REQUEST FOR A SPECIAL PROJECT 2013–2015

MEMBER STATE: Italy

Principal Investigator[1]: Dr. Elena Masciadri

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Project Title: Optical turbulence modelling for astronomical applications: towards the Extremely Large Telescopes (ELTs).

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** FOT	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2011	
Would you accept support for 1 year only, if necessary?	YES X ☐	NO ☐

Computer resources required for 2013-2015: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2015.)	**2013**	**2014**	**2015**
High Performance Computing Facility (units)	1760000		
Data storage capacity (total archive volume) (gigabytes)	300 Gb		

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): 4/4/2012

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

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

The Earth's atmosphere strongly limits the image resolution and sensitivity of all ground-based telescopes running in the near and mid-infrared and having a pupil larger than 10 cm. Knowing that telescope resolution outside the atmosphere is proportional to the telescope pupil size, we conclude that the larger is the pupil size, the more important is the limitation introduced by the atmosphere on the telescope resolution. The plane wavefront coming from the observed scientific object is perturbed by the fluctuations of the refractive index of the atmosphere so that the light that is focused on the detector is spread on a large surface destroying the details of the image. The 8-10 m class telescopes and even more the new generation of extremely large telescopes (diameter D ~ 30 m) will be able to attain fundamental scientific goals such as the detection of extra solar planets orbiting stars similar to our Sun provided we will be able to control and overcome the perturbations induced by the atmospheric turbulence that develops between us and the space. Techniques for the measurements and the correction of these perturbations exist and they are called 'Adaptive Optics' techniques. These techniques depends however on the status of the turbulence and it is therefore extremely important to be able to know how the turbulence is distributed in the space and how fast is to optimize the use of the AO techniques. Even more important is the prediction of the status of the turbulence with some hours/days in advance to plan the typology of instrument to be located at the focus of the telescope (with different constraints with respect to the turbulence conditions) as well as the scientific program to be carried on. It happens frequently, indeed, that astronomical observations related to the most challenging scientific programs could be realized only with excellent turbulence conditions. Our ability in forecasting these particular conditions is therefore crucial to guarantee the success of the new class of telescopes and to maintain the competitiveness of the ground-based astronomy with respect to the space-based one. Knowing that the cost of a night of observation is typically of the order of several K$, it is straightforward to catch the challenge related to the optimization of the management of the telescope use.

The optical turbulence develops on spatial and temporal scales that are much smaller than the scales at which classical meteorological parameters such as temperature and wind speed evolve on. General Circulation Models (GCM) have a too low resolution to describe numerically such a parameter. Direct Numerical Simulations (DNS) simulations can resolve the optical turbulence but they can hardly be used to link the atmospheric flow at small and synoptic scales. Meso-scale models are the right trade-off between DNS and General Circulation Models (GCM) and are therefore required to perform prediction of the OT. Our group has carried out several studies on this subject for more than a decade. The optical turbulence has been opportunely parameterized and successive progresses in model performances have been achieved thanks to techniques of model calibration (Masciadri & Jabouille, 2001).

We are currently involved in two major studies related to the employment of a numerical mesoscale model (Meso-Nh) for the forecast of the optical turbulence in astronomical applications.

(1) The first one aims to carry out a feasibility study for the European Southern Observatory (ESO) for the optical turbulence forecast at two main sites of ESO for ground-based facilities working in the near infrared and infrared: Cerro Paranal (site of the Very Large Telescope) and Cerro Armazones (the selected site for the European Extremely Large Telescope E-ELT). Both sites are located in the north part of Chile.

(2) The second project, supported by the Large Binocular Telescope (LBT) Consortium, aims to set-up an operational forecast system of the optical turbulence at Mt. Graham to support astronomical observations and management of instrumentations to be placed at the focus of the telescope.

The model validation is based on the comparison of model predictions with in situ observations. Observations are normally obtained with remote sensing instruments such as the generalized SCIDAR, the DIMM, ... that can estimate the integrated value of the optical turbulence on the whole column (from the ground up to the end of the atmosphere) as is the case of the DIMM or a vertical distribution of the optical turbulence (C_N^2 profiles) along ~ 20~km as is the case of the generalized SCIDAR. The model validation is also based on studying the ability of the model in reconstructing the atmospheric parameters from which the optical turbulence mainly depends on (principally the potential temperature and the wind speed).

In our researches we will focus our attention on these major critical points:
- Model calibration: a standard procedure has been proposed by Masciadri & Jabouille (2001). We intend to diversify the procedure with the aim to simplify as much as possible and possibly to by-pass the necessity of such a procedure.
- Parameterization of the optical turbulence (C_N^2) in the whole 20 km from the ground (i..e boundary layer as well as free atmosphere)
- Spatial and temporal variability of the optical turbulence in different regions of the atmosphere: it has been observed indeed (Hagelin et al. 2011) that the temporal variability of the C_N^2 in the high pert of the atmosphere is a critical point for mesoscale models.

The mesoscale model will be run in grid-nesting configuration and the model will be initialized and forced with products (forecasts) from the ECMWF. The most important constraints that gets important and critical for us the use of the c1a facility is the necessity to do several run to test different model calibration techniques that necessarily have to be done on a very rich sample of nights (the richer is the sample, the most representative is the calibration method). Besides, such a facility is fundamental for benchmark tests done on high horizontal and vertical resolution. At the status of art one of the most challenging objective is to improve the ability of the model in reconstructing the weakest and the strongest turbulence conditions in the free atmosphere.

We should need a disk space on C1a of 4.5 Gbyte. This is necessary to install the Meso-Nh model and the user libraries. We calculated a storing space equivalent to 150 Gbyte to store binary files related to ~ 100 simulations with the highest vertical resolution and one output each 6 hours. Each run with 64 proc. with medium and high vertical resolution requires, respectively, around 1500 SBUs and 4800 SBUs. We calculated a total of 400000 SBUs (equivalent to ~ 40-130 simulations depending on the vertical resolution).

Main bibliographic references (Peer Reviewed Journals):

-Masciadri, E., Vernin, J., Bougeault, P., 3D mapping of optical turbulence using an atmospherical numerical model. I: A useful tool for the ground-based astronomy, 1999, A&ASS, 137, 185
-Masciadri, E., Vernin, J., Bougeault, P., 3D mapping of optical turbulence using an amospherical numerical model. II: First results at Cerro Paranal, 1999, A&ASS, 137, 203
-Masciadri, E., Vernin, J., Bougeault, P., 3D numerical simulation of optical turbulence at Roque de Los Muchachos Observatory using the atmospherical model Meso-Nh, 2001, A&A, 365, 699

-Masciadri, E. & Garfias, T., Wavefront coherence time season variability and forecasting at San Pedro Martir site, 2001, A&A, 366, 708
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-Masciadri, E., Avila, R., Sanchez, L.X., First evidence of the finite horizontal extent of the optical turbulent layers. Implications for the new adaptive optics techniques, 2002, A&A, 382, 387
-Masciadri, E, Near ground wind simulations by a meso-scale atmospherical model for the ELTs site selection, 2003, RMxAA, 39, 249
-Masciadri, E., Avila, R., Sanchez, L. X., Statistic reliability of the Meso-Nh atmospherical model for the 3D C_N^2 simulations, 2004, RMxAA, 39, 249
-Masciadri, E. & Egner, S., First seasonal study of optical turbulence with an atmospheric model, 2006, PASP, 118, 1604
-Lascaux, F., Masciadri, E., Hagelin, S., Stoesz, J., Mesoscale optical turbulence simulations at Dome C, 2009, MNRAS, 398, 1093
-Lascaux, F., Masciadri, E., Hagelin, S., Mesoscale optical turbulence simulations at Dome C : refinements, 2010, MNRAS, 403, 1714
-Hagelin, S., Masciadri, E., Lascaux, F., Wind speed vertical distribution at Mt. Graham, 2010, MNRAS, 407, 2230
-Lascaux, F., Masciadri, E., Hagelin, S., Mesoscale optical turbulence simulations above Dome C, Dome A and South Pole, 2010, MNRAS, 411, 693
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February 2012: Request for extra resources

With the present we ask for a revision of the SBUs request for the year 2012 and 2013 mainly justified by results we obtained so far in the framework of this on-going project. Previous simulations done with 3 models in grid-nesting configuration (3MOD) with a highest horizontal resolution of 500~m gave an underestimation of the wind speed in proximity of the ground (tests carried out on a sample of 20 nights). Preliminary tests done with 5 models in grid-nesting configuration (5MOD) and a highest resolution of 100~m provided a not negligible improvement of model estimates of the wind speed in the first 30 m. As a consequence, we observed an improvement (i.e. a better correlation with measurements) of the model estimation of the turbulence in the planetary boundary layer (i.e. the first ~ 600~m from the ground). The optical turbulence developed in this vertical slab represents the most important contribution of the whole OT in the 20~km from the ground from a quantitative point of view.

The simulations in the new 5MOD configuration and a higher resolution require a number of SBUs four time larger than that used with the 3MOD configuration. Considering a double serie of runs necessary for the model calibration we calculated a minimum of 800000 SBU to cover the same set of 20 nights used for the 3MOD configuration to quantify the statistical model performances. An equivalent number of SBU (800000 SBU) is required to increase the number of nights used for the model calibration using, as a reference, observations provided by a different vertical profiler (MASS) having a lower vertical resolution but accessible on a larger sample of nights in different periods of the year. An equivalent number of SBU (800000 SBU) is required to finally calculate the model performances on a number of nights (at least 30) different from that used for the model calibration. At least an equivalent number of SBU (800000 SBU) is required to perform simulations at higher vertical resolution to be able to define the limits of the model in detecting temporal evolution of turbulent layers in the free atmosphere using, as an input, ECMWF products. The 3MOD configuration permitted us to provide a satisfactory value of the mean optical turbulence produced in the high part of the atmosphere but it underestimates the temporal variability (i.e. sudden triggering and/or vanishing of turbulent layers all along the night). It should be extremely challenging to improve the model performances in detecting such an effect because this has a critical impact on the application to astronomy that we are treating and it should be important to improve the model ability in reconstructing with better precision the instants at which turbulence events appear in this vertical slab. The SBUs estimate for this last part is conservative and might be modified all along the project. We finally calculated a sort of overhead of 10% of the total of 3200 KSBU obtaining a final request of 3520 KSBU for the two years. We do not exclude to conceive in the future a dedicated project for this last topic at conclusion of this