MECHANICAL ENGINEERING | PHYSICS | PRESERVATION OF THE ARCHITECTURAL HERITAGE | SPATIAL PLANNING AND URBAN DEVELOPMENT | STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING | URBAN PLANNING, DESIGN AND POLICY | AEROSPACE ENGINEERING | ARCHITECTURAL COMPOSITION | ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING | ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE | ARCHITECTURAL, URBAN AND INTERIOR DESIGN | BIOENGINEERING | DESIGN | ELECTRICAL ENGINEERING | ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY | **ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING** | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INFORMATION TECHNOLOGY | INTERIOR ARCHITECTURE AND EXHIBITION DESIGN | MANAGEMENT ENGINEERING | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING

DOCTORAL PROGRAM IN ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING

Chair:
Prof. Alberto Guadagnini

The Doctorate in Environmental and Infrastructure Engineering has been operating since the academic year 2008/2009. The program introduces doctoral students to the world of research on key theoretical and technological elements associated with water, environment, hydraulic and transportation infrastructures, geology, as well as geomatics.
In this context, the program is grounded on environmental, civil, and industrial applications where water is the primary unifying element.
The doctorate program is characterized by a strong inter- and multi-disciplinary structure and is organized according to the following key thematic areas.

- *Hydraulic Engineering*, where major research themes include: fluid mechanics; fluid-structure interactions; hydraulic measurements; river hydraulics; sediment mechanics; hydraulic risk assessment and management; flow and transport processes in porous systems; hydraulic networks, hydro-energy; oil and gas development and applications.
- *Hydrology, hydraulic structures, water resources and coastal engineering*, where the main research topics include: hydrology and water resources, with emphasis on the main physical processes of the hydrological cycle, water and energy budgets; hydrogeological hazard and mitigation strategies, including hydrological extremes, floods, droughts and precipitation, early warning operative systems, snow avalanching and flood risk; hydraulic networks engineering; and coastal engineering.
- *Environmental technologies*, with focus on: water and wastewater treatment technologies (including disposal/reuse of wastewater, sludge management and disposal, anaerobic digestion processes; management and planning of environmental resources (including water quality modelling, knowledge-based decision support systems); solid wastes management (including Life Cycle Assessment of energy and resource recovery initiatives); phenomenology of the atmospheric environment and treatment of gaseous emissions; contaminated soils and their remediation.
- *Transport infrastructures and geology*, with focus on: transport networks, including functional interactions with regional, national and international territory; sustainable development, in terms of dynamics of development and its relations with the infrastructure system; technological innovation, including methods and indicators for performance characterization of infrastructure construction and maintenance techniques; hydrogeological risk, landslide hazard; water resources identification and management, pollution problems.
- *Geomatics*, with focus on: physical geodesy and satellite geodesy; positioning and navigation; surface surveying with optical or other sensors, such as SAR, LIDAR; digital photogrammetry and image analysis; remote sensing; geographic information systems; cultural heritage reconstruction and archiving.

The curriculum of PhD students has been tailored to the general and specific research questions associated with the multifaceted interactions between the water sphere and the key evolving anthropogenic activities responding to the needs of modern society.
Career perspectives include opportunities at Universities, Research Centers, public bodies and Authorities, as well as private companies / industry. Small and medium size enterprises (SMEs) which cannot afford the development of an in-house specific know-how program may also require such highly professional profiles to guarantee critical innovation and competitiveness.

DOCTORAL PROGRAM BOARD		
Alberto Guadagnini	Maurizio Crispino	Monica Papini
Arianna Azzellino	Carlo De Michele	Alessio Radice
Gianfranco Becciu	Stefano Malavasi	Monica Riva
Barbara Betti	Francesca Malpei	Maria Cristina Rulli
Daniele Bocchiola	Marco Mancini	Sabrina Saponaro
Roberto Canziani	Federica Migliaccio	Emanuele Toraldo
		Giovanna Venuti

ADVISORY BOARD	
Sanchez-Vila Xavier	Universitat Politècnica del Catalunya - Barcelonatech, Barcelona (Spain)
Ruffo Paolo	ENI, Milano (Italy)
Burlando Paolo	ETH, Zurigo (Switzerland)
Sansalone John J.	Florida University (USA)
Marino Carlo	ARPA Lombardia
Bortone Giuseppe	ARPA Emilia-Romagna
Fanelli Roberto	Istituto Mario Negri, Milano (Italy)
Bernet Nicolas	LBE - INRA, Narbonne (France)
Losa Massimo	Università di Pisa
Dermanis Athanasios	Aristoteles University, Thessaloniki (Greece)
Radicioni Fabio	Università di Perugia, Perugia (Italy)

SCHOLARSHIP SPONSORS		
Metropolitana Milanese	Pibiviesse	Ricerche sul Sistema Energetico - RSE
Lario Reti S.p.A.	European Space Agency	Agenzia Spaziale Italiana
ENI	Fondazione Cariplo	

OBJECT BASED CLASSIFICATION TECHNIQUES FOR WATER ENVIRONMENTS MONITORING

Martina Aiello - Supervisor: Prof. Marco Gianinetto

Maritime activities over seas and oceans constitutes a large portion of human commercial trades and have turned to be essential to world's economy and international trade. Besides legal business, human smuggling and clandestine immigration, piracy, drug trafficking, illegal fishing, cross-border crime and marine pollution activities occur every day by sea. Therefore, surveillance, security and environmental protection themes are gaining increasing importance and efficient monitoring methods are required.

Satellites for Earth Observation have been successfully used in multiple scientific and commercial applications. Over the last years, their performances have been progressively improved, enabling many commercial and scientific satellites to effectively operate as reconnaissance instruments. Satellites for Earth Observation can easily extend visual and instrumental horizon limits, are not constrained by national boundaries and can operate even in adverse weather conditions, providing quick access to global imagery with high revisit time. Indeed, the combined use of multispectral and SAR (Synthetic Aperture Radar) images allows for a regular observation unrestricted by lighting and atmospheric conditions and complementarity in terms of geographic coverage, revisit time and geometric detail. Thus, in addition to conventional positioning and tracking systems, ship detection with satellites for Earth Observation could be an effective mean to monitor human movements across the sea.

This research focuses on the development of an automatic and robust image analysis approach to detect vessels on both optical and radar data. The dataset includes high resolution optical data (WorldView-2, QuickBird-2 and GeoEye-1), medium resolution optical data (Sentinel-2) and SAR data (COSMO-SkyMed). Optical images are first pre-processed through radiometric calibration and atmospheric correction. A Minimum Noise Fraction (MNF) transform is applied to multispectral images in order to select the component, which allows discriminating between ships, wakes and background. An Object Based Image Analysis (OBIA) is then adopted to detect vessels over optical and radar images, exploiting both spectral and geometric properties of the targets, together with textural and contextual/relational characteristics among objects. This approach is chosen for its adaptability to analyze images with different spatial resolution acquired by different sensors in various atmospheric and sea conditions.
For the optical module, the image processing chain is optimized to reduce computational time. The selected MNF component is tiled through a chessboard segmentation and only tiles including potential vessels are retained for further processing. This selection is made according to the skewness of the pixels reflectance distribution. Tiles with a Gaussian distribution are expected to include only sea, while tiles with a skewed distribution are candidates for containing vessels and are thus retained for further processing (Figure 1a, left panel). Processing of SAR images requires an additional step before OBIA: vessels candidates are detected using a Constant False Alarm Rate (CFAR) algorithm applied on amplitude data. This method is based on an adaptive threshold, which selects brighter pixels over a darker background, defined according to a Gaussian modelling of the sea statistics. Figure 1a (right panel) shows a comparison between image tiles including a ship and image tiles including sea, where cells with intensities greater than a threshold (determined from the background statistics in order to ensure a given probability of false alarm) and with a non-Gaussian distribution are labelled as belonging to a vessel. The output of this phase is a binary image, which is then processed through the OBIA pipeline described for optical images. Examples of object extraction with optical and radar images are shown in Figure 1b. A following spatial analysis developed in a GIS environment allows retrieving vessels length and movement parameters (position, heading) and a speed range is assigned. Besides, an image matching technique performed on Sentinel-2 images, allows estimating vessels speed with a higher accuracy.
Validation is carried out by comparing the retrieved parameters with the information provided by the Automatic Identification System (AIS), when available, or with manual measurement. The estimation of length have shown R^2=0.85 and estimation of heading R^2=0.92, computed as the average of R^2 values obtained for both optical and radar images.

Findings of this work confirm that the proposed approach based on a combined use of optical and radar data could be significant for monitoring purposes of small and large areas, within maritime security and surveillance perspectives. Foreseen developments of this work are mainly related to deepening relations between environmental conditions (sea roughness, wind and waves) with false alarms occurrence and to speed estimate refinement. Besides, in maritime surveillance or emergency monitoring perspective, it should be fundamental to automatize the whole processing, from images download and pre-processing, to vessels' movement parameters estimate, in a unique system and to reduce the time lag between data acquisition and results availability to end users. Observed performances are also analysed in comparison to the SUMO (Search for Unidentified Maritime Objects) software developed in the last years at JRC.

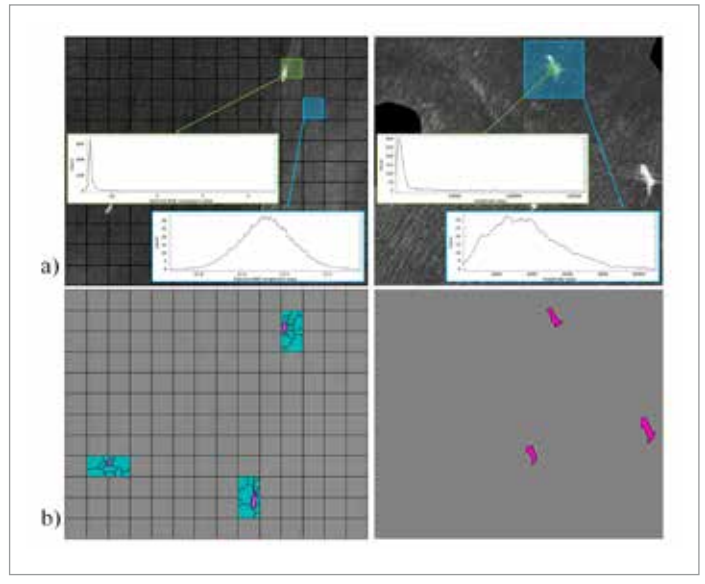

Fig. 1 - a) Image pre-processing prior to feature extraction: comparison between tiles including a ship and tiles with only sea. Sentinel-2 (left panel) and COSMO-SkyMed (right panel). b) Feature extraction: for optical images, OBIA is applied only over tiles with a skewed distribution of reflectance values (left panel). For SAR images, OBIA is applied on the binary image generated with CFAR. Detected vessels are in pink.

MODELING UNDER UNCERTAINTY OF REACTIVE PROCESSES IN SUBSURFACE SYSTEMS ACROSS SCALES

Giulia Ceriotti - Supervisor: Dr. Giovanni Michele Porta

This dissertation deals with the dynamics of liquid water in snow, including measuring and modeling activities. Liquid water in snow plays an important role in driving runoff timing and amount. It also rules snow albedo and viscosity during the melting season, provides suitable conditions for a variety of biological activities, and represents a key factor in triggering wet snow avalanches. Moreover, water storage capacity of snow and firn may play an important role in determining the time of sea level rise by Climate Change. However, wet snow mass dynamics are still a less investigated topic than dry snow dynamics. By way of examples, an exhaustive description and modeling of liquid water percolation in snow, as well as the set-up of non-destructive and automatic devices to measure the amount of liquid water in snow are still open issues. To gain more insight into this problem, a variety of laboratory experiments, field tests and modeling formulations are presented. First, a series of tomography-based observations of wet snow metamorphism during melt-freeze cycles was performed. These show a high degree of spatial heterogeneity in wet snow metamorphism, and a faster-than-expected decrease and a high variability in Specific Surface Area observations in time, if compared with a well-known model. Secondly, systematic laboratory-based observations of capillary barriers and preferential flow in layered snow were performed. These suggest that capillary barriers and preferential flow are relevant processes ruling water transmission in snow. An exhaustive inventory of capillary barrier properties was attempted. This shows peaks in Liquid Water Content (LWC) at the textural boundary up to ~ 33 vol% - 36 vol%. It was also found that heterogeneity in water flux increases with grain size. All experiments were reproduced using the model SNOWPACK: the water scheme chosen reproduces correctly the development of a capillary barrier. As a third step, the feasibility of a continuous-time monitoring of LWC using capacitance sensors was investigated by means of two field tests, two laboratory tests and a FEM model of sensors resonant circuit. Results are promising since it was observed that capacitance probes are sensitive to snow wetting and do not need a pit to be excavated. However, significant disturbances affect their measurement in continuous-time applications. As a final step, a one-dimensional one-layer model of snow mass dynamics is formulated. This considers the two phases of ice and liquid water separately, and implements a simple temperature-index or a coupled melt-freeze temperature-index approach to reconstruct hourly time-series of liquid water content, density, depth and snow water equivalent. It has been extensively evaluated in the US, in Italy, in France and in Japan. Results show that a calibrated melt-freeze temperature-index approach returns median absolute differences between data and predictions of volumetric liquid water content that are comparable with instrumental precision.

CHARACTERIZATION UNDER UNCERTAINTIES OF COMPACTION PROCESSES IN SEDIMENTARY BASIN

Ivo Colombo

Supervisors: Dr. Giovanni Michele Porta, Prof. Alberto Guadagnini

This contribution is focused on development and application of innovative uncertainty quantification techniques for the characterization under uncertainties of compaction processes in sedimentary basin. Different geological contexts, from synthetic settings to real field cases, and different scale problems, basin and reservoir scale respectively, are considered regarding three different aspects associated with sedimentary basin modeling: (i) the overpressure development in presence of low-permeability layers, (ii) the presence of highly layered stratigraphy and (iii) the possible occurrence of borehole cleaning and stability problems during the realization of a well.

In the first part, where basin scale problems are considered, we present a feasible methodology for a preliminary risk analysis of overpressure buildup in sedimentary basins characterized by simplified lithology: few thick layers of sandy and shaly materials alternately deposited. A one-dimensional numerical model is adopted for forward modeling fluid flow and vertical mechanical and geochemical compaction processes. A model reduction technique, based on sparse grid sampling technique and generalized polynomial chaos expansion, is employed in forward and inverse modeling context to obtain an efficient uncertainty quantification and model parameter estimation. The uncertainty propagation from uncertain input parameter to numerical model outputs is investigated and quantified. The methodology is applied to two real field settings. Different ensembles of input data are considered for calibration and the best result is found when different types of data are considered jointly. This modeling strategy allows to probe the relation between compaction and fluid flow processes in sedimentary basins, focusing on the quantification of relative importance of those phenomena which are the main drivers of overpressure development in presence of low-permeability layers.

A novel procedure to extend this methodology to highly layered domain is detailed in the second part of the work. In geological context characterized by highly layered lithology the considered methodology losses in accuracy and the generalized polynomial chaos expansion cannot be employed to approximate those model outputs which exhibit a discontinuous behaviour with respect to input parameters at interfaces between different lithological materials. Starting from the observation that physical interfaces positions are continuous with respect to parameters, a two-steps surrogate model is developed. In the first step, the interfaces positions are estimated with a sparse-grid approach in the physical domain then, in the second step, the model outputs are projected into a reference domain where the discontinuities in depth are aligned and the sparse grid approximation of the state variables can be performed. This procedure is applied to synthetic test cases characterized by realistic deposition and compaction history. Results associated with sparse grid approximation are in close agreement with those obtained with a direct simulation of the full model and characterized by lower computational costs in comparison to the latter.

An uncertainty quantification procedure is finally applied to a reservoir scale problem to analyse measurement techniques, associated with the drilling phase, which provide useful information for basin characterization. We consider measurements of a field device usually employed on the drilling rig to estimate the volume of excavated rock by measuring the weight of cuttings coming out of a well. Empirical models, suitable for converting the input cuttings raw weights in the output volumes, are considered and numerical coefficients appearing therein are taken as uncertain parameters. The uncertainty propagation from input parameters to empirical model outputs is investigated and quantified through a straightforward procedure implemented into a Monte Carlo framework. Values of uncertain model parameters are extracted from probability density functions suitably defined for different lithologies. This procedure is applied to a semi-synthetic case, where real cuttings measures are associated to a synthetic lithological context. The quantification of the uncertainty propagation from the uncertain input parameter to the numerical model output is provided together with a risk evaluation procedure associated with the probability to have borehole cleaning and/or stability problems during the drilling phase.

Results emphasize the relevance of presented uncertainty quantification techniques in terms of sedimentary basin characterization and risk evaluation and allow to point out their wide range of applicability.

CHARACTERISING MEDITERRANEAN CATCHMENTS: HYDROLOGICAL REGIME, RIVERINE EXPORT, NITROGEN BALANCE AND AGRICULTURAL WATER FOOTPRINT

D'Ambrosio Ersilia

Supervisors: Prof. Maria Cristina Rulli, Eng. Anna Maria De Girolamo

Agriculture has been identified as one of the main cause of water consumption and degradation, due to the large use of fertilizers and pesticides. Assessing agriculture sustainability is of dramatic importance for determine how the current use of water resources can affect their availability in the future, and to safeguard their quantity and quality. In a catchment, nitrogen (TN) export from terrestrial ecosystems to rivers is controlled by hydrological regimes and TN balance. Hence, before assessing the sustainability of agriculture and defining how the current use of water resources can affect their quantity and quality is important to characterise the hydrological regime, the anthropogenic TN input and the riverine export.
In such a context, this research was designed to develop a simple approach i) to classify the stream regime, ii) to quantify the soil system TN budget and the riverine export, and iii) to assess the sustainability of agriculture through a full agricultural Water Footprint Assessment at a catchment scale.
The study area was the north part of Puglia Region (southeast Italy) characterised by temporary streams (Fig. 1). In particular, in the first topic, the study area included the Candelaro, Carapelle and Cervaro catchments which have a total drainage areas of 2300, 990 and 775 km^2, respectively. Instead, in the last two topics, a sub-catchment of the Candelaro River Basin (Celone catchment, 72 km^2) is analysed, which is a typical Mediterranean agricultural catchment.

i) In the first topic, a methodology to characterise and classify the regime of temporary rivers based on hydrological indicators (HIs) computed with long-term daily flow records was presented. A set of 37 Hydrological Indicators (HIs) were examined in the Carapelle, Candelaro and Cervaro catchments. By using a principal component analysis (PCA), a set of non-redundant indices were identified describing the main characteristics of the hydrological regime in the study area. The indicators identified were the annual maximum 30- and 90-day mean (DH4 and DH5), the number of zero flow days (DL6), flow permanence (MF) and the 6-month seasonal predictability of dry periods (SD6). A methodology was also tested to estimate selected HIs in ungauged river reaches. Watershed characteristics such as catchment area, gauging station elevation, mean watershed slope, mean annual rainfall, land use, soil hydraulic conductivity and available water content were derived for each site. Selected indicators were then linked to the catchment characteristics using a regression analysis. Finally, MF and SD6 were used to classify streams regime.

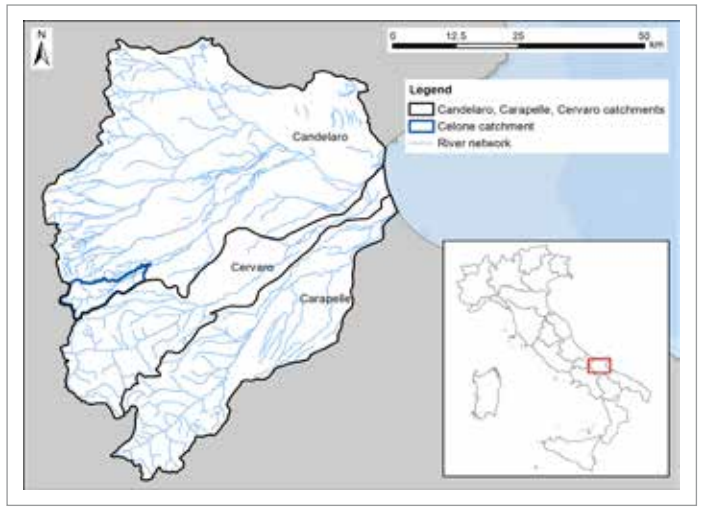

Fig. 1 - Study area: Candelaro, Carapelle, Cervaro and Celone catchments.

ii) The TN balance and the riverine export were quantified in the Celone watershed through several survey campaigns, continuous measures of streamflow and discrete samplings of nitrogen concentrations recorded from July 2010 to June 2011 at the Celone watershed's closing section. Major N inputs derived from fertilizers and animal manure correspond to 68 and 12 kg N ha^{-1} yr^{-1}, respectively. TN input from point sources was 1% of total input and atmospheric depositions measured in a gauging station near the study area was quantified in ~6 kg N ha^{-1} yr^{-1}. Crop uptake was the main TN output from agricultural land; it was estimated in ~37 kg N ha^{-1} yr^{-1} by using data on crop yields provided by local farmers. The riverine TN export (from diffuse sources) was estimated to be about 34.5 kg ha^{-1} yr^{-1}. TN fluxes in stream during flood events (occurred in 38 days) accounted for about 60% of the annual loading. On a yearly basis, the difference between N inputs and outputs including riverine export (from diffuse sources) was estimated in about 8.1 kg N ha^{-1} yr^{-1} for the whole watershed area. This amount partly accumulates in soils in different N forms and the remaining part, mainly in form of nitrate, percolates through unsaturated soil towards groundwater.

iii) A simple approach for the evaluation of agricultural sustainability, based on coupling the assessment of the total water footprint (WF) of catchment-scale crops and in-stream monitoring activities, was developed. The green and blue components of the WF were evaluated performing a soil-water balance on a 10-day time-interval. The surface runoff was calibrated based on continuous streamflow measurements. Meanwhile, the grey component of the WF related to nitrogen use was quantified by means of the results from in-stream monitoring activities. The study focussed on the Celone catchment, but the methodology could be applied to any catchment as well if soil, land use, weather, agricultural practices, nitrogen balance, and stream data are available. Results for the study period (July 2010 – June 2011) show the total WF to be 79.9 million m^3 y^{-1}, subdivided into 30.3% green water, 0.5% blue water and 69.2% grey water, thus highlighting the importance of grey water in the estimate of agricultural water use. Moreover, the results show the grey WF estimates to be highly sensitive both to leaching and runoff fractions, and applied water standards, and affected by large uncertainty. The sustainability assessment of present water consumption, subdivided into the three WF components, indicates sustainable use of green water, fluctuating sustainability of blue water resources, depending on the season and the environmental flow requirement, and unsustainable grey water production and water pollution level for the Celone River.

The methodologies and the results presented in this research constitutes a useful tool for ecologists and water resource managers in order to classify the 'river type', understand TN loss dynamics and execute more functional water management and land use planning, helping farmers and decision-makers in choosing crops suitable for locally-sustainable water use. Hence, this research constitutes a helpful analysis for the Water Framework Directive implementation process in Mediterranean watershed with a temporary river system.

ESTIMATION OF WATER QUALITY FROM SATELLITE MEASUREMENTS, NUMERICAL MODELS AND LABORATORY TESTS

Antonio Di Trapani - Supervisor: Prof. Marco Mancini

Total suspended matter concentration, TSM, and turbidity, TURB, are common parameters used to assess coastal and estuarine water quality, but are difficult to quantify due to the variability of the heterogeneous land-use types within and between watersheds and the magnitude and duration resulting from climactic, hydraulic, and biogeochemical factors. The practical interest in monitoring TSM and TURB in water bodies comes from the critical importance of water quality in tracking the transport of nutrients as well as pollutants threatening the health and well-being of aquatic ecosystems and manhood, and also for quantifying rivers sediment transport.
Traditional ground sampling techniques are well established, but their application requires investment in money and time to obtain accurate and precise loading estimates, still limited to the sampling grids. During the last decades, ocean color remote sensing has become a useful tool to give synoptic views of TSM and TURB variations at different spatial and temporal scales, often relying on freely available data. Different empirical and analytical algorithms to retrieve TSM and TURB from remotely sensed data are available in literature, but their application is generally limited by site-specific factors, such as study area dimensions, the properties of the sediments in the water column, and the ranges of variability of TSM and TURB, that can vary from extremely low to extremely high values.
The thesis objective is to improve the understanding of TSM and TURB estimation from remote sensing, ground measurements and semi-analytical and empirical models, through the understanding of the optical properties of turbid waters.
A first step was the evaluation of the impact that the Three Gorges Dam, China, had on the suspended sediment load of the Yangtze River. This has been performed using moderate resolution remote sensing techniques to estimates the TSM in the Three Gorges Reservoir, that is a water body characterized by extremely high values of TURB and TSM.
The second stage was the application of existing empirical and semi-analytical models to turbid waters in laboratory controlled experiments, retrieving water's optical properties, such as reflectance, attenuation coefficient, absorption and backscattering coefficients, and to relate them with turbidity and TSM.

DISINFECTION BY PERACETIC ACID (PAA): EVALUATION OF THE EFFECT OF WASTEWATER COMPOSITION ON PAA DECAY AND BACTERIAL INACTIVATION KINETICS AND DEFINITION OF PREDICTIVE MODELS

Laura Domínguez Henao - Supervisor: Prof. Manuela Antonelli

Disinfection of municipal wastewater plays a very important role in public health protection by controlling the release of pathogenic microorganisms into receiving water bodies. Chlorination is the most common method for disinfection of municipal wastewaters, largely due to its low cost and efficiency. However, it is well documented that chlorine-based disinfectants are highly reactive towards several compounds present in the waters, inducing the formation of a wide range of harmful disinfection by-products (DBPs) of concern to human health and the environment. Peracetic acid (PAA) has gained increasing attention over the last decade as a safe and suitable alternative to chlorine-based products for wastewater disinfection. PAA decomposes rapidly in water solution; thus in order to ensure a sufficient residual concentration of disinfectant while avoiding over dosages that entail environmental risks and over costs, it is fundamental foreseeing the disinfectant decay. Previous studies have suggested that the water matrix composition has a significant effect on PAA decomposition. However, there is a high uncertainty on the specific physical-chemical characteristics of the water that affect PAA decay and therefore the available concentration for bacterial inactivation during wastewater disinfection. A further key aspect is related to the disinfectant dose (mg/L min) as the main parameter determining disinfection efficiency, whose estimation is based on the actual concentration of disinfectant at which bacteria are exposed, defined by the area under the curve that describes PAA decay over time.

The present doctoral dissertation is focused on the optimization of PAA dosage in order to reach bacterial inactivation targets avoiding high residual concentrations that can entail environmental risks. The integration of both PAA decay and bacterial inactivation kinetics is fundamental to achieve this goal, and requires the definition of predictive models for both aspects.

First, a critical literature review has been performed regarding the environmental fate of PAA residuals and their effects on aquatic ecosystems, presenting a comprehensive overview covering aspects such as formation of DBPs, toxicity and potential genotoxic and mutagenic effects. This analysis highlights that PAA is an environmentally-friendly disinfection option, producing less environmental impacts than chlorine-based disinfectants, given that limited DBPs are formed while the toxic, mutagenic and genotoxic effects on different aquatic organisms are very modest. Then, considering the monitoring of PAA concentration over time to define its decay kinetics, which requires the implementation of an accurate and rapid measurement, a method to achieve this purpose has been validated and an additional measurement method for the H_2O_2 fraction in equilibrium with PAA has been proposed. For both methods, kinetic aspects and potential interferences were investigated. This constituted a valuable and reliable tool to be implemented in the subsequent aspects to be studied.

As regards to PAA decay, the effect of wastewater composition was evaluated firstly assessing the contribution of dissolved matter, with focus on the identification of the specific inorganic and organic compounds that affect PAA decay. Five inorganic compounds and six organic compounds were selected to perform decay tests, based on the typical composition of secondary effluents and one experimental plan based on the statistical method of Design of Experiments (DoE) was carried out for each set of compounds, in order to assess their effect in multicomponent test solutions. The inorganic compounds, namely the presence of reduced iron and phosphate, displayed an important effect on the exponential decay rate whereas the organic compounds, mainly proteins, had a significant instantaneous consumption of PAA. Stepwise regressions were carried out for each set of compounds in order to select the most relevant ones to describe both aspects of PAA decay kinetics, the exponential decay rate and the initial consumption for the inorganics and the organic respectively. Subsequently, two models were interpolated by means of linear least-square regressions based on the most relevant compounds. A unique predictive model for PAA decay was then formulated by merging the two aforementioned models and it was validated by means of a set of experiments assessing PAA decay in the simultaneous presence of inorganics and organics, which were compared with the outcomes of Monte Carlo simulations, used to propagate the uncertainty through the model.

The contribution of suspended matter on PAA decay was evaluated by preparing two different stock suspended solids (TSS) solutions from the activated sludge of two wastewater treatment plants. Various TSS concentrations were studied during PAA decay tests, which are representative of secondary effluents of good (well settled) and medium (not well-settled) quality, and combined sewer overflows. In addition, the contribution of the soluble matter associated to the suspended solids on PAA decay was also evaluated by performing the decay experiments in the presence of the equivalent volume of stock TSS solution, prior removal of the solids through filtration. The contributions of the suspended and the soluble fractions were found to be independent; therefore, a predictive model formed by two additive sub-models was proposed to describe the overall decay kinetics of PAA.

Lastly, the disinfectant dose was evaluated as the main parameter determining the inactivation performance of PAA by means of inactivation tests with a pure strain of *E.coli*. This was performed in two phases that aimed at (i) define the dose-response curve of the organism and (ii) test the invariance of the dose in determining the disinfection performance by comparing *E.coli* inactivation level by changing the combination of C_0 (initial disinfectant concentration) and t (contact time) at a fixed dose. The same levels of inactivation were observed for different combinations of C_0 and t and a model for bacterial inactivation kinetics has been proposed based on the response of *E.coli* to different disinfectant doses. Finally, the effect of TSS on the inactivation performance of PAA was investigated with a focus on "free-swimming" *E. coli*. Solids demonstrated to have an effect beyond PAA decay, interfering with the disinfection efficiency leading to a reduction in the log-inactivation obtained. It was hypothesized that this might be due to probable formation of bacteria aggregates, as defense mechanism, enhanced by the presence of the suspended solids.

STOCHASTIC ANALYSIS OF TROPOSPHERE'S NON-HYDROSTATIC REFRACTIVITY FIELD FOR SMALL- AND MID-SCALE GNSS NETWORKS

Alessandro Fermi – Supervisor: Prof. Giovanna Venuti

Spatio-temporal Precipitable Water Vapour (PWV) monitoring at regional and small scale is important both to deeper understand the initiation and development of local convection phenomena and to better forecast local heavy rainfall events. Along with scientific reasons, an accurate monitoring of PWV would be important also to support the activities of regional environmental protection agencies.
GNSS measurements represent an unexpected but interesting source of information to retrieve absolute and accurate time series of PWV measurements. In fact, the average zenith non-hydrostatic tropospheric delay (i.e. the Zenith Wet Delay) depends (linearly) on PWV. Thus, accurate estimates of GNSS signal tropospheric delays can lead to obtain reliable PWV data.
Our research lay within this field. It mainly focused on the analysis of GNSS observations from different GNSS networks with specific characteristics of receivers' electronics, spatial distribution and acquisition rate, in order to retrieve careful estimates of the non-hydrostatic tropospheric delay and to model its spatio-temporal variations.
To this extent, we carried out a comprehensive analysis of different approaches and estimation strategies of GNSS-derived Zenith Wet Delays (ZWDs) and we carried out a re-processing of the GNSS data acquired by the network MIST, deployed within the ESA project METAWAVE. The MIST network consisted of double-frequency geodetic receivers and was a dense network, i.e. a network with inter-distances of nearby stations less than 15 km. We analyzed several aspects both on the relative processing strategy (Double Difference method) and on the absolute processing one (Precise Point Positioning strategy). We have made extensive comparisons among these methods.
Along with this study, we gave a closer look at a mid-scale GNSS network, i.e. with nearby stations inter-distances of approximately 50 km. We analyzed two severe rainfall events occurred in Lombardy region on the 22nd and on the 26th of July 2016. These two severe storms showed a different meteorological nature: the one on the 22nd of July was characterized by a strong advective behavior with a weather front propagating from Southeast to North-West, whereas the event on the 26th showed strongly localized convective cells. To analyze whether ZWD time series would give evidence of these phenomena we processed GNSS data from 21st to 29th of July acquired by the interregional GNSS SPIN network. The aim of this analysis was assessing the accuracy of GNSS-derived ZWD and PWV and the potential use of GNSS observations for the determination of (2+1)-D ZWD maps - 2D for the spatial range and 1D for the time variable. We modelled the residual ZWD field – i.e. the ZWDs reduced by a height/time component - as an intrinsic stationary random field. We then computed for each epoch the spatial empirical variograms of the residual field and fitted these empirical spatial variograms with Fractional Brownian motion models.
At the end of the present work, we describe a procedure for the estimation of the mean transport velocity vector. This procedure relies on the conservation equation of the specific humidity and in its simplest form it turns out to be equivalent to Taylor's frozen flow hypothesis.

LAGRANGIAN AND EULERIAN STUDY OF BED-LOAD KINEMATICS

Seyed Abbas Hosseini Sadabadi

Supervisors: Prof. Francesco Ballio, Prof. Alessio Radice

Several processes in fluvial hydrodynamics such as erosion, deposition, bed-forms, etc. are governed by bed-load transport. For several decades, many theoretical and experimental studies were devoted to increasing our understanding of the phenomenological aspects of bed-load transport and, in turn, prediction performance.
The classical approach to bed-load transport, currently used in the engineering practice, relates the expected transport rate to the bulk properties of water flow and sediment. Uncertainties in the results provided by this approach have oriented the most recent research towards a deeper insight in particle motion by direct measurement and detailed analysis of sediment kinematics at small spatial and temporal scales. Most of these works have taken advantage of image-based methods, which are non-intrusive and can provide high-resolution data.
The investigation of sediment kinematics may be approached from a Lagrangian or Eulerian point of view. The former follows the individual particles as they move, whilst the second accounts for a finite control volume and studies the transport properties within this volume.

The present work was primarily aimed at investigating the kinematics of bed-load particles for weak transport conditions induced by one-dimensional turbulent flow. This study presents results from several laboratory experiments with the friction velocity ranging from 1.2 to 1.8 times the threshold value for sediment transport. The runs were performed releasing bed-load particles over a fixed, rough bed, that was created gluing sediment grains over plates.
Following that, image analysis was applied to track each moving particle along its trajectory.
A conceptual framework was proposed to define the relevant kinematic quantities to be analyzed, for both the Lagrangian and Eulerian approaches. The starting point of the framework is dividing the particle history into two states, namely motion and stillness. For that, an appropriate criterion for identification was conceived, that is based on comparing the position of the particle at a certain instant with all the positions taken before and after that instant.
Several Lagrangian and Eulerian kinematic properties were measured, including particle instantaneous velocity, hop length and duration, rest time, concentration of moving particles, entrainment and disentrainment rates, and solid discharge.
Experimental limitations were recognized and addressed when possible. Scaling analysis was performed to conclude how measured values could depend on the size of the observation area.
In addition, the dependency of the kinematic properties on the bed shear stress was investigated.
Encouragingly, the Lagrangian and Eulerian estimates were in good agreement, supporting the unified framework that was used.
An attempt was made towards interpreting the results in the light of the main expected physical mechanisms affecting the bed-load particle kinematics.

EXTREME ATLANTIC HURRICANES STATISTICAL ANALYSES

Seyed Reza Hosseini - Supervisor: Prof. Marco Scaioni

The occurrence probability estimation of extreme tropical cyclone intensity is an essential component in a vast number of fields and plays a crucial role in storm risk assessment, emergency planning, and insurance industry. The method typically employed for these analyses is based on the results of Extreme Value Theory (EVT). In this framework, the primary approach is Block Maxima (BM) which deals with modelling the behavior of sample extremes using the Generalized Extreme Value (GEV) asymptotic distribution. For the validity of this hypothesis, the number of events which among that the maximum is extracted assumes to be infinite. However, in practice, it is not the case for the extreme tropical cyclones due to their rarity. The other known limitation of the classical EVT is that only one value is selected per epoch (typically one year), which significantly reduces the available data. Alternative approaches such as the r-largest values, the method of independent storms (MIS) and Peak Over Threshold (POT) have been developed to overcome this limitation. The latter also leads to the GEV distribution by assuming a Poisson process of event occurrence and Generalized Pareto exceedances over a high threshold value. These hypotheses are also quite ad hoc and may be violated, e.g., due to the presence of interannual variability and clustering of storms. Furthermore, some decisions are required in the application of these methods (e.g., in the selection of a threshold), which may have a substantial impact on the estimation of quantiles and distribution parameters. In the first part of this thesis, the use of the recently developed Metastatistical Extreme Value (MEV) distribution to the analysis of extreme tropical cyclone intensity is introduced. The MEV distribution relaxes the restrictive assumptions of the traditional EVT, by taking into account the distribution of the entire range of recorded event magnitudes, rather than just the distributional tail. This work also comparatively assesses the performances of the MEV and of the classical EVT based on the 132-year long Maximum Sustained Wind (MSW) speed time series for all hurricanes in the Atlantic basin obtained from the US National Hurricane Center (Atlantic HURDAT2). The parameters of the GEV distribution were estimated using a range of methods to ensure an optimal estimator. The MEV distribution was fitted assuming a Generalized Pareto Distribution (GPD) for 'ordinary' values of MSW over 3-year blocks using Probability Weighted Moments (PWM). The statistical tests have been performed by dividing the dataset (of length-L) into two distinct parts: S years for calibration and *L-S* years for performance testing. The splitting of the dataset has been done by random sub-sampling, such that many realizations of the estimation error have been obtained. The results show that the MEV on average outperforms the widely used GEV, particularly for small samples and high quantiles. More specifically, the MEV is characterized by a smaller Root Mean Square Error (RMSE) than the EVT approaches when the average recurrence interval considered exceeds the size of the sample used for fitting, arguably the case of highest practical interest. Overall, for extreme hurricane intensity in the Atlantic Ocean, the MEV presents remarkable improvements in the estimation of high quantiles over the traditional EVT. The obtained values of the GPD parameters in the proposed MEV-GPD approach suggests the presence of an upper bound to the MSW speed under the current climate condition.

The second part of this study focuses on using the newly introduced MEV-GPD approach to examine the possible trend in the probability, frequency and intensity of hurricanes and their connection to climate change. There are different approaches to estimate the possible trend in hurricane activities such as the Maxima, Accumulated Cyclone Energy (ACE) and Potential Destructive Index (PDI). However, considering only the Maxima does not give complete information for analyses, and the disadvantage of using ACE and PDI is that as the duration of storm increase the ACE or the PDI also increase. It means that longer duration storms may produce a larger ACE or PDI compared to more powerful storms with shorter duration. In this study, the trend of extreme hurricanes is examined based on their probability of occurrence per year. The Moving Window (MW) analysis was used to investigate the probability of at least one Category five hurricane per year from 1886 to the present. This study suggests the presence of a long-term upward trend in the intensity of extreme hurricanes.

Comprehensive studies indicate that hurricane intensification can be linked to warm features. The formation of hurricanes has been linked to the Sea Surface Temperature (SST). The analyses in this work confirm this relationship and suggest a strong correlation between probability and frequency of hurricane and SST. Finally, based on the correlation between the GPD parameters and the number of events and SST the projection of the probability of extreme hurricanes in the Atlantic basin was performed up to the end of the century. Four different projection scenarios have been computed according to the four greenhouse gas concentration pathways considered in the

PROBABILISTIC RISK CONTOUR MAP OF RUNWAY-RELATED HAZARDS BASED ON AIRCRAFT BRAKING DISTANCE COMPUTATION EVALUATING EMAS FUNCTIONALITY AS THE SELECTED MITIGATION ACTION - APPLICATION OF RISK/SAFETY CONTOUR MAP

Misagh Ketabdari - Supervisor: Prof. Maurizio Crispino

Risk assessment methods in aviation greatly rely on the knowledge of the factors influencing risk and safety during daily operations. One of the weak points of the common approaches in aerodromes is the qualitative method to support decisions respect to quantitative evaluations. Air transport is one of the greatest contributors to the advancement of modern society. The air transport industry includes those activities that are directly dependent on transporting people and goods by air. The demand for air transport has increased steadily over the years. Passenger numbers have grown by 50[%] over the last decade and have more than doubled since the 1990s. In 2015 up to 3.5[billion] passengers have been carried by means of aviation transportation. Plus, around 180,000 [ton-km] freight of goods transported in the same day. These statistics highlight the level of importance and usefulness of aviation industry. Therefore by increasing in the demand of air transport, number of aircrafts each year consequently increased. Although the rate of accidents drops slightly each year but in overall, the number of accidents are bound to increase. This casts a gloomy shadow for the years to come.

The RSARA© (Runway Safety Area Risk Assessment) software, which is based on the Aircraft Cooperative Research Program (ACRP) model, has been utilized as a starting point for further sensitivity analyses of probabilistic risk assessment of each airport's runway with determined casual factors, including runway geometry, traffic characteristics, and weather conditions. A comprehensive airports incident/ accident database between years 2000 to 2015 was also used to perform the sensitivity analyses. In this study, six airports with diverse characteristics (i.e.; airport landlocked circumstance, aircraft annual movements, airfield geometry, runway features, and extreme weather condition) were selected for the analysis.
By providing different independent variables as input in the frequency model of RSARA, the outputs were useful to determine the influence of each of the casual factors on the accident probability of occurrence. Selected variables include: runway length in terms of declared distances, runway safety area geometry, instrumental landing system category, weather operational data and annual traffic growth rate. The sensitivity analyses showed that the weather condition and runway related factors played a major role in increasing or decreasing the probability of the accident; the probability of landing overrun (LDOR) can be increased by four times, for instance, due to specific combinations of runway length and climatic conditions. Engineered arrestor beds such as EMAS also has the potential to decrease by 50[%] the risk of LDOR and can be selected as an effective choice compared to other pavement materials within the RSA.
Runway excursions have formed the biggest share of runway-related accidents compare to all possible types of airport recorded events worldwide. Out of different possible event scenarios of excursions, runway overrun, which may occur in both landing and take-off phases of flight, is the most frequent one. Therefore many studies have been conducted focusing on determination of the contributing factors which have influence on the probability of runway overrun occurrence.
This probability is directly related to the difference between aircraft Landing Distance Required (LDR) and real-time braking distance. In this regard, aircraft braking distance under certain circumstances should be computed. Runway surface condition as a result of previous studies is known to be one of the most contributing factors in runway overrun accidents. Existence of different water-film thicknesses on the pavement decreases the pavement skid resistance which leads to lower friction, for instance; consequently, longer aircraft braking distance is needed and greater risk for aircrafts to overrun is expected. Skid resistance strongly depends on the complex relationship between the aircraft operating conditions and pavement surface properties. Five different MATLAB® codes have been conducted as one of the results of this study to model aircraft braking distance under certain circumstances of various water film thickness laying on the runway pavement, different weather conditions, various aircraft categories and different wheel loads applying on the pavement materials.
They are based on two separate algorithms. The first algorithm is based on a finite element model which is calculating dynamically the skid number between aircraft tire and pavement in existence of different water film thicknesses, and the results would collect in the second algorithm to calculate the aircraft braking distance. Braking distances for a selected set of aircrafts were calculated and plotted in probability distribution format. Based on the probability distribution compared to LDR for the selected set of aircrafts, the landing overrun probability contour map and safety/risk probability distribution is presented.
An additional framework has been conducted to check the functionality of Engineered Materials Arrestor System (EMAS) as one possible mitigation strategy to reduce the dangerous consequences of landing overrun. Another important output would be a risk contour map overlapped on the EMAS layout to give a comprehensive understanding of the percentage risk along its length as a function of the stopping distance. Deductions are presented at the end with the scope of more research to be done on this very important mitigation strategy.

Keywords: Airport, Aircraft braking distance, Landing overrun, Landing veer-off, Pavement friction, EMAS, Runway Safety Area, Probabilistic risk assessment, Mitigation measures

DEVELOPMENT OF A MULTI-SCALE MODELING SYSTEM FOR URBAN AIR QUALITY ASSESSMENT: CASE STUDY OVER THE MILAN AREA

Nicola Pepe - Supervisor: Prof. Giovanni Lonati

In the last decades, air pollution become one of the main issues that affected modern society. Despite a progressive reduction of pollutant emissions, the state of air quality in some countries, including Italy, overcome limit thresholds. Air quality alteration is mainly due to emissions, natural (e.g.: sea salt) and anthropogenic (e.g.: transport or domestic heating), and meteorology (e.g.: local anemological regime and atmospheric stability). The ever-increasing attention to the problem led to an ever-increasing development of the chemical-physical processes knowledge that involve both primary and secondary pollutants. Particularly, Po Valley area has always been affected by continuous exceeding of the thresholds, especially during winter time for PM_{10} and $PM_{2.5}$, determining a harmful situation for public health. Exceedances are mainly due to high concentration of dust emission sources over an area strongly disadvantaged in terms of atmospheric dispersion and very low wind speeds that favor the atmospheric stagnation of pollutants. Atmospheric modelling is one of the most suitable tools for studying the state of air quality and for the assessment of environemntal impact of policies.

The main goal of PhD was the development of a new modelling tool able to estimate air pollution levels in a complex urban area, considering local scale features (e.g.: roads and buildings) as well as the larger-scale phenomena. The modelling chain is composed by a meteorological model Weather and Forecast Research (WRF), the chemical and transport model at the regional scale CAMx, developed by US EPA and the local scale model AUSTAL2000. Both regional and local phenomena are properly treated obtaining reliable concentrations data over urban areas. The hybrid modelling system (HMS) was run over the whole Po Valley and in particular, over the city of Milan for 2010.

The first work was focused on estimating the NO_x concentration levels over a 1.6x1.6 km^2 domain with a spatial resolution of 20 m, centered on Duomo square, by HMS and CAMx. The contribution generated by sources located outside the urban domain was estimated through a simulation over the metropolitan area of Milan, with a resolution of 1.7 km, nested into a domain covering Po Valley with 5 km of resolution. PSAT algorithm allowed determining two distinct emissive areas: 1) the innermost one ("local") corresponding to the simulation domain 2) the area outside the local domain ("background"). The most important result achieved by the application of HMS was a more accurate reproduction of the concentration levels distribution over the local domain, with higher values on busiest road arches, considering the buildings effects. HMS and CAMx results were compared to 2 urban air quality stations within local domain.

The second work focused on source apportionment analysis (SSA), estimating the source categories and emissive regions contributions at an urban receptor located near the Duomo cathedral in Milan, by CAMx. This analysis focused on four pollutants: fine particulate ($PM_{2.5}$), the elemental carbon (EC), the nitrate ion, (NO_3^-), and a gas, the nitrogen dioxide (NO_2), never evalutated before by this approach. The 11 emission categories represented the typical sources (e.g.: vehicular traffic, agriculture and domestic heating). The SSA relied on 5 emissive regions: from the innermost local domain, centered over Duomo square, up to the outermost Po Valley region. $PM_{2.5}$ results showed that more than 50% of the contributions was generated far away from the receptor point (Lombardy and Po Valley regions). Focusing on the emission sources, the most impactful were transports, which contributed for 28% to the $PM_{2.5}$ annual average. The $PM_{2.5}$ components simluation highlighted opposite aspects. The primary component (EC) derives mainly from sources near the receptor; the local and urban background sources generated 73% of the final concentration (60% due to Milan and its province). The combination of transport and biomass burning contributions were again predominant, generating more than 80% of the final concentration. Conversely for NO_3^-, the larger part of contributions (more than 80%) were caused by emissive areas far away from receptor (Lombardy and Po Valley) and only transports provided the most important contribution (43% of the total concentration). Results obtained for NO_2 showed the main role of Milan metropolitan sources, that contributed for about 60%. Transport sector was the main source, generating more than 70% of the total concentration. Although these results could be useful for the assessment of environmental scenarios at local and regional scale, a validation of this tool was necessary. $PM_{2.5}$ results were compared to the Città Studi station measurements, obtained in the framework of the AIRUSE project, led by Fulvio Amato in 2013.

Similarly to previous work, the SSA was performed by the HMS, only for $PM_{2.5}$ and EC. The evaluation involved 3 urban receptors (high traffic exposure, urban park and residential area) in order to highlight the HMS capabilities, to capture some key features of the urban context. As expected, no relevant variations about concentration levels nor in their emission sources distribution were detected by CAMx stand-alone application. Conversely, HMS led to a clear difference of both concentration levels and emission sources distribution. To better understand differences between HMS and CAMx, the contributions of local sources were analyzed. Traffic receptor showed concentration levels 4 times higher than urban park site, both for $PM_{2.5}$ and EC, regardless the period. Relevant discrepancies were also found between emission sources distributions: transport sector was the main source at the traffic site, while at park site biomass burning reached an equal weight. Adding the contributions generated by background sources, these differences remained appreciable but attenuated, especially at the traffic receptor.

During the last period of PhD, experimental campaigns were performed in order to study the PM resuspension due to vehicular traffic. Given that constant PM underestimation by the models and the lack of the resuspension emission factors (EF) within emission inventories, we investigated two aspects: 1) the recovery rate of road dust after a rainy event 2) the impact of fleet composition and speed on resuspension EF. This experience was made possible thanks to Fulvio Amato (Instituto Diagnostico Ambiental y Estudios del Agua), and Marco Bedogni (AMAT, the environmental agency of Milan).

From October 2016 and March 2017, we measured the silt load deposited over the road surface by means a sampler with a flow rate of 30 l/min on a quartz filter. Operationally, the filters were left in the climatic chamber for 2 weeks removing the residual moisture and weighed on a 5 precision digits balance. The first results showed an exponential trend with a rapid growth during the first hours after the rainy event reaching the maximum value after about 48 hours.

The second campaign was divided into two parts, both with an exposure time of two weeks, considering the speed variation due to the installation of speed cameras and over 3 different Milan road arches. The resuspended mass was captured by passive samplers installed on light poles between the two carriageways or one side of the road. For each road, an array of 3 passive samplers were installed at different heights capturing lighter particles (higher samplers) and heavier ones (lower samplers). The results obtained on Via dei Missaglia and Via Ferrari showed a reduction of the resuspended mass, correlated with a reduction of travelling speed, in the lower samplers, while on the higher ones the mass was similar.

OPTIMIZATION OF ACTIVATED CARBON ADSORPTION FOR MICROPOLLUTANT REMOVAL FROM DRINKING WATER

Andrea Piazzoli - Supervisor: Prof. Manuela Antonelli

Granular activated carbon (GAC) adsorption is known to effectively remove many classes of micropollutants affecting drinking waters. However, GAC life- time in the fixed- bed process can strongly depend on the considered target contaminants and the water composition. In presence of a mixture of micropollutants, an optimization of the GAC adsorption phase is often required to improve the treatment process efficiency. The optimization process can be figured out as the completion of three consecutive steps: 1) evaluation of GAC adsorption efficiency towards the target contaminants; 2) process simulation under full-scale conditions; 3) definition of the optimal design and operating criteria. These three different engineering tasks were studied focusing on specific classes of micropollutants considered as target contaminants, namely: heavy metals (namely, Cr(VI)), disinfection by- products (DBPs, specifically *N*- nitrosamines) and synthetic organic compounds (namely, chlorinated solvents).
Regarding heavy metals, the efficiency of GAC adsorption in the removal of Cr(VI) from a real groundwater was investigated and compared with the strong base anion (SBA) exchange process (step 1). Various commercial GACs and SBA resins were tested by equilibrium and kinetic laboratory scale experiments, for the removal of Cr(VI) and other organic and inorganic contaminants. Kinetic and isotherm models were calibrated for the studied materials, estimating their specific throughputs under full-scale conditions. Cr(VI) removal was found to depend on GAC textural properties; however, SBA exchange resulted to be the best solution, providing sorbent usage rates much lower than GAC adsorption.
The possibility to control the formation of *N*-nitrosamines, a group of emerging DBPs, from nitrogenous micropollutants by GAC adsorption was investigated (step 1). Laboratory- scale experiments on model water solutions were carried out. Firstly, the formation of specific and total *N*- nitrosamines (TONO) from various micropollutants associated to pharmaceuticals and personal care products was studied, observing relevant TONO formation yields, mainly associated to unknown *N*-nitrosamine species and dependent on the precursor molecular structure. Secondly, the effectiveness of GAC adsorption in reducing the *N*-nitrosamine formation potential of the precursors was evaluated, testing two possible treatment solutions: adsorption phase before oxidation treatment, to reduce *N*- nitrosamine precursor concentration, and adsorption phase after oxidation treatment, to remove the formed *N*-nitrosamines. Pre- adsorption of *N*- nitrosamine precursors resulted to be an effective option, while post- adsorption efficiency was found to depend on TONO pool composition.
Among synthetic organic compounds, the problem of breakthrough prediction (step 2) for chlorinated solvents in a full-scale GAC adsorption system was firstly investigated. Practical criteria for the application of the Homogeneous Surface Diffusion Model (HSDM) to predict tetrachloroethylene and chloroform breakthrough in two full- scale GAC filters were proposed, focusing on the main aspects of the simulation process: i) experimental determination of model parameters for a multi-component groundwater, ii) model adaptation to case-specific conditions and sensitivity analysis, iii) validation with full-scale data. The accurate estimation of model parameters was found to depend on the contaminant characteristics. The importance of introducing time- varying parameters (such as flow rate and contaminant influent concentrations) was also highlighted to best simulate the full- scale process.
Secondly, the optimal design parameters and operating strategies for a full- scale GAC system treating groundwater contaminated by chlorinated solvents were investigated (step 3). Five full-scale operating GAC filters, containing different GAC types, were monitored to observe contaminant breakthrough profiles. The observed data were used to calibrate a predictive model, which was then used to simulate a large- scale GAC system under different scenarios, covering GAC configurations, main design and operating parameters, target contaminant and treatment objective. For each simulated scenario, GAC costs (derived from the specific throughput) and management complexity (in terms of GAC replacement strategy and frequency) were evaluated as process performance indicators during a long- term time frame. Results showed that the best configuration is a compromise between conflicting performance indicators.

FLOATING OFFSHORE WIND TURBINES: DESIGN AND ENGINEERING CHALLENGES

Luigia Riefolo - Supervisor: Prof. Arianna Azzellino

The research stems from the growing interest in renewable energy coming from waves, wind, currents, and tides. The number of deployments at sea is increasing especially surrounding the production of electricity from wind. Since there is a lack of space and a huge demand for wind turbine installations, the market is moving to build more offshore than land-based wind turbines. Offshore wind energy in particular is more competitive than other renewable energies because it offers conditions for power generation in favorable conditions (high winds with low turbulence), minimal visual impacts and high generation capacities.
The expected development of such marine renewable devices is likely to result in the further transformation of the maritime space, already heavily impacted by significant pressure from anthropic activities (fishery, vessel traffic, oil and spill industry etc.). For this reason, it is essential to consider the positive and negative effects on the marine habitats generated during the installation, operation and decommissioning of such devices. Therefore, the deployment of offshore wind turbines highlights specific effects such as collisions, underwater noise, and the generation of electromagnetic fields on the marine ecosystem (e.g. sea birds, fishes, marine mammals). Consequently, the spatial conflicts of sea users and the demand for sea space are in fact increasingly growing. The quantitative Marine Spatial Planning MSP criteria may help to evaluate the sustainability of conflicting human activities from the perspective of minimizing the overall environmental impacts. Trade-offs need to be made by considering all of these aspects, even from an economical point of view. In fact, the cost challenges are a critical issue for offshore installations when larger turbines need to be installed further from the coast.
Moreover, the offshore structures have the added complication of being placed in an ocean environment where hydrodynamic interaction effects and dynamic response become major considerations in their design.
The hydrodynamic response of offshore wind turbines need to be investigated through large-scale offshore engineering laboratory experiments and dedicated numerical models.
The recent interest in offshore wind technologies has increased the demand of quality tests to optimize the design of innovative floating offshore wind turbines and to collect reliable and accurate data for further calibration and verification of numerical models. However, there are still few studies on the spar buoy concept. To accurately predict the load on offshore wind turbines themselves, which is critical for ensuring a system's safe design, a numerical model that incorporates all the dynamics is usually required. In general, dynamic models account for wind inflow, aerodynamics, elasticity and control of the wind turbine, as well as the incident waves, hydrodynamics, and mooring dynamics of the floater.
Numerical analyses can be performed with several codes, such as the fully coupled, time domain aero-hydro-servo-elastic simulation Fatigue, Aerodynamics, Structures and Turbulence FAST tool. A calibrated numerical model could analyze the dynamics and the design of the floating wind turbines at a specific offshore site.
The design process of an offshore floating wind turbine includes the evaluation of loads, dynamic response and stability in normal and extreme operating conditions. This methodology is a key factor used in the design of the mooring system, which needs to maintain the structure's position during the extreme events occurring throughout its life.
For all these reasons, the main goal of this research is to study the dynamic response of the floating offshore wind turbines and the related engineering challenges, environmental and economic. The specific objective is to investigate the technical challenges that must be overcome for offshore wind turbines to achieve sustainability in a cost-benefit framework.
The research activity has been split into two areas. The first part is a review of the main environmental concerns generated by the offshore renewable installations and their effects on the marine habitats as well as the economic implications. The second part of the research focusses on the investigation of the hydrodynamic response of the floating wind turbine under different environmental loads from an experimental and numerical point of view.
Experimental tests on a floating wind turbine (spar buoy), were performed in the offshore wave basin at the Danish Hydraulic Institute (DHI) within the European Union-Hydralab IV, and the results analyzed. The related displacements and rotations of the physical model test have been investigated to better understand the hydrodynamic response caused by wind and wave loads. In particular, the experimental response of the spar buoy platform under regular and irregular waves and wind loads were studied. Measurements have been taken of hydrodynamics, displacements of the floating structure, wave induced forces at critical sections of the structure and at the mooring lines. Free decay test results have allowed the evaluation of the surge, sway, roll and pitch natural frequencies and damping ratios of the spar buoy wind turbine. Furthermore, measured displacements, rotations, accelerations and forces at the top and base of the tower have been examined in the time and frequency domains under parked and operational conditions.
The experimental results have been further analyzed to implement a unique dataset suitable for numerical modeling to be employed for the comparison with prototype measurements.
Based on the observed parameters, the numerical model FAST certified by the National Renewable Energy Laboratory (NREL) of the U.S. Department of Energy has been used to make a comparison with those simulated. In fact, the numerical results have been compared with data deriving from the experimental tests in order to validate the motion response and the mooring line tensions of the spar buoy wind turbine.
Finally, in collaboration with the Environmental Hydraulics Institute of Cantabria "IHCantabria" (Santander, Spain), a numerical application through FAST code has been conducted with reference to an offshore site in the South of Italy, suitable for the installation of a spar buoy wind turbine. The scope is to numerically investigate the effects of different wind turbulence models on the spar buoy and its station-keeping system.
Based on a specific number of simulations for each load case, which is a requirement to ensure statistical reliability of the load's estimation, time and frequency domain analyses are applied. A sensitivity analysis focuses on the minimum data requirements for the extreme mooring line load calculation, investigating the number of simulations required to get a statistical convergence of the results. The influence of wind turbulence models and their consideration in design methodology, along with the Ultimate Limit State ULS for the intact structure, has been evaluated. In fact, ULS analysis investigates the adequate strength of mooring systems to withstand the load effects imposed by extreme environmental actions. Based on the standards of, International Electrotechnical Commission IEC, Det Norske Veritas DNV, ISO and American Petroleum Institute API, it is recommended to design the position moorings under extreme wind loads which are represented by Kaimal, von Karman and API or Frøya turbulence models. Moreover, for time domain analysis DNV standards have been used to define the global maxima and then the extreme tensions along the mooring lines. Results of design tensions are found to be influenced on the choice of wind turbulence model.

BAYESIAN GRAVITY INVERSION BY MONTE CARLO METHODS

Lorenzo Rossi - Supervisor: Dr. Mirko Reguzzoni

The inverse gravimetric problem consists in the reconstruction of the Earth mass density distribution from the observation of its gravitational field. The solution to this problem is generally ill-conditioned and non-unique, but, introducing very strong constraints or numerical regularization, a unique solution can be retrieved. This could be not representative of the actual mass distribution, because of non-physical or too restrictive constraints. Moreover, a strong regularization may cause very smooth solutions in terms of estimated density. In this case, the identification of the boundaries between different materials becomes a hard task. To overcome these limitations, a possible option is to apply the Bayesian approach that easily allows to introduce prior information on the unknown parameters. Moreover, secondary parameters can be easily introduced, e.g. to characterize the different types of material, allowing a sharp classification of the subsurface.

In the present work, a Bayesian gravity inversion algorithm is developed, with the aim of estimating a mass density distribution together with a classification of the different types of material. The latter allows to identify the boundaries of the different materials and is developed by borrowing image analysis techniques. Consequently, the investigated volume is subdivided into volume units (voxels), each of them characterized by two random variables: the label defining the type of material (discrete) and the density (continuous). The a-priori geological information is translated in terms of this model, providing the mean density with the corresponding variability for each class of materials and the a-priori most probable label for each voxel with a set of neighbour rules. These rules have the aim of obtaining a clustered model in terms of geometry with smooth boundary surfaces between the different materials. The final solution is retrieved by invoking the Maximum A Posteriori principle (MAP). The MAP is determined by applying Markov Chain Monte Carlo optimization algorithms. In particular, a simulated annealing performed by a Gibbs sampler is chosen to maximize the posterior distribution. The obtained result is then refined by a deterministic optimization algorithm.

The proposed method has been implemented into a hybrid Matlab/C code. The combination is directly performed into the Matlab environment by means of the MEX library API by Mathworks. The advantage of coupling the two programming languages is that the final software maintains the easier Matlab data management and visualization, upgraded with the computational speed that is typical of the compiled C code. The performance improvement due to the C language is important when facing with loops, that can run until ten times faster on the same machine. Moreover, optimization in the memory management is allowed for C functions, thanks to the fact that the memory allocation is directly controlled by the programmer.

In the developed software, the C routines are already optimized by using BLAS/LAPACK libraries for matrix operations and/or OpenMP libraries for parallelization on multi-core processors. A remark is that the parallelization is performed only for few limited routines, due to the natural sequentiality of the Markov Chain Monte Carlo methods used in the solution.

The software is then applied in the frameworks of oil exploration and crustal investigation. The former application consists in retrieving the shape of the bottom of a salt dome, which is a typical application of oil exploration. In order to avoid border effects in the gravity data reduction and to allow a better understanding of the meaning of the parameters that define the prior probability, it is performed in a simulated scenario. The latter is related to the inversion of the crustal structure in the Guandgong province in South China, with the aim of improving its knowledge just below a detector of neutrinos and geoneutrinos, currently under construction. The prior probability is defined by exploiting all the available geological and geophysical information (e.g. deep seismic sound profiles, virtual sections, Moho maps, etc.). The obtained Bayesian solution is also compared with a classical solution to the inverse gravimetric problem, showing a good agreement in terms of estimated geometry of the Moho depth, with differences of about 1 km. However, the Bayesian solution improves the smoothness of the estimated geometry and allows to infer horizontal and vertical density variations.

In general, all the tests show that the method is able to retrieve an estimated model that is consistent with the given prior information and fits the gravity observations according to their accuracy. In this sense, one can conclude that the developed method is a sort of “artificial intelligence”, supporting the user by automatizing the trial-and-error techniques. In fact, an initial guess on the model parameters is required, but differently from a trial-and-error solution these parameters are automatically adapted to fit the gravity observations, according to the rules introduced by the user as prior probabilities. If the solution is not satisfactory, this should be attributed to the weak information provided by the gravity or to the wrong or incompatible geological information supplied by the user.

RECLAIMED ASPHALT PAVEMENT (RAP), A PRECIOUS RESOURCE FOR ROAD AN AIRPORT CONSTRUCTION: AGING EFFECTS, MECHANICAL PERFORMANCE AND ENVIRONMENTAL BENEFITS

Ehsan Ashouri Taziani - Supervisor: Prof. Emanuele Toraldo

The increasing consumption of natural resources and producing a high amount of waste materials during road and highway construction projects besides rapid reduction in energy sources due to gradually increasing demands, emphasize the importance of sustainability in case of pavement construction. For that reason, the tendency to find sustainable options for pavement construction, operating and maintaining the transportation infrastructures, keeping the pavement quality in good condition and extending service life is growing between pavement industries.
Environmental and economic benefits of incorporating recycled materials in pavement production have increased the tendency to use higher reclaimed asphalt pavement (RAP) in mixtures, which results in decreasing energy and virgin material consumption. RAP is a removed and reprocessed pavement material containing binder and aggregate, incorporating RAP can decrease the cost of construction, transportation, and energy consumption of virgin materials helps to conserve the environment by using fewer virgin aggregates in pavement construction. Although mechanical properties (strength and stiffness) and durability of RAP are the main concerns of pavement industries and researches conducted on improving RAP properties by blending them with virgin materials or using chemical additives, however, this method might not be environmentally friendly. As recycled aggregates and binders are still valuable even if they have reached the end of their service life, many types of research have been conducted in case of producing mixtures with a high content of RAP. However, there are various recycling methods such as hot/cold in plant/in situ, half warm asphalt mixtures and warm asphalt mixtures; there is still strict limitation in case of using higher content of recycled materials, RAP content of mixtures limited to 60% due to plant production issue in standards issued by policymakers. Even more, the possibility of using the total amount of RAP studied by several researchers around the world which highly depends on the material characteristics and requires more large-scale trials to evaluate the influence of RAP on the rutting, stiffness and fatigue performance of final mixture.
The present thesis aims to investigate a 100% RAP mixture through sieves of laboratory evaluations on both aged bitumen and mixture in terms of performance and environmental effects. Performance assessment was developed according to experimental data gathered and analyzed over laboratory assessments focuses on the effectivity of rejuvenator agents and compaction temperature in order to control the performance of final mixture.
The results showed the positive effect of rejuvenator agents in reactivating the RAP aged bitumen and proved the possibility of using 100% RAP in and sub-base as a reliable alternative to virgin materials. On the other hand, the mechanical performance tests confirmed the positive results obtained from the compaction and volumetric tests; indeed, stiffness performance, fatigue life, and rutting potential could be improved by using the compaction temperature to reactivate the aged bitumen of RAP.

MULTISCALE PHYSICAL AND MECHANICAL CHARACTERIZATION OF FAULT ROCKS WITH EMPHASIS ON NON-DESTRUCTIVE 3D IMAGE ANALYSIS

Nahid Vatanpour - Supervisor: prof. Laura Scesi

The presence of faults along all engineering constructions, especially in underground excavation can lead to significant problems. Rocks usually considered as a strong material, but when they are located under tectonic stress, behave like a weak material because of their fractured and weathered structure. So, they are usually under influence of physical, petrographic and alteration changes. Due to the complexity of fault zones and fault rock geotechnical characteristics, a clear and precise description of the physical, mechanical properties and terms are essential for all engineering purposes. Although the general physical phenomenon for weak rocks has been predicted, so far there is a little direct experimental knowledge about the association of fault rock structure with its physico-mechanical characteristics. In this study, the geomechanical characterization of fault rocks and the relationship between these characteristics and their variation considering the distance from the fault are investigated. To have a precise view, a series of laboratory experiments have been performed to identify and quantify the changes of these properties. The experiments were arranged in different categories; the physical, petrographic, and chemical changes were evaluated using thin section study, X-Ray powder diffraction, and X-Ray fluorescence spectrometry. Porosity as a fundamental microstructural parameter for most natural materials has been significantly influenced by the physical properties of these materials such as diffusion coefficient, elastic wave velocities, elastic moduli, Poisson's ratio yield, strength, capillarity and fluid permeability. So, to evaluate the porosity and pore network conductivity, we considered different techniques because such a kind of calibration seems helpful to the understanding of the physico-mechanical properties of geotechnical engineering materials. Different methods such as fluorescent thin section microscopy, X-Ray micro tomography, pycnometer analysis, mercury intrusion porosimetry and vacuum saturation techniques were used. In fluorescent microscopy imaging, the specimen is illuminated with a relatively short wavelength light. The specimen examines through a barrier filter which absorbs the short wavelength light used for illumination and transmits the fluorescence, which is therefore seen as bright signals against a relatively dark background. In X-ray micro-CT method, the porosity of samples (e.g. aggregates, air voids and other constituents) can be visualized and evaluated using the X-ray micro-CT scanner with the maximum resolution is 7 micrometers and thus this can be used to study the structure/ property relationships of the samples. Images of X-ray micro-CT evaluated with Avizo 9 software can give a precise 3D virtual reconstruction of pore network. The dynamic properties of all the samples have been defined by using ultrasonic pulse velocity measurements. Variation of rock structure could also be detected and quantified by the use of compression (Vp) and shear (Vs) wave velocity, but this velocity-medium rock relationship becomes complicated when micro-cracks exist in the rocks, because the elastic properties of a rock are more affected by the micro-cracks than by open porosity. So, in this project, statistical evaluation of shear (Vs) and compressional (Vp) wave velocities and the relationship between Weathering, porosity pattern, lithotype and distance of each sample from the fault are presented. Determining the geo-mechanical properties of the rocks as a first step of each civil engineering project, have a significant impact on costs, time and stability of the projects. Strength assessment of fault rock requires a precise geotechnical characterization using both field and laboratory measurements. Characterization of this kind of rock is not easy because of their great variability and heterogeneity. To investigate the mechanical characteristics of our samples, uniaxial compressive tests and multistage triaxial test were performed. The studied samples, apart from the lithology and petrography issue, are represented three different zones in almost all the results. The first and most weak zone is devoted to 0 to 18 meters from the fault. The second zone which showed a lower degree of alteration and fracturing is started from 18 to 85 meters far from the fault; and the last zone is between 85 to 89 meters from the fault which presented lower strength in compare to the second zone because of the presence of high percentage of phyllosilicate minerals inside the structure of the samples. Although a precise and useful way to evaluate these properties is performing the laboratory tests but mechanical tests are usually time-consuming, expensive and destructive. Using analytical and/or numerical tools is a very useful way to estimate these properties. So, the improvement or decay of the physical and elastic properties with the average values of the compressive strength and the distance from the fault are represented by regression analysis. To perform the analysis, this large amount of data multivariate analysis methods performed based on combining many variables in order to identify which input variables are important for contributing to the prediction of the output variable. Regarding to the statistical analysis, a significant correlation parameter is observed when average values of the compressive strength and Young's modulus are compared with the average porosity value and chemical index of alteration. Finally, a relation between the porosity at the micro scale and petrographic index of Hoek and Brown failure criterion is evaluated. Since the cost of micro-scale physical characterization is much lower than the mechanical tests, a precise estimation of the fault rock strength based on the pore network investigation has an economical advantage. According to the result of this study, we can avoid the overestimation from the routine existing fault rock classifications. Moreover, in the thesis by utilizing the multivariate data analysis, a statistical method is presented for having a precise prediction of mechanical properties of fault rocks based on only the results of non-destructive rock analysis.

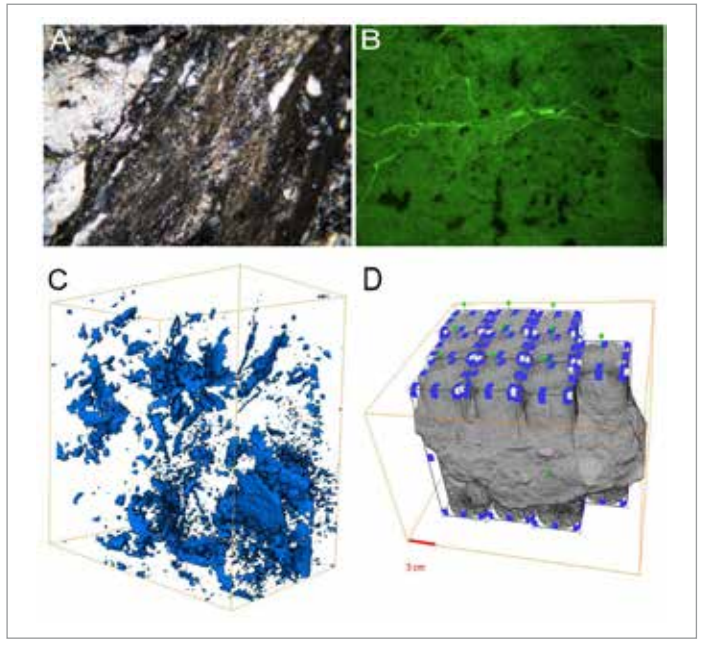

Fig. 1 - Different methods to evaluate the porosity. A: Thin section study under polarize light, B: Fluorescent thin section image analysis, C, D: X-Ray micro tomography image analysis (C shows the 3D structures of the pore system inside the sample and D shows the virtual coring process from whole the sample).