<u>LATE</u> REQUEST FOR A SPECIAL PROJECT 2014–2016

MEMBER STATE: ITALY

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Project Title: AERODYNAMIC RESPONSE OF PRECIPITATION GAUGES IMMERSED IN A TURBULENT WIND FIELD

Would you accept support for 1 year only, if necessary?	YES ☑	NO ☐

Computer resources required for 2014-2016: (The project duration is limited to a maximum of 3 years, agreed at the beginning of the project. For late requests the project will start in the current year.)	**2014**	**2015**	**2016**
High Performance Computing Facility (units)		$6 \cdot 10^6$	
Data storage capacity (total archive volume) (gigabytes)		750	

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 17 Nov. 2014
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Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

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Extended abstract

Scientific rationale

The reliability of liquid and solid precipitation measurements is a central requirement since they represent the fundamental input variables of many scientific applications such as hydrologic models, weather nowcasting and forecasting data assimilation, climate change studies, calibration and validation of weather radar reflectivity measurements and the design of water management system in urban and non-urban areas.

The study of the influence of the environmental conditions on the rain and snow gauges measurements reliability is traditionally carried out by means of experimental campaigns for the comparative evaluation of different co-located technical solutions. Among the other source of errors, the contribution of the wind has been recognized as the main responsible of significant measurement uncertainties in case of severe horizontal wind speeds (*Uw*). This effect reduces the collection efficiency (*CE*) of the gauges leading even to complete failures (no precipitation detected) in case of light rain or snow and strong wind.

The prevailing technique adopted for reducing the airflow velocity components around the collecting orifice of the gauges is represented by the installation of wooden, metallic or bush fences concentric to the instrument known as "wind shields". The general interest in defining the collection efficiency of the composite gauge/wind shield configurations is also proved by the fact that this topic has been recognized as a main objective of the on-going "Solid Precipitation InterComparison Experiment" (SPICE) field campaign, fostered by the World Meteorological Organization (WMO). This notwithstanding, the existence of several wind shields solutions, mainly designed on empirical bases, and the lack of knowledge about the actual aerodynamic effect of the fence bodies on the inner airflow (generation of turbulence), together with the strong variety of the falling particles microphysical characteristics, are elements that preclude any solid application of correction methodologies of the precipitation measurements.

In this scenario, the availability of a large parallel computational power would allow the coupling of an advanced Computational Fluid Dynamic (CFD) time dependent airflow model, based on the Large Eddy Simulations (LES) schemes, with a Lagrangian particle trajectories predictor for the numerical evaluation of the precipitation gauges collection efficiency.

Project objectives

Calculation of accurate 3D airflow fields obtained by imposing a turbulent wind (with an averaged horizontal speed lower than 10 m/s) and by modelling the aero-dynamics of a common un-shielded precipitation gauge with a time dependent LES turbulence approach.

Innovation Potentials

The innovative character of this project is constituted by the adoption of an advanced time-dependent CFD to model the collection efficiency of a precipitation gauge impacted by a fully turbulent airflow. A similar attempt has not been described in the literature yet.

The advantage of a physically based analysis of the turbulent airflows realized around the shapes of the more common precipitation gauges is to open the way to the development of accurate correction methods of the solid, liquid and mixed precipitation measurements. These methods could be easily applied to the real time and existing data sets whether a co-located wind anemometer is available, as for the more common automated meteorological stations.
Moreover, the project results would constitute a term of reference for future CFD activities aimed at the testing of wind-shielding solutions for rain gauges and the assessment of the best configuration. This would represent a first optimization attempt based on a sound theoretical approach.

State of the art

In recent years various authors have proposed numerical approaches for the theoretical collection efficiency estimation of rain gauges (NS99 and CK06) and snow gauges with wind shields (T12; C15). A good agreement with infield observations made under horizontal wind speeds Uw < 5 m/s was shown. On the other hand, a significant non-linearity of the actual collection efficiency observed when $Uw \geq 5$ m/s has yet to be explained. Moreover, the existing numerical approaches were in some cases characterized by the application of simplified turbulence models based on the Reynolds Averaged Naviér-Stokes equations (RANS), therefore avoiding to account for the strong time dependent turbulence issues (NS99, T12) or, in other cases, neglecting the complete airflow/particles trajectories problem (CK06). Figure 1 shows an example of the air velocity field obtained in the vicinity of an un-shielded universal gauge by executing a RANS simulation (C14).

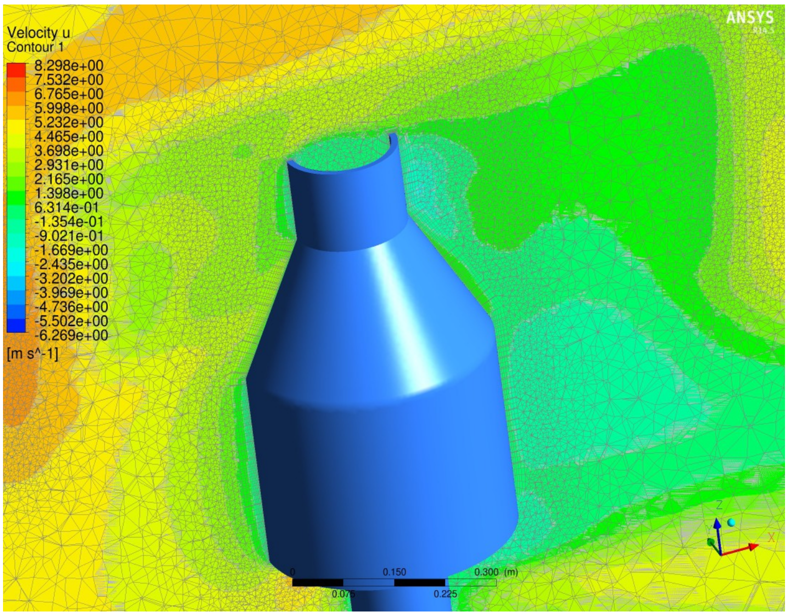

Fig. 1: Example of the time-dependent air velocity field u (RGB colour plot) computed in the vicinity of an un-shielded gauge (blue surfaces) and interpolated on a vertical stream-wise plan. Results from a RANS simulation executed by imposing an undisturbed wind speed Uw=5 m/s by Colli (C14).

Colli (C14) was the first to couple time-dependent airflow solutions based on a Large Eddy Simulations model for a single Alter shielded gauge with trajectories prediction schemes obtaining a good agreement with observations (Figure 2).

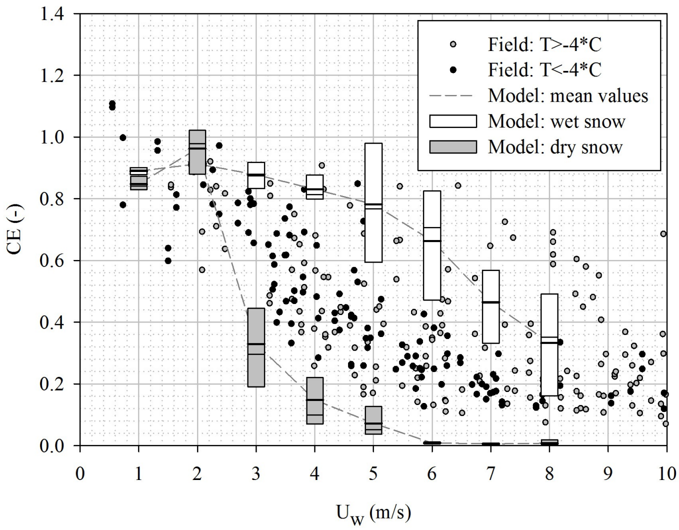

Fig. 2: Comparison between infield observations (grey and black dots) and modelled values (dashed curves with boxplots) of collection efficiency *(CE)* vs. undisturbed horizontal wind speed *Uw* by Colli (C14).

Furthermore, the work provided an unprecedented comparative analysis of shielded and un-shielded gauges catching efficiency thanks to the adopted CFD methodology.

This notwithstanding, the important assumption of a laminar airflow entering in the spatial domain was still accepted to simplify the simulations set-up. The continuation of the work will focus on the introduction of a base airflow characterized by some turbulence content, which is more representative of realistic wind-driven air velocity fluctuations.

Outcomes and high-impact scientific advances expected

The execution of LES airflow simulations sufficiently refined to solve the spatial and temporal scales of the hydrometeors motion in the vicinity of the precipitation gauge collecting section represents a fundamental tool for the development of accurate and innovative correction methodologies of the precipitation measurements.

Furthermore, the introduction of turbulent airflows in the inlet boundary of the spatial domain will permit the study of specific aerodynamic features that are not addressed in currently available CFD approaches. This would provide an explanation for the non-linear behaviour of the collection efficiency observed at high wind speed regimes thanks to an advanced time-dependent model.

The outcomes of this study will likely have an high-impact on the meteorological/climatological scientific community and a minimum of two articles will be submitted to international scientific journals (e.g. Journal of Applied Meteorology and Climatology, Atmospheric Research, etc.).

References

- NS99 – Nespor, V. and Sevruk, B., 1999. Estimation of wind-induced error of rainfall gauge measurements using a numerical simulation. Journal of Atmospheric and Oceanic Technology, 16(4), 1999, 450-464

- CK06 – Constantinescu, S.G., Krajewski, W.F., Ozdemir, C.E. and Tokyay, T., 2006. Simulation of flow around raingauges: Comparison of LES with RANS models. Journal of Advances in Water Resources, Vol. 30, 43-58.

- T12 - Thériault, J.M., Rasmussen, R., Ikeda, K., Landolt, S., 2012. Dependence of snow gauge collection efficiency on snowflake characteristics. Journal of Applied Meteorology and Climatology. 2012;51(4):745-62.

- C14 - Colli, M., 2014. Assessing the accuracy of precipitation gauges: a CFD approach to model wind induced errors. PhD dissertation, University of Genova, Italy.

REQUIREMENTS

System Billing Units

The completion of the project objectives requires a maximum of 6 milion System Billing Units (equivalent to 400'000 core*hours). The total SBU cost has been estimated as follows:

- 1 wind regime will be considered as general case-study
- 1 un-shielded gauge geometry will be simulated (the effect of wind shield will be the subject of future projects). The three-dimensional spatial domain will be discretized in 40 mln polyhedral volumes.
- The simulation will be executed as a single job composed by 512 parallel tasks.
- The complete development of the solution for this simulation experiment (numerical convergence and stability) will require an elapsed real time approximated to 20 days in a Cray architecture.
- The above mentioned total simulation time is calculated as the sum of 8-12 hour jobs to be run serially.

Data storage

Due to the execution of time-dependent solutions of the air velocity and pressure fields in a highly-refined spatial grid, the data storage necessary to save simulation outputs has been evaluated equal to 750 Gb.

Project duration

The CFD simulations will be performed within one year from the starting date of the project. Consequently, the computational resource allocated to this work will be completely used by the end of 2015.

Maximum number of usable tasks

- OpenFOAM CFD simulation executed in a parallel job which uses a maximum of 512 tasks

Software used or required

- OpenFOAM (version 2.0.0 or higher) finite-volume CFD solver executables to be compiled in the allocated user space. The source code is provided in C++ language.

- C++ compiler (GCC, Intel, PGI, PathScale or anything else).