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	2015
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)	Franck Lascaux, 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	1000000
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.

We dedicated, so far, the total allocated resources to the project (1) because this presented a higher level of priority.

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

As we had indicated in the report of the previous year we focused our attention this year mainly on two objectives:

1) we extended the analysis performed on a sample of 20 nights (Lascaux et al. 2013 – paper 10) to a much richer sample (129 nights) including nights in different part of the year and to different years to reinforce the model validation.

2) we repeated the analysis on an equivalent rich sample of nights using as initialization and forcing data, forecasts from the ECMWF.

Both objectives are definitely critical to quantify the effective impact that such predictions can have in application to service mode of the ground-based astronomy.

Considering the huge number of nights to be treated and the limited amount of allocated time we decided to perform the analysis first on Cerro Paranal. Paper (13), summarized the results obtained with analyses on 129 nights uniformly distributed along a solar year. This study covers therefore point (1). Nights have been selected in three different years (2007, 2010, 2011). The same strategy used in previous paper (see paper 10) has been employed. A set of simulations done with three domains imbricated in a grid-nesting configuration (highest horizontal resolution of 500 m) has been used for all the atmospheric parameters with exception of the wind intensity that has been treated with results obtained with 4 domains simulations (highest horizontal resolution of 100 m).
The BIAS, the root-mean square error RMSE and the SIGMA i.e. the bias-corrected RMSE for the whole sample have been calculated. Beside we performed the analysis of the contingency tables with a (3x3 tables for temperature and wind intensity and 4x4 for the wind direction) with a particular attention to two key parameters: the percent of correct prediction (PC) and the probability of correct detection (POD). Results we obtained basically confirmed the good preliminary results obtained on a sample of 20 nights. Model performances for the wind direction revealed to be even better on a richer statistical sample than on a limited sample of 20 nights. We could confirm that a resolution of 100 m is necessary to guarantee a good performance of the model in predicting the wind intensity features close the ground in the first 30 m. Table 1 reports the values of BIAS, RMSE, SIGMA and $RMSE_{rel}$ for the all the atmospherical parameters cited at different heights. Table 2 reports the median value, first and third quartiles of the cumulative distribution obtained considering the BIAS, RMSE and SIGMA in each single night. Both tables are extracted from the paper Lascaux et al., 2015 (paper 13). It is evident in Table 1 that a resolution of 100 m permits an improvement of the bias for the wind intensity of around 1 ms^{-1} with respect to the resolution of 500m and it provides a RMSE below 2.73 ms^{-1} at 10m above the ground and a SIGMA below 2.47 ms^{-1}.

	Temperature (°C) $\Delta X = 500$ m		Wind speed ($m\ s^{-1}$) $\Delta X = 500$ m		Wind speed ($m\ s^{-1}$) $\Delta X = 100$ m		Wind direction (°) $\Delta X = 500$ m	
Cerro Paranal	2 m	30 m	10 m	30 m	10 m	30 m	10 m	30 m
BIAS	−0.12	−0.37	−2.90	−1.39	−1.16	−0.24	3.4	−0.2
RMSE	0.99	1.02	4.03	3.04	2.73	2.70	36.7	35.7
σ	0.98	0.95	2.80	2.70	2.47	2.69	36.5	35.7
$RMSE_{rel}$							20.4 per cent	19.8 per cent

Table 1: Near surface BIAS, RMSE and SIGMA at Cerro Paranal for a sample of 129 nights. The relative RMSE is also reported for the case of the wind direction. The computations have been done considering the whole sample of data points. For the wind direction, data corresponding to a wind speed inferior to 3 ms^{-1} have been discarded from the computation (extracted from Lascaux et al, 2015).

	Temperature		Wind speed		Wind direction	
	2 m	30 m	10 m	30 m	10 m	30 m
BIAS	$-0.18^{+0.40}_{-0.73}$	$-0.48^{+0.12}_{-0.92}$	$-0.85^{+0.35}_{-2.50}$	$-0.14^{+0.91}_{-1.86}$	$+3.90^{+17.84}_{-12.22}$	$-0.32^{+12.06}_{-15.15}$
RMSE	$0.91^{+1.19}_{+0.60}$	$0.92^{+1.25}_{+0.58}$	$2.06^{+3.09}_{+1.41}$	$2.30^{+3.09}_{+1.63}$	$29.89^{+43.94}_{+17.20}$	$27.29^{+42.75}_{+14.57}$
σ	$0.54^{+0.76}_{+0.38}$	$0.48^{+0.69}_{+0.34}$	$1.25^{+1.70}_{+0.96}$	$1.45^{+2.01}_{+1.09}$	$15.94^{+27.32}_{+9.44}$	$15.30^{+31.22}_{+9.06}$

Table 2: Model performances for individual nights. Near surface median value of BIAS, RMSE and SIGMA. The subscripts and superscripts give the first and third quartiles respectively. Values for the wind intensity have obtained with a horizontal resolution of 100 m, values for the other parameters have been obtained with a horizontal resolution of 500 m (extracted from Lascaux et al., 2015).

The analysis of the contingency tables provided by the model for all the parameters (temperature, wind intensity and direction) are very satisfactory results too. We refer the reader to the paper Lascaux et al (2015) for details of this analysis. We summarize here the most important conclusions:

A) for the absolute temperature, the per cent of correct detection (CP) computed from 3x3 contingency tables is excellent. It is in the range of 75%, depending on the height above the ground (2 m and 30 m). POD are mostly larger than 66%. It is as good as 93.7 % at 30 m for the detection of temperature inferior to 11.5 °C.

B) for the wind speed, the per cent of correct detection (PC) computed from 3x3 contingency tables is good (around 60% when the best configuration, ΔX =10m is used). The probability to detect the wind speed in the three subsamples limited by the tertiles of the cumulative distribution is also good. The strongest winds are especially well detected by the model: POD3 is equal to 74% (at 10m) and is equal to 79% (at 30m).

C) for the wind direction, we have analysed a 4x4 contingency tables. We considered the four categories: (NE, SE, SW, NW) and the (N, E, S, W). The POD is very good in the quadrants from which the wind flows more frequently (N and NE) with POD of the order of 92.8% (N) and 81.7% (NE). The POD is not satisfactory (~27%) only in a narrow angular sector [225, 270]. However the occurrence of wind blowing from the SW is less probable (only 4% of the time for the observed sample of 129 nights). The impact of the model performances in this case can be considered negligible.

Besides this, as planned in the report of the previous year we focused our attention also on the relative humidity. This parameter is in reality of secondary importance in this region of the Earth because the RH is very low (region extremely dry). The average value of the observed measurements on the whole year is typically very weak (order of 10-15%). In previous studies we had observed that the model shows in general a tendency in overestimating the RH when values are so low of 10-20%. On the other side, it is not clear how much realistic is the measurement of the local instrumentation for such weak values (Travouillon private communication – see paper Lascaux et al. 2013). Considering that the real interest for astronomers is only to take care the temporal windows in which the RH is high we carried out a set of simulations associated to all the nights of 2011 and 2013 in which the relative humidity (RH) at Paranal was ≥ 80%. This is the value above which the dome of the four telescopes of the VLT have to be closed and observations can not be done at all. We identified only 7 nights with such characteristics that proves that the site is particularly dry. We could prove that the model succeeds in predicting these critical high values even though the frequency of occurrence of such an event sis very low (see Lascaux et al. 2015).

Point (2) i.e. the analysis done using as initialization data the forecasts from the ECMWF has been completed. We repeated the same analysis of point (10 but for the model performances obtained initializing the model with forecasts at 30, 36, 42 and 48 hours calculated at 12:00 UT of the day (J-2) on a sample of 129 nights.
In this way we can assure us to have results of the forecasts completed for the 14:00 LT before the night of observation. The same computations we did for the analyses have been completed for the forecasts. Results have not yet been published and analysed in detail but we can anticipate that model perform seems promising with a weak level of deterioration of the predictions.

A third research line is also that concerning the study performed on Cerro Pachon (Chile) aiming at validating the technics of measurement of the wind speed by a Multi-Conjugated Adaptive Optics system (see report of 2014 for more details). Considering the good level of wind speed reconstruction performed by the Meso-Nh model on the whole 20 km (see Masciadri et al., 2013), we use the Meso-Nh model as a reference to validate the Adaptive Optics system. Preliminary results obtained on 11 nights (Neichel et al., 2014) indicated that, the AO system provide in great part realistic estimate but at the same time, in some circumstance it can does some not-negligible errors. To reinforce statistically these results we have just completed a set of simulations on around 45 nights in which measurements from the AO system are available. This study is still on-going and a paper on a peer-reviewed journal is in preparation with our colleague of the Laboratoire d'Astrophysique de Marseille – LAM). In case we confirm preliminary results obtained on a sample of 11 nights this should indicate that the best practical solution to acquire wind speed measurements in real time for this MCAO system should be to joint the MCAO system to the Meso-Nh model.

List of publications/reports from the project with complete references

Peer-reviewed Jouranals

13) 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
12) Masciadri, E., Lombardi, G., Lascaux, F., *On the comparison between MASS and generalized SCIDAR techniques*, **MNRAS**, 2014, 438, 983
11) 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
10) 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
9) 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

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)

1) The main objective now in terms of the use of the ECMWF resources is the extended analysis on a rich statistical sample (similar to the one treated for Cerro Paranal) for Cerro Armazones. Simulations with 3 domains and 4 domains initialized with forecasts have been planned on a similar number of nights. This analysis would permit us to quantify the model performances in terms of prediction of the same atmospherical parameters above the site on which the European Extremely Large Telescope (E-ELT) will be built.

2) Starting from January 2015 the activities related to Mt.Graham, site of the Large Binocular Telescope (LBT) have been subject of a renovate interest. It is therefore probable that in the next year we will use some allocated time for this site too. Mt.Graham is located in Arizona, the geographical feature of this part of Arizona is substantially different from the Chilean Andes, the telescopes are surrounded by trees and also the atmospherical parameters are in general characterized by a more evident seasonal trend. At the LBT is running the AO system able to achieve the best images

3) Depending on results found with simulations performed above Cerro Pachon we will decide how to proceed on this research line. It is premature to plan now a scheduled work but we think we will be able to do that before the end of the 2015. As said previously, data reduction of measurements and simulations on a rich statistical sample of nights (around 45) has been completed. We remind that the MCAO system (called GeMS) running at the Gemini Telescope (8 m) at Cerro Pachon is the first of its category running on sky.