INTEGRATED ANALYSIS OF THE COMBINED RISK OF GROUND SUBSIDENCE SEA LEVEL RISE, AND NATURAL HAZARDS IN COASTAL DELTA REGIONS

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List of Principal Investigators (PIs)

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32294_1	*Prof. Antonio Pepe,* *Prof. Qing Zhao*	***DEtection and Interpretation of Time Evolution of Costal Environments Through integrated DInSAR, GPS and geophysical surveys***
32294_2	*Dr. Martin Gade,* *Prof. Jiayi Pan*	***Derivation of Storm Surge-induced Submerged Area and Ocean Wave Field Using Satellite Images and Data in coastal waters***
32294_3	*Prof. Ole Baltazar Andersen,* *Dr. Qing Xu*	***Projection of sea level rise and potential submerged area in coastal regions***

EXECUTIVE SUMMARY

The world s population density in flood-prone coastal zones and megacities is expected to grow up to 25% by 2050. Global sea-levels have risen during the 20th century, and they will rise by up to ~60 cm by 2100. Non-climate-related anthropogenic processes (such as ground subsidence due to groundwater extraction,ground settlements due to large scaleland-reclamation,and fast and non-linear subsidence phenomena of artificial sea wall), as well as frequently encountered natural hazards (such as storms and storm-surge) will exacerbate the risk to coastal zones and megacities and amplify local vulnerability.Making the situation worse is the combination of sea-level rise resulting from climate change, local sinking of land resulting from anthropogenic and natural hazards.The coastal vulnerability of Yangtze River Delta (YRD) and Pearl River Delta (PRD) is currently being amplified by the compounding effects of the time-dependent ground subsidence, the accelerated rate of sea level rise, and natural hazards.The provided examples of delta regions affected by the combination of sea-level rise, significant modifications over time, and natural hazards make clear the need of extended analyses for the understanding of the mechanisms at the base of the surface modifications of coastal areas, estimating of future regional sea level change, and evaluating the potential submerged land area. In this project, the use of well-established remote sensing technologies, based on the joint exploitation of multi-spectral information gathered at different spectral wavelengths, the advanced Differential Interferometric Synthetic Aperture (DInSAR) techniques, GPS/leveling campaigns aiming to perform sound and extended geophysical analyses,satellite altimeter data and tide gauge data, and the CoupledModelInter-comparisonProject Phase 5 (CMIP5) climate model projections will be employed for these purposes.The results obtained in this project represents an asset for the planning of present and future scientific activities devoted to the monitoring of such fragile environments. These analyses are essential to assess the factors that will continue to amplify the vulnerability of the low-elevation coastal zones.ObjectivesThe main goals are to provide a full characterization of the scene modifications over time and causes of the coastal delta region environments, to provide estimates of future regional sea level change, to derive coastal submerged area and wave field, and to provide suggestions for implementing coastal protection measures to adapt and mitigate the multi-factors induced coastal vulnerability.Methods The methods to be implemented in this project includes Small Baseline (SB)-oriented DInSAR, multilook SAR Tomography, GPS/leveling, DEM generation approaches, geotechnical laboratory test model, one-dimensional vertical consolidation model, Ensemble Empirical Mode Decomposition (EEMD), climate modeling, change detection methods, edge detection techniques, ocean wave model Simulating Waves Nearshore (SWAN), the current model Delft3D-FLOW, empirical orthogonal function analysis,multi-resolution spectral analysis techniques such as wavelet transformation and Contourlet transformation, fast Fourier transform (FFT), and complex modulation transfer function. Deliverables of the investigation 1. Scenarios of consideration of the individual effects of sea level rise effects, ground subsidence, and storm surges; 2. Presentation of several scenarios and comprehensive assessment of the hazards of these combined phenomena; 3.Presentation of scenarios considering combined effects in different time; 4.Suggestions for disaster mitigation measures in the coastal areas. Funding sources include Funding from National Natural Science Foundation of China, Research Grants of Ministry of Land and Resources of China, Special Funds for Public Industry Research Projects of the National Ministry of Water Resources of China, Hong Kong Innovative Fund, etc.

ABSTRACT 32294_1: "DEtection and Interpretation of Time Evolution of Costal Environments Through integrated DInSAR, GPS and geophysical surveys"	
European Principal Investigator Prof. Antonio Pepe (IREA-CNR,Italy)	***Chinese Principal Investigator*** Prof. Qing Zhao (East China Normal University,CHINA)

As sea level rise, there is increased concern about the growing urbanization of the world's low-lying deltaic coastal regions and the related costal hazards. Furthermore, the local relative sea-level rise can be significantly affected by vertical ground motions, either due to natural processes (e.g., global isostatic adjustment, tectonics, sediment consolidation and compaction, upstream sediment load reduction) and to human activities (e.g., groundwater extraction, land reclamation, buildings constructions and consolidation). Deformation phenomena can be in the same order of magnitude (or greater) than climate-induced sea level rise. However, coastal ground motions are in practice often poorly known, and in many cases, little information is available about the patterns and time evolution of ground motion. It is therefore worthwhile to monitor coastal delta regions through advanced Earth Observation (EO) systems that are capable to detect the ongoing surface deformation phenomena, recovering their spatial extent on the ground and following their temporal variability. This is beneficial for the subsequent interpretation of natural/antrophogenic processes causing surface motion.

Within this project, our interest will be focused on the analysis of modification processes characterizing the Yangtze River Delta and the Pearl River Delta in China. The two selected delta regions, which are affected by sea-level rise and natural/anthropogenic deformation phenomena making it clear the need of extended analyses for a better understanding of the mechanisms responsible for the observed surface modifications, and for the planning of actions devoted to risk prevention for populations living in coastal areas.

The main goal of the project is to provide a picture of the two above-mentioned costal delta region environments, giving a full characterization of the scene modifications over time and their causes. More specifically, our aim is to retrieve long-term displacement time-series from EO data, specifically satellite Synthetic Aperture Radar (SAR), of the investigated areas through advanced differential interferometric synthetic aperture (DInSAR) techniques, as well as to complement DInSAR results with information derived from GPS/leveling campaigns with the aim to perform sound and extended geophysical analyses, and coastal erosion or accretion rates, which will be obtained by jointly exploiting archives of SAR data and the new generation of optical remote sensing systems.

In order to evaluate the combined risk of sea level rise, storm surges, and ground subsidence in the whole project framework, the availability of high-resolution digital elevation models (DEM) of monitored coastal areas is mandatory. Added-value EO data-products, such as the updated DEMs of coastal areas subject to sea-level rise, the time-series of terrain displacement, mean displacement velocity maps, and time-series of SAR backscattering maps, will be obtained by exploiting archives of SAR data with different levels of spatial resolution spanning a long time interval of about 20 years since the beginning of 2000s to 2020. SAR data will be collected by the former (i.e., the ESA ENVISAT-ASAR) and the new generation of radar sensors (such as the Copernicus Sentinel-1 and the Cosmo-SkyMed constellations). Large scale DInSAR analysis over wide areas will be performed by exploiting the Small BAseline Subset (SBAS) algorithm, developed at IREA-CNR. For the specific case of the highly urbanized Yangtze River delta, this information will be integrated with the results at a finer spatial resolution achieved by the SAR Tomography technique.

The obtained EO data products will also be complemented (for areas where they are available for scientific purposes) with leveling and GPS measurements. Subsequent analyses based on these data products will be performed to derive a ground subsidence model for the analyzed coastal regions.

The scientific work will be financed from internal resources of the participants. Additional funding will also be recovered from National Natural Science Foundation of China, Research Grants of Ministry of Land and Resources of China, Research Grants of Science and Technology Commission of Shanghai Municipality, High-end Foreign Experts Recruitment Program of the State Administration of Foreign experts Affairs of China, the Fundamental Research Funds for the Central Universities of China, and in the framework of the China-Italy governmental cooperation.

Young students (post graduate and PhD) will also be trained.

The project deliverables will be papers on international journals as well as conference proceedings and reports.

ABSTRACT 32294_2: "Derivation of Storm Surge-induced Submerged Area and Ocean Wave Field Using Satellite Images and Data in coastal waters"	
European Principal Investigator Dr. Martin Gade (Institute of Oceanography, University of Hamburg,GERMANY)	***Chinese Principal Investigator*** Prof. Jiayi Pan (Nanjing university of information science and technology,CHINA)

Storm surge-induced coastal submerged area and waves may cause great hazards to coastal areas. In the coastal area, the waves experience substantial variability under the influence of coastal bathymetry and tidal currents. However, conventional measurements of coastal submerged area and waves are mainly based on in-situ tide gauges and buoys, which are too sparsely distributed to resolve the complex coastal wave fields. Recently, remote sensing technology has become an important manner to observe ocean surface parameters. The spatial resolution of satellite synthetic aperture radar (SAR) and optical sensors can be as high as from several meters to 1 meter, which allow detection of fine structures of coastal waves. This proposal aims to derive the coastal submerged area and wave field from these high resolution satellite images.
Firstly, the coastal submerged area caused by storm surges is estimated. Long time series of SAR and optical images under normal sea states are used to extract the zero-meter water lines at different tide levels. The flooding lines during storm are drawn from SAR image, and then the submerged area can be estimated from the difference between the flooding line and the zero-meter water line at the same tide level.
Secondly, the ocean wave spectrum and wave parameters in high sea state are inversed from SAR images. Conventional inversion algorithms of ocean wave spectrum from SAR image are based on fast Fourier transform (FFT) and complex modulation transfer function, and they are mainly used for low to moderate sea states in the open ocean, while wave breaking is important in high sea states for coastal areas. So breaking waves are detected and modelled from polarimetric SAR images, and then novel spectral analysis techniques are used to inverse the wave spectrum from SAR image. To reduce the complexity resulting from nonlinear imaging mechanisms of SAR, the phase information of interferometric SAR image and polarimetric orientation of polarimetric SAR image are utilized to inverse ocean wave spectrum. Besides, field experiments will be carried out to evaluate the inversion methods.
Thirdly, the coastal wave field in normal sea state is mapped, including the wave pattern, wave ray, wave energy concentration and wave parameters. The wave patterns and wave directions are extracted from the textures of SAR and optical images by using digital image process techniques. The wave ray equation is fitted from the wave directions along each wave ray, and then the concentration area can be determined. The wave periods and wave lengths along each pair of wave rays are estimated by the wave action conservation equation, and the wave heights along each pair of wave rays are deduced by the conservation theory of wave energy flux.
Two funding are available to run the project, including:
1) Hong Kong Innovative Fund: Development of a Realtime Monitoring System for Hong Kong Offshore Dynamic Characteristics Based on Satellite Remote Sensing (US$200,000);
2) Hong Kong Innovative Fund: Development of a Novel, Fine Prediction System of Storm Surge Inundation for Hong Kong Coastal Area (US$300,000).

ABSTRACT 32294_3: "Projection of sea level rise and potential submerged area in coastal regions"	
European Principal Investigator Prof. Ole Baltazar Andersen (Technical University of Denmark,Denmark)	***Chinese Principal Investigator*** Dr. Qing Xu (Hohai University,CHINA)

The change of sea level in response to the global warming is of great interest for both scientific and socio-economic reasons. More frequent occurrences of land loss, flooding, storm surges, and hurricanes will be a consequence of sea level rise (Sweet et al., 2013). Thus, many groups, such as climate scientists, politicians, economists, insurance companies, public utilities, coastal property owners, and civil engineers, have a need for accurate and reliable projection of future sea level change and its regional variation.

It has been documented that the rise in global mean sea level in the 20th century is mainly due to ocean thermal expansion and glacier melting caused by anthropogenic global warming, which is almost certain to continue in the future (IPCC, 2013; Li et al., 2013).Thus it is beneficial to investigate sea level rise over the 21st century under this scenario. Although the latest projections of global sea level change using coupled atmosphere-ocean general circulation models (GCMs) under global warming scenarios have contributed to a general knowledge of sea level changes on a global scale (Church et al., 2013), local sea level rise is still not well studied, e.g., the coast of the Yangtze (Changjiang) River Delta (YRD)in China. Regional sea level change could differ substantially from the global mean sea level, due to regional differences in heating and circulation changes (Wu et al., 2007; IPCC, 2013; Zuo et al., 2013; Hamlington et al., 2014). Therefore, the objective of our proposal is to combine the satellite observations, in situ observations, and climate modeling to provide estimates of future regional sea level change and potential submerged land area during the 21st century in the Yangtze River Delta and adjacent coastal areas (hereafter called YRD). The YRD is a highly developed region and an economic hotspot in China. It has a low altitudes, which is likely to suffer from sea level rise in the future.

Projecting regional sea level change begins with improving our understanding of past sea level change. Then we can use existing climate models to project future sea level change and its regional variations. To accomplish our objective, we intend to investigate past regional sea level change from a combination of satellite altimeter data and tide gauge data, and analyze the Coupled Model Intercomparison Project Phase 5 (CMIP5) climate model projections of global sea level change. We can use all this information to project regional sea level change in the YRD using (1) observation-based approach and (2) modified semi-empirical approach. The proposal also includes a plan to estimate high-resolution digital elevation model (DEM) and vertical land subsidence along the coasts from available Global Positioning System (GPS) and Synthetic Aperture Radar (SAR) data. This will allow us to determine the total relative sea level change in the YRD and calculate the potential submerged land area.

Of particular interest is the effect of coastal erosion and hence the opportunity to investigate the fine resolution scales of the near-coastal sea level changes using new high resolution SAR Altimetry which will be flown on Sentinel-3. SAR altimetry enables a better study of the near coastal sea level.

The ultimate outcome of this proposal will be projection of regional relative sea level change in the YRD at different time intervals, e.g., in 2030, 2050, 2070, and 2100. We also intend to estimate the potential submerged area due to sea level rise. The results will help to improve our understanding of the influence of ongoing global warming on coastal areas, and the study is beneficial for implementing coastal protection measures to mitigate and adapt to the potential damages caused by climate change.

Availability of funding to run the project: Currently, the Co-Is from China are leading projects about the sea level change in the East China Sea and north-west Pacific. These projects supported by National Natural Science Foundation of China and Special Funds for Public Industry Research Projects of the National Ministry of Water Resources, China (the total funding is about 1,200,000 RMB) will provide financial support to run this project.

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