extend from May 2011 until April 2012 and overlap the C-band data spatially but not temporally. These X-band data, analyzed using a combined permanent and distributed scatterer algorithm, provide a higher density of scatterers (1122 per square kilometer) than do the C-band data (12 per square kilometer). The TerraS AR-X observations resolve 1 to 2 cm of deformation due to water injection into a Northwest Geysers enhanced geothermal system well, initiated on October 2011. The temporal variation of the deformation is compatible with estimates from coupled numerical modeling.
ACCESS: https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=DE151165074

MONITORING EVAPORITE KARST ACTIVITY AND LAND SUBSIDENCE IN THE HOLBROOK BASIN, ARIZONA USING INTERFEROMETRIC SYNTHETIC APERTURE RADAR (InSAR).
CITATION: Brian D. Conway and Joseph P. Cook. , National Cave and Karst Research Institute (NCKRI) Symposium, 2013. National Cave and Karst Institute (NCKRI), Carlsbad, NM. Carlsbad, NM, United States (USA). Vol. 2, 187-194.
ABSTRACT: The Holbrook Basin located in east-central Arizona is home to more than 500 evaporite-karst depressions. The Arizona Department of Water Resources (ADWR) recently acquired, processed, and interpreted archived Interferometric synthetic aperture radar (InSAR) data to evaluate historical deformation patterns in the Holbrook Basin in preparation for monitoring potential future subsidence related to planned potash mining activities around the Petrified Forest National Park. Three active land subsidence features were identified by ADWR using InSAR data from the European Space Agency's ERS 1 and 2 satellites between 1992 and 1997. Continued subsidence in two of the three features was also identified by ADWR using InSAR data from the Japan Aerospace Exploration Agency's ALOS satellite collected from 2006 to 2011.In June 2012 Arizona Geological Survey (AZGS) and ADWR staff visited one of the more prominent subsidence features identified using InSAR. Numerous steep-walled evaporite-karst sinkholes were observed en route to the field site. These roughly circular collapse features ranged in size from 40-130 m across and 10-30 m deep. The subsidence features identified through InSAR are much more extensive, up to 1,100 m across; are not as deep, up to 15 m; and do not have steep walls. Local subsidence has resulted in broad closed basins with drainage reversals and numerous expanded joints in the Coconino Sandstone exposed at the surface. A thin sandy soil above the Coconino covers the basin floor except where collapsed into open joints. Expansion along both joint orientations was observed. Which orientation was expanded depended on location relative to ongoing subsidence. Based on field observations and comparison with other collapse features in the region, these three subsidence features are relatively young, constitute different collapse morphology than nearby sinkholes, and warrant further study. InSAR will remain a critical remote-sensing tool for monitoring land subsidence in the Holbrook Basin.
ACCESS:
http://www.azwater.gov/AzDWR/Hydrology/Geophysics/documents/2013_SinkholeConference_HolbrookKarst.pdf

MONITORING OF A CREEPING LANDSLIDE IN CALIFORNIA USING SPACEBORNE RADAR INTERFEROMETRY.
CITATION: O. Suncar, D. Yang, E.M. Rathje, et al. , GeoCongress 2012, 2010. American Society of Civil Engineers. Vol. 225, Pg. 2991-3000.

ABSTRACT: Radar interferometry using Synthetic aperture radar (SAR) and the Persistent Scatterer approach (PS-InSAR) uses the differences in the phases of nearly-coincident SAR images collected at different times to measure the surface movements that occur along the radar line-of-sight (LOS). PS-InSAR analysis was applied to the Penitencia Creek landslide located in the hills east of San Jose, CA. Deformations at Penitencia Creek have been monitored continuously using inclinometers since 1972 and these measurements indicate most of the landslide is moving at a rate of between 0.25 to 0.7 cm/year. PS-InSAR derived deformations of the persistent scatterers on the landslide were referenced to a control point off of the landslide, and the resulting deformations were geometrically corrected to represent downslope movements. The downslope deformation rates were compared with those measured via traditional means, such as slope inclinometers. These comparisons indicated that the remote sensing measurements of deformation agreed favorably with the field, with the InSAR analysis indicating deformation rates of about 0.5 cm/yr.
ACCESS: http://dx.doi.org/10.1061/9780784412121.306

MULTISCALE MONITORING FOR HEALTH ASSESSMENT OF LEVEES IN NEW ORLEANS.
CITATION: Bennett, V., Lv, X., Zeghal, M., et. al. Geo-Congress 2014 Technical Papers, 2014, 10p.
ABSTRACT: Maintaining distributed levee systems has been an increased concern in the wake of natural disasters such as Hurricane Katrina and Superstorm Sandy. Ultimately, civil engineers strive to assess the health of these geotechnical systems; however, the variability of properties makes predictions of soil behavior extremely difficult, especially when soil models are not calibrated with field measurements. As climate change progresses in the form of continuous land subsidence and rising sea water level, weather-related extremes may also increase in their intensity and frequency. Coastal and waterfront zones are left especially susceptible. A remote sensing-based, i.e., satellite or airborne radar, health assessment of this spatially distributed system that can identify weak sections and impending failures can be a key to the sustainability of this infrastructure, helping prioritize maintenance and upgrade efforts. This paper presents the development of affordable sensing technologies, such as satellite-based interferometric synthetic aperture radar (InSAR), for use in a new health assessment framework to monitor and manage systems of a flood-control infrastructure. Historic and newly acquired TerraSAR-X StripMap data over a 1500 km2 footprint in New Orleans have been utilized to monitor ground settlements from February 2009 to February 2012. Local measurements from GPS and ShapeAccelArrays (SAAs) are integrated with the satellite-based InSAR measurements into a smart network to monitor the response of flood-control levees.
ACCESS: http://dx.doi.org/10.1061/9780784413272.025

NEW APPLICATIONS FOR INTERFEROMETRIC SYNTHETIC APERTURE RADAR [INSAR]; FIELD VALIDATION STUDIES OF PERSISTENT, DISTRIBUTED, AND TEMPORARY SCATTERERS.
CITATION: Brian S. Bruckno, Edward Hoppe, Andrea Vaccari, et al. , Abstracts with Programs - Geological Society of America, 2014. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 46, No. 2, 92.
ABSTRACT: As part of the USDOT-funded research program RITA-RS-11-H-UVA, "Sinkhole Detection and Bridge/Landslide Monitoring for Transportation Infrastructure by Automated Analysis of Interferometric synthetic aperture radar [InSAR] Images," the authors conducted a validation study of new interpretations of InSAR data for early detection of geohazards and infrastructure failures, targeting sinkhole development, geotechnical assets, and rock slope hazard. The authors acquired over one million InSAR data points (persistent, distributed, and temporary "scatterers") within a 40X40 km dataframe in the Valley and Ridge of Virginia. The authors then developed a quantitative field-verification method keyed to asset distress and geomorphological observations, ingested the various scatterers into a GIS dataframe, and georeferenced the data to locations of sinkholes, bridges, fills, pipes, and geotechnical assets. The authors identified kinematic differences in scatterer behavior with respect to their proximity to mapped karst geohazards, and used this method to identify previously-unmapped sinkholes. The authors then used displacement time-series of scatterers to screen for patterns suggesting compromised geotechnical assets and deteriorating infrastructure. In the case of both karst geohazards and infrastructure distress, the field validation yielded robust verification. Lastly, the authors correlated the InSAR data with kinematic analysis of rock slopes using point-cloud data generated by digital photogrammetry and LiDAR, and correlated the data to rock slope behavior. The novel use of temporary scatterers, and their interpretation in the light of persistent and distributed scatterers, greatly increased the utility of the InSAR dataset as a whole. Disclaimer: The views, opinions, findings and conclusions reflected in this paper are the responsibility of the authors only and do not represent the official policy or position of the US DOT/RITA, or any State or other entity.
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NEW INSIGHTS ON THE SALMON FALLS CREEK CANYON LANDSLIDE COMPLEX BASED ON GEOMORPHOLOGICAL ANALYSIS AND MULTITEMPORAL SATELLITE INSAR TECHNIQUES.
CITATION: Marius Necsoiu, Ronald N. McGinnis and Donald M. Hooper. , Landslides, 2014. Springer

Science+Business Media, Netherlands. Vol. 11, No. 6, 1141-1153.
ABSTRACT: Multitemporal satellite Interferometric synthetic aperture radar (InSAR) techniques can characterize line-of-sight displacements of active landslide areas with resolution (mm scale) and accuracy comparable to or higher than differential GPS, sensor network, or photogrammetry techniques. This study improves understanding of the rate of movement and the lateral extent of the active domain of a landslide complex within Salmon Falls Creek Canyon near Twin Falls, Idaho. Specifically, we were able to estimate displacement of yearly motion rates in early and late stages of the event by analyzing a collection of archived radar satellite imagery. Small baseline subset (SBAS) InSAR performed better than persistent scatterer (PS) InSAR for analyzing distributed scatterers because of its ability to capture strongly nonlinear displacement rates. In addition, comparison with GPS field measurements showed agreement with InSAR-derived displacements. Geostatistical analysis was used to describe surface and morphometric characteristics of two separate landslides within Salmon Falls Creek Canyon. Each was divided into representative geomorphologic units, and morphometric analysis focused on two key parameters: topographic texture and mean slope. Scarp units are topographically rough because of their greater relief and steep slopes, while a displaced headwall block has retained a smooth topography. Each landslide upper body has a higher topographic texture than the corresponding body unit. Both landslides display a progressive decrease in mean slope from upper body to toe to body. InSAR SBAS results showed that headwall block and transverse scarp of the landslide complex at Salmon Falls Creek Canyon had the highest mean annual velocity in the radar line-of-sight (LOS) direction. Velocity of movement in each landslide toe and body was less, signifying that LOS movement was more active in the upper reaches of the landslides, although lateral translation may have been greater in the body and toe compared to the headwall region due to the curved shape of the landside detachment surface.
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PRELIMINARY CONSIDERATIONS ON THE APPLICABILITY OF DINSAR TECHNIQUES FOR THE DETECTION OF PREMONITORY SIGNS OF SINKHOLES.
CITATION: Fabiana Calo, Gianfranco Fornaro and Mario Parise. , Abstracts with Programs - Geological Society of America, 2010. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 42, No. 5, Pg. 449.
ABSTRACT: Sinkholes are very subtle hazards typical of karst areas, and related to presence of natural cavities produced by dissolution processes in soluble rocks (carbonates, evaporites), or to man-made cavities deriving from different types of human activities in different historical ages (ancient aqueducts, underground mines and quarries, subterranean storage, etc.). Sinkholes are widespread all over the world, in very different geological and morphological settings. Notwithstanding the related hazard is extremely high, and the likely damage to built-up areas and human infrastructures may result very severe, causing heavy losses to the society, these phenomena have been for a long time underestimated in Italy, when compared to other geological hazards such as slope movements and earthquakes. Nevertheless, in recent years they are occurring at an increasing rate, covering wide areas of the country, so that the interest of both the scientific community and the mass media on the topic has strongly raised. Even more than for many other geohazards, the application of satellite Interferometric techniques to analyze and monitor these phenomena may result very useful and productive. Spaceborne Differential SAR interferometry (DInSAR) is a useful tool for detecting and monitoring surface deformation at different scales. In the last years, the Interferometric techniques have been applied to the analysis of different types of natural phenomena, but very few applications regarding karst collapses are present in the scientific literature. The presented work analyses the applicability of advanced Interferometric techniques in the evaluation of sinkhole hazard. Despite the suddenness of the final catastrophic collapse, in fact, sinkhole occurrence is typically preceded by slow deformations, thus availability of data archives, wide coverage of satellite frames, and high accuracy of the satellite measurements make DInSAR particularly suitable for sinkhole analysis and monitoring of precursors of the phenomenon. Furthermore, the first results from an ongoing research project focused on the application of DInSAR to karst areas in Apulia (southern Italy) affected in the last years by an impressive number of sinkholes (both natural and anthropogenic in origin) will be briefly described.
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QUANTIFICATION OF TEMPORAL DECORRELATION EFFECTS AT L-BAND FOR POLARIMETRIC SAR INTERFEROMETRY APPLICATIONS.
CITATION: Seung-Kuk Lee, Florian Kugler, Konstantinos P. Papathanassiou, et al. , IEEE Journal on Selected Topics in Applied Earth Observations and Remote sensing, 2013. Institute of Electrical and Electronics Engineers, Inc. United States. Vol. 6, No. 3, 1351-1367.
ABSTRACT: Temporal decorrelation is the most critical issue for the successful inversion of polarimetric SAR interferometry (Pol-InSAR) data acquired in an interferometric repeat-pass mode, typical for satellite or lower frequency airborne SAR systems. This paper provides a quantitative estimation of temporal decorrelation effects at L-band for a wide range of temporal baselines based on a unique set of multibaseline Pol-InSAR

data. A new methodology that allows to quantify individual temporal decorrelation components has been developed and applied. Temporal decorrelation coefficients are estimated for temporal baselines ranging from 10 min to 54 days and converted to height inversion errors caused by them. The temporal decorrelations of gamma rm TV (volume temporal decorrelation) and gamma rm TG (ground temporal decorrelation) depend not only on the wind-induced movement but also strongly on the rain-induced dielectric changes in volume and on the ground at temporal baseline on the order of day or longer. At temporal baselines on the order of minutes, the wind speed is a critical parameter and the speed of 2 m/s already hampers the application of Pol-InSAR forest parameter inversion. The approach is supported and validated by using L-band E-SAR repeat-pass data acquired in the frame of three dedicated campaigns, BioSAR 2007, TempoSAR 2008, and TempoSAR 2009.
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RECONNAISSANCE EVALUATION OF A POTENTIAL FUTURE SINKHOLE USING INTEGRATED SIMPLE SURFACE GEOPHYSICS AND SURFACE MONITORING POINTS.
CITATION: Michael L. Rucker, Sean Hulburt and Mark D. Edwards. , National Cave and Karst Research Institute (NCKRI) Symposium, 2013. National Cave and Karst Institute (NCKRI), Carlsbad, NM. Carlsbad, NM, United States (USA). Vol. 2, 221-229.
ABSTRACT: The Arizona Department of Water Resources (ADWR), using satellite-based Interferometric synthetic aperture radar (InSAR) to assess subsidence in parts of Arizona, has identified several subsidence features consistent with potential future sinkholes in an area with several hundred natural evaporite karst depressions or sinkholes. An initial reconnaissance geophysical subsurface evaluation at the most significant of these features was performed in September 2012. Subsurface geo-material strength profiles to depths commonly in excess of 100 meters can be obtained using relatively simple, unobtrusive and inexpensive seismic surface wave (s-wave) geophysical methods such as Refraction Microtremor (ReMi). ReMi can utilize ambient ground vibrations from natural sources or deliberate sources such as vehicle traffic or construction equipment. Shallow ReMi has been applied in conjunction with seismic refraction to characterize shallow subsurface material strength as part of assessing the potential for collapse of an evaporate brine cavern into a large sinkhole in southeast New Mexico, but had not been specifically applied to assessing subsurface conditions in the deeper subsurface above and in the vicinity of a possible impending sinkhole. Two deep ReMi surface wave soundings and two resistivity soundings using the Wenner array method were performed, one each within and outside of the extent of current subsidence as derived from the InSAR. Surface wave velocity profiles indicated relatively low velocity materials extending to depths of 36 to 50 meters; surface wave velocities within the subsidence zone were lower (weaker material) than surface wave velocities outside the zone. The underlying horizon had high surface wave velocities indicating relatively competent rock. Deep resistivity soundings indicated possible lithologic change at depths of roughly 120 to 150 meters. Results of this work, including interpretations and assessments of knowledge gained, practical additional assessment work that could be performed, and some as yet unanswered questions are presented.
ACCESS: http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1130&context=sinkhole_2013

REGIONAL LANDSLIDE MAPPING AND MONITORING IN NORWAY USING SBAS INSAR.
CITATION: T. R. Lauknes, J. F. Dehls, Y. Larsen, et al. , EOS Transactions, American Geophysical Union, 2007. American Geophysical Union, Washington, DC, USA, Vol. 88, No. 52.
ABSTRACT: Being a mountainous country, with long steep fjords and valley sides, Norway is particularly susceptible to large rock avalanches. In the last 100 years, over 170 people have been killed by tsunamis in fjords caused by large rock avalanches. In each case, the rock avalanche was preceded by many years of slow movement, with acceleration prior to slope failure. At present, three similar unstable areas have been identified in Norway, and are being monitored using extensive instrumentation. With several thousand kilometers of inhabited coastline and valleys, the challenge we currently face is the identification of similar hazards in an efficient manner. The Geological Survey of Norway (NGU) is responsible for landslide mapping throughout the country. Since 2005, Norut AS has been helping NGU establish a Norwegian facility for InSAR processing. The goal is to be able to systematically perform Interferometric processing of SAR images from multiple satellites to assist in geohazard mapping and monitoring. Once hazardous slopes are identified, continued monitoring using InSAR can be augmented with ground-based systems. Over 700 ERS and ENVISAT scenes, covering 19 overlapping frames, are currently being processed using the Small Baseline Subset (SBAS) algorithm. These scenes cover the area of northern Norway with highest topographic relief, stretching from the Lofoten islands in the southwest to Alta in the northeast. The first results, based on ERS scenes from 1992-1999 only, are from around the Lyngen peninsula, just east of the city of Tromso. Processing challenges are atmospheric stratification due to high topographic relief and nonuniform temporal sampling due to long winter season with snow cover possibly lasting from October to May. However, the first results show remarkably good coherence due to the lack of vegetation above 700 m. Nordnesfjellet is one of the three sites currently being monitored. InSAR results clearly show the outline of the moving block, and

velocity estimates are in agreement with earlier GPS measurements, though the accuracy of the GPS measurements so far is somewhat questionable due to the short time series (yearly measurements since 2004 only). Numerous other areas within the processed area have downwards velocities of up to one centimeter per year. Extensive field checking this summer has identified active fracture systems with evidence of movement in each of these areas. In at least one case, differential movement across multiple fault scarps is shown by different movement rates of the sub-blocks. InSAR analysis of the almost two decades long time series available in the ERS and ENVISAT archives enables rapid identification of landslides within a large region, allowing us to focus field mapping in areas with known hazards. Without the use of such remote sensing tools, it would take decades to map the same area. Over the course of the next year, we will process the rest of northern Norway, and then begin work on the most hazardous areas of western Norway, where several active landslides have been identified.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

REMOTE MONITORING OF BRIDGES FROM SPACE.
CITATION: Cusson, D., Ghuman, P., Gara, M., et. al. Anais do 54° Congresso Brasiliero do Concreto, 2012, 25p.
ABSTRACT: The widespread deterioration and some recent collapses of highway bridges have highlighted the importance of developing effective bridge monitoring strategies that can help identify structural problems before they become critical and endanger public safety. A typical major urban centre may possess several hundreds of bridges, which makes it difficult to instrument all these bridges with surface-mounted sensors to monitor their structural performance due to practical and economic reasons. A two-step approach may be used, in which potentially critical bridges are first identified through a screening process by remote satellite-based monitoring, and then further investigated with in-situ monitoring and detailed inspection. The capability of Canadas RADARSAT-2 advanced Synthetic aperture radar (SAR) satellite is being investigated for use in the first step of the proposed approach, which can help prioritize in-situ monitoring and maintenance of critical bridges. Interferometric SAR (InSAR) is an advanced processing technique applied to radar images of the Earths surface that can detect very small movements from ground features such as infrastructure systems, including roadway and railway bridges and their major components. By applying InSAR processing techniques to a series of radar images over the same region, it is possible to detect vertical movements of infrastructure systems on the ground in the millimetre range, and therefore identify abnormal or excessive movement indicating potential problems requiring detailed ground investigation. A major advantage of this technology is that a single radar image, which can be obtained in darkness and in any weather, can cover a major urban area of up to 100 km by 100 km, and therefore all bridges in the area could be monitored cost effectively. Preliminary results from the application of this technology to transportation infrastructure assets in selected major Canadian urban centres like Vancouver and Montreal are presented NRC Pub: yes
ACCESS: http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?action=shwart&index=an&req=21268240&lang=en

REMOTE SENSING APPLICATIONS FOR LANDSLIDES, SLOPES AND EMBANKMENTS.
CITATION: S. Anderson. , Geo-Congress 2013, 2013. American Society of Civil Engineers. 2204-2223. Note: 23; M1: 3; doi:10.1061/9780784412787.221.
ABSTRACT: Airborne, satellite and ground-based remote sensing methods are valuable for the study of landslides, slopes and embankments. Airborne laser surveys can create ground surface maps with great detail to help identify landslides and geohazards, even on forested slopes. Satellite based InSAR can detect millimeter scale movements from many kilometers above the earth. New satellites and new processing algorithms are being developed and deployed for ongoing movement and archives of previously recorded InSAR images allow one to look back in time for historic movement. Ground-based methods currently used for slopes include radar, InSAR, lidar and photogrammetry. Using radar and InSAR it is possible to monitor the initiation of small movements on slopes and use thresholds to trigger immediate action and response. Using lidar and photogrammetry it is possible to geologically map a rock slope without physically touching the slope, and then to immediately apply the data in models to evaluate failure mode, hazard and risk. These remote sensing applications are explained and demonstrated; their limitations are discussed and possibilities for the future are envisioned.
ACCESS: http://dx.doi.org.vdot.idm.oclc.org/10.1061/9780784412787.221

SIMULATING SAR GEOMETRIC DISTORTIONS AND PREDICTING PERSISTENT SCATTERER DENSITIES FOR ERS-1/2 AND ENVISAT C-BAND SAR AND INSAR APPLICATIONS: NATIONWIDE FEASIBILITY ASSESSMENT TO MONITOR THE LANDMASS OF GREAT BRITAIN WITH SAR IMAGERY.
CITATION: Francesca Cigna, Luke B. Bateson, Colm J. Jordan, et al. , Remote Sens.Environ., 2014. , United States. Vol. 152, 441-466.
ABSTRACT: We assess the feasibility of monitoring the landmass of Great Britain with satellite Synthetic aperture radar (SAR) imagery, by analysing ERS-1/2 SAR and ENVISAT IS2 Advanced SAR (ASAR) archive

data availability, geometric distortions and land cover control on the success of (non-)interferometric analyses. Our assessment both addresses the scientific and operational question of whether a nationwide SAR-based monitoring of ground motion would succeed in Great Britain, and helps to understand controlling factors and possible solutions to overcome the limitations of undertaking SAR-based imaging of the landmass. This is the first time such a nationwide assessment is performed in preparation for acquisition and processing of SAR data in the United Kingdom, and any other country in the world. Analysis of the ERS-1/2 and ENVISAT archives reveals potential for multi-interferogram SAR interferometry (InSAR) for the entirety of Britain using ERS-1/2 in descending mode, with 100% standard image frames showing at least 20 archive scenes available. ERS-1/2 ascending and both ENVISAT modes show potential for non-interferometric and single-pair InSAR for the vast majority of Britain, and multi-interferogram only for 13% to 38% of the available standard frames. Based on NEXTMap registered Britain Digital Terrain Model (DTM) we simulate SAR layover, foreshortening and shadow to the ERS-1/2 and ENVISAT Lines-Of-Sight (LOS), and quantify changes of SAR distortions with variations in mode, LOS incidence angles and ground track angles, local terrain orientation, and the effect of scale due to the input DTM resolution. The simulation is extended to the ~230,000 km2 landmass, and shows limited control of local topography on the radar terrain visibility. According to the 50 m to 5 m DTM-based simulations, ~1.0-1.4% of Great Britain could potentially be affected by shadow and layover in each mode. Only ~0.02-0.04% overlapping between ascending and descending mode distortions is found, this indicating the negligible proportion of the landmass that cannot be monitored using either imaging mode. We calibrate the CORINE Land Cover 2006 (CLC2006) using Persistent Scatterer (PS) datasets available for London, Stoke-On-Trent, Newcastle and Bristol, to quantify land cover control on the PS distribution and characterise the CLC2006 classes in terms of the potential PS density they could provide. Despite predominance of rural land cover types, we predict potential for over 12.8 M monitoring targets for each acquisition mode using a set of image frames covering the entire landmass. We validate our assessment by processing with the Interferometric Point Target Analysis (IPTA) 55 ERS-1/2 SAR scenes depicting South Wales between 1992 and 1999. Although absolute differences between predicted and observed target density are revealed, relative densities and rankings among the various CLC2006 classes are found constant across the calibration and validation datasets. Rescaled predictions for Britain show potential for a total of 2.5 M monitoring targets across the landmass. We examine the use of the topographic and land cover feasibility maps for landslide studies in relation to the British Geological Survey's National Landslide Database and DiGMapGB mass movement layer. Building upon recent literature, we finally discuss future perspectives relating to the replication of our feasibility assessment to account for higher resolution SAR imagery, new Earth explorers (e.g., Sentinel-1) and improved processing techniques, showing potential to generate invaluable sources of information on land motions and geohazards in Great Britain.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

A SPATIALLY VARIABLE POWER LAW TROPOSPHERIC CORRECTION TECHNIQUE FOR INSAR DATA.
CITATION: DPS Bekaert, A. Hooper and T. J. Wright. , Journal of Geophysical Research: Solid Earth, 2015. Blackwell Publishing Ltd., United States. Vol. 120, No. 2, 1345-1356.
ABSTRACT: Microwave signals traveling through the troposphere are subject to delays. These delays are mainly described by spatial and temporal variations in pressure, temperature, and relative humidity in the lower part of the troposphere, resulting in a spatially varying tropospheric signal in Interferometric synthetic aperture radar (InSAR). Tropospheric correction techniques rely either on external data, often limited by spatial and temporal accuracy or can be estimated from the high-resolution interferometric phase itself. However, current phase-estimated correction techniques do not account for the spatial variability of the tropospheric properties and fail to capture tropospheric signals over larger regions. Here we propose and test a novel power law correction method that accounts for spatial variability in atmospheric properties and can be applied to interferograms containing topographically correlated deformation. The power law model has its reference fixed at the relative top of the troposphere and describes, through a power law relationship, how the phase delay varies with altitude. We find the power law model reduces tropospheric signals both locally (on average by 0.45cm for each kilometer of elevation in Mexico) and the long-wavelength components, leading to an improved fit to independent Global Navigation Satellite Systems data. The power law model can be applied in presence of deformation, over a range of different time periods and in different atmospheric conditions, and thus permits the detection of smaller-magnitude crustal deformation signals with InSAR. Key Points * Topography-correlated SAR delays describable by a power law and reference height * New correction method for InSAR allows for spatial variations in the troposphere * Spatial band filtering can be used to separate tectonic signals from troposphere.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

A TERRASAR-X INSAR STUDY OF LANDSLIDES IN SOUTHERN KYRGYZSTAN, CENTRAL ASIA.
CITATION: Mahdi Motagh, Hans-Ulrich Wetzel, Sigrid Roessner, et al. , Remote sensing Letters, 2013. Taylor & Francis Group Ltd., United Kingdom. Vol. 4, No. 7, 657-666.

ABSTRACT: In this letter, we assess the capability of X-band SAR interferometry (InSAR) in landslide investigation in southern Kyrgyzstan, Central Asia. SAR data acquired by the X-band German TerraSAR-X satellite in the Uzgen region, southwestern Kyrgyzstan, are analysed for landslide detection and monitoring, and the results are compared with field observations and optical remote sensing data. X-band interferograms show several features indicative of areas of active slope movement coinciding with areas of previously mapped landslides in the region. InSAR time-series analysis provides an opportunity for continuous and efficient monitoring of ground deformation associated with landslides for large areas, complementing results from field mapping and the interpretation of optical data with the goal of establishing landslide inventories.
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TRANSPORTATION TECHNOLOGIES TAKE TO THE PARKS: CONTEXT-SENSITIVE INNOVATIONS IMPROVE AESTHETICS, COMMUNICATIONS, AND SAFETY.
CITATION: G. Brown L, M. Gourdine, B. Roberts J, et al. , TR News, 2004. Transportation Research Board. No. 233, Pg. p. 4-13.
ABSTRACT: National parks are successfully deploying innovative, transportation-related technologies through a partnership between the U.S. Department of Transportation's Federal Highway Administration (FHWA) and the U.S. Department of Interior's National Park Service (NPS). Through its three Federal Lands Highway (FLH) Divisions, FHWA is responsible for engineering safe and environmentally sensitive roadways and bridges at national parks and on other federal lands. This article presents highlights of key technologies that the FLH Divisions have deployed or plan to deploy in national parks. Among these technologies are electronic enhancements such as Advanced Traveler Information Systems, Global Positioning System technology to monitor buses, and intelligent transportation systems; grassy pull-offs; software customizing; FLH's Road Inventory Program software; Interferometric synthetic aperture radar; high-performance concrete; materials recycling; seismic reflection-holography technique for assessing ground conditions around an existing tunnel and a proposed parallel facility; an historic wall management program; and a time domain reflectometry system of sensors for remote road monitoring, air quality monitoring and other uses.
ACCESS: http://onlinepubs.trb.org/onlinepubs/trnews/trnews233.pdf

UTILIZING INSAR FOR GEOTECHNICAL ASSET MANAGEMENT OF LANDSLIDES IN COLORADO.
CITATION: Kenneth C. Fergason, Bibhuti B. Panda and Danielle Smilovsky. , Abstracts with Programs - Geological Society of America, 2014. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 46, No. 6, 650.
ABSTRACT: Interferometric synthetic aperture radar (InSAR) is a satellite-based remote sensing technique that has the ability to observe ground deformation at a centimeter-scale. Currently, AMEC Environment & Infrastructure, Inc is performing a Landslide Asset Management Pilot Project for the Colorado Department of Transportation (CDOT) to assess the applicability of incorporating InSAR technology into a risk based Geotechnical Asset Management plan. The goal of this project is to evaluate InSAR as a method for monitoring ground displacement. A primary objective is to determine if InSAR can be used as an indicator of slope or other geological hazard-related movement that could affect the conditions of highways or indicate a potential for a geotechnical asset condition change. For the pilot study, CDOT select three existing landslides to evaluate: 1) Slide Creek Slide (I-70 milepost 212), 2) Vail Golf Course Slide (I-70 milepost 177), and 3) Jackson Mountain Slide (US 160 milepost 151). The ground deformation interpreted by InSAR in this preliminary analysis has been shown to closely match existing data, including inclinometer data, for the three pilot areas and is able to delineate areas experiencing known and potentially unrecognized ground deformation. InSAR is also able to quantify a rate of movement as defined by line of site from the satellite that should prove to be useful in geotechnical asset management. Preliminary results including interferograms and deformation maps for the three pilot study locations will be discussed and indicate that InSAR can be a valuable tool for geotechnical asset management of landslides.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

UTILIZING REMOTE SENSING TECHNOLOGY IN POST-DISASTER MANAGEMENT OF TRANSPORTATION NETWORKS.
CITATION: Hani Nassif H, Kaan Ozbay and Ayman Elawar. , 2011. Pg. 45p.
ABSTRACT: Infrastructure system components such as bridges, highways, tunnels, traffic systems, road pavements, and other systems are considered assets that should be protected and properly managed. Yet, the degree of deterioration and the risk of exposure to natural (e.g., earthquakes, floods, etc.) as well as malicious disasters are dangerously high. Major decisions must be made to allocate the available but limited funds for maintaining and safeguarding our national infrastructure. Additionally, transportation services play an important role in post-disaster recovery and are an integral part of most response functions. These services are vital for initial rescue operations and disaster assistance. Traffic delays that occur during the reconstruction period can be greatly minimized through effective traffic management strategies. The need for

vulnerability assessment and disaster mitigation in densely populated areas, such as the NY/NJ metropolitan area, is obvious. In this project, the authors propose the use of novel remote sensing technologies to quickly assess damage to the transportation infrastructure. Some of the latest remote sensing technologies can detect very small displacements of infrastructure elements, such as roads and bridges, up to centimeter accuracy. Thus, this information along with historic information about transportation infrastructure components combined with simple yet accurate structural engineering models can be used to determine individual components of a given network that are susceptible to failure under various loading conditions. This probabilistic failure mapping of the infrastructure can then be used to develop robust transportation and emergency response plans that minimize the risk of disruptions. Based on the preliminary findings of this research project, it is shown that the information obtained from remote sensing technology is important in providing reliable support for the decision-making system for preparedness and mitigation. However, the availability of high-resolution images is key to the future success of the research initiative described in this report. In the absence of such high-resolution satellite images, the proposed post-disaster management approach cannot be realistically tested unless simulated images are employed. Even though using simulated images is beyond the scope of this project, the authors hope to be able to access high-resolution satellite SAR data of earthquake-prone urban areas in the near-future. This option will allow to further study the appearance of bridges and highways in synthetic aperture radar (SAR) and the advanced InSAR images, and extract as much information as possible on their conditions. Once the feasibility of damage assessment is verified using real satellite images, the next step will be to use this information in conjunction with probabilistic routing and dynamic traffic assignment algorithms that can generate low risk routes for evacuation and other post-disaster operations in dense urban areas.
ACCESS: http://utrc2.org/research/assets/156/Remote-Sensing1.pdf

VALIDATION OF INTERFEROMETRIC SYNTHETIC APERTURE RADAR AS A TOOL FOR IDENTIFICATION OF GEOHAZARDS AND AT-RISK TRANSPORTATION INFRASTRUCTURE.
CITATION: DigitalCommons@University of Nebraska - Lincoln
ABSTRACT: As part of the USDOT-funded research program RITA-RS-11-H-UVA, Sinkhole Detection and Bridge/Landslide Monitoring for Transportation Infrastructure by Automated Analysis of Interferometric synthetic aperture radar [InSAR] Images, the authors broadly validated the use of InSAR data as a tool for early detection of geological hazards and failing infrastructure, including sinkhole development, potentially dangerous rock slopes, distressed bridges, rock buttresses, and other geotechnical assets. By bringing the InSAR dataset into a GIS dataframe and correlating the data to published maps of sinkhole locations and karst terranes, the authors were able to correlate average displacement velocities of InSAR data points (scatterers) with respect to their proximity to mapped sinkholes. Additionally, the authors correlated the InSAR signal characteristics with kinematic analysis of rock slopes using point-cloud data generated using digital photogrammetry and LiDAR. Lastly, the displacement time-series of the InSAR scatterers were used to screen for compromised geotechnical assets and infrastructure, and the findings were strongly confirmed by field inspection of distressed bridges and a failing rock buttress. The validation of InSAR data for these purposes thus allows generation of GIS-based geohazard and at-risk infrastructure/asset maps and provides the opportunity to augment or eventually replace a periodic inspection-based infrastructure management system with continuous performance-based system.
ACCESS: http://digitalcommons.unl.edu/geosciencefacpub/402

VALIDATION OF NEW APPLICATIONS FOR INTERFEROMETRIC SYNTHETIC APERTURE RADAR [INSAR] DATA; GEOHAZARDS AND INFRASTRUCTURE DISTRESS.
CITATION: Brian S. Bruckno, Edward Hoppe, Andrea Vaccari, et al. , Abstracts with Programs - Geological Society of America, 2013. Geological Society of America (GSA), Boulder, CO. Boulder, CO, United States (USA). Vol. 45, No. 7, 719.
ABSTRACT: As part of the USDOT-funded research program RITA-RS-11-H-UVA, "Sinkhole Detection and Bridge/Landslide Monitoring for Transportation Infrastructure by Automated Analysis of Interferometric synthetic aperture radar [InSAR] Images," the authors validated new applications of InSAR data as a tool for early detection of geological hazards and incipient infrastructure failures, including sinkhole development, potentially dangerous rock slopes, distressed bridges, rock buttresses, and other geotechnical assets. First, by bringing the InSAR dataset into a GIS dataframe and georeferencing to published maps of sinkhole locations, locations of repaired sinkholes, and karst terranes, the authors were able to detect differences in average displacement velocities of InSAR data points ("scatterers") with respect to their proximity to karst geohazards. Second, the authors correlated the InSAR signal characteristics with kinematic analysis of rock slopes using point-cloud data generated using digital photogrammetry and LiDAR. Third, the authors used displacement time-series of various InSAR scatterers to screen for compromised geotechnical assets and deteriorating infrastructure, and the findings were strongly confirmed by field inspection of previously-unidentified distressed bridges and a failing rock buttress, with strongly positive correlation values. Lastly, the

authors used points yielded by a new processing method, referred to as "temporary scatterers," to reveal areas of sudden or variable motion, greatly expanding the nature and number of data points and adding yet greater value to InSAR data. The validation of InSAR data for these purposes thus allows generation of GIS-based geohazard and at-risk infrastructure/asset maps and provides the opportunity to augment or eventually replace a periodic field inspection-based infrastructure management system with continuous performance-based system. Initial cost-benefit analyses suggest that deployment of such a system would yield positive cost benefits if the system allowed early stabilization of only one geotechnical failure, rather than a repair subsequent to failure.
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ADDITIONAL READING: The following citations should be reviewed after initial reading. They are listed in alphabetical order by title, not in order of relevance, with key terms highlighted for context.
(Return to Contents…)

AIRBORNE INSAR DEMONSTRATION FOR URBAN AND RURAL APPLICATIONS.
CITATION: van Valkengoed, E.; Boks, S. Begeleidingscommissie Remote sensing, Delft (Netherlands), 2000, 48p.
ABSTRACT: This project is actuated by the strong need for a low-cost-all-weather system that can produce high-resolution intensity images and height models. The objective of this project is to demonstrate the capabilities of Interferometric SAR (InSAR) for both thematic mapping and volume assessment in urban and rural areas. A drawback of aerial photography and laser scanning, when used for DTM production purposes, is the dependence on favorable weather conditions. INSAR (Interferometric Synthetic aperture radar) is not hindered by cloud coverage and can also be operated at night. Although the INSAR technique will probably have its biggest market in developing countries, test sites in the Netherlands have been chosen to reduce the cost for the flight operation. Validation of the radar data took place by comparing it with other datasets (photogrammetry and laser) of the same region. It showed that INSAR is more accurate in rural areas; noise is of great influence in urban and suburban areas. When considering large areas, INSAR proved to be a good alternative to laser and photogrammetry. It can provide accurate information on terrain height, land-cover types and line features. Especially in tropical areas, where near permanent cloud coverage prevents the acquisition of aerial photography and optical satellite imagery, INSAR seems to be an ideal tool to acquire detailed height and land-cover information on a large scale.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=PB2002105854

ANALYSIS AND DETECTION OF GROUNDWATER EXPLOITATION-INDUCED URBAN DEFORMATION DISASTER BASED ON PS-INSAR AND GIS.
CITATION: M. He and X. He. , J.Aerosp.Eng., 2011. American Society of Civil Engineers. Pg. 135.
ABSTRACT: Interferometric synthetic aperture radar (InSAR) is a very effective technique for measuring surface deformation, but the temporal and geometrical decorrelation and atmospheric disturbances can strongly compromise the accuracy of the results. Persistent scatterer InSAR (PS-InSAR) overcomes the decorrelation and atmospheric disturbances problem by identifying resolution elements which echo is dominated by a single scatterer in a series of interferograms. The results obtained by PS-InSAR technique are not the field deformation information but persistent scatterers deformation. In this paper, PS-InSAR and Geographical Information System (GIS) are used to investigate surface deformation caused by groundwater overexploitation in Nantong, China. For improving the accuracy of extracting the atmospheric effects in the PS-InSAR technique, an automatic determining method of the best filter method and filter window size is proposed when extracting the atmospheric effects from the residual phase by filtering. The proposed method is based on structure function of residual phases. The linear deformation rate of permanent scatterers was analyzed by using ArcGIS tools in order to examine the distribution of data and detect outliers. The ground deformation rate was interpolated using Kriging method, and a ground subsidence rate map with high resolution was developed. The experimental results show that the method can improve the accuracy of the extraction of atmospheric effects. A ground subsidence rate map of Nantong with high resolution was generated. The subsidence rate of most zones in Nantong city is less than 8mm/a, and the interpolation accuracy of subsidence rate can be improved by using the spatial analysis and interpolation tools of ArcGIS. 8 subsidence funnels are found in Nantong downtown during the period of 2006–2009, but there are not large subsidence funnels in Nantong downtown
ACCESS: http://dx.doi.org/10.1061/(ASCE)AS.1943-5525.0000177

ANALYSIS OF GEOSEISMIC FAULTS MOVEMENT AND AFTERSHOCKS MIGRATION FOR YUSHU EARTHQUAKE BASED ON INSAR CO-SEISMIC DEFORMATION.
CITATION: X. Yao, Y-S Zhang, T-Y Xiong, et al. , Journal of Jilin University (Earth Science Edition), 2012. Jilin University. Vol. 42, No. 2, Pg. 440-448.
ABSTRACT: On April 14, 2010, a M sub(s) 7.1 earthquake struck the Yushu County, Qinghai Province, China. The authors observed the co-seismic deformation of Yushu M sub(S) 7.1 scale earthquake, on July, 14, 2010, using two periods PALSAR by Interferometric synthetic aperture radar (InSAR) technology, and yielding a clearly wrapped InSAR image and solving a absolutely deformation map covering most earthquake impact region. Furthermore, referencing to the amount, region, direction and gradient of InSAR co-seismic deformation, as well as combining with tectonic setting and mechanics of strike-slip fault, this paper infers its tectonic activity features: 1) Yushu earthquake triggered a NWW extend, sinistral step, "S" shape strike-slip fault deformation belt, which contains 5 sub-sections, average slip dislocation ranging from 10.2 cm to 133.2 cm, maximum up to 195 cm, and two of them near Jiegu Town and Longbao Town presented clear surface ruptures. 2) The difference of two walls' movement in direction and amount shows that the seisgenic fault is a sinistral strike-slip and SW wall is an initiative wall. 3) The macro-epicenter can be located on mutation belt of NW 16 km of Yushu County; 4) The deformation amount, surface track and rupture amplitude of seisgenic fault indicate that the aftershocks will migrate towards NW alone fault. 5) This earthquake is the results of Qiangtang Block's activity and does not directly related with Wenchuan Earthquake induced by Bayan Har Block.
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ANNOTATED BIBLIOGRAPHY: EMPIRICAL AND ANALYTICAL METHODS FOR GEOMECHANICAL MODELING OF UNDERGROUND STRUCTURAL EXCAVATIONS, STOCHASTIC INVERSIONS TECHNIQUES, AND RECENT DEVELOPMENTS IN INTERFEROMETRIC SYNTHETIC APERTURE RADAR (InSAR).
CITATION: Foxall, W.; Templton, D.; Ramirez, A. Lawrence Berkeley National Lab., CA.; Department of Energy, Washington, DC., 2009, 12p.
ABSTRACT: Not available.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=DE2009956834

APPLICATION OF COMPRESSION ALGORITHM COMBINED WITH ROBUST FILTERING AND IMPORTANT POINTS EXTRACTING.
CITATION: Juqing Zhang, Jing Zhang and Xinyuan Guo. , Geomatics and Information Science of Wuhan University, 2014. Periodicals Press of Wuhan Technical University of Surveying and Mapping, Vol. 39, No. 1, 80-84.
ABSTRACT: It is necessary to compress InSAR monitoring results because redundant information will affect the efficiency of deformation mechanism inversion. Combining the characteristics of the InSAR datum and necessary post-processing, an algorithm based on important points extraction is proposed in this paper. This proposed algorithm is simple but has high compression efficiency. Considering that is contains a variety of errors which affect the reliability of results and the efficiency of compression, a robust filtering modification is adopted. Then, the data compress method combining robust filtering and important points extracting is proposed. A practical example shows that the proposed combined method is effective for improving the compression ratio.
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THE APPLICATION OF DIFFERENTIAL INTERFEROMETRIC SYNTHETIC APERTURE RADAR TO IDENTIFY, MEASURE, AND ANALYZE SUBSIDENCE ABOVE UNDERGROUND COAL MINES IN UTAH.
CITATION: Fitra Ismaya. , Masters Abstracts International. Vol. 49, no. 01, 184 p. 2010., 2010. Pg. 184.
ABSTRACT: Subsidence is a major consequence of underground mining. Over 1000 underground coal mines are operating in the United States and affect a surface area of more than 1 million hectares. Surface subsidence associated with underground coal mining is expected to remain a major environmental and engineering issue. The comprehensive subsidence engineering and management to characterize the nature, extent, and magnitude of expected and actual surface displacements are developed while simultaneously identifying subsidence impacts with high risk levels and/or severe consequences. This is a difficult task and one that is currently limited by shortcoming in data collection and assessment. Differential Interferometric synthetic aperture radar (DInSAR) is a growing technology in surface displacement monitoring and has the potential to improve the efficiency and accuracy of subsidence monitoring by significantly increasing the quantity and accuracy of measurement data. In this study, the validation of DInSAR was conducted with respect to four underground coal mines in Utah. The subsidence associated with pillar collapse at Crandall Canyon mine and longwall panel extraction at Deer Creek mine, Dugout Canyon mine, and West Ridge mine were used to compare DInSAR derived subsidence measurements with traditional field data collection

methods. The comparison to the mine development history in all four mines showed that the DInSAR measured subsidence troughs correlated well with the mine location, and the troughs development indicated to follow the longwall face advance. At Crandall Canyon mine, the DInSAR measured the subsidence of 27.5 cm, which compares favorably to 30 cm of GPS measurement. At Dugout Canyon mine, the maximum rate of subsidence of 14 cm per month was measured using DInSAR, while the GPS showed a maximum rate of 10 cm per month. Measurement using DInSAR above a second panel at Dugout Canyon mine during 2006 and 2007 indicated 18 cm of subsidence, nearly identical to the 20 cm measured via GPS. At Deer Creek and West Ridge mines, the DInSAR results correlate well with field data collected via an aerial photogrammetric survey.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

APPLICATION OF INSAR AND GIS TECHNIQUES TO GROUND SUBSIDENCE ASSESSMENT IN THE NOBI PLAIN, CENTRAL JAPAN.
CITATION: Minxue Zheng, Kaoru Fukuyama and Kazadi Sanga-Ngoie. , Sensors, 2014. Molecular Diversity Preservation International, Switzerland. Vol. 14, No. 1, 492-509.
ABSTRACT: Spatial variation and temporal changes in ground subsidence over the Nobi Plain, Central Japan, are assessed using GIS techniques and ground level measurements data taken over this area since the 1970s. Notwithstanding the general slowing trend observed in ground subsidence over the plains, we have detected ground rise at some locations, more likely due to the ground expansion because of recovering groundwater levels and the tilting of the Nobi land mass. The problem of non-availability of upper-air meteorological information, especially the 3-dimensional water vapor distribution, during the JERS-1 observational period (1992-1998) was solved by applying the AWC (analog weather charts) method onto the high-precision GPV-MSM (Grid Point Value of Meso-Scale Model) water-vapor data to find the latter's matching meteorological data. From the selected JERS-1 interferometry pair and the matching GPV-MSM meteorological data, the atmospheric path delay generated by water vapor inhomogeneity was then quantitatively evaluated. A highly uniform spatial distribution of the atmospheric delay, with a maximum deviation of approximately 38 mm in its horizontal distribution was found over the Plain. This confirms the effectiveness of using GPV-MSM data for SAR differential interferometric analysis, and sheds thus some new light on the possibility of improving InSAR analysis results for land subsidence applications.
ACCESS: http://www.mdpi.com/1424-8220/14/1/492

APPLICATION OF SYNTHETIC APERTURE RADAR INTERFEROMETRY (INSAR) IN DEFINING GROUNDWATER-WITHDRAWAL-RELATED SUBSIDENCE, DIAMOND VALLEY, NEVADA.
CITATION: Rei Arai. , ProQuest Dissertations and Theses, 2009. University of Nevada, Reno. United States -- Nevada.
ABSTRACT: Interferometric Synthetic Aperture Rader (InSAR) technique has been recently used in detecting and monitoring ground displacements such as volcanic activities, earthquakes, landslides and surface deformations caused by fluid extraction. Ground subsidence related to groundwater withdrawal has occurred in many places such as urban areas and large scale agricultural areas. This study utilizes interferometry to detect ground subsidence in an agricultural field, where a large volume of groundwater has been pumped for decades, in Diamond Valley, Nevada. InSAR has proven to have great potential to detect and quantify ground subsidence caused by aquifer system compaction. It mapped ground deformation signals with high spatial detail and resolution of displacement, developed in a groundwater basin in the area, using radar data collected from the ERS-1/ERS-2 and Envisat satellites. The subsidence signal at the south part of the valley, where irrigation wells exist, shows a minimum of 37.6 cm of cumulative subsidence between July 17, 1992 and November 27, 1999 and a 17.5 cm of cumulative subsidence between October 16, 2004 and December 15, 2007. The profile views of the subsidence signals assist in visualizing the deformation geometry which indicates that the subsurface lithology can increase or decrease the deformation. The subsurface model estimated from the history of water table decline and the subsurface lithology distribution approximately correlate with the subsidence signals. Poor correlation occurred where limited availability of good subsurface data and limited spatial coverage of well logs existed.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

AN APPLICATION OF THE SBAS-DINSAR TECHNIQUE FOR THE ASSESSMENT OF STRUCTURAL DAMAGE IN THE CITY OF ROME.
CITATION: Stefania Arangio, Fabiana Calò, Maria Di Mauro, et al. , Structure and Infrastructure Engineering, 2014. Taylor & Francis. Vol. 10, No. 11, pp 1469-1483.
ABSTRACT: The remote sensing technique known as Differential Synthetic aperture radar (SAR) Interferometry (DinSAR) allows the detection and monitoring of ground settlements, by generating deformation velocity maps and displacement time-series having centimeter to millimeter accuracy. These measurements can contribute to the evaluation of the structural conditions of the constructions. Given the settlements, different approaches exist for the assessment of the structural damage, ranging from empirical

estimates to detailed finite element calculations. In this work, the authors integrate the results of a DinSAR analysis with an intermediate semi-empirical model to investigate three buildings located in the southern part of the city of Rome. The model, originally proposed by Finno et al. (2005). ASCE Journal of Geotechnical and Geoenvironmental Engineering, 131(10), 1199–1210], considers each building as an equivalent laminated beam, where the layers represent the floors and the core material reproduces the infill walls. The results obtained by the model have been compared to the damages observed on the buildings, showing a good agreement and demonstrating that the proposed approach represents an effective and, at the same time, simple assessment tool for rapidly evaluating the conditions of several structures.
ACCESS: http://dx.doi.org/10.1080/15732479.2013.833949

APPLICATIONS OF DINSAR FOR MEASURING MINE-INDUCED SUBSIDENCE AND CONSTRAINING GROUND DEFORMATION MODEL.
CITATION: James Donovan and Fitra Ismaya. , GeoCongress 2012, 2010. American Society of Civil Engineers. Vol. 225, Pg. 3001-3010.
ABSTRACT: Differential Interferometric Synthetic aperture radar (DInSAR) was used to measure subsidence above an underground longwall mine in Book Cliffs coal field Utah. DInSAR is a remote sensing technique capable of producing high-density displacement maps with sub-centimeter accuracy. In this study several SAR images covering an area of the West Ridge mine were used to produce displacement maps of the three-dimensional subsidence troughs developed above the active longwall panels. The results were validated using traditional field methods and subsequently used for constraining a ground deformation model. DInSAR identified the maximum amount of subsidence as 1.1 meters, nearly identical to the 1.2 meters measured using survey controlled photogrammetry. Time-lapsed DInSAR subsidence profiles were fit to the active longwall mining sequence and were able to properly identify the dynamic progress of subsidence trough development above the extracted panels. Finally, DInSAR results were used to constrain a subsidence model and the result indicates that DInSAR is not only capable of providing high accuracy data for subsidence measurement but can also be used for model validation and improvement.
ACCESS: http://dx.doi.org/10.1061/9780784412121.307

ASSESSING SINKHOLE ACTIVITY IN THE EBRO VALLEY MANTLED EVAPORITE KARST USING ADVANCED DINSAR.
CITATION: Jorge Pedro Galve, Carmen Castaneda, Francisco Gutierrez, et al. , Geomorphology, 2015. , Netherlands. Vol. 229, 30-44.
ABSTRACT: Sinkholes in karst areas may cause subsidence damage in transportation infrastructures, demolition of buildings and even the loss of human lives when they occur in a catastrophic way. Differential Interferometry (DinSAR) is a promising technology for detecting and characterizing sinkholes, as well as for reducing the associated risk when combined with other sources of data such as a sinkhole inventory. In this work, the usefulness of InSAR techniques and data for sinkhole risk management has been analyzed through the comparison of three DinSAR-derived velocity maps with a comprehensive sinkhole inventory in the Ebro Valley, NE Spain. The DinSAR maps have contributed to improve the sinkhole inventory in different ways: (1) detection of non-inventoried sinkholes; (2) revision of sinkhole areas previously classified as inactive as active; and (3) refinement of underestimated sinkhole boundaries. The obtained results suggest that DinSAR products are suitable for analyzing active dissolution-induced subsidence. The application of these techniques may help in recognizing and better characterizing previously unknown karst subsidence problems and in preventing personal and property losses. However, the analysis reveals that the available DinSAR maps combined overlook about 70% of the previously mapped active sinkholes mainly due to decorrelation.
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AUTOMATIC DEM GENERATION TECHNOLOGY BY AIRBORNE INSAR DATA AND ITS APPLICATION TO FENGZHEN, INNER MONGOLIA.
CITATION: Yan-Hua Liu, Zheng Zhao and Guo-Man Huang. , Dixue Qianyuan / Earth Science Frontiers, 2006. China University of Geosciences, Vol. 13, No. 3, Pg. 104-107.
ABSTRACT: Synthetic aperture radar interferometry (InSAR) is a new imaging remote sensing technique developed by incorporating conventional SAR techniques and interferometry techniques that have been used in radio astronomy for several decades. The InSAR becomes a very important tool for earth observation and scientific research because of its considerable potential in large scope measurement of surface topography and deformation. Compared to the spaceborne InSAR, the role of airborne InSAR system lies in regional mapping at high resolution. The flexibility in scheduling airborne acquisitions in acquiring data from different orientations and in configuring a variety of radar modes are key assets of airborne systems, which will ensure their usefulness well into the future. In this paper, the basic principles of surface topographic measurement by airborne InSAR data are described in detail. Then a corresponding flowchart of automatic digital elevation model (DEM) generation is presented. Some experimental research based on airborne InSAR data acquired at

Fengzhen, Inner Mongolia is introduced. Therefore, a solid foundation for further application to regional mapping by InSAR techniques has been prepared.
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CHARACTERIZING AND ESTIMATING NOISE IN INSAR AND INSAR TIME SERIES WITH MODIS.
CITATION: William D. Barnhart and Rowena B. Lohman. , Geochem.Geophys.Geosyst., 2013. American Geophysical Union, United States. Vol. 14, No. 10, 4121-4132.
ABSTRACT: InSAR time series analysis is increasingly used to image subcentimeter displacement rates of the ground surface. The precision of InSAR observations is often affected by several noise sources, including spatially correlated noise from the turbulent atmosphere. Under ideal scenarios, InSAR time series techniques can substantially mitigate these effects; however, in practice the temporal distribution of InSAR acquisitions over much of the world exhibit seasonal biases, long temporal gaps, and insufficient acquisitions to confidently obtain the precisions desired for tectonic research. Here, we introduce a technique for constraining the magnitude of errors expected from atmospheric phase delays on the ground displacement rates inferred from an InSAR time series using independent observations of precipitable water vapor from MODIS. We implement a Monte Carlo error estimation technique based on multiple (100+) MODIS-based time series that sample date ranges close to the acquisitions times of the available SAR imagery. This stochastic approach allows evaluation of the significance of signals present in the final time series product, in particular their correlation with topography and seasonality. We find that topographically correlated noise in individual interferograms is not spatially stationary, even over short-spatial scales (<10 km). Overall, MODIS-inferred displacements and velocities exhibit errors of similar magnitude to the variability within an InSAR time series. We examine the MODIS-based confidence bounds in regions with a range of inferred displacement rates, and find we are capable of resolving velocities as low as 1.5 mm/yr with uncertainties increasing to 6 mm/yr in regions with higher topographic relief. Key Points * We statistically estimate error bounds in InSAR time series using MODIS * Atmospheric noise in InSAR is neither stationary nor isotropic * We are able to assign confidence bounds with min vel. of ~1.5mm/yr.
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A CLUSTER-ANALYSIS-BASED NOISE-ROBUST PHASE-UNWRAPPING ALGORITHM FOR MULTIBASELINE INTERFEROGRAMS.
CITATION: Huitao Liu, Mengdao Xing and Zheng Bao. , IEEE Trans.Geosci.Remote Sens., 2015. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 53, No. 1, 494-504.
ABSTRACT: Two-dimensional phase unwrapping (PU) is a key step of synthetic aperture radar interferometry (InSAR). Moreover, the conventional single-baseline PU method is restricted to the phase continuity assumption, so it cannot work correctly in the case that phase jumps between adjacent pixels are larger than π. To effectively solve this problem, multibaseline PU is put forward. The performance of conventional multibaseline PU methods is directly related to the noise level. In order to improve noise robustness, a cluster analysis (CA) based noise-robust PU algorithm for multibaseline interferograms (CANOPUS) is proposed in this paper, which is the extension and improvement of the CA-based efficient multibaseline PU algorithm proposed by H. Yu. For the sake of overcoming the disadvantages of the CA method, the dimension of the recognizable mathematical pattern is expanded. Under this condition, due to the density discrimination in spatial space, different clusters are able to be distinguished by the density-based clustering algorithm, and clusters are regarded as a set of density-connected patterns. Compared with the conventional CA method, the significant advantage of the new algorithm is that it improves noise robustness. What is more, the proposed algorithm runs in linear time. From the experiment results, it can be seen that the proposed method may be effectively applied to multibaseline InSAR data sets.
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COMPARATIVE STUDY OF SPECKLE NOISE REDUCTION APPROACHES FOR INTERFEROMETRIC SYNTHETIC APERTURE RADAR IMAGES.
CITATION: Yi Fei Chen and Hua Ping Xu. , Applied Mechanics and Materials, 2013. Trans Tech Publications Ltd., Switzerland. Vol. 427-429, No. Mechanical Engineering, Industrial Electronics and Information Technology Applications in Industry, 1735-1738.
ABSTRACT: Speckle noise appearing in the interferometric SAR (InSAR) phase image degrades the quality of interferogram seriously and makes interferogram reflect the scattering characteristics of the target inaccurately, reducing the capability of extracting DEM information of target areas. Therefore, speckle noise reduction plays a major role in InSAR processing by using interferogram filtering. First, according to a terrain model with the assumed geometrical parameters in InSAR system, the paper simulated an interferometric SAR phase image with noise, which can be characterized by the multilook phase distribution based on the circular Gaussian assumption [1]. Second, the paper explores three interferogram filtering algorithm to remove speckle noise: Goldstain filter, Rotating Kernel Transformation and Lee filter; the proper

implementation of three methods is given. Last, the paper discusses about the performance comparatively based on experimental results and gives broad conclusions and presents recommendations.
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COMPARISON AND FUSION OF LIDAR AND INSAR DIGITAL ELEVATION MODELS OVER URBAN AREAS.
CITATION: P. Gamba, F. Dell'acqua and B. Houshmand. , Int.J.Remote Sens., 2003. Taylor & Francis Ltd , UK, Vol. 24, No. 22, Pg. 4289-4300.
ABSTRACT: In this paper we analyse a multiple sensor dataset corresponding to three-dimensional data coming from Interferometric radar (InSAR) or laser ranging (LIDAR) measurements. We consider digital elevation models (DEMs) extracted from a single LIDAR scan plus multiple SAR scans of the same area, downtown Denver, CO, USA. Horizontal resolution for both datasets is 2.5 m, a value allowing good characterization of sparse tall buildings. Fusion of DEMs extracted from InSAR data originated during flights orthogonal to each other allows reduction of layover and shadowing. A novel strategy combining advantages of existing fusion techniques is proposed. Results from individual and combined techniques are presented, compared and discussed. The ability of characterizing buildings allows us to raise the fusion strategy scope from the pixel-level up to the feature level, once 3D features are extracted. Related results are presented and discussed. Finally, fusion of InSAR and LIDAR data is considered. LIDAR can reliably determine building footprints, thus relieving the problem of multiple bouncing radar pulses. Some results show that analysis of combined InSAR and LIDAR data on a small area can provide an improvement in DEMs extracted from a much larger area where only InSAR data are available.
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CORRELATION BETWEEN INSAR SATELLITE REMOTE SENSING AND IN-SITU MEASUREMENTS.
CITATION: Adrian Andronic, Ioan Boti, Daniel-Marcel Manoli Daniel-Marcel Manoli, et al. , International Multidisciplinary Scientific GeoConference : SGEM : Surveying Geology & mining Ecology Management, 2014. Surveying Geology & Mining Ecology Management (SGEM). Vol. 2, 235.
ABSTRACT: The usage of satellite borne SAR monitoring techniques has become wider spread in the last years due to the data becoming more accessible both for research purposes and commercial projects. The paper presents the correlation between the displacements velocity maps obtained from satellite monitoring and the in-situ measurements (inclinometric and piezometric monitoring). The research site has been chosen to be Galati city escarpment, due to the occurrence of several phenomena producing soil mass instability. The escarpment is mainly an artificial ground structure built about 50 years ago using infill with the purpose of extending and remodel this Danube escarpment, using unfit materials and steep slopes. Also, the existing urban networks are old and faulty, generating spills in the collapsible soils present in the area. These deformations are monitoring on a macro scale using the InSAR system and validated through local insitu monitoring. The research is part of a project financed by the Romanian Space Agency and bears the acronym ILUSTRO.
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DEEP-SEATED GRAVITATIONAL SLOPE DEFORMATIONS NEAR THE TRANS-ALASKA PIPELINE, EAST-CENTRAL ALASKA RANGE.
CITATION: Stephen Delmont Newman Jr. , Masters Abstracts International. Vol. 52, no. 06, 267 p. 2013., 2013. 1-267.
ABSTRACT: I investigated active deep-seated gravitational slope deformation (DSGSD) near the Trans-Alaska Pipeline and Richardson Highway in the east-central Alaska Range, Alaska, USA. I documented the presence, spatial extent, and rates of DSGSD using field-geology methods and optical, SAR, and D-InSAR remote-sensing images. I also documented and mapped many of the morphological, geological, and structural characteristics of slopes undergoing DSGSD, and constructed conceptual numerical models to better understand potential deformation mechanisms. Results confirm that many large DSGSD slopes in the study area are actively deforming. Deformation rates range from less than a millimetre per month to more than ten centimetres per month, and are spatially and temporally varient within each slope. Deforming slopes are characterized by differential movement of kilometre-scale rock blocks. Recent climatic changes and strong seismic shaking, especially during the recent 2002 Denali Fault earthquake, have exacerbated ongoing deformation. Study-area DSGSDs should be considered capable of generating long-runout rock avalanches that could directly sever the Trans-Alaska Pipeline and Richardson Highway, or that could dam up valleys and lead to the buildup and catastrophic failure of landslide-dammed lakes capable of impacting said infrastructure. Keywords: Deep-seated gravitational slope deformation; sackung; Trans-Alaska Pipeline; geomorphology; InSAR; Alaska Range.
ACCESS: http://summit.sfu.ca/item/13795

DETECTING GROUND SETTLEMENT OF MEGACITIES USING INSAR TECHNIQUES.
CITATION: Peter Damoah-Afari. , Dissertation Abstracts International. Vol. 71, no. 03, suppl. B, 244 p. 2009., 2009. Pg. 244.
ABSTRACT: Subsidence phenomenon in Shanghai has been monitored by Interferometric synthetic aperture radar (InSAR) techniques in this study. The research employed different InSAR techniques to study both the spatial and the temporal variations of the land subsidence phenomenon in Shanghai, using datasets acquired by four SAR systems--the L-band JERS-1 SAR system, the C-band ERS-1 and ERS-2 systems, and the C-band ENVISAT ASAR system. The behaviour of scatterers in Shanghai has been assessed with time by means of coherence analysis using L-band JERS-1 and C-band ERS-1/2 SAR data. Results obtained showed that InSAR pairs in Shanghai do not maintain coherence after a period of 7 months, and that the L-band JERS-1 SAR is more suitable than the C-band ERS-1/2 SAR for mapping land subsidence phenomenon in Shanghai that is characterised as slow. Residual phases from differential interferograms were successfully minimised using a higher order polynomial and the least squares method. Accumulative land subsidence maps have been produced for Shanghai at three different periods: 1992-1998, 1999-2000 and 2003-2007, using different SAR datasets. Results obtained showed that not all places in Shanghai are subsiding, but the city centre and its surroundings are under the threat of land subsidence. Quantitative measurements indicated that the downtown area subsided at a rate of 30 mm/year from 1992-1998 (L-band JERS-1 SAR data); 20 mm/year from 1999-2000 (C-band ERS-1/2 SAR data); and 10 mm/year from 2003-2007 (C-band ENVISAT ASAR data). Qualitative analysis of L-band JERS-1 differential interferograms has revealed three stages of land subsidence from 1992 to 1998. The urban areas in Shanghai have been successfully mapped by using Interferometric coherence maps and point targets. Areas mapped as urban match those that were mapped as areas experiencing land subsidence. The later finding confirmed the assertion by some researchers (Gong et al., 2005; Xue et al., 2005; Zhang and Wei, 2005; Zhang et al., 2002) that massive engineering constructions and large number of high-rise buildings in Shanghai contribute to the land subsidence problem. Empirical models have been developed, both in time and spatial domains, for the prediction of the amount of land subsidence using 10 JERS-1 deformation maps. The models were developed using the method of least squares and higher order polynomials. Results obtained indicate that such an approach could be employed to predict the amount of land subsidence, in both spatial and time domains. The study was limited by the fact that some auxiliary data, such as location of wells or underground water pumping stations in the city, elevation data, number of construction units, and building loads, that could be useful for analyses and validation of results were not available. However, the main success of this study is that, it demonstrated the power of using InSAR techniques for ground surface deformation monitoring over large areas such as Shanghai.
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DETECTING LAND SUBSIDENCE NEAR METRO LINES IN THE BAOSHAN DISTRICT OF SHANGHAI WITH MULTI-TEMPORAL INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: Tao Li, Guoxiang Liu, Hui Lin, et al. , Journal of Modern Transportation, 2014. Springer Verlag. Vol. 22, No. 3, pp 137-147.
ABSTRACT: Land subsidence is a major factor that affects metro line (ML) stability. In this study, an improved multi-temporal Interferometric synthetic aperture radar (InSAR) (MTI) method to detect land subsidence near MLs is presented. In particular, our multi-temporal InSAR method provides surface subsidence measurements with high observation density. The MTI method tracks both point-like targets and distributed targets with temporal radar backscattering steadiness. First, subsidence rates at the point targets with low-amplitude dispersion index (ADI) values are extracted by applying a least-squared estimator on an optimized freely connected network. Second, to reduce error propagation, the pixels with high-ADI values are classified into several groups according to ADI intervals and processed using a Pearson correlation coefficient and hierarchical analysis strategy to obtain the distributed targets. Then, nonlinear subsidence components at all point-like and distributed targets are estimated using phase unwrapping and spatiotemporal filtering on the phase residuals. The proposed MTI method was applied to detect land subsidence near MLs of No. 1 and 3 in the Baoshan district of Shanghai using 18 TerraSAR-X images acquired between April 21, 2008 and October 30, 2010. The results show that the mean subsidence rates of the stations distributed along the two MLs are −12.9 and −14.0 mm/year. Furthermore, three subsidence funnels near the MLs are discovered through the hierarchical analysis. The testing results demonstrate the satisfactory capacity of the proposed MTI method in providing detailed subsidence information near MLs.
ACCESS: http://dx.doi.org/10.1007/s40534-014-0047-x

DETECTION AND CORRECTION OF PHASE UNWRAPPING ERRORS IN INSAR TIME SERIES ANALYSIS WITH DISCRETE COHERENT POINTS.
CITATION: Yongsheng Li, Jingfa Zhang, Zhenhong Li, et al. , Geomatics and Information Science of Wuhan University, 2014. Periodicals Press of Wuhan Technical University of Surveying and Mapping, Vol. 39, No. 10,

1199-1203, 1213.
ABSTRACT: Due to temporal and spatial decorrelation and other noise, the integer-cycle jumps always appear in the unwrapped phase. It is well known that phase unwrapping errors represent one of the major limitations of Interferometric SAR (InSAR). A phase closure method is presented to detect and correct phase unwrapping errors for discrete coherent points in InSAR time series analysis. Its application to ENVISAT Advanced Synthetic aperture radar (ASAR) data over the coastal zone of Cangzhou, Hebei Province showed a significant improvement in the InSAR time series results, with the number of valid coherent pixels increasing from 68 000 to 186 400 and the root mean square (RMS) decreasing from 13.1 mm to 5.3 mm and 17.5 mm to 4.3 mm for two deforming areas respectively.
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DETECTION AND MEASUREMENT OF LAND SUBSIDENCE USING GLOBAL POSITIONING SYSTEM AND INTERFEROMETRIC SYNTHETIC APERTURE RADAR, COACHELLA VALLEY, CALIFORNIA, 1996-98.
CITATION: Sneed, M.; Ikehara, M. E.; Galloway, D. L.; Amelung, F. Geological Survey, Sacramento, CA. Water Resources Div.; Coachella Valley County Water District, CA, 2001, 31p.
ABSTRACT: Land subsidence associated with groundwater- level declines has been recognized as a potential problem in Coachella Valley, California. Since the early 1920s, ground water has been a major source of agricultural, municipal, and domestic supply in the valley, resulting in waterlevel declines as large as 15 meters (50 feet) through the late 1940s. In 1949, the importation of Colorado River water to the lower Coachella Valley began, resulting in a reduction in groundwater pumping and a recovery of water levels from the 1950s through the 1970s. Since the late 1970s, the demand for water in the valley has exceeded the deliveries of imported surface water, again resulting in increased pumping and ground-waterlevel declines. The magnitude and temporal occurrence of land subsidence in the lower Coachella Valley are not well known; data are sparse and accuracy varies. Also, the area is tectonically active and has subsided during the past several million years, which further complicates interpretations of the data.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=PB2002100512

DETECTION AND MEASUREMENT OF LAND SUBSIDENCE USING INTERFEROMETRIC SYNTHETIC APERTURE RADAR AND GLOBAL POSITIONING SYSTEM, SAN BERNARDINO COUNTY, MOJAVE DESERT, CALIFORNIA.
CITATION: Sneed, M.; Ikehara, M. E.; Stork, S. V.; Amelung, F.; Galloway, D. L. Geological Survey, Sacramento, CA. Water Resources Div.; National Geodetic Survey, Sacramento, CA.; Rosenstiel School of Marine and Atmospheric Science, Miami, FL. 2003, 69p.
ABSTRACT: Land subsidence associated with ground- water-level declines has been recognized as a potential problem in parts of the Mojave Desert, California. Ground water has been the primary source of domestic, agricultural, and municipal water supplies in the desert since the early 1900s. Pumping of ground water from the Mojave River and Morongo ground-water basins in the southwestern Mojave Desert resulted in water-level declines of more than 30 meters (100 feet) between the 1950s and the 1990s. A Global Positioning System (GPS) survey of a geodetic network was used to determine the location, extent, and magnitude of vertical land-surface changes in Lucerne Valley in the Morongo ground-water basin. The GPS survey was conducted in 1998 to estimate historical elevation changes by comparing GPS-derived elevations with historical elevations (which were available for some of the monuments in the network as early as 1944) and to establish baseline values that can be used for comparisons with future GPS surveys. The GPS measurements indicated that about 600 millimeters (2 feet) (plus or minus 1,500 millimeters (5 feet)) of subsidence occurred at three of the monuments between 1969 and 1998 but that very little to no vertical change in position occurred at seven other monuments in the network. Water levels in the area of subsidence in Lucerne Valley declined about 15 meters (50 feet) during 1970-98. Interferometric Synthetic aperture radar (InSAR) methods were used to characterize vertical land-surface changes in the Mojave River and Morongo ground-water basins during various intervals of time between 1992 and 1999.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=PB2003103563

DETERMINING SNOW DEPTH USING AIRBORNE MULTI-PASS INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: Evans, J. Naval Postgraduate School, Monterey, CA. 2013, 221p.
ABSTRACT: Snow accumulation is a significant factor for hydrological planning, flood prediction, trafficability, avalanche control, and numerical weather/climatological modeling. Current snow depth methods fall short of requirements. This research explores a new approach for determining snow depth using airborne interferometric synthetic aperture radar (InSAR). Digital elevation models (DEM) are produced for Snow Off and Snow On cases and differenced to determine elevation change from accumulated snow. Interferograms are produced using Multi-pass Single Look Complex airborne Ku-band SAR. Two approaches were attempted.

The first is a classical method similar to spaceborne InSAR and relies on determining the baseline of the interferometric pair. The second used a perturbation method that isolates and compares high frequency terrain phase to elevation to generate a DEM. Manual snow depth measurements were taken to verify the results. The first method failed to obtain a valid baseline and therefore failed. The second method resulted in representative DEMs and average snow depth errors of -8cm, 95cm, -49cm, 176cm, 87cm, and 42cm for six SAR pairs respectively. Furthermore, Ku-band appeared to be a high enough frequency to avoid significant penetration of the snow. Results show that this technique has promise but still requires more research to refine its accuracy.
ACCESS: https://ntrl.ntis.gov/NTRL/dashboard/searchResults.xhtml?searchQuery=ADA589792

D-INSAR TECHNOLOGY APPLIED IN THE FIELD OF DEFORMATION MONITORING IN URBAN RAIL TRANSIT.
CITATION: Yunming Liu, Quanming Ma, Dayong Chen, et al. , Urban Rapid Rail Transit/Dushi Kuaigui Jiaotong, 2014. China. Vol. 27, No. 4, 62-66.
ABSTRACT: D-InSAR technology is a new type of space geodetic techniques, characterized by its all-day, all-weather, and wide range observation ability to obtain high-precision, high-resolution, and large-scale surface deformation without requiring ground control points. Therefore, D-InSAR technology was introduced into urban rail transit for deformation monitoring. Experiment of using SBAS-DinSAR technology and precision leveling technology was carried out to monitor the ground subsidence along Beijing metro line 6; the comparison shows that the test data of D-InSAR is in accordance with the data test by precision technology. Specific engineering applications of D-InSAR technology in the deformation monitoring of urban rail transit projects were discussed. It is feasible to apply D-InSAR technology for deformation monitoring in urban rail transit.
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EFFECT OF DISTRIBUTED POS TRANSFER ALIGNMENT ON INSAR INTERFEROMETIC MEASUREMENT.
CITATION: Zhuang-sheng ZHU and Tao GUO. , Zhongguo Guanxing Jishu Xuebao / Journal of Chinese Inertial Technology, 2014. Chinese Society of Inertial Technology. Vol. 22, No. 4, 432-438.
ABSTRACT: In order to get the flexural angel error caused by distributed POS due to atmospheric disturbances and find this error's corresponding relationship with the altitude error caused by Interferometric synthetic aperture radar(InSAR), a transfer alignment method using the "velocity + attitude" matching algorithm was proposed. Then the error of the estimation is used as the input parameter of the height measurement model to obtained the altitude error caused during transfer alignment. A distributed measurement platform was built to verify the experiment, and the following analyses were made about the platform: 1) according to the motion model of the flexural wings, the flexural angel in y coordinate axis was added to the Kalman filter's state variables; 2) the absolute error expressions of InSAR interferometry measurement and the method of selecting the parameters was deduced; 3) according to the filtering results and the mechanism of altitude measurement, the roll angel error's influence on InSAR altitude information was analyzed. The simulation results show that the horizontal and azimuth misalignments by the proposed method are superior to 0.009[degrees] and 0.015[degrees] respectively, and when the roll angel error is within + or -0.089[degrees], the altitude error is less than 4.2m.
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EFFECTS OF PHASE ERROR ON THE RELATIVE HEIGHT ACCURACY IN INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: Shi-Qi Ge, Liang Chen, Ze-Gang Ding, et al. , Transactions of Beijing Institute of Technology, 2012. China. Vol. 32, No. 2, Pg. 179-183.
ABSTRACT: To investigate the variation of relative height accuracy measured by InSAR system, how the phase error impacts on the relative height accuracy is analyzed on the basis of InSAR elevation measurement principle. The factors, which affect phase error, are researched in detail, such as signal to noise ratio, volume scattering, and temporal decorrelation, etc. Above methods has been used to analyze the relative height accuracy for spaceborne InSAR system with different wave bands. The results show that, under the condition of short wave length and fixed baseline, there is a look downwards angle that would optimize the relative height accuracy. Further, the numerical simulation has verified the existence of optimum look-down angle. The method and conclusions presented in this article are helpful for parameter design and performance analysis of InSAR system.
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ERROR MODELING AND ANALYSIS FOR INSAR SPATIAL BASELINE DETERMINATION OF SATELLITE FORMATION FLYING.

CITATION: Jia Tu, Defeng Gu, Yi Wu, et al. , Mathematical Problems in Engineering: theory, methods and applications, 2012. Hindawi Publishing Corporation, United States. Vol. 2012,
ABSTRACT: Spatial baseline determination is a key technology for Interferometric synthetic aperture radar (InSAR) missions. Based on the intersatellite baseline measurement using dual-frequency GPS, errors induced by InSAR spatial baseline measurement are studied in detail. The classifications and characters of errors are analyzed, and models for errors are set up. The simulations of single factor and total error sources are selected to evaluate the impacts of errors on spatial baseline measurement. Single factor simulations are used to analyze the impact of the error of a single type, while total error sources simulations are used to analyze the impacts of error sources induced by GPS measurement, baseline transformation, and the entire spatial baseline measurement, respectively. Simulation results show that errors related to GPS measurement are the main error sources for the spatial baseline determination, and carrier phase noise of GPS observation and fixing error of GPS receiver antenna are main factors of errors related to GPS measurement. In addition, according to the error values listed in this paper, 1 mm level InSAR spatial baseline determination should be realized.
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ESTIMATION AND REMOVAL OF ATMOSPHERIC EFFECTS IN INSAR TOPOGRAPHIC MAPPING.
CITATION: Q. Wan, L. Zhang, H. Jiang, et al. , Yaogan Xuebao - Journal of Remote sensing, 2012. Kexue Chubanshe. Vol. 16, No. 5, Pg. 1074-1088.
ABSTRACT: In order to further improve the practicability of InSAR technology, it is essential to study how to estimate and eliminate the undesired impact of atmospheric effects. In this study, the causes of atmospheric path delay are elaborated and their temporal/spatial distributions in repeat-pass InSAR are analyzed. A new method is proposed to correct the atmospheric effects in high-resolution tandem-mode InSAR through the use of an existing low-resolution DEM. The resultant elevation models obtained with and without the atmospheric correction are compared with the 30m-resolution ASTER GDEM to verify the effectiveness of the proposed method in terms of topographic mapping accuracy.
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AN ESTIMATION METHOD FOR INSAR INTERFEROMETRIC PHASE USING CORRELATION WEIGHT JOINT SUBSPACE PROJECTION.
CITATION: Hai Li and Renbiao Wu. , EURASIP Journal on Advances in Signal Processing, 2013. Hindawi Publishing Corporation. United States. Vol. 2013, No. 1, 1-11.
ABSTRACT: In this article, we propose a method to estimate the synthetic aperture radar interferometry (InSAR) interferometric phase based on the model of correlation weight joint pixel by using the joint subspace projection technique. In the method, the correlation weight joint data vector is constructed and the data vector can make the noise subspace dimension of the corresponding weight covariance matrix which is not affected by the coregistration error, thus avoiding the trouble of calculating the noise subspace dimension before estimating the InSAR interferometric phase. The method takes advantage of the coherence information of neighboring pixel pairs to auto-coregister the SAR images and employs the projection of the joint signal subspace onto the corresponding joint noise subspace to estimate the terrain interferometric phase. The method can auto-coregister the SAR images and reduce the interferometric phase noise simultaneously. Theoretical analysis and computer simulation results show that the method can provide accurate estimate of the interferometric phase (interferogram) even when the coregistration error reaches one pixel. The effectiveness of the method is verified via simulated data and real data.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

EVALUATING IFSAR AND LIDAR TECHNOLOGIES USING ARCINFO: RED RIVER PILOT STUDY.
CITATION: Damron, J. J.; Daniel, C. Army Topographic Engineering Center, Alexandria, VA. Engineer Research and Development Center, 2000, 122p.
ABSTRACT: The 1997 Red River flood resulted in catastrophic damage to residential, commercial, industrial, agricultural, and public properties in large portions of the Red River Valley in Minnesota and North Dakota, and in the Province of Manitoba, Canada. In the aftermath of the flood, the U.S. and Canadian governments asked the International Joint Commission (IJC) to analyze the cause and effects and to recommend ways to reduce the impact of future floods. In support of the IJC study, the U.S. Army Engineer District, Saint Paul, requested assistance from the U.S. Army Engineer Research and Development Center (ERDC), Topographic Engineering Center (TEC) to evaluate emerging airborne remote-sensing technologies for application to crisis management support. A pilot study was conducted using both Interferometric Synthetic aperture radar (IFSAR) and LIght Detection and Ranging (LIDAR) collection systems to determine the correct mix of technologies required. The major objectives of the study were to develop and implement a data fusion technique to merge IFSAR and LIDAR DEMs and to test the hydrological flow of water over each respective DEM. The results of this study will provide the Red River task force with a cost comparison for each of the

technologies tested during this project and a list of recommendations for performing the remainder of the basin collection.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA434465

EXPERIMENTAL ANALYSIS ON INTEGRATED FILTERING DENOISING OF INSAR INTERFEROGRAM.
CITATION: Jing-Bo Yu, Guo-Lin Liu, Zhen-Tan Cao, et al. , Science of Surveying and Mapping, 2013. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 38, No. 5, 129-132.
ABSTRACT: Based on analyzing the effect of mean filtering, circular mean filtering, median filtering, adaptive median filtering, two-dimensional adaptive filtering and irregular window adaptive median filtering for the interference pattern graph of analog data, the integrated filter was introduced in the paper. The noise from the interference graph of real data InSAR was filtered, whose result was analyzed on term of both the qualitative and the quantitative aspects. The validity and feasibility of the integrated filtering was shown by the experiment result.
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FAST STATISTICALLY HOMOGENEOUS PIXEL SELECTION FOR COVARIANCE MATRIX ESTIMATION FOR MULTITEMPORAL INSAR.
CITATION: Mi Jiang, Xiaoli Ding, Ramon F. Hanssen, et al. , IEEE Trans.Geosci.Remote Sens., 2015. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 53, No. 3, 1213-1224.
ABSTRACT: Multitemporal Interferometric synthetic aperture radar (InSAR) is increasingly being used for Earth observations. Inaccurate estimation of the covariance matrix is considered to be the most important source of error in such applications. Previous studies, namely, DeSpecKS and its variants, have demonstrated their advantages in improving the estimation accuracy for distributed targets by means of statistically homogeneous pixels (SHPs). However, these methods may be unreliable for small sample sizes and sensitive to data stacks showing large time spacing due to the variability of the temporal sample. Moreover, these methods are computationally intensive. In this paper, a new algorithm named fast SHP selection (FaSHPS) is proposed to solve both problems. FaSHPS explores the confidence interval for each pixel by invoking the central limit theorem and then selects SHPs using this interval. Based on identified SHPs, two estimators with respect to the despeckling and the bias mitigation of the sample coherence are proposed to refine the elements of the InSAR covariance matrix. A series of qualitative and quantitative evaluations are presented to demonstrate the effectiveness of our method.
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FINAL REPORT (OO-ERD-056) MEDIOS: MODELING EARTH DEFORMATION USING INTERFEROMETRIC OBSERVATIONS FROM SPACE.
CITATION: Vincent, P.; Walter, B.; Zucca, J.; Larsen, S.; Goldstein, P.; Foxwall, W.; Ruerson, F. Lawrence Livermore National Lab., CA.; Department of Energy, Washington, DC.. 2002, 6p.
ABSTRACT: This final report summarizes the accomplishments of the 2-year LDRD-ER project 'MEDIOS: Modeling Earth Deformation using Interferometric Observations from Space' (00-ERD-056) which began in FY00 and ended in FY01. The structure of this report consists of this summary part plus two separate journal papers, each having their own UCRL number, which document in more detail the major results in two (of three) major categories of this study. The two categories and their corresponding paper titles are (1) Seismic Hazard Mitigation ('Aseismic Creep Events along the Southern San Andreas Fault System'), and (2) Ground-based Nuclear Explosion Monitoring, or GNEM ('New Signatures of Underground Nuclear Tests Revealed by Satellite Radar Interferometry'). The third category is Energy Exploitation Applications and does not have a separate journal article associated with it but is described briefly. The purpose of this project was to develop a capability within the Geophysics and Global Security Division to process and analyze InSAR data for the purposes of constructing more accurate ground deformation source models relevant to Hazards, Energy, and NAI applications. Once this was accomplished, an inversion tool was to be created that could be applied to many different types (sources) of surface deformation so that accurate source parameters could be determined for a variety of subsurface processes of interest to customers of the GGS Division. This new capability was desired to help attract new project funding for the division.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=DE200515013366

FUSION OF HIGH-RESOLUTION DEMS DERIVED FROM COSMO-SKYMED AND TERRASAR-X INSAR DATASETS.
CITATION: Houjun Jiang, Lu Zhang, Yong Wang, et al. , Journal of Geodesy, 2014. Vol. 88, No. 6, 587-599.
ABSTRACT: Voids caused by shadow, layover, and decorrelation usually occur in digital elevation models (DEMs) of mountainous areas that are derived from Interferometric synthetic aperture radar (InSAR) datasets. The presence of voids degrades the quality and usability of the DEMs. Thus, void removal is considered as an integral part of the DEM production using InSAR data. The fusion of multiple DEMs has been

widely recognized as a promising way for the void removal. Because the vertical accuracy of multiple DEMs can be different, the selection of optimum weights becomes a key problem in the fusion and is studied in this article. As a showcase, two high-resolution InSAR DEMs near Mt. Qilian in northwest China are created and then merged. The two pairs of InSAR data were acquired by TerraSAR-X from an ascending orbit and COSMO-SkyMed from a descending orbit. A maximum likelihood fusion scheme with the weights optimally determined by the height of ambiguity and the variance of phase noise is adopted to syncretize the two DEMs in our study. The fused DEM has a fine spatial resolution of 10 m and depicts the landform of the study area well. The percentage of void cells in the fused DEM is only 0.13 %, while 6.9 and 5.7 % of the cells in the COSMO-SkyMed DEM and the TerraSAR-X DEM are originally voids. Using the ICESat/GLAS elevation data and the Chinese national DEM of scale 1:50,000 as references, we evaluate vertical accuracy levels of the fused DEM as well as the original InSAR DEMs. The results show that substantial improvements could be achieved by DEM fusion after atmospheric phase screen removal. The quality of fused DEM can even meet the high-resolution terrain information (HRTI) standard.
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FUSION OF DIGITAL MULTISPECTRAL VIDEOGRAPHY WITH INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: Fischer, R. L.; Anderson, J. E.; Satterwhite, M. B.; Ware, J. A., Army Topographic Engineering Center, Alexandria, VA, 1997, 11p.
ABSTRACT: As new remote sensing systems possessing different spectral and spatial capabilities become available, the fusion of sensors utilizing different regions of the electromagnetic spectrum will accelerate. This paper describes the techniques used to merge Interferometric Synthetic aperture radar (IFSAR) with digital multispectral videography (DMSV). A thirty-five frame digital multispectral mosaic was constructed and merged with the Digital Elevation Model (DEM) and backscatter layers derived from an IFSAR airborne X-band radar system. Two methods were incorporated in an effort to utilize the combined DMSV-IFSAR data. First, a comparison was made between minimum distance classifications run using the DMSV data only, and with the DMSV combined with the IFSAR backscatter file. Classification accuracies improved when separating trees from other green vegetation. A simple cosine correction algorithm derived form the IFSAR DEM was used to radiometrically adjust the DMSV data for slope and aspect effects. The utility of this technique was not conclusive. However, a small test area consisting of a grass cover appears to have been successfully modified.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA355162

GPS AND INSAR TIME SERIES ANALYSIS: DEFORMATION MONITORING APPLICATION IN A HYDRAULIC ENGINEERING RESETTLEMENT ZONE, SOUTHWEST CHINA.
CITATION: Ruya Xiao and Xiufeng He. , Mathematical Problems in Engineering: theory, methods and applications, 2013. Hindawi Publishing Corporation, United States. Vol. 2013,
ABSTRACT: Booming development of hydropower in China has resulted in increasing concerns about the related resettlement issues. Both global positioning system (GPS) and persistent scatterer Interferometric synthetic aperture radar (InSAR) time series analysis are applied to measuring the magnitude and monitoring the spatial and temporal variations of land surface displacement in Hanyuan, a hydraulic engineering resettlement zone, southwest China. The results from the GPS monitoring system established in Hanyuan match well the digital inclinometer results, suggesting that the GPS monitoring system can be employed as a complement to the traditional ground movement monitoring methods. The InSAR time series witness various patterns and magnitudes of deformation in the resettlement zone. Combining the two complementary techniques will overcome the limitations of the single method.
ACCESS: http://www.hindawi.com/journals/mpe/2013/601209/

GROUND DEFORMATION MONITORING BASED ON GPS-INSAR.
CITATION: Ming-Lian Jiao and Ting-Chen Jiang. , Cehui Kexue / Science of Surveying and Mapping, 2008. Chinese Academy of Surveying and Mapping, Beijing, China, Vol. 33, No. 6, Pg. 57-59.
ABSTRACT: The powerful tool of GPS-InSAR integration is drawing more and more attention in deformation monitoring. By analyzing the characteristic and the complement of the GPS and InSAR, the paper presents a data fusion plan of GPS-InSAR integration. Based on internal and international researches, it illustrates that this integrated technology is practical for monitoring deformation and surely has a wider future application.
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GROUND SUBSIDENCE GEO-HAZARDS INDUCED BY RAPID URBANIZATION: IMPLICATIONS FROM INSAR OBSERVATION AND GEOLOGICAL ANALYSIS.
CITATION: Copernicus GmbH.
ABSTRACT: Due to the convenient transportation and construction, cities are prone to be situated in areas with flat terrain and unstable sediments, resulting in the concurrence of ground subsidence and urbanization.

Here the interaction between geology, anthropogenic processes and ground subsidence geo-hazards were investigated in the Greater Pearl River Delta region of China. Geological evidences and 20062010 persistent scatterer data indicate that anthropogenic activities are dominant, although the distribution of river system and Quaternary sediments are also highly related to significant displacements (primarily at a rate of 15 to 15 mm a^{1}). The surface displacements derived by synthetic aperture radar interferometry suggest that the urbanization rhythm has to be routinely monitored. Considering analogous urbanization modes, particularly in developing countries, ground subsidence monitoring together with the analysis of its driving force are critical for geo-hazards early-warning, city planning as well as sustainable urbanization.
ACCESS: http://www.nat-hazards-earth-syst-sci.net/12/935/2012/nhess-12-935-2012.pdf

HYBRID APPROACH FOR UNBIASED COHERENCE ESTIMATION FOR MULTITEMPORAL INSAR.
CITATION: Mi Jiang, Xiaoli Ding and Zhiwei Li. , IEEE Trans.Geosci.Remote Sens., 2014. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 52, No. 5, 2459-2473.
ABSTRACT: The coherence of radar echoes is a fundamental observable in Interferometric synthetic aperture radar (InSAR) measurements. It provides a quantitative measure of the scattering properties of imaged surfaces and therefore is widely applied to study the physical processes of the Earth. However, unfortunately, the estimated coherence values are often biased due to various reasons such as radar signal nonstationarity and the bias in the estimators used. In this paper, we focus on multitemporal InSAR coherence estimation and present a hybrid approach that mitigates effectively the errors in the estimation. The proposed approach is almost completely self-adaptive and workable for both Gaussian and non-Gaussian SAR scenes. Moreover, the bias of the sample coherence can be mitigated with even only several samples included for a given pixel. Therefore, it is a more pragmatic method for accurate coherence estimation and can be applied actually. Different data sets are used to test the proposed method and demonstrate its advantages.
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HYDROLOGIC DYNAMICS OF THE GROUND-WATER-DEPENDENT SIAN KA'AN WETLANDS, MEXICO, DERIVED FROM INSAR AND SAR DATA.
CITATION: Bibi R. N. Gondwe, Sang-Hoon Hong, Shimon Wdowinski, et al. , Wetlands (Wilmington, NC), 2010. Springer for The Society of Wetland Scientists, Wilmington, NC, Vol. 30, No. 1, Pg. 1-13.
ABSTRACT: Not available.
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IMAGE DISTORTION EFFECTS IN SAR SUBSURFACE IMAGING AND A NEW ITERATIVE APPROACH FOR REFOCUSING AND COREGISTRATION.
CITATION: Adel Elsherbini and Kamal Sarabandi. , IEEE Trans.Geosci.Remote Sens., 2014. Institute of Electrical and Electronics Engineers, Inc. United States. Vol. 52, No. 5, 2994-3004.
ABSTRACT: High-resolution subsurface imaging and topography estimation in deserts is very useful in many applications such as oil-field and ground-water explorations and archaeological surveys. To address this problem, we previously developed a subsurface imaging Interferometric synthetic aperture radar (InSAR) concept that can estimate the subsurface topography. However, the image resolution of such a system is rather limited by the current techniques available for SAR focusing and InSAR image coregistration as the propagation effects and phase-front distortion caused by the top layer are not accounted for. In this paper, we discuss different image aberrations that result from the top-surface topography, including geometric and defocusing distortion. The issue created by subsurface caustics and their effect on SAR imaging are discussed. We then present a new approach to estimating and correcting such aberrations. By using simulations and measurements, it is shown that up to an order of magnitude improvement in the subsurface image resolution as well as significant improvement on subsurface interferogram coherence can be achieved. The proposed approach is based on the application of a previously developed subsurface inversion algorithm and a newly developed fast subsurface InSAR simulator. The results are verified numerically using 3-D simulations of different sand-dune geometries and an experiment using scaled-model measurements under laboratory conditions.
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IMAGING DECADAL AND SEASONAL DEFORMATION IN THE SAN FRANCISCO BAY AREA USING PERMANENT SCATTERER INSAR METHODS.
CITATION: G. E. Hilley, R. Burgmann, A. Ferretti, et al. , EOS Transactions, American Geophysical Union, 2006. American Geophysical Union, Vol. 87, No. 52,
ABSTRACT: In this contribution, we image decadal and seasonal deformation in the San Francisco Bay Area during the 1992- 2001 time-period using Permanent Scatterer Synthetic aperture radar Interferometric (PS-InSAR) methods. Unlike traditional InSAR methods that necessarily decrease the spatial and temporal resolution of SAR acquisitions to reduce the component of the signal unrelated to surface deformation, the

PS-InSAR method uses only objects that show phase-stable, radar-bright behavior in a large number of SAR scenes to isolate the deformation signal from these noise sources. This method greatly increases the spatial and temporal resolution of the Interferometric line-of-sight (LOS) displacements relative to traditional InSAR methods under urbanized conditions such as those present in the San Francisco Bay Area. We use these methods to image slow-moving landslides in the eastern San Francisco Bay area, and find that their LOS displacement rates vary between 5-7 mm/yr, and show a strong seasonal component of motion. During the 1997-1998 El Nino event, precipitation doubled, and the yearly-averaged LOS displacements increased to 11 mm/yr, showing that increased precipitation may lead to acceleration of these features. Depending on the direction in which these slides moved, decadally-averaged displacement rates may have been as large as 27-38 mm/yr. These results show that PS- InSAR may be used to identify and monitor the details of motion of km-scale features that have a strong seasonal component of deformation. Over a regional scale, we used PS-InSAR measurements with horizontal GPS velocities to estimate the vertical displacement rate distribution throughout the San Francisco Bay Area. Furthermore, we identified scatterers located on stable bedrock to isolate those points that likely reflect the effects of regional tectonic deformation versus those that may be sensitive to hydrologic effects associated with near- surface aquifer recharge. Interestingly, when considering only bedrock points, the PS-InSAR measurements show a significant seasonal component of deformation, indicating that deformation due to local hydrologic effects may extend far into the upland topography and may be coherent over large areas.
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IMPROVED MAXIMUM LIKELIHOOD HEIGHT ESTIMATION METHOD FOR MULTI-BASELINE INSAR ELEVATION INVERSION.
CITATION: Fen-Fen Hua, Ji-Xian Zhang, Guo-Man Huang, et al. , Science of Surveying and Mapping, 2014. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 39, No. 3, 13-18.
ABSTRACT: Multi-Baseline InSAR got more and more attention because of its no requirement in phase unwrapping, ground control points and so on. This paper introduced MLHE method of multi-baseline elevation inversion, analysed the limitation and pointed out that it does not apply to the real airborne data. To improve the algorithm, a strict geometric model made by RD model and ellipsoid equations was introduced into MLHE. Finally, the experimental data obtained by CASMSAR-X system were processed to verify the feasibility of the algorithm, and got good results.
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IMPROVED TOPOGRAPHIC MAPPING THROUGH HIGH-RESOLUTION SAR INTERFEROMETRY WITH ATMOSPHERIC EFFECT REMOVAL.
CITATION: Mingsheng Liao, Houjun Jiang, Yong Wang, et al. , ISPRS Journal of Photogrammetry and Remote sensing, 2013. , P.O. Netherlands. Vol. 80, 72-79.
ABSTRACT: The application of SAR interferometry (InSAR) in topographic mapping is usually limited by geometric/temporal decorrelations and atmospheric effect, particularly in repeat-pass mode. In this paper, to improve the accuracy of topographic mapping with high-resolution InSAR, a new approach to estimate and remove atmospheric effect has been developed. Under the assumptions that there was no ground deformation within a short temporal period and insignificant ionosphere interference on high-frequency radar signals, e.g. X-bands, the approach was focused on the removal of two types of atmospheric effects, namely tropospheric stratification and turbulence. Using an available digital elevation model (DEM) of moderate spatial resolution, e.g. Shuttle Radar Topography Mission (SRTM) DEM, a differential interferogram was firstly produced from the high-resolution InSAR data pair. A linear regression model between phase signal and auxiliary elevation was established to estimate the stratified atmospheric effect from the differential interferogram. Afterwards, a combination of a low-pass and an adaptive filter was employed to separate the turbulent atmospheric effect. After the removal of both types of atmospheric effects in the high-resolution interferogram, the interferometric phase information incorporating local topographic details was obtained and further processed to produce a high-resolution DEM. The feasibility and effectiveness of this approach was validated by an experiment with a tandem-mode X-band COSMO-SkyMed InSAR data pair covering a mountainous area in Northwestern China. By using a standard Chinese national DEM of scale 1:50,000 as the reference, we evaluated the vertical accuracy of InSAR DEM with and without atmospheric effects correction, which shows that after atmospheric signal correction the root-mean-squared error (RMSE) has decreased from 13.6 m to 5.7 m. Overall, from this study a significant improvement to derive topographic maps with high accuracy has been achieved by using the proposed approach.
ACCESS:
http://core.ecu.edu/geog/wangy/papers_in_pdfs/2013_Improved%20topographic%20mapping%20through%20high-resolution%20SAR%20interferometry%20with%20atmospheric%20effect%20removal.pdf

IMPROVING THE ACCURACY OF LOCAL FREQUENCY ESTIMATION FOR INTERFEROMETRIC SYNTHETIC APERTURE RADAR INTERFEROGRAM NOISE FILTERING CONSIDERING LARGE COREGISTRATION ERRORS.

CITATION: Jiao Guo, Weitao Zhang, Yanyang Liu, et al. , IET Radar, Sonar and Navigation, 2014. Institution of Engineering and Technology, United Kingdom. Vol. 8, No. 6, 676.

ABSTRACT: This study deals with the problem of estimating the local frequencies for Interferometric synthetic aperture radar (InSAR) phase image (i.e. interferogram) noise filtering, considering large co-registration errors. The estimation of local frequencies is frequently applied to achieving high performance of interferometric phase noise filtering, which is a key step in InSAR processing procedures. Unfortunately, the generated interferograms suffer seriously from co-registration errors especially for complicated topographies, thus imposing strong limits on the accuracy of local frequencies estimation by the existing methods. Taking large co-registration errors into account, the proposed method makes full use of the neighbouring pixels to construct joint pixel vector and take the separation extent of the signal and noise subspaces as the criterion to accurately estimate the local frequencies so that the effects of the envelope misalignment can be mitigated. Theoretical analysis and the simulated data as well as the real ERS-1/2 data show that the presented method has the ability to provide accurate estimation of local frequencies even if the co-registration error reaches one pixel.

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INSAR ACCURACY: UNCERTAINTY IN RANGE CHANGE AND RATE.

CITATION: D. F. Argus and P. R. Lundgren. , EOS Transactions, American Geophysical Union, 2006. American Geophysical Union, Washington, DC, Vol. 87, No. 52.

ABSTRACT: To quantify how long an InSAR mission must be to resolve plate boundary deformation and interseismic strain accumulation, we assess InSAR accuracy. Lateral variations in troposphere delay are the main error source in InSAR range. SCIGN GPS estimates of troposphere delay in southern California show the error to increase with lateral distance [Emardson et al., JGR 2003]. The range error is 8 mm across 10 km, 18 mm across 50 km, and 25 mm across 100 km (standard errors). Range rate error across 50 km is 6 mm/yr for a 3-year mission, and 3.6 mm/yr for a 5-year mission. Because troposphere delay is nearly uncorrelated over times longer than a day, range rate error can be reduced by stacking interferograms if rates are nearly constant. Stacking interferograms every 24 days reduces range rate error by 62% to 2.3 mm/yr for a 3-year mission and by 70% to 1.1 mm/yr for a 5-year mission. Because InSAR accuracy of 1 mm/yr is needed to usefully constrain earthquake strain buildup and fault slip rates, a 5-year mission is needed. We will present comparisons between InSAR and GPS estimates of range and range rate supporting this conclusion. We will further assess InSAR accuracy by analyzing InSAR range-time series.

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INSAR COHERENCE ESTIMATION FOR SMALL DATA SETS AND ITS IMPACT ON TEMPORAL DECORRELATION EXTRACTION.

CITATION: Mi Jiang, Xiaoli Ding, Zhiwei Li, et al. , IEEE Trans.Geosci.Remote Sens., 2014. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 52, No. 10, 6584-6596.

ABSTRACT: A novel coherence estimation method for small data sets is presented for Interferometric synthetic aperture radar (SAR) (InSAR) data processing and geoscience applications. The method selects homogeneous pixels in both the spatial and temporal spaces by means of local and nonlocal adaptive techniques. Reliable coherence estimation is carried out by using such pixels and by correcting the bias in the estimated coherence caused by the non-Gaussianity in high-resolution SAR scenes. As an example, the proposed method together with coherence decomposition is applied to extract the temporal decorrelation component over an area in Macao. The results show that the proposed algorithms work well over various types of land cover. Moreover, the coherence change with time can be more accurately detected compared to other conventional methods.

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INSAR COHERENCE MAGNITUDE ESTIMATION BASED ON DATA STACK.

CITATION: Xiao-Li Ding. , Diqiu Wuli Xuebao, 2013. Kexue Chubanshe, Vol. 56, No. 3, 799-811.

ABSTRACT: In this paper, we present a novel approach for accurate coherence estimation, based on InSAR data stack. The main advantage of the proposed method is to meet the assumptions that the complex signals are local stationary, and meanwhile take into account the computational efficiency. Therefore, it is possible to obtain a very accurate coherence estimate without loss of resolution. Concretely, two-step is applied to adaptive algorithm: (1) nonparametric hypothesis test is firstly employed to cluster pixels with same statistical distributions; (2) the modified version of maximum likelihood fringe rate estimate is then used to eliminate the non-stationarity of complex signals. The accuracy of such estimation is improved by Cramer-Rao bounds. Experimental results with Envisat ASAR datasets over Los Angeles areas show that the new method

performs well under different situations.
ACCESS: http://manu16.magtech.com.cn/geophy/EN/abstract/abstract9327.shtml#

INSAR DETECTION OF GROUND DEFORMATION IN MEGALOPOLISES OF PEARL RIVER DELTA.
CITATION: Qing Zhao. , ProQuest Dissertations and Theses, 2010. The Chinese University of Hong Kong (Hong Kong). Hong Kong.
ABSTRACT: Megalopolises in the Pearl River Delta, including Guangzhou and Hong Kong, have experienced various degree of ground subsidence. The causes can be divided into two categories: natural subsidence and the human-induced subsidence. Monitoring the ground subsidence can not only help people to find out the distributions in both spatial and temporal fields, but also guide people to minimize the hazard ahead. Thus, it is significant to monitor the ground subsidence accurately, timely and frequently. This dissertation research uses the Environmental Satellite Advanced Synthetic aperture radar (ENVISAT ASAR) data received at the Chinese University of Hong Kong Satellite Remote sensing Receiving Station and SAR interferometry (InSAR) technology as a powerful tool for large-scale ground deformation monitoring in Guangzhou and Hong Kong areas. Persistent Scatterer Interferometry (PSI) method is used to detect ground deformation in the urban area of Guangzhou city. A ground deformation rate map with scattered distribution of point targets shows the maximum subsidence (rise) rate as high as -26 to -20 mma -1 (16-21 mma-1), implying that the study area is an active zone for ground deformation. Based on the point target map, a contour ground deformation rate map is generated. All the six ground collapse accidents that occurred in 2007-2008 fall within the subsidence zones, qualitatively validating the IPTA results. Ground subsidence and geological conditions on Datansha Island are examined. The results indicate that the local geological conditions and underground engineering projects are responsible for ground subsidence and ground collapse accidents occurred there. To interpret the distribution of active ground subsidence zones, a local geological map is used as a reference for generating a series of thematic maps. The results show that geological faults, rock distribution, over-development, and underground engineering projects may be four factors leading to the distribution of the active ground subsidence zones. The Hong Kong International Airport (HKIA) was built on a site of 12.5 km2 , of which 75% is reclaimed foundation. Thus, the stability of ground foundation of HKIA is of public concern. I use the PSI method and ENVISAT ASAR data to detect the residual settlement rate from 19 April 2006 to 9 January 2008. I use ground truth data to develop empirical correction models for correcting systematic biases in the ASAR PSI-detected settlement rate. The corrected data follow the Lorentz distribution well, implying that the residual settlement process is dominated by two modes or categories of settlement rates. I find unreasonable positive values of the ASAR PSI-detected annual ground settlement rate, which follow a normal distribution. I draw a scatter plot with ground deformation rate value and coherence value of each point targets. Point targets with lower coherence values and greater positive values are extracted and drawn on a geographical map. Most of these point targets are located at the airport Midfield, which is under construction. A ground settlement rate map of HKIA shows that an area of the Passenger Terminal Building, and an area of the Southern Runway are two relatively stable areas, and one major continuous settlement area covers the airport Midfield. General spatial distribution patterns of ASAR PSI-detected ground settlement rate agree well with model-predicted residual settlement rates.
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INSAR IDENTIFIES MINE-DEWATERING ASSOCIATED BEDROCK COMPACTION AND SUBSIDENCE IN NORTH- CENTRAL NEVADA.
CITATION: K. W. Katzenstein, J. W. Bell and R. J. Watters. , EOS Transactions, American Geophysical Union, 2007. American Geophysical Union, Washington, DC, Vol. 88, No. 52.
ABSTRACT: During the last decade, InSAR has been used extensively for the delineation of aquifer-system response to heavy groundwater pumping. A number of studies have demonstrated the vastly improved spatial resolution afforded by InSAR relative to traditional surveying techniques in detecting groundwater-related effects, including subsidence. This has allowed for further understanding of the complexity of subsidence bowls and the role of secondary factors such as structure, aquifer material properties and other previously unforeseen factors. In the western U.S., ground subsidence related to mine dewatering is a common occurrence due to the very large volumes of water (as high as 100,000 acre-ft/yr) that are typically pumped in order to lower the local groundwater table to facilitate the excavation of open pit and underground mines. Several gold mines located along the Carlin Trend of Central Nevada have produced distinct InSAR-identified subsidence signals of greater aerial extent and magnitude than most municipal groundwater signals, including signals partly or entirely within bedrock. One signal in particular shows a minimum of 54 cm of cumulative dewatering related subsidence between June 1, 1992 and September 21, 2000. Our study has produced many (> 50) interferograms, each covering different time intervals, allowing a better understanding of how the subsidence signal has evolved in response to varied pumping rates from dewatering wells. Since the spatial resolution of the InSAR is much better than that of the monitoring well locations, the complexity of the signal is better delineated. The aerial extent of the subsidence feature is impressive as it extends as far as 20 km

away from the location of the extraction wells used for dewatering. The area of maximum subsidence correlates well with the area of maximum groundwater drawdown, however the subsidence signal extends well beyond (as much as 8-10 km) the observed groundwater drawdown pattern. This suggests a much deeper zone of compaction and/or subsidence. The large aerial extent is likely a result of the fact that the vast majority of the pumping is from the deeper bedrock aquifer, with very small amounts of pumping from shallower siltstones and unconsolidated basin fill. The geology within the deformation signal is very complex. The dewatering is occurring in deep carbonates which are overlain by varying thicknesses of basin fill, volcanics, siliceous siltstones and mudstones and other limestone units. Close inspection of these units in the main open pit as well as a nearby underground mine suggests that while many of these units are highly fractured, most of the fractures have been healed with silica or are so tight that minimal fracture closing is possible. This suggests another mechanism causing the ground surface to subside, including compaction of intact bedrock. Groundwater related bedrock subsidence of this scale is rarely, if ever, observed, and therefore, poorly understood. Ongoing work at this site is focused on better understanding the mechanics of the observed bedrock compaction/sidence, and possible implications to other high volume groundwater pumping sites.
ACCESS: VDOT Employees may request this document by contacting Barb.Neyman@VDOT.Virginia.gov

INSAR IMAGE REGULARIZATION AND DEM ERROR CORRECTION WITH FRACTAL SURFACE SCATTERING MODEL.
CITATION: Donny Danudirdjo and Akira Hirose. , IEEE Trans.Geosci.Remote Sens., 2015. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 53, No. 3, 1427-1439.
ABSTRACT: This paper presents a method for removing spikes in digital elevation models (DEMs) caused by residues in Interferometric synthetic aperture radar (InSAR) phase image. We consider that the scattering mechanism is properly modeled by the small perturbation method for fractal surfaces and present a model that relates the phase and magnitude in InSAR image. This data model provides the regularization term of the method, without directly enforcing smooth phase or magnitude. Noise models are given by additive Gaussian for the phase and multiplicative non-unit-mean gamma for the magnitude. Experiments with simulated and real L-band data show that the proposed method considerably improves DEM accuracy and simultaneously suppresses speckle and phase noise.
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INSAR MISSION CONCEPTS FOR SOLID EARTH AND OTHER SCIENCE APPLICATIONS.
CITATION: P. A. Rosen, C. W. Chen, A. Donnellan, et al. , EOS Transactions, American Geophysical Union, 2006. American Geophysical Union, Washington, DC, Vol. 87, No. 52.
ABSTRACT: Repeat-pass Interferometric synthetic aperture radar (InSAR) mission design is influenced by a variety of factors: science objectives and measurement requirements, temporal characteristics of the observed science targets, available power, mass, and volume for the mission, and spectrum allocation, among others. In addition to system design trades, technology and technology readiness must be considered in terms of the overall system performance and cost. InSAR observations to date have been acquired with spacecraft carrying SAR instruments with rectangular passive or active array antenna systems, including Seasat, SIR-C, ERS, Radarsat, Envisat, JERS, and ALOS. Several planned systems will also carry phased array systems, including Radarsat-2 and Terrasar-X. Now, a generation of reflector technologies has matured in the communications satellite arena that has the potential for reducing mission complexity and cost, and several systems are being planned with this technology. We have carried out a trade study of InSAR missions in the context of specific science missions that are of interest to the science community: InSAR for solid earth deformation, biomass and soil moisture characterization, coastal processes, and rapid response to disasters. The approach is to examine the space of technology, implementation, and science return, searching for breakpoints that can point to missions with maximized science value.
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INSAR MONITORING OF PROGRESSIVE LAND SUBSIDENCE IN NEYSHABOUR, NORTHEAST IRAN.
CITATION: Maryam Dehghani, Mohammad Javad Valadan Zoej, Iman Entezam, et al. , Geophysical Journal International, 2009. Blackwell Publishing Ltd , UK. Vol. 178, No. 1, Pg. 47-56.
ABSTRACT: The area of Neyshabour, a small historical city located in Northeast Iran, is subject to land subsidence. To monitor the temporal evolution of the subsidence, the small baseline subset (SBAS) algorithm is used for Interferometric synthetic aperture radar (SAR) time-series analysis. To limit the spatial and temporal decorrelation phenomena, the interferograms produced from the raw ENVISAT ASAR data are characterized by small spatial and temporal baselines. Accordingly, four independent SAR acquisition data sets separated by large spatial and temporal baselines are used in the time-series analysis. To link the separate data sets, a smoothing constraint that minimizes the curvature of the subsidence temporal evolution is added to the least-squares method. The optimum smoothing factor estimated in the smoothed time-series

analysis reduces the atmospheric noise, unwrapping and orbital errors whereas it preserves the non-linear seasonal deformation features. The time-series results show an incremental lowering of the ground surface, accompanied by small seasonal effects. The mean LOS deformation velocity map computed from the time-series analysis demonstrates a considerable subsidence rate of up to 19 cm yr-1. Comparison between the InSAR time-series and continuous GPS measurements verifies the accuracy of the obtained results.Moreover, the quantitative integration of the InSAR-derived displacement measurements with observations of the hydraulic head fluctuations causing these displacements yields information about the compressibility and storage properties of the aquifer system.
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INSAR PHASE NOISE REDUCTION BASED ON EMPIRICAL MODE DECOMPOSITION.
CITATION: Fangfang Li, Donghui Hu, Chibiao Ding, et al. , IEEE Geoscience and Remote sensing Letters, 2013. Institute of Electrical and Electronics Engineers, Inc. United States. Vol. 10, No. 5, 1180-1184.
ABSTRACT: A novel method of Interferometric synthetic aperture radar phase filtering that combines empirical mode decomposition (EMD) with Holder exponent adjustment is presented in this letter. First, intrinsic mode functions (IMFs) of different levels are obtained by decomposing the real and imaginary parts of the noisy interferometric phase in complex formulation respectively employing EMD, which is a totally data-driven method without parameters to be selected. Then, we increase the Holder exponents of every IMF to appropriate extent according to the features of the signal and noise contained in them to realize different filtering effects. Thus, noise can be efficiently filtered without the loss of detailed information of the interferogram. Finally, the filtered IMFs are reconstructed to form the denoised interferogram. The experiments of simulated data with various correlation coefficients and real data verify the effectiveness and adaptability of the method.
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INSAR TERRAIN MAPPING USING ICESAT LASER ALTIMETRY.
CITATION: D. Atwood, R. Guritz, R. Muskett, et al. , EOS Transactions, American Geophysical Union, 2006. American Geophysical Union, NW, Washington, DC, Vol. 87, No. 52.
ABSTRACT: High quality geodetic ground control is time-consuming and costly to acquire in remote regions, where logistical operations are difficult to support. Hence, there is a strong interest in establishing new sources of ground control points that can be used in conjunction with Interferometric SAR (InSAR) for producing accurate digital elevation models (DEMs). In January 2003, NASA launched the Geoscience Laser Altimeter System (GLAS) into high polar orbit onboard the Ice, Cloud, and land Elevation Satellite (ICESat). A major objective of this spaceborne laser altimeter system, with orbital coverage extending from 86deg N to 86deg S, is to provide elevation measurements of the Earth's topography with unprecedented accuracy. The intent of our project is to assess the accuracy of ICESat elevation data and evaluate its utility as ground control for topographic mapping. Our study area lies near Barrow, Alaska; 15,650 sq. km of coastal plain adjacent to the Arctic Ocean, characterized by vast expanses of tundra, lakes, and arctic wetlands of such low relief as to be nearly devoid of terrain features. Accuracy of the ICESat elevation measurements is assessed through comparison with differential GPS (DGPS) data, acquired along ICESat ground tracks crossing our study area. Using DGPS as the reference, ICESat yields a mean offset of -0.04 pm 0.15 m for fast static measurements on frozen tundra lakes and 0.22 pm 0.96 m for two kinematic DGPS profiles along the ICESat ground track. These results suggests that ICESat-derived elevations on the Arctic coastal plain are more than sufficiently accurate for use as ground control in DEM generation. The only clear limitation of the ICESat data is the non-uniform distribution of the ICESat tracks within the 33 day near-repeat sub-cycle. Although the coverage is poor at equatorial latitudes, track separation in the Arctic is on the order of tens of kilometers because of orbital convergence at the Poles. To test whether these data can be used for terrain mapping, we employ ICESat-derived elevations for ground control in the InSAR processing of spaceborne ERS-1 and -2 tandem mission SAR imagery. The ICESat ground control points (gcps) are used in two distinct InSAR processing steps to generate a DEM of the Barrow peninsula: 1.) Selected points are used to perform baseline refinements, which improves the ERS-1,- 2 SAR interferograms. This technique represents a substantial improvement over the Alaska National Elevation Data (NED), that otherwise would have been used for this purpose. 2.) The along-track ICESat data are also used as control points in mosaicking multiple InSAR-derived DEMs. The thousands of ICESat gcps yield an InSAR DEM mosaic with an accuracy of -1.11 pm 6.3 m, when compared with a commercial airborne SAR- derived DEM of 0.5 m RMS accuracy. This accuracy easily meets DTED 2 standards and suggests that DEMs derived using only ICESat altimetry for ground control should be expected to meet similar standards in other areas of low terrain relief. This is a critical finding for those interested in developing high accuracy maps outside of the current SRTM DEM coverage, north of 60deg and south of 56deg.
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INSAR-DEM ANALYSES INTEGRATED WITH GEOLOGIC FIELD METHODS FOR THE STUDY OF LONG-TERM SEISMOGENIC FAULT BEHAVIOR: APPLICATIONS IN THE AXIAL ZONE OF THE CENTRAL APENNINES (ITALY).
CITATION: A. Pizzi and G. Pugliese. , J.Seismol., 2004. Kluwer Academic Publishers Group, Vol. 8, No. 3, Pg. 313-329.
ABSTRACT: The integration of terrain computer modeling with field methods may provide a powerful mechanism for understanding active faults geometry, kinematics and long-term fault behavior. Radar interferometry was used on ERS tandem images to create a geocoded DEM (InSAR-DEM) with a nominal 20-m spatial-resolution of the central Apennines axial zone, a seismically active area characterized by historical destructive earthquakes with M < 7. The potential was tested of InSAR-DEM application to the Fucino and Sulmona basin boundary faults, which have well-defined seismological, paleoseismological and/or geological evidence for their having seismogenic sources. In particular, slope maps extracted from the InSAR-DEM were used for fault scarps detection, whether on carbonate bedrock ("fault scarp type 2") or affecting continental deposits within the basin ("fault scarp type l "), and compared with the available geological and new field data. In order to assess the DEM accuracy and to evaluate morphometric parameters related to the long-term slip-rates of the faults, a set of topographic profiles was extracted from the InSAR-DEM and compared with analogous profiles derived from the available topographic map (i.e., 1/25,000, with 25 m contour interval). In particular, the use of InSAR-DEM analyses showed its better results, with respect to the standard topography, for urban/agricultural gently sloped areas where fault scarps affected unconsolidated and particularly soft sediments (e.g., Fucino basin fault systems), while in severely sloped carbonate ridge and forested areas low coherences and layover effects made InSAR-DEM application problematic. A maximum value of 1.1 f 0.2 mm yr-1 slip-rate was obtained for the Fucino boundary fault. Finally, the recognized en-echelon pattern of the Sulmona basin boundary fault, provided a segmentation model for this structure corroborated by geological-structural field data.
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INTEGRATION OF HYPERSPECTRAL AND IFSAR DATA FOR IMPROVED 3D URBAN PROFILE RECONSTRUCTION.
CITATION: P. Gamba and B. Houshmand. , Photogramm.Eng.Remote sensing, 2001. American Society for Photogrammetry and Remote sensing. Vol. 67, No. 8, Pg. p. 947-956.
ABSTRACT: The authors analyze the problem of how to use airborne hyperspectral (AVIRIS) data and radar (AIRSAR/TOPSAR) images to characterize the built-up areas in an urban structure. In particular, they use the classification capabilities provided by the AVIRIS sensor to improve the three-dimensional profile reconstruction of the buildings obtained by working with the Interferometric synthetic aperture radar (IFSAR) measurements, and eventually extract building models. Two classification schemes are evaluated for AVIRIS data clustering, while the effect of the radar view angle is studied in assessing the quality of the associated digital elevation models. A detailed analysis of what is possible to extract and to what extent these data are useful is produced, considering precise two-dimensional and three-dimensional ground truth of the University of California Los Angeles campus.
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INTEGRATION OF INSAR AND GPS FOR HYDRAULIC ENGINEERING.
CITATION: Xiufeng He, Haibin Luo, Qihuan Huang, et al. , Science in China.Series E: Engineering & Materials Science, 2007. Chinese Academy of Sciences, Vol. 50, Pg. 111-124.
ABSTRACT: Interferometric synthetic aperture radar (InSAR) is a potential earth observation approach, and it has been demonstrated to have a variety of applications in measuring ground movement, urban subsidence and landslides. Currently InSAR provides the ability to map accurate DEM and measure ground deformation to sub-centimeter accuracy. However, many factors affect InSAR to measure ground movement since dam constructions are built in a large scale area with a complicated climate and unstable geology. This paper discusses potential applications of integrated InSAR and GPS to monitor a large-scale ground movement due to hydropower developments. The integration of InSAR and GPS can provide a cost-effective means for monitoring deformation of hydropower developments. Moreover, two novel methods, both the improved spatial interpolating method and estimation of 3D surface motion velocities method, are proposed and the experimental results and analysis are given in this paper.
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LAND SUBSIDENCE ALONG THE DELTA-MENDOTA CANAL IN THE NORTHERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA, 2003-10.
CITATION: U.S. Dept. of the Interior, U.S. Geological SurveyReston, Va.
ABSTRACT: Extensive groundwater withdrawal from the unconsolidated deposits in the San Joaquin Valley caused widespread aquifer-system compaction and resultant land subsidence from 1926 to 1970--locally

exceeding 8.5 meters. The importation of surface water beginning in the early 1950s through the Delta-Mendota Canal and in the early 1970s through the California Aqueduct resulted in decreased pumping, initiation of water-level recovery, and a reduced rate of compaction in some areas of the San Joaquin Valley. However, drought conditions during 1976-77 and 1987-92, and drought conditions and regulatory reductions in surface-water deliveries during 2007-10, decreased surface-water availability, causing pumping to increase, water levels to decline, and renewed compaction. Land subsidence from this compaction has reduced freeboard and flow capacity of the Delta-Mendota Canal, the California Aqueduct, and other canals that deliver irrigation water and transport floodwater. The U.S. Geological Survey, in cooperation with the U.S. Bureau of Reclamation and the San Luis and Delta-Mendota Water Authority, assessed land subsidence in the vicinity of the Delta-Mendota Canal as part of an effort to minimize future subsidence-related damages to the canal. The location, magnitude, and stress regime of land-surface deformation during 2003-10 were determined by using extensometer, Global Positioning System (GPS), Interferometric synthetic aperture radar (InSAR), spirit leveling, and groundwater-level data. Comparison of continuous GPS, shallow extensometer, and groundwater-level data, combined with results from a one-dimensional model, indicated the vast majority of the compaction took place beneath the Corcoran Clay, the primary regional confining unit. Land-surface deformation measurements indicated that much of the northern portion of the Delta-Mendota Canal (Clifton Court Forebay to Check 14) was fairly stable or minimally subsiding on an annual basis; some areas showed seasonal periods of subsidence and of uplift that resulted in little or no longer-term elevation loss. Many groundwater levels in this northern area did not reach historical lows during 2003-10, indicating that deformation in this region was primarily elastic. Although the northern portion of the Delta-Mendota Canal was relatively stable, land-surface deformation measurements indicated the southern portion of the Delta-Mendota Canal (Checks 15-21) subsided as part of a large subsidence feature centered about 15 kilometers northeast of the Delta-Mendota Canal, south of the town of El Nido. Results of InSAR analysis indicated at least 540 millimeters of subsidence near the San Joaquin River and the Eastside Bypass during 2008-10, which is part of a 3,200 square-kilometer area--including the southern part of the Delta-Mendota Canal--affected by 20 millimeters or more of subsidence during the same period. Calculations indicated that the subsidence rate doubled in 2008 in some areas. The GPS surveys done in 2008 and 2010 confirmed the high subsidence rate measured by using InSAR for the same period. Water levels in many shallow and deep wells in this area declined during 2007-10; water levels in many deep wells reached historical lows, indicating that subsidence measured during this period was largely inelastic. InSAR-derived subsidence maps for various periods during 2003-10 showed that the area of maximum active subsidence (that is, the largest rates of subsidence) shifted from its historical (1926-70) location southwest of Mendota to south of El Nido. Continued groundwater-level and land-subsidence monitoring in the San Joaquin Valley is important because (1) regulatory- and drought-related reductions in surface-water deliveries since 1976 have resulted in increased groundwater pumping and associated land subsidence, and (2) land use and associated groundwater pumping continue to change throughout the valley. The availability of surface water remains uncertain; even during record-setting precipitation years, such as 2010-11, water deliveries have fallen short of requests and groundwater pumping was required to meet the irrigation demand. Due to the expected continued demand for irrigation supply water and the limitations and uncertainty of surface-water supplies, groundwater pumping and associated land subsidence is likely to continue in the future. Spatially detailed information on land subsidence is needed to facilitate minimization of future subsidence-related damages to the Delta-Mendota Canal and other infrastructure in the San Joaquin Valley. The integration of subsidence, deformation, and water-level measurements--particularly continuous measurements--enables the analysis of aquifer-system response to increased groundwater pumping, which in turn, enables identification of the preconsolidation head and calculation of aquifer-system storage properties. This information can be used to improve numerical model simulations of groundwater flow and aquifer-system compaction and allow for consideration of land subsidence in the evaluation of water-resource management alternatives.
ACCESS: http://pubs.usgs.gov/sir/2013/5142/

LAND SUBSIDENCE AND EARTH FISSURES DUE TO GROUNDWATER PUMPING.
CITATION: Ibrahim Bahadir Adiyaman. , ProQuest Dissertations and Theses, 2012. The University of Arizona. United States -- Arizona.
ABSTRACT: In this research, the fundamental mechanics for the changes in stresses and strains states due to groundwater pumping is formulated. This was accomplished by developing a 3D closed form solution. The results from this research are compared with results of finite element (FE) analyses and data obtained from Interferometric synthetic aperture radar (InSAR). Land subsidence (LS) due to groundwater pumping from a single well for different geological profiles and the reason why LS continues after groundwater pumping cessation were investigated. FE analyses for four different scenarios were used to investigate the effects of cemented layers and non-cemented layers above the aquifer on EF initiation. A practical method which is based on the stiffness and cementation strength of the cemented layer and the gradient of the slope of the subsidence bowl (α) was proposed to determine earth fissure (EF) initiation. Three-point bending beam

test was conducted in the lab to determine the mode of failure and the modulus of rupture of a local cemented soil that occurs in areas where EFs were observed. The major findings are as follows. LS due to groundwater pumping consists of i) isotropic compression and ii) simple shear on vertical planes with rotation. For a parabolic distribution of groundwater level in a homogenous aquifer, simple shear on vertical planes will be dominant when the characteristic length of the aquifer is larger than [Special characters omitted.] times the aquifer thickness. Fine-grained soils are responsible for LS occurring after the cessation of pumping and for sagging in LS profiles. Regardless of the stiffness and cementation strength of the top layer above the aquifer, EF will not initiate if α is less than 8 ×10 -5 . When the stiffness of the top cemented layer increases, it becomes more prone to EF initiation. However if the layer is stiff enough to be classified as "rock" then a higher value of α is needed to initiate an EF. The experiments show that the preferred mode of failure of a cemented soil is shear rather than bending and existing cracks significantly influence the results of EF formation.
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LAND SUBSIDENCE AND GROUND FISSURES IN XI'AN, CHINA 2005-2012 REVEALED BY MULTI-BAND INSAR TIME-SERIES ANALYSIS.
CITATION: Feifei Qu, Qin Zhang, Zhong Lu, et al. , Remote Sens.Environ., 2014. , United States. Vol. 155, 366-376.
ABSTRACT: Xi'an, China has been undergoing significant land subsidence along with ground fissure development. These geohazards have brought about severe damages to buildings, bridges and other facilities. In order to warn of and mitigate disasters, it is urgently necessary to obtain the latest rate, extent, and temporal evolution of land subsidence in Xi'an. With multiple SAR datasets as well as leveling, GPS and ground water level of aquifers, we study and map the spatial and temporal evolution of land subsidence and ground fissures over Xi'an. First, 62 synthetic aperture radar (SAR) images acquired by Envisat, ALOS, and TerrSAR-X during 2005-2012 are used to form three independent interferometric stacks to unveil the spatial and temporal variations of land subsidence and ground fissures by using the time-series Interferometric synthetic aperture radar (InSAR) technique. GPS and leveling measurements are applied to calibrate the InSAR results. Precision of our InSAR annual subsidence results is less than 9mm. We derive the east-west and vertical components of the observed land deformation in 2009 using descending and ascending InSAR observations, finding out that the horizontal component of land deformation cannot be ignored if the deformation is large or ground fissures are active. Second, four main land subsidence zones are detected in Xi'an, with an average subsidence rate of 50mm/a during 2005-2012. Time-series InSAR results indicate that land subsidence rates in Xi'an increased by 200% from 2005-2007 to 2008-2010, extending existing ground fissures. Third, InSAR-derived land subsidence correlates with the change in ground water level, and seasonal variations in subsidence correlate with changes in ground water pumping. Last, the consistency on the spatial-temporal distribution variation between ground fissures and land subsidence could be drawn from the time series results and profile analysis. Shapes of subsiding zones follow the general trends of mapped ground fissures and main faults in an ENE direction. Changes in the subsidence gradient are also observed over most of the ground fissures and faults. Subsidence-triggered fissures can cause localized surface displacements, aggravate localized subsidence, discontinue the integrity of ground water flow, and limit the horizontal spread of subsidence funnels. With continuing mass construction projects in Xi'an, monitoring ground deformation with satellite InSAR therefore can provide efficient means to image land subsidence, movements of fissures and faults, and the associated geohazards.
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LAND SUBSIDENCE IN BEIJING CITY FROM INSAR TIME SERIES ANALYSIS WITH SMALL BASELINE SUBSET.
CITATION: Yongsheng Li, Jingfa Zhang, Zhenhong Li, et al. , Geomatics and Information Science of Wuhan University, 2013. Periodicals Press of Wuhan Technical University of Surveying and Mapping, Vol. 38, No. 11, 1374-1377.
ABSTRACT: To investigate land subsidence in Beijing city and its surrounding region, two adjacent descending tracks of Envisat images collected during the period from 2003 to 2010 were interferometrically processed and a time series analysis was applied to their small baseline interferograms to recover displacement evolution. A high correlation coefficient, 0.87, was observed between two mean velocity maps from the adjacent tracks. The small RMS difference, 4.9 mm/yr; provides strong supporting evidence for the InSAR time series results. Our findings suggest that Beijing city exhibited rapid subsidence in several key subsidence areas during 2003 and 2010 with an accelerating trend, especially during the period of 2007 to 2010. During this period, the maximum subsidence rate rose to 100 mm/a in some subsidence areas around Chaoyang and Tongzhou.
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LAND SUBSIDENCE IN TEHRAN DISTRICT, IRAN.
CITATION: Said Ghorbanbeigi and Jafar Najihamodi. , Sixth International Conference on Case Histories in Geotechnical Engineering and Symposium in Honor of Professor James K. Mitchell, 2008. Missouri University of Science and Technology.
ABSTRACT: Land subsidence is a worldwide phenomenon, where there is a sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion. In Iran, this phenomenon is noticed to take place in many areas among which are Meshhed, Kerman, Tehran, Hamedan and others. In some of the above areas, water well installations seem to rise into the air, or some times to produce fissures in the soil and/or showing sinkhole in carbonated rocks. Land subsidence could causes damages in surface and subsurface installations. UNISCO was concerning with this worldwide phenomenon and tried to study it in different parts of the world through groups of work by using GPS, SAR and InSAR techniques that uses radar satellite image. The Iranian authorities in cooperation with others were interesting to see the extension and reasons for Tehran's land subsidence by using the new InSAR techniques, which assured later on the existence of 2 profiles (namely NE-SW profile 1 and N-S profile 3) in a V shape in SW Tehran with 15 cm and 16 cm Land subsidence respectively. The subsidence is mainly due to depletion of aquifer (i.e. water level drop), which causes aquifer compaction.
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LAND SUBSIDENCE IN THE MODERN YELLOW RIVER DELTA BASED ON INSAR TIME SERIES ANALYSIS.
CITATION: Jin-Zhi Zhang, Hai-jun Huang and Hai-bo Bi. , Nat.Hazards, 2015. Springer Science+Business Media, Netherlands. Vol. 75, No. 3, 2385-2397.
ABSTRACT: To study the complex environmental characteristics of the modern Yellow River Delta (YRD), the Interferometric synthetic aperture radar (InSAR) time series analysis technique based on 39 ERS1/2 SAR images was applied to obtain the spatial distribution and temporal changes of ground displacement of the YRD in the period of 1992-2000. The results show that land subsidence in the modern YRD is widespread and unevenly distributed with large differences. The average subsidence rate is -5.1 mm/year, while the highest subsidence rate of -33.2 mm/year occurs in the subsidence funnel formed in an oil field. The results of the InSAR are reliable, when compared with those measured by leveling surveys. In combination with various thematic maps, i.e., the river channels and shoreline changes, the distribution of the soft soil thickness, the development of residential areas and oil fields over the corresponding time period, and the effects of the factors controlling the land subsidence processes were determined in representative regions. Our results reveal that the factors leading to the land subsidence of modern YRD include oil extraction, sediment consolidation and compaction, surface load increases, and groundwater extraction. Our analyses also show that sediment consolidation and compaction, and oil extraction play a key role in contributing to the land subsidence in the modern YRD.
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LANDSLIDE MONITORING OF HIGASHI-NARUSE DISTRICT IN AKITA PREFECTURE BY INSAR IMAGE OF ALOS/PALSAR DATA.
CITATION: Takaki Okatani, Hiroshi P. Sato, Takayuki Nakano, et al. , Journal of the Japan Society of Photogrammetry and Remote sensing, 2013. Japan Society of Photogrammetry and Remote sensing. Vol. 51, No. 2, 95-102.
ABSTRACT: InSAR image is well-known as detecting crustal movement in wide area when hazardous events like earthquakes and volcanic activities occur. In addition to grasping such wide movement, small and regional movements like landslide can be also detected from InSAR image. On the basis of the previous study on Noto Hanto Earthquake in 2007, the authors delved into possibility of the detection and monitoring at Higashi-Naruse village in Akita prefecture using ALOS/PALSAR data in this study. Also, landslide delimitation was done by making out micro-topography map created by air-borne laser data.
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LARGE-SCALE DEFORMATION MONITORING IN MINING AREA BY D-INSAR AND 3D LASER SCANNING TECHNOLOGY INTEGRATION.
CITATION: Bingqian Chen, Kazhong Deng, Hongdong Fan, et al. , International Journal of Mining Science and Technology, 2013. , Netherlands. Vol. 23, No. 4, 555-561.
ABSTRACT: Large-scale deformation can not be detected by traditional D-InSAR technique because of the limit of its detectable deformation gradient, we propose a method that combines SAR data with point cloud data obtained by 3D laser scanning to improve the gradient of deformation detection. The proposed method takes advantage of high-density of 3D laser scanning point cloud data and its high precision of point positioning after 3D modeling. The specific process can be described as follows: first, large-scale deformation points in the interferogram are masked out based on interferometric coherence; second, the interferogram

with holes is unwrapped to obtain a deformation map with holes, and last, the holes in the deformation map are filled with point cloud data using inverse distance weighting algorithm, which will achieve seamless connection of monitoring region. We took the embankment dam above working face of a certain mining area in Shandong province as an example to study large-scale deformation in mining area using the proposed method. The results show that the maximum absolute error is 64 mm, relative error of maximum subsidence value is 4.95%, and they are consistent with leveling data of ground observation stations, which confirms the feasibility of this method. The method we presented provides new ways and means for achieving large-scale deformation monitoring by D-InSAR in mining area.
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MAXIMUM-LIKELIHOOD ESTIMATION FOR MULTI-ASPECT MULTI-BASELINE SAR INTERFEROMETRY OF URBAN AREAS.
CITATION: Michael Schmitt and Uwe Stilla. , ISPRS Journal of Photogrammetry and Remote sensing, 2014. , Netherlands. Vol. 87, 68-77.
ABSTRACT: The reconstruction of digital surface models (DSMs) of urban areas from Interferometric synthetic aperture radar (SAR) data is a challenging task. In particular the SAR inherent layover and shadowing effects need to be coped with by sophisticated processing strategies. In this paper, a maximum-likelihood estimation procedure for the reconstruction of DSMs from multi-aspect multi-baseline InSAR imagery is proposed. In this framework, redundant as well as contradicting observations are exploited in a statistically optimal way. The presented method, which is especially suited for single-pass SAR interferometers, is examined using test data consisting of experimental airborne millimeterwave SAR imagery. The achievable accuracy is evaluated by comparison to LiDAR-derived reference data. It is shown that the proposed estimation procedure performs better than a comparable non-statistical reconstruction method.
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MECHANICS OF INSAR-IDENTIFIED BEDROCK SUBSIDENCE ASSOCIATED WITH MINE-DEWATERING IN NORTH-CENTRAL NEVADA.
CITATION: Kurt W. Katzenstein. , ProQuest Dissertations and Theses, 2008. University of Nevada, Reno. United States -- Nevada.
ABSTRACT: In terferometric S ynthetic A perture R adar, or InSAR, has proven to be an invaluable tool for ground motion studies in the geosciences. It was not until recently that InSAR has been used extensively for the delineation of aquifer system response to heavy groundwater pumping. A number of studies have demonstrated the vastly improved spatial resolution afforded by InSAR relative to traditional surveying techniques in detecting groundwater-related subsidence. Ground subsidence related to mine dewatering is a common occurrence due to the large volumes of water that are pumped in order to lower the local groundwater table to facilitate open pit and underground mining operations. Several mines located along the Carlin Trend of Central Nevada have produced InSAR identified subsidence signals of greater aerial extent and magnitude than most municipal groundwater signals. The dewatering signal at Betze-Post shows a minimum of 45.8 cm of cumulative subsidence between June 1, 1992 and September 21, 2000. Our study has created many (>50) interferograms, allowing a better understanding of how the subsidence signal evolved in response to varied pumping rates from dewatering wells. The deformation signal correlates well with the observed groundwater drawdown characteristics. However, since the spatial resolution of the InSAR is much better than that of the monitoring well locations, the complexity of the signal is better delineated. The maximum aerial extent of the subsidence feature extends as far as 20 km away from the location of the extraction wells used for dewatering. Of greatest interest is the fact that this subsidence signal exists mostly in areas of very shallow or exposed bedrock. Groundwater related bedrock subsidence of this scale is rarely, if ever, observed, and therefore, poorly understood. This study utilizes InSAR results to devise a simple, one dimensional bedrock subsidence model that utilizes easily obtained rock mass characteristics.
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MEO SAR SYSTEM CONCEPTS AND TECHNOLOGIES FOR EARTH REMOTE SENSING.
CITATION: Curtis W. Chen and Alina Moussessian. , Space 2004 Conference and Exhibit; San Diego, CA; USA; 28-30 Sept. 2004, 2004.
ABSTRACT: Next-generation Interferometric synthetic aperture radar (InSAR) systems may provide the basis for establishing an earthquake-forecasting capability within a twenty-year time frame. Such systems would need to provide data with fine temporal resolution, so the system architecture would need to allow for wide-area coverage in order to minimize the effective Interferometric repeat time. This paper discusses the coverage advantages associated with medium-Earth orbit (MEO) InSAR systems for observing geophysical phenomena. As MEO architectures dictate the need for large radar antennas, this paper also presents a discussion of advanced antenna technologies - and associated challenges - that might provide revolutionary

decreases in the mass densities of large radar aperture antennas.
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A METHOD OF TOPOGRAPHIC CHANGE DETECTION BASE INSAR TERRAIN MATCHING TECHNOLOGY.
CITATION: S-W Yin and Q. Shao. , Geomatics and Information Science of Wuhan University, 2010. Periodicals Press of Wuhan Technical University of Surveying and Mapping. Vol. 35, No. 1, Pg. 119-121.
ABSTRACT: This paper studies the lower accuracy of Position and Attitude Measurement Device in InSAR system and puts forward a method of topographic change detection base on terrain matching. This is a new method in topographic change detection with InSAR data. It can improve the degree of automation data processing in topographic change detection with poor Direct Georeferencing of InSAR system.
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MONITORING LAND SUBSIDENCE IN CANGZHOU REGION USING INSAR TECHNOLOGY.
CITATION: Qing-cheng He, Zhi-lei Fang, Zhi-ming Li, et al. , Dixue Qianyuan / Earth Science Frontiers, 2006. China University of Geosciences, Vol. 13, No. 1, Pg. 179-184.
ABSTRACT: With development of cities, damage due to land subsidence becomes more and more severe. Although routine measures for determining subsidence have higher accuracy, their costs are very high, their sample density is very low, and their intervals between determinations are very long. Accordingly, routine techniques cannot satisfy the demands of modern society. Interferometric synthetic aperture radar (InSAR) has become the technique in their place, with the most potential. It can sample densely, measure land subsidence in short intervals, and its cost is cheaper. For example, in the region of Cangzhou, land subsidence had amounted up to 2 236 mm in 2001. This paper introduces the essential principles of Interferometric synthetic aperture radar (InSAR) and the processing of InSAR data. In addition, it reports an experimental InSAR land subsidence study in the Cangzhou region. Results of the Cangzhou region study are reported and the utility of the InSAR methodology is discussed.
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MONITORING LAND SUBSIDENCE IN GUANGZHOU AND FOSHAN USING INSAR.
CITATION: Hua Wang, Ying-Ping Yu and Li-Long Jiang. , Science of Surveying and Mapping, 2014. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 39, No. 7, 67-71.
ABSTRACT: Aiming at the study of land surface subsidence monitoring, the paper used InSAR and ESA's Envisat/ASAR radar images to measure the magnitude and extent of land subsidence in Guangzhou and Foshan. The result showed that most of the region is stable, with land subsidence rate of less than 2mm/yr, but the maximum is up to 6mm/yr~8mm/yr. Considering that global sea level rise is up to about 3 mm/yr and the this region has low elevation (less than 2 meters in most parts), more attentions should be paid to the threat of land subsidence and sea level rise. The result could provide a reference to the subsidence monitoring and hazard prevention for other river deltas.
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MONITORING OF GROUND DEFORMATION WITH PS INSAR.
CITATION: Ming-Lian Jiao and Ting-Chen Jiang. , Quanqiu Dingwei Xitong / GNSS World of China, 2008, Vol. 33, No. 4, Pg. 7-10.
ABSTRACT: Monitoring of Ground Deformation with InSAR is one of the most advanced research topics for remote sensing study nowadays in the world, which can be improved by PS InSAR. The factors restricting the application of InSAR in monitoring of ground deformation is analysed, the basic principles and key technologies of data processing in PS InSAR is introduced, and its developmental tendency based on the present application of PS InSAR home and abroad is forecasted.
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MULTICHANNEL ALONG-TRACK INTERFEROMETRIC SAR SYSTEMS: MOVING TARGETS DETECTION AND VELOCITY ESTIMATION.
CITATION: Alessandra Budillon, Vito Pascazio and Gilda Schirinzi. , International Journal of Navigation and Observation, 2008. Hindawi Publishing Corporation. Vol. 2008, Pg. 16p.
ABSTRACT: In this paper, the authors review the problem of detecting the presence of a ground moving target and estimating its radial velocity by means of along-track inteferometric synthetic aperture radar (AT-InSAR) systems, mounted on moving platforms. This kind of system can be used, for example, for continuous (day and night and with any weather condition) traffic monitoring. Along-track Interferometric synthetic aperture radar (AT-InSAR) systems are used to estimate the radial velocity of targets moving on the ground, starting from the Interferometric phases, obtained by the combinations of two complex SAR images acquired

by two antennas spatially separated along the platform moving direction. Since the radial velocity estimation obtained from a single-phase interferogram (single-channel) suffers from ambiguities, multichannel AT-InSAR systems using more than one interferogram can be used. In this paper, the authors first analyze the moving target detection problem, evaluating the systems performance in terms of probability of detection and probability of false alarm obtained with different values of target radial velocity, signal-to-clutter ratio, and clutter-to-thermal noise ratio. They then analyze the radial velocity estimation accuracy in terms of Cramer-Rao lower bounds and of mean square error values, obtained by using a maximum likelihood estimation technique. They consider the cases of single-baseline and dual-baseline satellite systems, and we evaluate the detection and estimation performance improvement obtained in the dual-baseline case with respect to the single-baseline one. Sensitivity of the presented method with respect to the involved target and system parameters is also discussed.
ACCESS: http://www.hindawi.com/journals/ijno/2008/310656.html

MULTICHROMATIC ANALYSIS OF INSAR DATA.
CITATION: Fabio Bovenga, Vito Martino Giacovazzo, Alberto Refice, et al. , IEEE Trans.Geosci.Remote Sens., 2013. Institute of Electrical and Electronics Engineers, Inc. United States. Vol. 51, No. 9, 4790-4799.
ABSTRACT: The multichromatic analysis (MCA) uses interferometric pairs of SAR images processed at range subbands and explores the phase trend of each pixel as a function of the different central carrier frequencies to infer absolute optical path difference. This approach allows retrieving unambiguous height information on selected pixels, potentially solving the problem of spatial phase unwrapping, which is instead critical in the standard monochromatic processing. The method, based on concepts originally introduced by Madsen and Zebker, has been developed in previous work both theoretically and through simulations. This paper presents the first MCA experimental validation of the procedure, through application to a wideband SAR single-pass interferometric data set acquired by the AES-1 airborne sensor. An evaluation of the impact of the MCA processing parameters on the height estimation performances is obtained through a parametric analysis. The results confirm the indications derived by the theoretical analysis, demonstrating the feasibility of the MCA absolute phase measurement, provided that a sufficient bandwidth is available.
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MULTI-PHASE-CENTER IFSAR.
CITATION: DeLaurentis, J.; Bickel, D. Sandia National Labs., Albuquerque, NM.; Department of Energy, Washington, DC., 2006, 45 p.
ABSTRACT: The authors present new methods for resolving IFSAR ambiguities and SAR layover. The analytic properties of these techniques make them well suited for reliable, efficient computation.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=DE2006877713

A NOVEL MULTITEMPORAL INSAR MODEL FOR JOINT ESTIMATION OF DEFORMATION RATES AND ORBITAL ERRORS.
CITATION: Lei Zhang, Xiaoli Ding, Zhong Lu, et al. , IEEE Trans.Geosci.Remote Sens., 2014. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 52, No. 6, 3529-3540.
ABSTRACT: Orbital errors, characterized typically as longwavelength artifacts, commonly exist in Interferometric synthetic aperture radar (InSAR) imagery as a result of inaccurate determination of the sensor state vector. Orbital errors degrade the precision of multitemporal InSAR products (i.e., ground deformation). Although research on orbital error reduction has been ongoing for nearly two decades and several algorithms for reducing the effect of the errors are already in existence, the errors cannot always be corrected efficiently and reliably. We propose a novel model that is able to jointly estimate deformation rates and orbital errors based on the different spatial-temporal characteristics of the two types of signals. The proposed model is able to isolate a long-wavelength ground motion signal from the orbital error even when the two types of signals exhibit similar spatial patterns. The proposed algorithm is efficient and requires no ground control points. In addition, the method is built upon wrapped phases of interferograms, eliminating the need of phase unwrapping. The performance of the proposed model is validated using both simulated and real data sets. The demo codes of the proposed model are also provided for reference.
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PARALLEL PROCESSING OF INSAR INTERFEROGRAM FILTERING WITH CUDA PROGRAMMING.
CITATION: Sheng Gao, Qi-Ming Zeng, Jian Jiao, et al. , Science of Surveying and Mapping, 2015. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 40, No. 1, 67-88, 67.
ABSTRACT: As an important step in InSAR processing, interferogram filtering is one of the most time-consuming step. In the paper, a method of filtering acceleration based on GPU aiming at the widely used Goldstein filtering algorithm was proposed, the filtering effects were quantitatively evaluated, and the relationship between the filtering time with GPU and the data volumes and the filtering kernel sizes were

discussed then. Furthermore, the drawbacks of current GPUs in parallel computing were pointed out. Experimental result proved that the method could achieve the same accuracy as CPUs do, with a speedup ratio as high as 22.
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PHASE UNWRAPPING APPROACH USING EQUIVALENT RESIDUES FOR INSAR.
CITATION: Rui Jiang, Daiyin Zhu and Zhaoda Zhu. , J.Nanjing Univ.Aeronaut.Astronaut., 2013. Nanjing University of Aeronautics & Astronautics, China. Vol. 45, No. 2, 209-216.
ABSTRACT: A two-dimensional phase unwrapping approach using equivalent residues is proposed for Interferometric synthetic aperture radar (InSAR). In the proposed approach, the relationship between quality map and residues is used to find out the low quality unreliable regions, which are residues dense distribution and regarded as equivalent residues. Then, different phase unwrapping strategies are applied to different quality regions. With this methodology, integration path crossing of unreliable regions, which may produce a phase error propagating to all the pixels in integration path, is prevented because that the unreliable regions are treated as equivalent residues. Each pixel inside equivalent residue is unwrapped based on its unwrapped neighbors, which allows the absolute value of phase gradient between two adjacent pixels larger than pi . Simulated and real SAR data validate the new approach.
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POINT TARGET INTERFEROMETRY AS APPLIED TO THE CHARACTERIZATION OF LOCALIZED DEFORMATION FEATURES.
CITATION: Deepak Manjunath. , ProQuest Dissertations and Theses, 2008. University of Missouri - Columbia. United States -- Missouri.
ABSTRACT: Monitoring of ground deformation is a critical component of geotechnical engineering practice. This study investigated the application of synthetic aperture radar interferometry (InSAR) using point target analysis (IPTA) for detecting and characterizing localized deformation features that are often associated with geotechnical engineering activities. In contrast to discrete point in-situ deformation measurement techniques, InSAR can be used to obtain a broader view of deformation processes at a site. The objectives of this research were to (1) evaluate the feasibility of using IPTA to detect localized deformation features, (2) investigate the influence of SAR data characteristics on the ability to successfully apply IPTA processing and (3) quantify the dependence of the IPTA-derived deformation estimates on the number of SAR acquisitions used to constrain the analysis. To address these objectives, 52 SAR scenes acquired over Los Angeles, CA, during construction of the Los Angeles Metro Rail Red Line between 1992 and 2000 were used. This site was chosen due to the availability of extensive SAR data and the known occurrence of localized settlements along the Red Line alignment during construction. Results from IPTA processing of the complete dataset successfully demonstrated the ability to detect the localized deformations associated with the subway construction. Deformation time histories for points along the Red Line alignment exhibited episodic settlements that were not observed for points located away from the alignment. To address the second objective of this study, IPTA processing was applied to subsets of the 52 SAR acquisitions available for the site. The number of Interferometric pairs required for successfully applying point target analysis without patch errors was found to range between 20 and 25. The average baseline of interferograms constituting a dataset was hypothesized to have a dominant influence on the ability to successfully apply IPTA processing to a dataset. However, no clear baseline dependence was identified. To address the third objective, the variability of the estimated rate of deformation was estimated using the standard deviation from one thousand runs of the IPTA analysis as applied to datasets of varying sizes. Irrespective of the deformation rate of a point target, the variability of the estimated deformation rates was found to vary inversely with the size of the dataset used to constrain the analysis. In addition, the coefficient of variation of deformation rates was observed to decrease with an increase in the size of the dataset used for analysis. Irrespective of the deformation rate of a point target, both the mean and the standard deviation of the associated uncertainty (U G) was observed to decrease with an increase in the size of the dataset used for IPTA analysis.
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POLARIMETRIC INTERFEROMETRIC EXPERIMENT TRIALS FOR YEARS 2001 AND 2002: EXPERIMENT DESIGN GROUND TRUTHING DATA QUALITY AND ANALYSIS.
CITATION: Yeremy, M.; Livingstone, C.; Mattar, K.; Gallop, L.; Lang, J. Defence Research and Development, Ottawa, Canada. (Ontario), 2003, 148p.
ABSTRACT: Synthetic aperture radar (SAR) theory has several disciplines which includes Polarimetric SAR (PolSAR) and Interferometric SAR (InSAR). Recent research in the past decade has introduced a new method which utilizes both of these disciplines and is called Polarimetric Interferometric SAR (Pol InSAR). Research to date has been focussed on determining forest heights from interferograms constructed from PolSAR data which has been decomposed so that the data can be preferentially weighted with respect to dominant

environmental scattering mechanisms associated with a forest. In this way, phase difference interferograms can be constructed utilizing forest foliage scattering and ground interaction near the forest floor information, in order to estimate forest heights. While these applications are of some interest to Department of National Defence (DND) Canada (i.e. Mapping and Charting), the Experimental Trials, documented here, were designed for utilizing both conventional Pol InSAR methods and developing new Pol InSAR methods specifically for military applications. Three Trials collected repeat pass Pol InSAR data for several experiments. The data were collected by Environmental Canada's SAR C/X system which has similar properties to the future RADARSAT 2. Key areas of Pol InSAR research associated with this study include: (1) motion effects and motion detection with PolSAR and Pol InSAR data, and (2) the utilization of propagation models for inversion of military targets such as tall obstructions, maritime vessels, internal and external building attributes. The experiment design and ground truthing are documented here in reference to the objectives. Some preliminary results and comments regarding lessons learned are also documented. This technical memorandum is a companion to another DRDC report which documents a Pol InSAR literature review and DND objectives for the Pol InSAR project experiments, and simulation results.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA418214

POLARIMETRIC INTERFEROMETRIC SAR: LITERATURE REVIEW AND AN ASSESSMENT OF ITS UTILITY FOR DND: TIF PROJECT MEMORANDUM.
CITATION: Mattar, K. E.; Yeremy, M. L.; Livingstone, C. Defence Research and Development, Ottawa, Canada. (Ontario), 2003, 29p.
ABSTRACT: Polarimetric Interferometric Synthetic aperture radar (SAR) is a recent area of research that has had significant attention from the mid-1990s. This area of research has combined the utility of two SAR technologies: Polarimetric SAR (PolSAR) and Interferometric SAR (InSAR). Polarimetric SAR provides four channels which can be used to determine the polarimetric ellipse, and hence, structural information of the scatterer. Therefore PolSAR is suitable for target recognition and detection applications. InSAR data combines two SAR image data sets acquired from nearly the same perspective. The phase difference between these images provides information about the topography, or changes in the topography between the two image dates. InSAR methods have been used to map terrains, detect environmental changes and determine velocities of moving targets. By combining both technologies, polarimetric InSAR (Pol InSAR) permits distinction between different distributed targets at different elevations. In particular, most current research is investigating use of this technology for measuring the height of forest, and to help estimate its biomass. Other applications under research include terrain moisture estimation, terrain roughness estimation, and (of more interest in mapping applications) vertical obstruction detection.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA418212

POTENTIAL OF SMALL-BASELINE SAR INTERFEROMETRY FOR MONITORING LAND SUBSIDENCE RELATED TO UNDERGROUND COAL FIRES: WUDA (NORTHERN CHINA) CASE STUDY.
CITATION: Liming Jiang, Hui Lin, Jianwei Ma, et al. , Remote Sens.Environ., 2011. Elsevier Science. United States. Vol. 115, No. 2, Pg. 257-268.
ABSTRACT: Uncontrolled coal fires can result in massive surface displacements due to the change in volume of burning coal and thermal effects in the adjacent rock mass; simultaneously, the resultant surface breakings provide greater access to air and water that in turn can aggravate the problem of underground coal seam burning. In this case study, we have investigated the feasibility and potential of detecting the land subsidence accompanying coal fires by means of satellite InSAR observations. Three groups of small-baseline InSAR approaches (PSI, stacking and 2-passDInSAR) were applied to the Wuda coalfield (Northern China) to reveal the spatial and temporal signals of the land subsidence in the areas affected by the coal fires. The Interferometric results agree well with GPS observations and coal fire data obtained by field investigation, which demonstrates that the small-baseline InSAR techniques have remarkable potential to detect this land subsidence of interest. In particular, our results show that the development of coal fires can lead to new subsiding areas and also accelerate the ongoing surface subsidence, typically within the areas of mature coal fires, through a comparison of the Interferometric observations and the multi-temporal coal fire maps. This timely and reliable information on land subsidence will be useful for the detection and mapping of the coal fire affected regions and thereby assist in fighting and controlling coal seam burning.
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PRE-, CO-, AND POST- ROCKSLIDE ANALYSIS WITH ALOS/PALSAR IMAGERY: A CASE STUDY OF THE JIWEISHAN ROCKSLIDE, CHINA.
CITATION: C. Zhao, Q. Zhang, Y. Yin, et al. , Natural Hazards and Earth System Sciences, 2013. European Geosciences Union. France. Vol. 13, No. 11, 2851-2861.
ABSTRACT: On 5 June 2009, a catastrophic rockslide debris flow occurred at the crest of the Jiweishan range, Chongqing Municipality, China, killing 74 people and injuring an additional eight. We use L-band

ALOS/PALSAR imagery to address landslide processes before, during and after the slide. We employ three different SAR methods, i.e., short baseline subsets (SBAS) interferometric SAR (InSAR), SAR backscattering intensity change, and InSAR stacking algorithm, to study any ground deformation before the rockslide, investigate the affected area, and calculate the topographic change by this slide, respectively. First, continuous deformation has been observed based on the available ALOS/PALSAR InSAR imagery during June and December 2007. Second, the area affected by the landslide can be inferred based on changes in SAR backscattering intensity as well as surface topography, with an estimated area of 0.47 million m super(2). Last, an InSAR-derived post-slide digital elevation model has allowed us to estimate surface height changes due to the slide, reaching about -80 m at the source region and about 60 m in the deposit region, respectively. Our InSAR-derived estimates have been validated using in situ data and 3-D lidar measurements.
ACCESS: http://www.nat-hazards-earth-syst-sci.net/13/2851/2013/nhess-13-2851-2013.html

PROCESSING OF SYNTHETIC APERTURE RADAR DATA AS APPLIED TO THE CHARACTERIZATION OF LOCALIZED DEFORMATION FEATURES.
CITATION: Richard A. Coffman. , ProQuest Dissertations and Theses, 2009. University of Missouri - Columbia. United States -- Missouri.
ABSTRACT: Satellite-based Interferometric synthetic aperture radar (InSAR) has been used by the Geoscience community for many years to obtain ground deformation measurements of large-scale spatial features. Researchers have also begun applying InSAR to detect small-scale spatial features associated with geotechnical engineering applications. However, there is a significant lack of understanding on how to obtain ground deformation measurements associated with civil infrastructure because of the generally large spatial resolution of the imagery as compared with the limited spatial scale of the deformation features. In this study, InSAR processing techniques were evaluated for two demonstration sites to enhance the understanding of detection of small-scale spatial features. The sites consist of a predominately urban site (Los Angeles, California, USA) and a predominately rural site (outside of Mosul, Iraq). Both sites are known to have experienced localized deformation associated with construction of the Los Angeles Red Line subway tunnel system and deformation associated with gypsum dissolution causing subsidence of Mosul Dam. A parametric study was conducted using the Los Angeles site to evaluate spatial phase unwrapping parameters. Thirty-three combinations of parameters (multi-looking, filter size, filter type, and coherence mask threshold) were investigated. The combination of parameters that provided the least amount of filtering (least amount of multi-looking, smallest filter size, and no coherence mask threshold) produced output in which the feature associated with the Los Angeles Red Line construction deformation was most readily observable. In addition to minimal filtering, stacking image pairs that just spanned the time of construction provided the best results. Three spatial ("traditional", "spatial", and "enhanced spatial") and two time-dependent ("Interferometric Point Target Analysis (IPTA)" and "multiple baseline") InSAR processing techniques were evaluated for the Los Angeles site. The "spatial", "enhanced spatial", and "multiple baseline" InSAR processing techniques were also evaluated for the Mosul Dam site. The "enhanced spatial" processing technique using minimal multi-looking (1 and 5 looks), a very small filtering window size (2), and no coherence mask produced the best output for the Los Angeles Red Line site. The "multiple baseline" technique produced images in which the progression of the tunnel boring with time was detected but these images contain more speckle than those produced using the enhanced spatial method. The "spatial" processing technique using minimal multi-looking (1 and 5 looks), a small window size (8), and a coherence mask threshold of 50 percent produced the best output for the Mosul Dam site. In addition to the subsidence feature associated with the movement of the dam displayed in the "spatial" processing output, subsidence features associated with sinkholes around the dam were detected using the "enhanced spatial" processing technique. InSAR coverage allows for the detection of small movements (<1 cm) covering small spatial extents (<100 meters) by scanning large areas (100 km2) instead of or in addition to current surveying practices which provide spatially limited point measurements. This coverage and the ability to conduct deformation investigations on civil infrastructure using archived InSAR data make the use InSAR well suited for geotechnical engineering applications.
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QUANTIFICATION OF MASS WASTING VOLUME ASSOCIATED WITH THE GIANT LANDSLIDE DAGUANGBAO INDUCED BY THE 2008 WENCHUAN EARTHQUAKE FROM PERSISTENT SCATTERER INSAR.
CITATION: Qiang Chen, Haiqin Cheng, Yinghui Yang, et al. , Remote Sens.Environ., 2014. , United States. Vol. 152, 125-135.
ABSTRACT: The spaceborne Interferometric synthetic aperture radar (InSAR) with persistent scatterer (PS) is utilized to retrieve the spatial characteristics of the largest coseismic landslide Daguangbao, induced by the Ms 8.0 Wenchuan earthquake in Sichuan Province, China. The available twenty interferometric pairs with good coherence selected from the ALOS/PALSAR imagery data covering the Longmen Shan mountainous area are

used in the study. We have constructed a natural geodetic observation network with numerous scattered bare rocks emerging after the earthquake and coseismic landslide events, which are effectively recognized as the radar persistent scattering objects. The spatial connections between adjacent PS are established to form observation baselines with differential parameters related to topography and deformation, which are determined by the least squares method from time-series interferometric phase analysis. The post-seismic topographic change relative to the pre-seismic over the landslide area is spatially mapped from the PS network adjustment solution. The quantitative estimation of local elevation change, mass sliding volume and deposit thickness associated with the landslide is conducted. The spatial pattern of mass movement suggests that the giant landslide is characterized by a major sliding length of 4350m along the NE-SW directions with an extension width of 3400m along the Huangdongzi gully, and a peak height change of 535m in the vertical direction. The affected area of landslide mass movement reaches 7.2km2 with the volume up to 1.28billion m3. The study also demonstrates the potential of persistent scatterer InSAR technique as an alternative to allow the quantitative measurement of mass wasting volume associated with earthquake-induced giant landslides.
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RECENT LAND SUBSIDENCE CAUSED BY THE RAPID URBAN DEVELOPMENT IN THE HANOI REGION (VIETNAM) USING ALOS INSAR DATA.
CITATION: V. K. Dang, C. Doubre, C. Weber, et al. , Natural Hazards and Earth System Sciences, 2014. European Geosciences Union. France. Vol. 14, No. 3, 657-674.
ABSTRACT: Since the 1990s the land subsidence due to the rapid urbanization has been considered a severely destructive hazard in the center of Hanoi City. Although previous studies and measurements have quantified the subsiding deformation in Hanoi center, no data exist for the newly established districts in the south and the west, where construction development has been most significant and where groundwater pumping has been very intensive over the last decade. With a multi-temporal InSAR approach, we quantify the spatial distribution of the land subsidence in the entire Hanoi urban region using ALOS images over the 2007-2011 period. The map of the mean subsidence velocity reveals that the northern bank of the Red River appears stable, whereas some areas in southern bank are subsiding with a mean vertical rate up to 68.0 mm yr super(-1), especially within the three new urban districts of Hoang Mai, Ha Dong - Thanh Xuan and Hoai Duc - Tu Liem. We interpret the spatial distribution of the surface deformation as the combination of the nature of the unsaturated layer, the lowering of groundwater in the aquifers due to pumping withdrawal capacity, the increase of built-up surfaces and the type of building foundation. The piezometric level in Q sub(p) aquifer lowers particularly after 2008, whereas the groundwater level in Q sub(h) aquifer remains steady, even if it loses its seasonal fluctuation in urban areas and drawdowns in neighboring water production plants. The time evolution deduced from the InSAR time series is consistent with previous leveling data and shows that the lowering rate of the surface slightly decreases till 2008. The analysis of groundwater levels in instrumented wells shows a correlation between the behavior of groundwater with the urban development and the acceleration of groundwater withdrawal. Also, the time variations suggest that the deformation became non-stationary, with upward and downward transient displacements related to the charge and discharge of the aquifers.
ACCESS: http://www.nat-hazards-earth-syst-sci.net/14/657/2014/nhess-14-657-2014.html

REGIONAL SUBSIDENCE STABILITY EVALUATION ALONG JINGJIN HIGH-SPEED RAILWAY BASED ON MT-INSAR.
CITATION: Hongyun Shi, Guang Liu and Songlin Yang. , Beijing Jiaotong Daxue Xuebao (Journal of Beijing Jiaotong University), 2014. Beijing Jiaotong University, Vol. 38, No. 6, 78-81.
ABSTRACT: There are a series of strict limits for the high-level track regularity and the stability of sub-rail foundation of high-speed railway (HSR), while the subsidence along HSR with a large geographic scope can't be acquired effectively in time by the traditional ground surveying methods, which make the stability evaluation of the rail difficult and threaten the safety of the running trains. Multi-temporal SAR interferometry (MT-InSAR) technique is adopted to monitor the subsidence along Jingjin HSR (Yongle-Tianjin segment) based on C-band SAR data from Feb. 2007 to Jul. 2010 in the study area. Average subsidence velocity of vertical section varying with time along HSR is extracted as well as the average subsidence rate of change curve. The characteristics of subsidence are comparatively analyzed and the results indicate that the subsidence difference value has a crucial influence on the stability of the lines. The subsidence classification is divided and the stability evaluation of the lines is put forward, which are significant and practical to operate and maintain the rail lines.
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RESEARCH ON GROUND SUBSIDENCE MONITORING OF TIANJIN AREA BASED ON D-INSAR TECHNIQUE.

CITATION: Tao Wang, Li-Juan Gu, Hua-Ming Zhan, et al. , Science of Surveying and Mapping, 2013. Zhongguo Cehui Kexue Yanjiuyan, China. Vol. 38, No. 6, 49-51.
ABSTRACT: In this paper, ENVISAT ASAR images were processed by D-InSAR technique to acquire ground subsidence distribution maps from 2006 to 2009 in Tianjin region. The D-InSAR results were used to analyze the ground subsidence displayed through profiles, contour lines and 3D views. Finally, numerous error sources in InSAR were analyzed roughly. Comparing with leveling data, D-InSAR could give the distribution of ground subsidence area clearly and reliably. Furthermore, the range and location of the ground subsidence with D-InSAR method were basically consistent with the actual range and location. The subsidence magnitude was consistent with the leveling data.
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RESEARCH ON MINE SUBSIDENCE WITH INTERFEROMETRIC SYNTHETIC APERTURE RADAR.
CITATION: L. Yan and C. -Y Zhao. , Meitan Jishu / Coal Technology, 2009. Harbin Coal Mine Machinery Research Institute. Vol. 28, No. 10, Pg. 117-118.
ABSTRACT: Land subsidence of coal mining is a typical geo - hazard. While Interferometric synthetic aperture radar (InSAR) technique can be applied to the monitoring of land subsidence history and evolution of coal mining since 1990s. This paper mainly focuses on the monitoring of Daliuta Coal Mine, Shanbei region with D - InSAR, and the errors from DEM and atmospheric effects are discussed.
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THE RESEARCH PROGRESS IN MEASUREMENT OF FAULT ACTIVITY BY TIME SERIES INSAR AND DISCUSSION OF RELATED ISSUES.
CITATION: Chun-Yan Qu, Xin-Jian Shan, Guo-Hong Zhang, et al. , Dizhen Dizhi (Seismology and Geology), 2014. Institute of Geology, China Earthquake Administration,. Vol. 36, No. 3, 731-748.
ABSTRACT: In the past few years, the improved InSAR technology based on time series analyses to many SAR images has been used for measurement of interseismic deformation along active fault. In the paper, we first made a summary and introduction to the basic principle and technical characteristics of existing Time Series InSAR methods(such as Stacking, PSInSAR, SBAS). Then we presented a case study on the central segment of Haiyuan Fault in west China. We attempt to use the PS-InSAR(Permanent Scatter InSAR)technique to estimate the motion rate fields of this fault. We processed and analyzed 17 scenes of ENVISAT/ASAR images in descending orbits from 2003-2010 using the PS-InSAR method. The results reveal the whole movement pattern around the Haiyuan Fault and a remarkable velocity gradient of about 5mm/a across the central segment of the fault. The motion scenes are consistent with left-lateral strike-slip. On this basis, we make a discussion on some issues about observation of fault activity using Time Series InSAR methods, such as the changes of LOS deformation rates with fault strike and region width observed across a fault, fault reciprocity and motion style indicated by Time Series InSAR rate map and the relationship between the InSAR LOS deformation and the ones from other methods. All these studies will benefit the promotion of InSAR application in detection of tectonic movement.
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SIMULATED ANALYSIS AND OPTIMIZATION OF A THREE-ANTENNA AIRBORNE INSAR SYSTEM FOR TOPOGRAPHIC MAPPING.
CITATION: G. Corsini, M. Diani, F. Lombardini, et al. , IEEE Trans.Geosci.Remote Sens., 1999. Institute of Electrical and Electronics Engineers, Inc , Piscataway, NJ, Vol. 37, No. 5, Pg. 2518-2529.
ABSTRACT: A three-antenna synthetic aperture radar interferometer (InSAR) with a statistically optimal data processor for three-dimensional (3D) terrain mapping has been proposed recently to reduce the phase ambiguity and data-noise drawbacks of the conventional two-antenna SAR interferometry technique. In this paper, a numerical simulator is developed to assess the achievable performance and various design tradeoffs of the three-antenna InSAR. The most critical conditions for the new reduced-ambiguity system operating on realistic scenes are taken into account. The phase-unwrapping procedure is included in the simulator to compare the new and the conventional technique in terms of both phase and height-estimation accuracy. The performance achievable by a three-antenna airborne InSAR system on a given site are analyzed, and the parameter optimization of the new system is investigated. The results of several case studies show that the new technique can outperform the conventional one significantly for a typical airborne configuration, especially for high-terrain steepness. It provides reduced-phase aliasing and better estimation accuracy. So, the phase unwrapping Is simplified and high-quality maps of terrain height can be obtained. As a limit, absolute phase retrieval can be achieved with good accuracy and the unwrapping procedure can be avoided.
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SPARSE REGULARIZATION OF INTERFEROMETRIC PHASE AND AMPLITUDE FOR INSAR IMAGE FORMATION BASED ON BAYESIAN REPRESENTATION.

CITATION: Gang Xu, Meng-Dao Xing, Xiang-Gen Xia, et al. , IEEE Trans.Geosci.Remote Sens., 2015. Institute of Electrical and Electronics Engineers, Inc., United States. Vol. 53, No. 4, 2123-2136.
ABSTRACT: Interferometric synthetic aperture radar (InSAR) images are corrupted by strong noise, including interferometric phase and speckle noises. In general, the scenes in homogeneous areas are characterized by continuous-variation heights and stationary backscattered coefficients, exhibiting a locally spatial stationarity. The stationarity provides a rational of sparse representation of amplitude and interferometric phase to perform noise reduction. In this paper, we develop a novel algorithm of InSAR image formation from Bayesian perspective to perform interferometric phase noise reduction and despeckling. In the scheme, the InSAR image formation is constructed via maximum a posteriori estimation, which is formulated as a sparse regularization of amplitude and interferometric phase in the wavelet domain. Furthermore, the statistics of the wavelet-transformed image is modeled as complex Laplace distribution to enforce a sparse prior. Then, multichannel imaging is realized using a modified quasi-Newton method in a sequential and iterative manner, where both the interferometric phase and speckle noises are reduced step by step. Due to the simultaneously sparse regularized reconstruction of amplitude and interferometric phase, the performance of noise reduction can be effectively improved. Then, we extend it to joint sparse constraint on multichannel data by considering the joint statistics of multichannel data. Finally, experimental results based on simulated and measured data confirm the effectiveness of the proposed algorithm.
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STRUCTURALLY-CONTROLLED INSTABILITY, DAMAGE AND SLOPE FAILURE IN A PORPHYRY ROCK MASS.
CITATION: F. Agliardi, G. B. Crosta, F. Meloni, et al. , Tectonophysics, 2013. Elsevier Science. United Kingdom. Vol. 605, 34-47.
ABSTRACT: Rock slopes fail through structurally-controlled mechanisms, global circular failures, or complex mechanisms depending on structural patterns and rock mass damage. Here, structural geology, rock mass characterisation. Terrestrial Laser Scanning (TLS), ground-based radar interferometry (GB-InSAR) and Finite Element modelling are integrated to explore relationships between structure, damage and global slope failure at Mt Gorsa (Trentino, Italy). There a porphyry quarry has been excavated in complex, strongly anisotropic rhyolitic ignimbrite rock masses. The slope was affected by a major rockslide in 2003 and undergoes continuing instability. Site investigations and GB-InSAR monitoring revealed that the 2003 failure was a roto-translational rockslide involving about 400,000 m(3) of disrupted rock. Structural analysis of TLS and field data shows that the slope is affected by widespread structurally-controlled mechanisms (sliding, toppling, strain localization in kink bands). The non-obvious relationships between structurally-controlled and global roto-translational slope failure mechanisms are investigated by characterising rock mass damage in different slope sectors. A new approach to quantify rock mass damage by mapping the Geological Strength Index and interpreting its topographic signatures in TLS point clouds is presented. A persistent geological marker is systematically mapped in TLS point clouds, and correlations between attitude variability statistics and rock mass damage are established, providing an efficient assessment tool. Rock mass damage increases in kinematic domains affected by structurally-controlled instability (GSI = 35-40) and is maximum in areas of ongoing global instability (GSI = 15-20). The 2003 rockslide occurred inside a damaged rock mass zone with GSI < 35-40, also suggested to be a threshold condition for the onset of global slope displacements by GB-InSAR data. Finite-Element numerical modelling allows integrating available data and observations. It is suggested that rock mass damage induced by local, structurally-controlled slope instability provides the required conditions (loss of structural pattern, block size reduction, cohesion loss) for transition to equivalent continuum behaviour and global slope failure.
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STUDY OF GROUND SUBSIDENCE IN NORTHWEST HARRIS COUNTY USING GPS, LIDAR, AND INSAR TECHNIQUES.
CITATION: Shuhab D. Khan, Zheng Huang and Ayca Karacay. , Nat.Hazards, 2014. Springer-Verlag. Germany. Vol. 73, No. 3, 1143-1173.
ABSTRACT: Subsidence has been affecting many cities around the world, such as Nagoya (Japan), Venice (Italy), San Joaquin Valley and Long Beach (California), and Houston (Texas). This phenomenon can be caused by natural processes and/or human activities, including but not limited to carbonate dissolution, extraction of material from mines, soil compaction, and fluid withdrawal. Surface deformation has been an ongoing problem in the Houston Metropolitan area because of the city's location in a passive margin where faulting and subsidence are common. Most of the previous studies attributed the causes of the surface deformation to four major mechanisms: faulting, soil compaction, salt tectonics, and fluid withdrawal (groundwater withdrawal and hydrocarbon extraction). This work assessed the surface deformation in the greater Houston area and their possible relationship with fluid withdrawal. To achieve this goal, data from three complimentary remote sensing techniques Global Positioning System (GPS), Light Detection and

Ranging (LiDAR), and Interferometric synthetic aperture radar were used. GPS rates for the last 17 years show a change in surface deformation patterns. High rates of subsidence in the northwestern areas (up to ~4 cm/year) and signs of uplift in the southeast are observed (up to 2 mm\year). High rates of subsidence appear to be decreasing. Contrary to previous studies in which the location of subsidence appeared to be expanding toward the northwest, current results show that the area of subsidence is shrinking and migrating toward the northeast. Digital elevation model generated from airborne LiDAR, revealed changes between salt domes and their surrounding areas. The persistent scatterer interferometry was performed using twenty-five (25) European remote sensing-1/2 scenes. Rates of change in groundwater level and hydrocarbon production were calculated using data from 261 observation wells and 658 hydrocarbon wells. A water level decline of 4 m/year was found in area of highest subsidence, this area also show ~70 million m super(3)/year of hydrocarbon extraction. This study found strong correlation between fluid withdrawals and subsidence. Therefore, both groundwater and hydrocarbon withdrawal in northwest Harris County are considered to be the major drivers of the surface deformation.
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STUDY ON TWO PASS D-INSAR USINE SRTM DATA FOR URBAN LAND SUBSIDENCE MEASUREMENT.
CITATION: C. -S Zhang, J. -J Zhu, J. Hu, et al. , Science of Surveying and Mapping, 2009. Vol. 34, No. 2, Pg. 44-47.
ABSTRACT: Differential Synthetic aperture radar interferometry (D-InSAR) is a newly developed technique for monitoring large-scale ground deformation with some prominent advantages such as high accuracy and pantoscopic view. This paper firstly gives an introduction to the principle of D-InSAR. Then, the ground subsidence from1992.9 to 1993.4 over center area of Shanghai has been successfully detected using D-InSAR technique. Compared with the ground-based measurements, the results are viable and reliable. It also proved that the D-InSAR technique has a good prospect in urban land subsidence monitoring field in the future.
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STUDYING THE EARTH WITH INTERFEROMETRIC RADAR.
CITATION: HA Zebker. , Computing in Science & Engineering, 2000. Institute of Electrical and Electronics Engineers, Inc. Vol. 2, No. 3.
ABSTRACT: High-speed and large-volume computational capabilities have affected many branches of scientific research. Interferometric synthetic aperture radar (InSAR) and its spatially dense, accurate deformation measurements have advanced studies of the Earth's crust. The most important contributions are related to seismic and volcanic processes and the mapping of glacier and ice-sheet motions in the environmentally-sensitive and diagnostic polar regions.
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SURVEY OF TERRAIN MODELING TECHNOLOGIES AND TECHNIQUES.
CITATION: Gorkavyi, N.; Snyder, J.; Lashlee, J. D. Army Topographic Engineering Center, Alexandria, VA. Engineer Research and Development Center, 2007, 153p.
ABSTRACT: Test planning, rehearsal, and distributed test events for Future Combat System (FCS) require rapid generation of high-fidelity synthetic environments. These environments consist of high resolution synthetic scenes of test and training images, which use high and low resolution digital terrain surface models, 2-D and 3-D smiace objects and other geospatial data to replicate site conditions. The largest component of developing synthetic 3-D scenes is the commercially available Interferometric Synthetic aperture radar (IFSAR) and Light Detection And Ranging (LIDAR) data collected from airborne platforms. These industries are seeing rapid growth in data availability, and numbers and types of sensors, but the commercially available software based to process these types of data to provide high resolution, high accuracy topographic products is limited in its ability to process and produce data quickly and accurately for FCS. This work assessed the fidelity and quality of the commercial digital surface model (DSM) and digital terrain model (DTM) from Intermap; developed algorithms based on automated feature extraction (AFE) for LIDAR data that can be applied to processing IFSAR data (to perform foliage/vegetation removal and building/structure filtering while maintaining accurate terrain profile), and assessed improvements in consfliicn.ng DSM/DTM using the ComputationalConsulting Services (CCS)-developed methods.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA492698

SYSTEMATIC COMPARISONS OF EARTHQUAKE SOURCE MODELS DETERMINED USING INSAR AND SEISMIC DATA.
CITATION: Jennifer Weston, Ana MG Ferreira and Gareth J. Funning. , Tectonophysics, 2012. , United Kingdom. Vol. 532-535, Pg. 61-81.
ABSTRACT: Robust earthquake source parameters (e.g., location, seismic moment, fault geometry) are essential for reliable seismic hazard assessment and the investigation of large-scale tectonics. They are

routinely estimated using a variety of data and techniques, such as seismic data and, more recently, Interferometric synthetic aperture radar (InSAR). Comparisons between these two datasets are frequently made although not usually in a comprehensive way. This review compares source parameters from global and regional seismic catalogues with those from a recent database of InSAR parameters, which has been expanded with 18 additional source models for this study. We show that moment magnitude (Mw) estimates agree well between the two datasets, with a trend for thrust events modelled using InSAR to have slightly larger Mw estimates. Earthquake locations determined using InSAR agree well with those reported in regional catalogues, with a median difference of 6.3 km between them, which is smaller than for global seismic catalogues. We also investigate the consistency of source parameters and source directivity by comparing ISC hypocentres with GCMT and ICMT centroid locations for earthquakes with Mw greater than or equal to 6.5. In some cases the source directivity is qualitatively comparable with previous studies, especially when comparing ISC and ICMT locations. The average difference between InSAR-determined depths and those in the EHB catalogue is reduced if a layered half-space is used in the inversion of InSAR data. Overall, faulting geometry (strike, dip and rake angles) remain in good agreement with values from the GCMT catalogue, and any large discrepancies can be attributed to tradeoffs between parameters. With continued investment in satellites for radar interferometry, InSAR is a valuable technique for the estimation of earthquake source parameters. The observed trends and discrepancies between InSAR and seismically determined source parameters are the result of issues with the data, different inversion techniques and the assumed Earth structure model.
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TAIYUAN CITY SUBSIDENCE OBSERVED WITH PERSISTENT SCATTERER INSAR.
CITATION: Wei TANG and Mingsheng LIAO. , Wuhan Univ.J.Nat.Sci., 2014. Wuhan University, Dept. of Chemistry Wuchang Hubei China. Vol. 19, No. 6, 526-534.
ABSTRACT: C- and X-bands Synthetic aperture radar (SAR) images acquired from February 2009 to September 2010 were processed with Persistent Scatterer Interferometry (PS-InSAR) algorithm to investigate spatial and temporal variations in deformation over Taiyuan City, China. The spatial pattern of subsidence and the magnitude of subsidence rate are similar in the velocity field maps achieved by the algorithm from these two data sets. It shows that there are four primary subsidence centers in Taiyuan City: Xiayuan, Wujiabao, Xiaodian, Sunjiazhai, which are near the groundwater extraction wells. The maximum subsidence rate is up to 70 mm/year at Sunjiazhai. The locus of maximum subsidence has shifted from its historical location in the north to the south. In view of the severe shortage of water resources and presented features of subsidence over Taiyuan City, we inferred that excessive pumping of groundwater was the dominant reason of land subsidence.
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A THREE-DIMENSIONAL BASELINE CALIBRATION METHOD OF SPACEBORNE INSAR.
CITATION: Gang Chen, Xiaotao Tang and Fangming Qian. , Geomatics and Information Science of Wuhan University, 2014. Periodicals Press of Wuhan Technical University of Surveying and Mapping, Vol. 39, No. 1, 37-41.
ABSTRACT: Accuracy of baseline vector is one of important factors that affect the accuracy of height in spaceborne InSAR. By calibrating the baseline vector can effectively improve target's position accuracy, now most baseline calibration methods adopt two-dimensional model. This model ignores along-track baseline, which decrease calibration accuracy. According to working theroy of spaceborne InSAR, this paper presents a three-dimensional baseline model. By constructing the local moving coordinate system, the proposed method simplifies parameters and optimizes process in calibration. Results show that the proposed method has practical value and can be used in the calibration of high accuracy baseline vector.
ACCESS: http://ch.whu.edu.cn/EN/abstract/abstract2860.shtml

TIME-SERIES ANALYSIS OF SUBSIDENCE ASSOCIATED WITH RAPID URBANIZATION IN SHANGHAI, CHINA MEASURED WITH SBAS INSAR METHOD.
CITATION: Shaochun Dong, Sergey Samsonov, Hongwei Yin, et al. , Environmental Earth Sciences, 2014. Springer Science+Business Media, Netherlands. Vol. 72, No. 3, 677-691.
ABSTRACT: River delta plains (deltas) are susceptible to subsidence producing undesirable environmental impact and affecting dense population. The City of Shanghai, located in the easternmost of Yangtze Delta in China, is one of the most developed regions in China that experiences the greatest land subsidence. Excessive groundwater withdrawal is thought to be the primary cause of the land subsidence, but rapid urbanization and economic development, mass construction of skyscrapers, metro lines and highways are also contributing factors. In this paper, a spatial-temporal analysis of the land subsidence in Shanghai was performed with the help of the Small Baseline Subset Interferometric synthetic aperture radar. Twenty l-band ALOS PALSAR images acquired during 2007-2010 were used to produce a linear deformation rate map and to derive time

series of ground deformation. The results show homogeneous subsidence within the research area, but exceptionally rapid subsidence around skyscrapers, along metro lines, elevated roads and highways was also observed. Because groundwater exploitation and rapid urbanization responsible for much of the subsidence in the Shanghai region are expected to continue, future subsidence monitoring is warranted.
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TOPOGRAPHIC MAPPING FROM INTERFEROMETRIC SYNTHETIC APERTURE RADAR OBSERVATIONS.
CITATION: H. A. Zebker and R. M. Goldstein. , Journal of Geophysical Research, 1986. American Geophysical Union, USA, Vol. 91, Pg. 4993-4999.
ABSTRACT: The production of high-resolution topographic maps derived from interferometric synthetic aperture radar observations of the earth is reported. Topographic maps are typically determined from stereo-pair optical photographs. Vertical relief causes the same terrain to appear in a slightly different projection for differing look angles, and this shift in appearance is interpreted in terms of the height of the terrain. The radar interferometric approach is related to the stereo technique in that the terrain is viewed at two different angles; however, in this case, the angular separation of the antennas is extremely small, on the order of a milliradian or less, as compared to tens of degrees for the optical case. Thus, the geometrical distortion and subsequent rectification correction algorithms are much less severe in the reduction of interferometric data. (R.J.F.).
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TWO RADAR INTERFEROMETRIC APPROACHES TO MONITOR SLOW AND FAST LAND DEFORMATION.
CITATION: E. Biescas, M. Crosetto, M. Agudo, et al. , J.Surv.Eng., 2007. American Society of Civil Engineers. Vol. 133, No. 2, Pg. 66-71.
ABSTRACT: Differential Interferometric synthetic aperture radar (DInSAR) is a deformation measurement technique that couples two interesting characteristics. First, being based on remotely sensed data it offers operational advantages, like low cost data acquisition, wide area coverage, and temporally regular acquisitions. Second, it can be based on rigorous modeling and estimation procedures, which allows some of the most advanced techniques to derive measurements with high quality standards, comparable with those of some geodetic methods. The scope of this paper is to describe two complementary approaches to measure slow (from a few millimeters up to some centimeters per year) and fast land deformation (up to few meters per year). Emphasis is given to the description of the former approach, which requires multiple SAR images of the same phenomenon and an advanced analysis procedure. The effectiveness of both approaches is illustrated through two applications on mining areas of small spatial extent located in Spain. In one case the DInSAR capability to fully detect shape and magnitude of an unknown fast deformation phenomenon is highlighted, whereas in the second one a detailed deformation map is derived over an urban area, where deformations up to 30mm/year occur.
ACCESS: http://dx.doi.org/10.1061/(ASCE)0733-9453(2007)133:2(66)

URBAN SUBSIDENCE MONITORING USING RADAR INTERFEROMETRY: ALGORITHMS AND VALIDATION.
CITATION: Michele Crosetto, Manuel Castillo and Roman Arbiol. , Photogramm.Eng.Remote sensing, 2003. American Society for Photogrammetry and Remote sensing. Vol. 69, No. 7, Pg. pp 775-783.
ABSTRACT: Interferometric SAR (synthetic aperture radar) is a remote sensing technique used for applications such as the generation of digital elevation models (DEMs), the monitoring of surface movements and deformations, and thematic mapping. The differential Interferometric SAR (DInSAR) technique has proved capable of detecting small surface deformations in several types of applications. This article reports on the use of the DInSAR as a quantitative subsidence monitoring tool. The authors describe the complete procedure, giving emphasis to the algorithms that have a major impact on the quality of the DInSAR results: the calibration of the InSAR geometry based on ground control points, which guarantees a high accuracy of the InSAR geometric model; a filtering procedure suitable to reduce the atmospheric effects in small-scale subsidences; and a data fusion procedure for multiple observations, which represents a key step to improve the quality of the DInSAR products. The authors describe how the procedure was used in the analysis of a small-scale urban subsidence located in Catalonia, northeastern Spain. The authors conclude that their results obtained with the DInSAR procedure are encouraging, but further studies are needed to achieve the goal of a fully quantitative subsidence monitoring.
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USING INSAR AND HYDROSTRATIGRAPHIC-SIMULATION TO DETERMINE LAND SUBSIDENCE DUE TO GROUND WATER WITHDRAWAL IN THE PUMPERNICKEL VALLEY-KELLY CREEK BASIN, NORTH

CENTRAL NEVADA.
CITATION: Edmund Baffoe-Twum. , ProQuest Dissertations and Theses, 2007. University of Nevada, Reno. United States -- Nevada.
ABSTRACT: Land subsidence due to groundwater withdrawal occurs in almost every part of the world. This has some effect on infrastructures and economic development. In order to better understand this situation, various techniques and applications have been developed by many researchers in the study of subsidence and its related features. This study uses the following techniques: Interferometric synthetic aperture radar (InSAR), a recently developed remote sensing technology, and hydrostratigraphic calculated subsidence from to determine the extent and the relationship of subsidence with stratigraphic units, the possible causes of the subsidence and to derive specific storage coefficients in Pumpernickel Valley - Kelly Creek Basin, Nevada. The study focused mainly on groundwater extraction activities at the Lone Tree mine site for mine dewatering between the years 1992 and 2000. Although both the InSAR derived and the calculated methods applied predicted that a substantial amount of subsidence has occurred during the period under review, there were some discrepancies in the values of subsidence generated. The differences are likely due to assumptions used in the subsidence calculations as well as uncertainties in the representation of the geology and hydrology of the basin.
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USING OPEN-SOURCE COMPONENTS TO PROCESS INTERFEROMETRIC TERRASAR-X SPOTLIGHT DATA.
CITATION: Michael Jendryke, Timo Balz, Houjun Jiang, et al. , International Journal of Antennas and Propagation, 2013. Hindawi Publishing Corporation. United States. Vol. 2013,
ABSTRACT: We address the processing of interferometric TerraSAR-X and TanDEM-X spotlight data. Processing steps necessary to derive interferograms at high spatial resolution from bi- and monostatic satellite images will be explained. The spotlight image mode is a beam steering technique focusing the antenna on a specific ground area. This results in a linear Doppler shift frequency in azimuth direction, which has to be matched to the master image. While shifting the interpolation kernel in azimuth during resampling, the frequency spectrum of the slave image is aligned to the master image. We show how to process bistatic TanDEM-X images and propose an integrated processing option for monostatic TerraSAR-X data in the Delft Object-oriented Radar Interferometric Software (DORIS). The paper focuses on the implementation of this algorithm for high-resolution spotlight InSAR in a public domain tool; hence, it becomes available to a larger research community. The results are presented for three test areas: Uluru in Australia, Las Vegas in the USA, and Lueneburg in Germany.
ACCESS: http://www.hindawi.com/journals/ijap/2013/275635/

UTILIZING RESULTS FROM INSAR TO DEVELOP SEISMIC LOCATION BENCHMARKS AND IMPLICATIONS FOR SEISMIC SOURCE STUDIES.
CITATION: M. Begnaud. , STAR, 2002. NASA, USA, Vol. 40.
ABSTRACT: Obtaining accurate seismic event locations is one of the most important goals for monitoring detonations of underground nuclear teats. This is a particular challenge at small magnitudes where the number of recording stations may be less than 20. Although many different procedures are being developed to improve seismic location, most procedures suffer from inadequate testing against accurate information about a seismic event. Events with well-defined attributes, such as latitude, longitude, depth and origin time, are commonly referred to as ground truth (GT). Ground truth comes in many forms and with many different levels of accuracy. Interferometric synthetic aperture radar (InSAR) can provide independent and accurate information (ground truth) regarding ground surface deformation and/or rupture. Relating surface deformation to seismic events is trivial when events are large and create a significant surface rupture, such as for the M(sub w) = 7.5 event that occurred in the remote northern region of the Tibetan plateau in 1997. The event, which was a vertical strike slip even appeared anomalous in nature due to the lack of large aftershocks and had an associated surface rupture of over 180 km that was identified and modeled using InSAR. The east-west orientation of the fault rupture provides excellent ground truth for latitude, but is of limited use for longitude. However, a secondary rupture occurred 50 km south of the main shock rupture trace that can provide ground truth with accuracy within 5 km. The smaller, 5-km-long secondary rupture presents a challenge for relating the deformation to a seismic event. The rupture is believed to have a thrust mechanism; the dip of the field allows for some separation between the secondary rupture trace and its associated event epicenter, although not as much as is currently observed from catalog locations. Few events within the time period of the InSAR analysis are candidates for the secondary rupture. of these, we have identified six possible secondary rupture events (mb range = 3.7-4.8, with two magnitudes not reported), based on synthetic tests and residual analysis. All of the candidate events are scattered about the main and secondary rupture. A Joint Hypocenter Determination (JHD) approach applied to the aftershocks using global picks was not able to identify the secondary event. We added regional data and used propagation path

corrections to reduce scatter and remove the 20-km bias seen in the main shock location. A&r preliminary analysis using several different velocity models, none of the candidate events proved to relocate on the surface trace of the secondary rupture. However, one event (mb = not reported) moved from a starting distance of (approximately)106 km to a relocated distance of (approximately)28 km from the secondary rupture, the only candidate event to relocate in relative proximity to the secondary rupture.
ACCESS: https://ntrlr3.ntis.gov/fullText.php?ABBR=ADA530292

WEIGHTED JOINT CALIBRATION FOR INTERFEROMETRIC SAR.
CITATION: Yongfei Mao, Maosheng Xiang, Yunzhong Han, et al. , Journal of Systems Engineering and Electronics, 2013. Vol. 24, No. 5, 761-771.
ABSTRACT: Calibration is a processing procedure for across-track Interferometric synthetic aperture radar (InSAR) to achieve an accurate three-dimensional location. A calibration technique, called weighted joint calibration, for the generation of wide-area geocoded digital elevation models (DEMs) is proposed. It calibrates multiple InSAR scenes simultaneously, and allows reducing the number of required ground control points (GCPs) by using tie points (TPs). This approach may ensure the continuity of three-dimensional location among adjacent scenes, which is necessary for mosaic and fusion of data coming from different scenes. In addition, it introduces weights to calibration to discriminate GCPs and TPs with different coherences and locations. This paper presents the principles and methodology of this weighted joint calibration technique and illustrates its successful application in airborne InSAR data.
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WEIGHTED KALMAN FILTER PHASE UNWRAPPING ALGORITHM BASED ON INSAR IMAGE.
CITATION: M. Yan and L. Wang. , Engineering Review, 2013. University of Rijeka, Faculty of Engineering/Faculty of Civil Engineering. Vol. 33, No. 3, 227-231.
ABSTRACT: The Kalman filter deals simultaneously with phase unwrapping and noise elimination procedure. But the errors produced by the original radar signal and post-processing can cause phase discontinuity so that the unwrapped result is not accurate. Therefore, the weighted Kalman filter phase unwrapping algorithm based on InSAR image is proposed. Through the low-quality region where the wrapped phase is masked, the Kalman filter phase unwrapping algorithm is implemented in the high-quality region. When the high-quality region is correctly unwrapped, the weighted Kalman filter phase unwrapping algorithm is implemented in masking off the low-quality region, and as a consequence a reliable result is obtained. In this paper InSAR data is chosen for performing the experiment, and for comparison with both a network flow algorithm and a quality map guided algorithm. It is subsequently verified that the proposed algorithm is effective and reliable.
ACCESS:
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCMQFjAA&url=http%3A%2F%2Fhrcak.srce.hr%2Ffile%2F163758&ei=XPiKVbO4F4nosAWlt5LwBA&usg=AFQjCNGtISJBf7DSfPWxiHzb-QaagQpSwg&sig2=mldHQoovlgryTBnFL7ZQGQ&bvm=bv.96339352,d.b2w

RESEARCH IN PROGRESS: The following references are to research projects that are "in progress." They are listed alphabetical order by title. The names of principal investigators are listed to provide points of contact.
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INSAR REMOTE SENSING FOR PERFORMANCE MONITORING OF TRANSPORTATION INFRASTRUCTURE AT THE NETWORK LEVEL.

RiP Record:	http://rip.trb.org/view/2014/P/1357467
Record Type:	Project
Language:	English
Record URL:	http://viva-lab.ece.virginia.edu/foswiki/InSAR/RitaRs14
Source Agency:	University of Virginia, Charlottesville P. O. Box 400195 Charlottesville, VA 22904 United States

Source Data:	RiP Project 36634
Abstract:	This project proposes a network-level remote-sensing based inspection of a transportation corridor. The automated inspection process uses novel space-based radar technology to detect subsidence due to bridge settlement, rockslides/landslides and sinkholes in the corridor. Inspection is incorporated seamlessly in a geographic information system (GIS) based decision support system usable by state departments of transportation. This project pushes satellite-based inspection from the validation stage to the network implementation stage.
TRIS Files:	UTC, RiP
Contract Numbers:	RITARS-14-H-UVA
Funding:	800000.00
Start Date:	20140115
Actual Completion Date:	20160114
Performing Agencies:	University of Virginia, Charlottesville P. O. Box 400195 Charlottesville, VA 22904 United States
Funding Agencies:	Office of Assistant Secretary for Research and Technology Office of Assistant Secretary for Research and Technology 1200 New Jersey Avenue, SE Washington, DC 20590 United States
Responsible Individuals:	Singh, Caesar
Index Terms:	Bridges; Decision support systems; Geographic information systems; Inspection; Landslides; Remote sensing; Rockslides; Settlement (Structures); Sinkholes
Subject Areas:	Bridges and other structures; Highways; Planning and Forecasting; Transportation (General)

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