International Workshop Tribute to Luigi Cavazza

Understanding the interactions between soil functions and structure with innovative methods

Bologna, 5 April 2018 - Accademia di Agricoltura Archiginnasio Via Galvani 1

Organizing Committee

Francesco Morari, Nicola Dal Ferro, Andrea Monti, Carlo Grignani, Celine Duwig

Scientific Committee

Francesco Morari, Nicola Dal Ferro, Celine Duwig, Patrice Delmas, Carlo Grignani, Karin Müller, Marcella Giuliani

PROTINUS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°645717

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10.00-10.15 **Welcome**
Carlo Grignani, Italian Society for Agronomy
Giorgio Cantelli Forti, Accademia Nazionale di Agricoltura

10.15-10.45 **L'attività scientifica di Luigi Cavazza -** Gianpietro Venturi,University of Bologna, Italy

10.45-11.15 **Soil Physics in Italy** - Mariana Amato, University of Basilicata, Italy

11.15-11.25 **The project PROTINUS "Providing New Insight Into Interactions Between Soil Functions and Structure**" Celine Duwig, IRD - Institut Français de Recherche pour le Développement, France

11.25-11.50 **Water repellency characterization for soils across three continents (Greenland, Japan and New Zealand)** Emmanuel Arthur, Aarhus University, Denmark.

11.50-12.15 **Coffee break**

12.15-12.40 **Influence of X-ray micro-CT resolution on the direct numerical computation of flow and transport properties in granular soils** Patricia Ortega, Laurent Oxarango, University Grenoble Alpes, France

12.40-13.05 **Effect of long-term irrigation and cultivation practices on soil properties**
Karin Müller (Hamilton):. New Zealand Life Cycle Management Centre, New Zealand

13.05-13.30 **Investigating the interaction between soil carbon dynamics and soil structure using X-ray micro-CT -** Francesco Morari, Nicola Dal Ferro, Ilaria Piccoli University of Padova, Italy

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13.30-14.30 **Lunch**

14.30-14.55 **Emergent contaminants (antibiotics) fate in soils -** Celine Duwig , IRD - Institut Français de Recherche pour le Développement, France

14.55-15.20 **Development of appropriate technologies for pollution control and environmental restoration at solid waste landfills: The role of soil physics -** Ken Kawamoto, Saitama University, Japan

15.20-15.40 **Coffee break**

15.40-16.05 **Analysis of phase distribution in vertical flow constructed wetlands using X-ray micro-CT** German-Dario Martinez-Carvajal, Laurent Oxarango, Pascal Molle and Nicolas Forquet. IRSTEA Lyon, University of Grenoble-Alpes, France

16.05-16.30 **Application of image analysis in soil physics -**Patrice Delmas, University of Auckland, NZ

16.30-16.50 **Experiments in Washington State,Svalbard, Alaska and Concordia: 20 years of research to understand liquid water, ice and soil interactions -** Marco Bittelli, University of Bologna, Italy

16.50-17.00 **Conclusions and perspective**
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La partecipazione al Workshop è gratuita: per motivi organizzativi e di disponibilità di posti in sala si chiede di iscriversi inviando una mail alla Segreteria Protinus? Sia? entro il 29 febbraio

Crediti formativi per le Scuole di Dottorato

La partecipazione al corso dà diritto a 1 credito formativo per le varie Scuole di dottorato previa verifica dell'apprendimento.

Contributi alla partecipazione di giovani

La Società Italiana di Agronomia intende promuovere la partecipazione di 3 giovani (under 35) che stiano svolgendo un Dottorato di Ricerca o Assegno di Ricerca su tematiche collegabili alla tematica del workshop, attraverso l'intera copertura delle spese di trasferta. Per poter partecipare alla selezione è necessario mandare una mail con la propria candidatura (completa di curriculum vitae) al seguente indirizzo: segreteria@siagr.it entro il **29 febbraio 2018**.

Organizing Committee
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PROOTINUS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°645713

The international workshop "Understanding the interactions between soil functions and structure with innovative methods" and the tribute to Luigi Cavazza

Giorgio Cantelli Forti[A], Carlo Grignani[B]

[A]*National Academy of Agriculture*, [B]*Italian Society of Agronomy*

The International Workshop "Understanding the interactions between soil functions and structure with innovative methods" was organized by the PROTINUS project, in collaboration with the National Academy of Agriculture and the Italian Society of Agronomy. The aim of the workshop was to broaden the technological advancements and the knowledge of PROTINUS members to the scientific community in the field of soil physics, and lay the foundations for a promising relationship between PROTINUS members and the scientific community. Moreover, with the occasion of the international workshop, the aim was also of providing a tribute to prof. Luigi Cavazza, whose activity in the field of soil physics was pioneering in the national and international agricultural scientific community.

Professor Luigi Cavazza began his academic career after graduating in Agricultural Sciences at the University of Bari (Italy) and then moved to the University of Logan, Utah, United States, where he received his Master of Science in Soil Physics with Prof. S.A. Taylor in the early 1950's. During the period in the United States, prof. Cavazza provided important contributions to the understanding of coupled heat and water transport in soils. After the studies in the USA, prof. Cavazza returned to Italy and became Professor of Soil Physics and Agronomy at the University of Bologna, where his research activity proceeded for over forty years, mainly in the field of soil physical and hydrological aspects of the soil-plant-atmosphere *continuum*, with particular interests for many practical aspects of irrigation problems. His scientific work is documented by more than 340 publications in national and international journals, a soil physics textbook and many technical reports. He actively participated in the research for planning and developing the Emilia-Romagna Irrigation Channel, providing still today irrigation water to thousands of farms in the Po Valley. Luigi Cavazza spent several research periods abroad, such as at the Institute of Plant Physiology at the ETH Zurich (Switzerland) and at the Experimental Station of Rothamsted (United kingdom). Prof. Cavazza was an honorary member of many institutions, including the Superior Council of the Italian Ministry of Agriculture and Forestry, Emeritus of the Academic of Georgofili of Florence, and also received the Knight insigna of the Ministry of Agriculture of France.

Water repellency characterization for soils across three continents (Greenland, Japan and New Zealand)

Emmanuel Arthur[A]*, *Federico M. Meléndez*[B], *Karin Müller*[C], *Lis W. De Jongei*[A], *Per Moldrup*[D] *Toshiko Komatsu*[E], *Mogens H. Greve*[A], *Peter W. Jensen*[A], *Cecilie Hermansen*[A], *and Ken Kawamoto*[E]

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Abstract

Soil water repellency (WR) is a widespread phenomenon that affects agricultural processes like water infiltration with consequences such as losses of water, nutrients and pesticides. Characterizing soil WR and identifying soil properties that control it is crucial to mitigating the negative effects of WR. In this study, we characterized WR for soils obtained from Japan, New Zealand and Greenland, investigated the persistence of the observed WR, and examined the effect of carbon content on the WR.

Thirty-nine soil samples were obtained from the three regions, air dried and sieved to 2-mm prior to analyses. We measured bulk soil organic carbon (SOC) and nitrogen (SON) with a CN analyser and WR by the contact angle (CA) using the sessile drop method. Further, the samples were equilibrated at increasing soil water contents and the time dependency of the samples was measured. To further elucidate the contribution of the various carbon pools on the contact angle, we measured surface C, N, and O using x-ray photoelectron spectroscopy (XPS) on selected samples.

For all three regions, the trend of bulk SOC followed that of SON The XPS-derived fractions of carbon and nitrogen were significantly higher than bulk SOC and SON. The C:N ratios of the two methods (XPS and CN analyser) were comparable, but samples from Greenland consistently had smaller surface C:N ratios than the bulk C:N ratio from the CN analyser. The initial WR for the soil samples was weakly related to bulk SOC, surface SOC and both C:N ratios. Further analyses of the XPS carbon pools and comparison to initial CA did not show any correlations. For majority of the samples (regardless of origin), the apparent contact angle increased with increasing water content until a peak at an intermediate water content and declined afterwards. The time dependence of the CA initially decreased sharply with water content followed by an increased suggesting that beyond a critical water content, soil water repellency can be mitigated. Results showed that the dynamics and trends of soil water repellency across the three regions were quite similar and for mitigation of soil WR, consideration of soil water content is critical. Further analyses of the hydrophobic/hydrophilic nature of the carbon pool is necessary to fully understand the effect of carbon on WR.

Effect of X-ray CT resolution on the quality of permeability computation for granular soils: Definition of a criterion based on morphological properties

Patricia Ortega Ramirez[A], *Alfonso Gastélum Strozzi*[B],*Laurent Oxarango*[A]

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The quality of soil permeability, estimated by Computational Fluid Dynamics methods, applied to 3D images, derived from X-ray CT imaging is discussed. Numerical methods normally use the image voxel as computational mesh element. In this framework, the resolution is associated to the quality of the numerical computation. However, the computational cost increases drastically while the resolution increases. The proposed methodology analyses the dependence of soil morphological and dynamical properties with respect to the image resolution. An original method based on the morphological closing operation is proposed to derive the PSD.

Two material were studied: a virtual pack of spheres and a sample of Fontainebleau sand with original X-ray CT scan resolution of 4.5 micrometers. Using the rescaling method, versions of the original image with decreasing resolution were built. Both materials exhibit the same behavior. As resolution decreases, the permeability and specific surface values diverge, from the reference value obtained at the original resolution. This effect is less sensitive for porosity. The shape of the PSD exhibits a shift toward badly resolved pores. If less than 50% of the total pore volume is contained in pores smaller than 4 voxels in diameter, the permeability computation can be considered reliable. This criterion is supported by an analysis of the flow rate distribution between the pore size classes.

Effect of long-term irrigation and intensive tillage on topsoil carbon stocks and structure

Karin Müller [A,E], *Nicola Dal Ferro*[B], *Craig Tregurtha*[C], *Filippo Zanini*[D], *Simone Carmignato*[D] *and Francesco Morari*[B]

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Abstract

Agricultural intensification in New Zealand has been driven by the Government's ambitious target of the Business Growth Agenda to double the export earnings of the country's primary industries by 2025. Irrigation plays a key role: From 2002 to 2012, irrigated land increased by 54%, mainly caused by expanding irrigated dairying, cropping and viticulture in the South Island. It seems timely to analyse the effects of irrigation on soil quality and functions.

In this study we analysed the effect of long-term irrigation and intensive cultivation practices on the chemical and physical soil quality of an arable soil. Our hypothesis is that long-term intensive management practices will deplete topsoil carbon stocks, which in turn affects structural characteristics including pore size distribution, connectivity and tortuosity of surface soil. Such potential changes will also influence the soil's capacity to deliver its key functions including water infiltration, nutrient and water cycling and storage as well as gas exchange.

Chemical and physical soil health parameters including carbon and nitrogen contents, total biomass, Olsen-P and bulk density were analysed on bulk topsoil (0-5 cm) samples collected from different treatments of a long-term tillage and irrigation research site in Canterbury, New Zealand. In addition, the 3D-macro-pore networks of undisturbed topsoil cores (5 cm diameter x 5 cm depth) collected from the same sites were derived with X-ray computed tomography (CT).

Long-term irrigation and tillage significantly ($P<0.05$) reduced the topsoil's chemical soil quality in all parameters analysed with the exception of soil pH. Based on these results, we expected less macro-pores and more small pores under the intensive management. The traditional physical soil health analysis confirmed this: bulk density was significantly ($P<0.05$) higher for intensively tilled soils, which reduced their total porosities. The same trend was found for the irrigation treatment but the results were not significant. The X-ray CT analysis revealed a macro-porosity of about 7 cm^3 cm^{-3} for all topsoils, and this was not affected by management. However, the pore size distribution was significantly changed by long-term irrigation, and warrants a more in depth analysis of other morphological parameters of the macro-pore network. In conclusion, long-term intensive management of arable soils can lead to topsoil quality degradation. Therefore, careful monitoring is required to ensure that soil quality is not sacrificed for short-term productivity gains.

Understanding soil carbon processes with three-dimensional models

Francesco Morari, Nicola Dal Ferro, Ilaria Piccoli

Department of Agronomy, Food, Natural Resources, Animals and Environment, Agripolis, University of Padova, Viale Dell'Università 16, 35020 Legnaro, Italy

A close relationship exists between soil organic carbon dynamics (SOC) and soil structure, whose macro- and micro-heterogeneity are pivotal in characterizing biogeochemical processes in the vadose zone. The structure-SOC interactions are commonly included for basic conceptual models that describe SOC protection mechanisms although, so far, reliable predictions on carbon storage-carbon dioxide emissions are far from being completely understood. In this context, it becomes critical to develop models that provide deeper insight into the spatial architecture of soils, providing new information on microbial accessibility, enzymatic reactions, water and gas movements. Nevertheless, despite the importance of spatial arrangement of different soil phases (mineral, organic and microbiological), sufficient data are lacking mainly due to technical limitations on soil phases detection among the 3D soil matrix.

Recently X-ray computed microtomography (μCT) has been proven to be a valuable tool in 3D soil structure characterization, and its ability to render the soil "transparent" has uncovered the interior spatial arrangement of complex structures in a nondestructive way. As a result, real-world situations that mimic the soil spatial architecture can be developed: at first, with the development of theoretical models that include the spatiotemporal SOM-soil interaction. Although the recognition of SOM and soil mineral phase on μCT-derived images is still challenging, some advancements have been made by staining the organic phase with heavier elements to obtain a 3D map of SOM distribution inside the pore space: at second, by exploiting the advantages that can be provided by 3D-printing techniques, that in recent years are becoming available at high resolution and at relatively low costs. As a result, the combination of both mathematical and physical models would provide new opportunities to study unrevealed aspects on the movement of microorganisms within the three-dimensional pore network, pore occlusions and accessibility to liquid and gaseous phases, etc., contributing to the prediction of SOC dynamics.

Emergent contaminants (antibiotics) fate in soils

Denisse Archundia[A,B], *Céline Duwig*[A,*] , *Marie-Christine MOREL*[A,C], *Lorenzo Spadini*[A], *Jean Martins*[A]

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The fate of antibiotic contaminants in soils depends on several processes: sorption, mobility, speciation and biochemical transformations. Their sorption is affected by pH, organic matter, ionic strength and the presence of inorganic compounds. Soil pollution by antibiotics can lead to selective proliferation of resistant bacteria, which can further pose public and animal health problems.
In a subcatchment of the Titicaca Lake, significant concentrations of Sulfamethoxazole (SMX) were detected in river waters and in soils irrigated with wastewaters close to El Alto City. Ten soils were sampled according to the altitude gradient, to the two main soil types of the subcatchment (Regosol and Cambisol), and to the main soil usages. Static (batch) and dynamic (repacked columns) experiments were performed to study SMX sorption and mobility in these soils. Both studies were conducted at constant ionic strength. Column studies were performed in saturated conditions and breakthrough curves were analyzed by inverse modelling with the CXTFIT code. Impacts on bacterial populations and presence of resistance genes to SMX (*sulI*, *sulII*, and *sulIII*) were assessed by molecular techniques applied to one month batch experiments.
Sorption kinetics studies showed that equilibrium was reached in 48h. Sorption isotherms were well fitted with linear or Freundlich models depending on soil types. SMX sorption was influenced in a positive way by (decreasing order): organic matter content > cation exchange capacity > silt content > clay content. Soils located upstream of the watershed (Regosol) showed a higher adsorption capacity than soils located downstream (Cambisol). The presence of resistance genes (*sulI* and *sulII*) was observed only in one soil regularly receiving wastewaters. SMX impacts on bacterial diversity varied between soils and were interpreted in the light of soil physical chemical properties.

Development of appropriate technologies for pollution control and environmental restoration at solid waste landfills: The role of soil physics

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Abstract

Landfills are the most common way of disposing solid waste in developing countries due to the lower cost over the other waste management techniques. Most of waste landfills are operated as unmanaged and uncontrolled open dumping as a result of lack of engineered technologies and capacities of operation and maintenance. The open dumping of solid waste under unsanitary conditions causes various kinds of problems: 1) Damage to human health surrounding the dumping sites (water-born infectious diseases), 2) Environmental pollution (water, air, soil, and sea), 3) Disaster (landslide, explosion), 4) Global warming (emission of greenhouse gases), and so on. Due to rapid urbanization and increase in population, amount of solid waste generation is expected to increase rapidly in upcoming years. In order to avoid and prevent those problems, appropriate techniques for pollution control and environmental restoration should be adopted.

Based on the agreement between Sri Lanka and Japan, JST-JICA SATREPS (Science and Technology Research Partnership for Sustainable Development) project entitled "Development of pollution control and environmental restoration technologies of waste landfill sites taking into account geographical characteristics in Sri Lanka" has been carried out from 2011 to 2016. Besides, a new SATREPS project entitled "Establishment of Environmentally Sound Management of Construction and Demolition Waste and Its Wise Utilization for Environmental Pollution Control and for New Recycled Construction Materials in Vietnam" has recently begun from 2017 to 2021.

For both SATREPS projects, one of main activities is to develop pollution control and environmental restoration techniques for waste landfills. Especially, those projects aim to develop appropriate techniques for pollution control and remediation utilizing site-specific and low-cost materials. In this presentation, some of developed techniques with the use of locally available geo-, bio-, construction materials are introduced. Especially, to develop appropriate techniques such as gas exchangeable landfill cover, permeable reactive barrier to treat contaminated groundwater, and water retentive roadbed materials, the knowledge on soil physics are highly incorporated.

Analysis of phase distribution in vertical flow constructed wetlands using X-ray micro-CT

German-Dario Martinez-Carvajal[A], *Laurent Oxarango*[B], *Pascal Molle*[A] *and Nicolas Forquet*[A]

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Abstract

Vertical Flow Constructed Wetlands (VFCWs) have known an outstanding success with more than 3000 4000 plants constructed in France. The “French type Wetland” specificities are to use gravel as porous media, and to be fed with raw domestic wastewater and implementing alternative feeding and resting periods. The fouling caused by raw wastewater feeding increases suspended solids retention and influent residence time and therefore improves treatment performances. However, the fouling may cause clogging which could negatively impact the system performance.

In order to gain a better understanding of filtration and wetting/drying processes taking place in VFCW, X-ray Computerd tomography has been applied to four samples extracted from full-scale plants. The image analysis pipeline is composed of filtering, multi-phase segmentation, computation of volumetric fraction of phases, interfacial area and percolating pathways based on the skeleton computation. This methodology proved to be be well adapted to identify the 3D distribution of gravels, organic matter deposit (OrM) and pore phases. Considering the scan resolution, the OrM phase is, in practice, composed of solid deposit, water and potentially air contained in pores of a dimension smaller than the scan resolution. Despite this limitation, X-ray CT provides an original insight on the phase distribution: On top of the sample, a layer created by the clogging process is composed of OrM and pores only. At the bottom, the pack of gravels is partially filled by OrM due to the fouling process. In between, a 5 to 10 cm thick transition zone composed of a mixture of gravels, OrM and open pores is observed. Scanning a sample before and after a low temperature drying provides an original information concerning the increase of the porous network due to the deposit shrinkage. A significant increase of the infiltation capability in the dryed condition is strongly suggested by the evolution of percolating pathways in the cake layer and the transition zone. While combining the skeleton of the open pore phase with the distance mapdescribing the local sizes of pores, it is possible to extend this analysis to identify percolating pathways accessible to a given class of suspended solid size. This preliminary result opens very promising perspective concerning the improvement of models describing the collection of particles within VFCW filter media. The 3D morphological description of the pore space inside these filters should be used to compute flow and transport in order to gain a better understanding of these complex mechanisms.

IP4S$_2$: Image processing for soil physics (sciences)

Patrice Delmas[A], *Jonas Debes*[A], *Alfonso Gastelum Strozzi*[B], *Jorge Marquez*[B]

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Abstract

Image Processing tasks for Soil sciences ranges from low-level processes, e.g. low or high frequency pass filters pre-processing acquired images, to high-level complex approaches to extract physical and geo-morphological measurements to provide readily available soil descriptors (e.g. texture, morphometrics, concentration, 3D pore networks and so on). Current challenges are to provide this information to Soil Science researchers with minimal knowledge in Image Processing (IP) or interaction with IP specialists. X-ray Computed Tomography is now widely used to produce volumetric representations of soil structures (3D). The tomographic images are generated by computer based on X-ray images taken from different angles (360º in total), representing density of the soil core materials (clay, silt, sand, pores, organic, inorganic matters and so on) as intensity levels (in the image) representing X-ray attenuation coefficients. Separating objects of interests in images requires a segmentation step which divides an image into its constituent regions or objects. Most of segmentation algorithms are based on discontinuity or similarity of pixel/voxel-wise grey-levels/intensity. The performance of segmentation depends on the image properties and objects of interest given that noise is inevitable in digital images. Histogram thresholding makes an assumption that the objects of interest can be partitioned in one or multiple sub-regions and thresholds. We recently proposed a two-step Kriging segmentation approach which tackles most type of image histograms (see Fig.1).

The images are initially segmented in one, two or multiple regions separated by thresholds calculated using Rosin's Unimodal, Bi-regional EM, or ISODATA/ K-Means algorithms. One

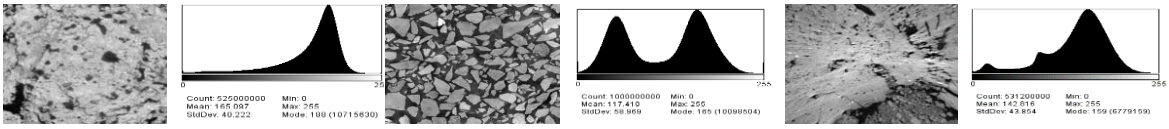

Figure 1. Examples of image and histograms with unimodal, bi-modal and multi-modal properties

or several 2D or 3D semi-variograms are calculated to produce a region estimator for all undetermined pixels, typically transitions between two regions and two histogram peak distribution. The method performed well on natural and artificial soil cores from Mexico, New Zealand, France and Japan (see Fig. 2).

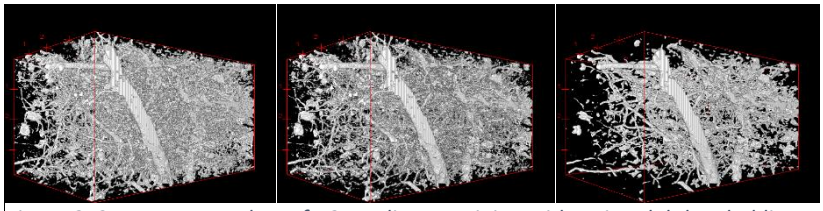

Figure 2. 3D pore networks. Left: 2D Indicator Kriging with Unimodal thresholding. Middle: 2D Multi-regional Kriging (k=5) Cluster 2, 3, 4 and 5 are merged. Right: 3D Bi-regional Kriging.

Experiments in Washington State, Svalbard, Alaska and Concordia: 20 years of research to understand liquid water, ice and soil interactions

Marco Bittelli, University of Bologna, Italy.

Abstract

In this presentation research performed over a period of about 20 years was presented, regarding the interaction of soil, liquid water and ice. A prototype

was first developed to measure the freezing characteristic curves and the soil water retention curve (Bittelli et al., 2003). The soil freezing characteristic relates the soil temperature with its water content below zero degrees Celsius. It depicts the existence of liquid water even below zero, given by absorptive and cohesive forces, exerted by soil surfaces on water, decreasing the water freezing point. This feature has relevant applications in studies of permafrost melting and planetary research.

The study of water and heat balance in frozen soils was performed later in an experimental station in Svalbard, where measurements of soil water content, temperature and weather were performed. Samples were collected and a method to independently quantify ice and liquid water was developed, based on the different relaxation frequencies of ice and water (Bittelli et al., 2004).

Current research in Alaska is investigating evapotranspiration in northern latitudes (Ruaiuen et al., 2017), to assess the water and energy budget of permafrost soils. Limitations in current numerical models for evaporation were discussed.

Finally, an ongoing project in Antarctica, at the Concordia Station, was briefly described. The aim of the project is to better characterize the real and imaginary part of the dielectric permittivity of ice and firn in the frequency range 0.4-2 GHz, to improve the physical-mathematical model for microwave attenuation. Knowledge of this variable is now not accurate enough for a correct quantification of ice sheet thickness, from satellite remote sensing.

The research is performed in collaboration with the French team from the University of Grenoble, which is collecting ice cores at the Concordia station and brought to the cold laboratory of the University of Florence for dielectric spectroscopy. Measurements *in situ* will also be performed by the Italian team with ground penetrating radar and vector network analyser.

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Programma Nazionale di Ricerca in Antartide (National Program of Research in Antarctica) – Project number: PNRA D.D. 651 del 05/04/2016 PNRA16_00212 - A2

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