SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2016
Project Title:	Optical turbulence modelling for Extremely Large Telescopes
Computer Project Account:	SPITFOT
Principal Investigator(s):	Elena Masciadri
Affiliation:	INAF-Istituto Nazionale di Astrofisica Osservatorio Astrofisico di Arcetri
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Alessio Turchi
Start date of the project:	01/01/2014
Expected end date:	31/12/2016

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	2000000	2000000	1000000	105065.23
Data storage capacity	(Gbytes)	450	450	450	450

Summary of project objectives

(10 lines max)

The project is centred on the employment of a numerical mesoscale model (Meso-NH) for the forecast of the optical turbulence in astronomical applications. Optical turbulence is the main source of deterioration of the image quality for ground-based telescopes. We are, at present, mainly involved in two projects:

(1) We are in charge of a feasibility study (MOSE) for the European Southern Observatory (ESO) for the optical turbulence forecast at the two main ESO sites for ground-based facilities that are conceived to work in the near infrared and infrared ranges: 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 (Arizona) to support astronomical observations and management of instrumentations to be placed at the focus of the telescope.

Summary of problems encountered (if any)

(20 lines max)

No major problems encountered.

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

We completed the set of simulations we had planned to be able to quantify the model performances in reconstructing temperature, wind speed and direction and relative humidity in the surface layer and boundary layer above the ESO astronomical sites described in the report of the previous year (see point 1 in Section "Summary of plans for the continuation of the project").

(A) More precisely we performed simulations related to around 45 nights (4 domains configuration) above Cerro Armazones to perform for Armazones an equivalent study already concluded for Cerro Paranal (see paper Lascaux et al., 2015 in peer-reviewed journal). Cerro Armazones is the site of the European Extremely Large Telescope (39 m). It is important for us to collect simulations above Armazones, located just 22 km far away from Paranal, done with the same model configuration to complete the analysis in a homogenous way.

This will permit us to quantify if the local geographic topographies present particular features that get more or less difficult to achieve the same specifications in terms of model performances. The model configuration consisted on four domains in grid-nesting with a horizontal resolution of the innermost domain equal to 100 m. Preliminary results on a sub-sample of outputs indicate an equivalent good model performances even if with some small differences (or typical features) with respect to Cerro Paranal. Table 1 and Table 2 show the contingency tables for the temperature at 2 m and the wind speed at 11 m above the ground for a subsample of 42 nights. In Table 1 POD_1 and POD_3 related to the temperature are well above 90 %. POD_2 has a more modest result (66 %) as it is natural to expect because the first and third tertiles calculated on a climatologic temporal scale are very close and differ of just 2 degrees. POD_2 is in any case well above 33% corresponding to the random case. In Table 2 we can observe that POD1 and POD3 are both well above 79 %. The most critical and challenging information from an astronomical point of view is to achieve a good score for POD3 because we are interested in detecting the cases in which the wind speed is strong. POD2 has modest performances but it is not so relevant for an application to astronomy.

	Division by tertiles (climatology) C. Armazones - 2 m	OBSERVATIONS $T < 7°C$	$7°C < T < 9°C$	$T > 9°C$
MODEL	$T < 7°C$	296	65	0
	$7°C < T < 9°C$	13	193	40
	$T > 9°C$	0	34	493

Total points = 1134; PC=86.6%; EBD=0.0%
POD_1=95.8%; POD_2=66.1%; POD_3=92.5%

Table 1: Contingency table related to the temperature at 2 m above the ground calculated on a sample of 42 nights at Cerro Armazones. Thresholds correspond to the first and third tertiles calculated on a climatological time scale (a few years).

	Division by tertiles (climatology) C. Armazones - 11 m	OBSERVATIONS $WS < 6\ m{\cdot}s^{-1}$	$6\ m{\cdot}s^{-1} < WS < 10.5\ m{\cdot}s^{-1}$	$WS > 10.5\ m{\cdot}s^{-1}$
MODEL	$WS < 6\ m{\cdot}s^{-1}$	407	97	4
	$6\ m{\cdot}s^{-1} < WS < 10.5\ m{\cdot}s^{-1}$	93	87	73
	$WS > 10.5\ m{\cdot}s^{-1}$	12	27	307

Total points = 1107; PC=72.4%; EBD=1.4%
POD_1=79.5%; POD_2=41.2%; POD_3=79.9%

Table 2: Contingency table related to the wind speed at 11 m above the ground calculated on a sample of 42 nights at Cerro Armazones. Thresholds correspond to the first and third tertiles calculated on a climatological time scale (2007-2008).

It should be our intention to submit a paper on a peer-reviewed journal on the model performances in reconstructing the optical turbulence. This should be the result of the feasibility study we carried out for ESO (MOSE). This should include a solution to improve the spatio-temporal variability of the optical turbulence in the high part of the atmosphere.

Concerning the atmospheric parameters, we proved that the deterioration of the model performances using as initialisation data forecast (instead of analyses) selected as in an operational scheme is not very important. This could be verified through a comparison of measurements and model outputs using statistical operators such as bias, RMSE and sigma calculated on a rich statistical sample of nights (129) uniformly distributed in a solar year. This is very promising because it tells us that, even if there is space to improve the system, for example by initialising the model with data calculated at a closest delay time with respect to the start of the simulation, we have an already reliable and performant system.

(B) Part of the computational resources allocated for the 2015 have been used also in the context of the research activities related to the astronomical site of LBT (see point (2) of the Project objectives), the Mt.Graham summit. Mt.Graham is located in Arizona, it is 3200 m height and the geographic features of this location is mostly different from the Chilean astronomical sites. High trees are present all around the summit which is surrounded by a vast forecast. The presence of trees instead of very small stones typical of Chilean site determines an important impact on atmospheric circulation close to the surface. We identified a model configuration suitable for this study and
Preliminary results will be presented soon at the International Conference SPIE Astronomical Telescopes and Instrumentation that will take place in Edinburgh on June 26th, 2016 (see paper (10) Turchi et al., 2016, SPIE). We observed similar good model performances above Mt.Graham. Among the most relevant outputs we cite two elements:

- We observed a not negligible improvement of model performances for RMSE and sigma related to the wind direction above Mt.Graham with respect to what observed above Cerro Paranal and Armazones. Considering the results obtained above the two Chilean sites were already very good, we conclude that modle performances are really excellent
- In all the three sites we observed that the model can well discriminate the high and low relative humidity (RH). However, the model has more difficulties in correctly detect RH when it is observed to have very high values (larger than 70 %). This is translated in a relative low value of POD_3 when the threshold is equal to the large value correspondent to the third tertile of the climatologic distribution (72 %). This similar trend has been observe above all the three sites (Paranal, Armazones and Mt.Graham).

(C) As we had described in the precedent report, since 2015 we started a collaboration with colleagues from the Laboratoire d'Astrophysique de Marseille (LAM) and the Pontificia Universidad de Chile aiming to validate a method of measurement of the wind speed and direction stratification all along the 20 km relevant for astronomical applications of a sophisticated adaptive optics system placed at the focus of a 8 meters class telescope (Gemini South). The instrument is called GeMS, it is a multi-conjugated adaptive optics, it is the first instrument in its genre to be run on sky and aims to achieve the wave-front correction on a wide field of view (order of a few arcminutes). Even if this study was not planned in our original program (see project submitted on 2014) this application fits perfectly with the motivations of this study. Due to the fact that the Meso-Nh model was previously validated on a very rich statistical sample of 50 radiosoundings (see Masciadri et al., 2013, MNRAS), we could use the model as a reference to test a new technique to measure vertical stratification of the wind speed along the 20 km relevant for astronomical applications. Results of this study will be presented soon at the International Conference SPIE Astronomical Telescopes and Instrumentation that will take place in Edinburgh on June 26th, 2016 (see paper (11) Masciadri et al., 2016, SPIE).

List of publications/reports from the project with complete references

Peer-reviewed Jouranals

5) Lascaux, F., Masciadri, E. Fini, L., Forecast of the surface layer meteorological parameters at Cerro Paranal with a mesoscale atmospherical model; **MNRAS**, 2015, 449, 1664
4) Masciadri, E., Lombardi, G., Lascaux, F., *On the comparison between MASS and generalized SCIDAR techniques*, **MNRAS**, 2014, 438, 983
3) Masciadri, E., Lascaux, F., Fini, L., *MOSE: operational forecast of the optical turbulence and atmospherical parameters at European Southern Observatory ground-based sites – I. Overview and vertical stratification of atmospheric parameters at 0-20km*; **MNRAS**, 2013, 436, 1968
2) Lascaux, F., Masciadri, E., Fini, L., *MOSE: operational forecast of the optical turbulence and atmospherical parameters at European Southern Observatory ground-based sites – II. Atmospheric parameters in the surface layer 0-30m;* **MNRAS**, 2013, 436, 3147
1) Masciadri, E., Lascaux, F., Fuensalida, J., Lombardi, G., Vazquez-Ramio, H, *Recalibrated generalized SCIDAR measurements at Cerro Paranal (the site of the Very Large Telescope);* **MNRAS**, 2012, 420, 2399

No-peer reviewed Journals

11) Masciadri, E, Turchi, A., Fini, L., Operational optical turbulence forecast for the Service Mode of top-class ground based telescopes, SPIE 2016, 26 June – 1 July, Edinburgh, UK
10) Turchi, A., Masciadri, E., Fini, L., *Forecast of the atmospheric parameters close to the ground at the LBT site in the context of the ALTA project*, SPIE 2016, 26 June – 1 July, Edinburgh, UK
9) Masciadri, E., Neichel, B., Guesalaga, A., Turchi, A., *Towards an automatic system for monitoring of C_N^2 and wind speed profiles with GeMS*, SPIE 2016, 26 June – 1 July, Edinburgh, UK
8) Masciadri, E., Lascaux, F., Fini, L., *Dealing with the forecast of the optical turbulence as a tool to support astronomy assisted by AO facilities*; Journal of Physics, Conferences Series, 2015, 595, DOI: 10.1088/1742-6596/595/1/012020
7) Lascaux, F., Masciadri, E., Fini, L., *MOSE: verification of the Meso-Nh forecasts of the atmospheric surface parameters at Cerro Paranal and Cerro Armazones using contingency tables*; SPIE, 2014, id. 914865
6) Neichel, B., Masciadri, E., Guesalaga, A., Lascaux, F., Bechet, C., *Towards a reliability assessment of the C_N^2 and wind speed vertical profiles retrieved from GeMS*; SPIE, 2014, id.914863
5) Masciadri, E., Lascaux, F., Fini, L., *MOSE: a feasibility study for the prediction of the optical turbulence and meteorological parameters at Cerro Paranal and Cerro Armazones*; AO4ELT3, 2013, DOI: 10.12839/AO4ELT3.13219
4) Lascaux, F., Masciadri, E., Fini, L., *MOSE: meso-scale prediction of near-ground meteorological parameters at ESO sites (Cerro Paranal and Cerro Armazones);* AO4ELT3, 2013, DOI: 10.12839/AO4ELT3.13217
3) Masciadri, E., Rousset, G., Fusco, T., Basden, A., Bonifacio, P., Fuensalida, J., Robert, C., Sarazin, M., Wilson, R., Ziad, A., *A roadmap for the new era turbulence studies program applied to the gorund-based astronomy supported by AO*; AO4ELT3, 2013, DOI: 10.12839/AO4ELT3.13542
2) Masciadri, E., Lascaux, F., MOSE: a feasibility study for optical turbulence forecast with the Meso-Nh model to support AO facilities at ESO sites (Paranal and Armazones); 2012, SPIE, 8447, id. 84475A
1) Lascaux, F., Masciadri, E., 2012, *MOSE: zooming on the Meso-Nh mesoscale model performances at the surface layer at ESO sites (Paranal and Armazones);* SPIE, 8447, id. 84475B

Summary of plans for the continuation of the project

(10 lines max)

The project concludes the period of three years 2014-2016. We achieved answers to open questions related to points 1, 3 5 and 6 (see submission of the project on 2014). We had no time to carry out an analysis for points 2 and 4. Point 1 was by far the most critical one. Apart points 2 and 4 as described above there are a few further elements we are considering at this stage: (1) To better analyse the causes of a not perfect model performances in reconstructing RH when RH > 70%. This is an important feature for an astronomical application; (2)The new algorithm for dynamic turbulence in stable regime on which the colleagues from the CNRM are working on is not yet ready. In the meanwhile, it is our intention to go deeper on the approach we followed to improve the the spatio-temporal variability of the C_N^2 in the high atmosphere that is giving positive feedbacks.