REQUEST FOR A SPECIAL PROJECT 2014–2016

MEMBER STATE: Italy

Principal Investigator[1]: Dr. Elena Masciadri

Affiliation: INAF – Osservatorio Astrofisico di Arcetri

Address: L.go Enrico Fermi 5, 50125 Firenze, Italy

E-mail: masciadri@arcetri.astro.it

Other researchers: Dr. Franck Lascaux

Project Title: Optical turbulence modelling for Extremely Large Telescopes (ELTs).

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP**ITFOT	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2014	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for 2014-2016: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2016.)	**2014**	**2015**	**2016**
High Performance Computing Facility (units)	1000000	1000000	1000000
Data storage capacity (total archive volume) (gigabytes)	450 Gb	450 Gb	450 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): 17/7/2013

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 - 40 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 (called *optical turbulence* OT) 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 and of the OT prediction.

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) to perform prediction of the OT. Our group has carried out several studies on this subject for more than a decade using the Meso-Nh model (Lafore et al., 1998). The Meso-Nh code has been developed by the CNRM-LA (Meteo France, Toulouse, France). The same team has deeply tested the model on the ECMWF clusters in the past years certifying its portability on this system. We developed a package for the optical turbulence prediction (Masciadri et al. 1999) that we run normally on local machines as well as on ECMWF machines. The optical turbulence has been opportunely parameterized and successive progresses in Meso-Nh model performances, in terms of OT, have been achieved (see reference list).

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.

Project (1) is called MOSE; it is co-funded by INAF and the ESO. It started on March 2011 and the Phase A has been completed on March 2013. As described in the project SPITFOT we submitted to the ECMWF on 2011 the main goals for that phase were to validate the model performances in reconstructing the optical turbulence and the atmospheric parameters from which it depends on above Cerro Paranal and Cerro Armazones.

To validate the model performances in reconstructing the optical turbulence (C_N^2 profiles and integrated astroclimatic parameters derived from the C_N^2 i.e. the seeing (ε), the isoplanatic angle (θ_0) and the wavefront coherence time (τ_0)) measurements provided by different instruments have been used. Among these we cite the DIMM (Differential Image Motion Monitor), an instrument based on a remote sensing principle measuring the integrated turbulence all along the whole atmosphere (typically 20 km above the ground for our applications); the Generalized-SCIDAR, able to provide the vertical stratification of the optical turbulence all along the 20 km above the ground with a vertical resolution that is not constant and we can consider, for simplicity, of the order of around 1 km; a MASS (Multi Aperture Scintillation Sensor), another vertical profiler with a much lower vertical resolution (typically 6 layers between 500 m and 20 km). The latter instrument is therefore not sensitive to the turbulence near the ground. Besides, a detailed study of the model performances in reconstructing the atmospheric parameters from which the optical turbulence mainly depends on (temperature, wind speed and direction) have been carried out. Measurements provided by radiosoundings (50 distributed in 23 nights equally distributed in summer and winter time) and by mast and Automatic Weather Stations (AWS) have been used for this second part of the study. Besides that a dedicated study on an optimized procedure for the model calibration has been carried out as described in the project submitted on 2011.

A great amount of results have been achieved (see Technical Report in reference). Among these:

1) A very simplified calibration procedure has been identified and validated.

2) The model ability in reconstructing all the classical atmospheric parameters (at the surface layer i.e. the first 30m and all along 20km above the ground) from which the optical turbulence depends on has been validate on a rich statistical sample providing very satisfactory results (see report of previous project).

3) It has been proved that the optical turbulence reconstructed by the model has a reasonably good vertical stratification when is compared to observations. The main integrated astroclimatic parameters also reconstruct with a promising score of success, particularly the wavefront coherence time and the wavefront coherence time. We proved however that the isoplanatic angle is well reconstructed in average during an individual night but the model shows some limits in reconstructing the temporal evolution of the peak-to-peak amplitude during each individual night.

In this new project, to be carried out in the 2014-2016 period, it is our intention to attack a new set of open questions and/or new problems that appeared during the Phase A and/or old problems that for some reason we could not solved during the Phase A. We summarize here the main goals that we intend to achieve in the context of this new project:

1) The most urgent problem is, at present, to overcome the problem of the limited temporal variability of the turbulence (peak-to-valley amplitude) in the free atmosphere during the night (typical stable regime) that mainly affects the model performances in reconstructing the isoplanatic angle. This aspect includes studies on the parameterization of the turbulence in these regimes that we are currently doing in the context of an international collaboration with colleagues from the CNRM (Toulouse, France - ref. V. Masson) and the FMI (Helsinki, Finland ref: S. Zilitinkevich). We are at present working on this topic following three different approaches. Preliminary results indicate that there are good premises to achieve this goal or at least to improve the present status of art.

2) When the horizontal resolution of the innermost domain is larger than 500m we observed a tendency of the model in overestimating the turbulence near the ground. A more detailed analysis of the causes of such an effect is necessary.

3) The promising results obtained for the atmospheric parameters should be confirmed on a richer statistical sample (preferably one year).

4) For what concerns the optical turbulence it should be important to quantify the frequency of the bad initialization data (i.e. cases in which the initialization data are bad) and their impact on the final score of success.

5) It is important to quantify how the model performance decreases with the forecasted delay time. We plan therefore statistical analysis on a large number of nights (at least 50) and different delay times. This is important in vision of a more systematic application of the technique to support the astronomical observations.

6) It should be our intention to verify if the new initialization data (GRIB files) at 137 levels recently available since June 2013 permit us to gain something in terms of spatio-temporal variability of temperature and wind speed gradients and, as a consequence, in terms of spatio temporal variability of the optical turbulence.

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 C2a facility is the necessity to do several runs because most of conclusions we need to reach requires a statistical analysis. 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.

Request of resources

We should need a disk space on C2a of 4.5 Gbyte. This is necessary to install the Meso-Nh model and the user libraries. We calculated a storing space equivalent to 450 Gbyte to store binary files related to ~ 100 simulations with the highest vertical resolution and one output each 6 hours. Based on resources used in our previous project we estimate a number of SBU for each year of the order of 1000000. We intend to modify the requests in the next years according to the progress of the study.

Main bibliographic references (Peer Reviewed Journals):

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