SPECIAL PROJECT PROGRESS REPORT

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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	2018
Project Title:	SPHERA (Special Project: High rEsolution ReAnalysis over Italy)
Computer Project Account:	spitcere
Principal Investigator(s):	Ines Cerenzia, Tiziana Paccagnella
Affiliation:	ARPAE Emilia-Romagna, SIMC, Viale Silvani, 6 Bologna, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………… ………………………………………………………
Start date of the project:	01/01/2018
Expected end date:	31/12/2020

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)	-	-	50.240.000	8.149.096,2
Data storage capacity	(Gbytes)	-	-	55.000	6.000

Summary of project objectives

(10 lines max)

The SPHERA special project aims at developing a high resolution atmospheric regional reanalysis over Italy (convection permitting resolution of 2.2km), performed with the COSMO non-hydrostatic Limited Area Model. SPHERA is performed by means of a dynamical downscaling of the ERA5 global reanalysis and by employing the observational nudging during the model integration. Three-dimensional hourly model output are produced. At the end of the project, SPHERA will cover 25 years, from 1995 to 2020. The main purposes of SPHERA are:

- to provide a high resolution, space and time consistent, description of the past decades climate (statistics for extreme events, specific-site series, application in scenarios)
- to provide a COSMO model validation based on long term performance, to be used as a reference for the operational forecast and to calibrate the COSMO based forecasting systems.

Summary of problems encountered (if any)

(20 lines max)

Some of the preliminary steps for the definition of the proper SPHERA setup had been underestimated. In particular, the definition of the deep temperature to assign to soil (see the Summary section for details) required some time consuming steps (the evaluation of three different parameterizations, the verification against real data, the preparation of a proper field to provide to SPHERA), which had not been considered at the time of the project submission. Another time consuming step was the development of the verification tool box. This step was part of the SPHERA-PRE special project (July 2017-Dec 2017), but since the development was slower than expected, some of the preliminary tests allocated within SPHERA-PRE were delayed and performed within SPHERA. Moreover, the amount of time needed to perform the model integration had been underestimated at the time of the project submission. Indeed, the data assimilation was erroneously not active and the elaboration of the observations required for the assimilation was not considered in the suite used for the estimation. Because of these time-consuming steps, the actual time needed to perform a 24h run was about 50% higher than estimated. Therefore, the performed preliminary tests were slower than originally foreseen.

Due to the combination of these factors, the activity accumulated about 4 months of delay from the estimated timetable. Since the beginning of the reanalysis production is delayed, only a part of the foreseen period will be actually simulated by December 2018. This means that the allocated SBU for 2018 will be only partially consumed up to that date and that an increment of SBU will be required for 2019.

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

<u>Introduction</u>

ARPAE Emilia-Romagna, SIMC is developing a high resolution atmospheric regional reanalysis over Italy, SPHERA, performed with the COSMO non-hydrostatic Limited Area Model. COSMO is developed in the framework of the COSMO (COnsortium for Small scale MOdelling, Schättler et al., 2011) consortium cooperation. It is used in the operational NWP suites in Italy, as well as in several other ECMWF Member States (Switzerland, Germany, Greece) and Co-operating States (Romania, Israel).

SPHERA is performed by means of a dynamical downscaling of ERA5 global reanalysis and by employing observational nudging during the model integration. SPHERA will cover 25 years (1995-2020) and will produce three-dimensional hourly model output.

At the time of submitting this project, the idea was to feed SPHERA with the initial and boundary conditions from COSMO-REA6 reanalysis archive: a regional reanalysis dataset covering Europe with a 6km resolution, based on the COSMO model and forced by Era-Interim. However, at the first stage of the special project, it was decided to force SPHERA with ERA5, the global reanalysis currently under production at ECMWF. The intent was to provide SPHERA with a more complete, accurate and up-to-date set of initial and boundary conditions . It was hypothesised that ERA5 could provide more accurate information than Era-Interim (up-to-date IFS code, newly reprocessed observation dataset that could not be ingested in Era-Interim, 31km horizontal resolution, hourly output) and even more precise and consistent than a regional reanalysis archive based on Era-Interim (COSMO-REA6 is based on a COSMO version of 2012). Furthermore, the timetable of ERA5 production was quite coherent with the one of the SPHERA production. Therefore, the activity was in part reviewed in order to follow this new project development.

The late special project SPHERA-PRE (lasting from July 2017 to December 2017) dealt with some of the preliminary steps required to SPHERA production. In particular, (I) the set up of the SPHERA production suite using ECFLOW package, (II) the development of a verification and monitoring tool box and (III) the definition of the data to be ingested into the assimilation process, (IV) the definition of the COSMO configuration and (V) the preparation of one of the tests needed to define the SPHERA configuration, i.e. the definition of the nesting modality in ERA5. Results of points I, II and III are detailed in the SPHERA-PRE final report. The configuration of COSMO (point IV) is summarized in Table 1. Finally, the test about the nesting modality (point V) was accomplished during the SPHERA project and the results are reported in the following paragraph. After the definition of the nesting modality, the following question regarded the definition of the deep soil temperature to assign to SPHERA. Deep soil signal are relevant in long lasting simulation since small inaccuracies at the soil level can trigger systematic errors associated to the soil hydrological cycle and surface fluxes balance. The experimentation performed to answer this point is reported herein as well, although not all the results are already available (simulations are still ongoing).

	SPHERA setup
Initial condition	ERA5
Boundary condition	ERA5, updated every hour
Nesting modality	1-way nested, directly nested in ERA5 (see paragraph 1)
Sea Surface Temperature	Interpolated from ERA5 every day
Deep soil temperature	To be defined (see paragraph 2)
Observations assimilated	SYNOP (not temperature at 2m and precipitation), SHIP (not temperature at 2m and precipitation), TEMP, PILOT and AIREP
Code version	INT2LM 2.04 (pre-processing) COSMO 5.03 in single precision (to be upgraded to COSMO 5.05)
Domain	38N, 5.7W- 53N,18.2W
Resolution	2.2km horizontal, 65vertical levels (0-22km), 7 soil level (0-14.58m)
Physical schemes:	
Radiation	δ two-stream scheme after Ritter and Geleyn, 1992
Turbulence	Prognostic turbulent kinetic energy closure at level 2.5 including effects from subgrid-scale condensation and from thermal circulation (Raschendorfer 2001)
Transfer	Surface layer scheme coupled with the turbulence scheme

	(Raschendorfer)
Land-Surface	Multi-layer soil after Jacobsen and Heise (1982)
Convection	Only shallow convection (reduced Tiedtke 1989)
Microphysics	Grid scale cloud and precipitation scheme (3 categories ice scheme) and a statistical scheme for sub-grid clouds (Sommeria and Deardorff, 1977)
Subgrid scale Orography	Lott and Miller, 1997
Lake	Two-layer bulk model after Mironov (2008)
External parameters	
Orography	GLOBE
Land cover	Global Landcover 2000 Database
Soil type	Digital Soil Map of the World (FAO/UNESCO)

Table1. SPHERA setup

1. Definition of the nesting modality in ERA5

One of the main questions tackled during the setting up process regarded the selection of the modality by which COSMO is nested into the driver dataset ERA5. As a general practice, high resolution runs are nested in coarser resolution integration of the same model, in order to ensure a ratio of spatial resolution between 2:1 and 5:1 (e.g. Warner et al. 1997, Denis et al. 2001). However, some recent studies (Marsigli et a. 2013) and experiences in the operational chain building-up (Arpagaus, MeteoSwiss, pers. comm.) demonstrated a neutral or improved performance of the high resolution run, when the intermediate step with the coarser resolution model was avoided.

Regarding this choice, two options had been considered for SPHERA:

- 2step: COSMO-I2 was one-way nested in COSMO-10M (a COSMO model configuration with horizontal resolution of 10km, domain covering the whole Mediterranean Sea and convection parameterized by Tiedtke scheme, Tiedtke, 1989), which in turn was one-way nested in ERA5. The ratios of spatial resolutions between COSMO-I2, COSMO-10M and ERA5 were respectively 5:1and 3 :1, in agreement with the traditional practice.

- 1step: COSMO-I2 was directly one-way nested in ERA5, with a resolution step of 15:1. The integration domain is enlarged by 16 grid points at the border in each direction with respect to the one used in SPHERA-2step, in order to dump the border effects potentially associated to a nest using a large ratio between model resolutions.

These two configurations were tested on two parallel suites over one year (2015), plus 6 months of initialization used to spin up the model soil fields. The comparison between the two configurations was performed in terms of (I) temporal trend of the domain average of some specific surface variables (daily accumulated precipitation, surface pressure, mean surface pressure, noon and midnight temperatures at 2m), (II) verification against observations for daily accumulated precipitation and temperature at 2m.

The time trend verification (Figure 1) showed that:

1. no constant trends associated to mass or humidity from the beginning to the end of 2015
2. high seasonality in the difference between SPHERA-1step and SPHERA-2step for the surface pressure and the midday 2m temperature. These indicate a warmer atmosphere in SPHERA-1step than in SPHERA-2step during spring, summer and autumn. Potential reasons are: the usage of the deep convection scheme in the intermediate integration domain in SPHERA-2step and the different soil status (COSMO-2I in SPHERA-2step is not

autonomously evolved but it interpolates the soil fields from the intermediate integration domain COSMO-10M)

3. high seasonality in the difference between SPHERA-1step and SPHERA-2step for the midnight 2m temperature. It indicates that the low level atmosphere of SPHERA-1step is colder than in SPHERA-2step during winter
4. SPHERA-1step always shows a lower precipitation (in term of domain average) than SPHERA-2step.

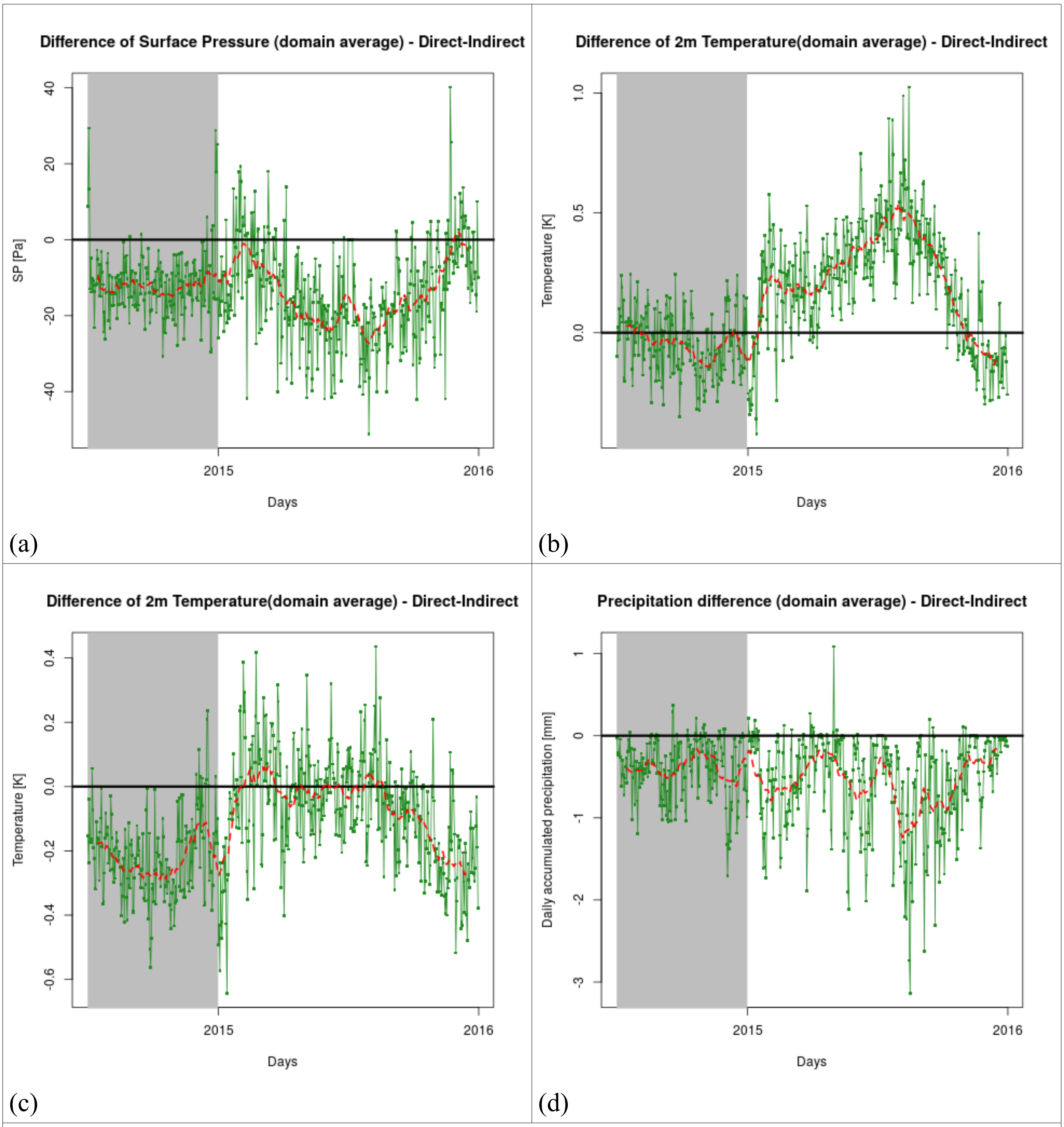

Figure 1. Difference of the domain-averaged (a) surface pressure, (b) noon temperature at 2m, (c) midnight temperature at 2m, (d) daily accumulated precipitation simulated by SPHERA-1step and SPHERA 2-step, plotted against the integration time. The shaded box indicates the spin-up period.

The verification of precipitation was performed over 0.2°x0.2° boxes covering the Italian domain and comparing the maximum of the daily accumulated precipitation in each box between model and observations. Notice that the observations used in this phase (from the Italian Civil Protection network, http://www.mydewetra.org/) had not been ingested into the data assimilation procedure.

The performance diagrams for different precipitation thresholds and divided per season (Figure 2) showed that:

1. SPHERA-1step performs better (with less false alarm ratio and smaller bias) than SPHERA-2step, almost at every threshold and especially during summer
2. SPHERA-1step presents generally less precipitation than SPHERA-2step, especially at the end of summer and during autumn (i.e. when more intense rainfall events occur). This indicates a larger instability in SPHERA-2step than in SPHERA-1step. Potential reasons are: the usage of the deep convection scheme in the intermediate integration domain in SPHERA-2step or some border effects associated to the 2step nesting mode.
3. as a general remark, SPHERA performs better than the driver ERA5 for precipitation thresholds higher than 15-25mm, especially during summer. This effect could be associated to an improved localization of the convective cells in SPHERA

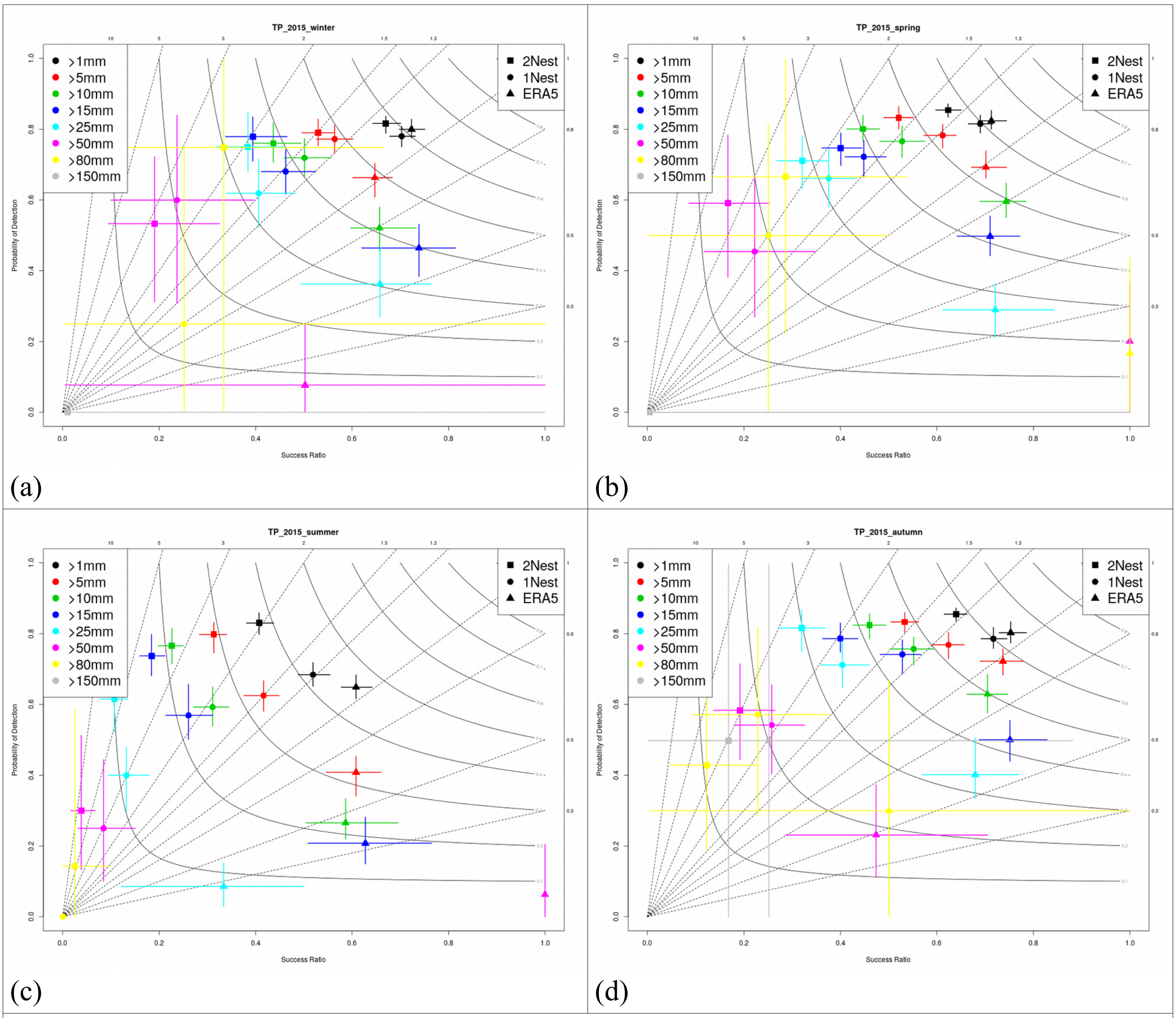

Figure 2. Performance diagram of the daily accumulated precipitation at different thresholds aggregated over 0.2°x0.2° boxes for SPHERA-1step (labelled “1Nest”), SPHERA-2step (labelled “2Nest”) and ERA5 during (a) winter, (b) spring, (c) summer, (d) autumn 2015.

The verification of the temperature at 2m has been performed using the nearest point method and calculating the bias and RMSE scores every three-hours. Height altitude correction has been performed if the difference between model grid point and observation was lower than 500m, while the data was discarded if the delta was larger than 500m. Observations include data from the high resolution monitoring network (which densely covers Northern Italy) and from the SYNOP stations. These observations have not been ingested into the data assimilation procedure.

The bias and RMSE scores aggregated over the day hours for each season (Figure 3) indicated that:

1. SPHERA-1step performs better (smaller bias and RMSE) than SPHERA-2step during daytime in summer and during night time in winter. In spring and autumn the differences are not evident
2. as a general remark, the regional reanalysis reduces the cold bias (about 0.5K) that ERA5 shows in any season and it reduces the RMSE. However, SPHERA does not remove the diurnal cycle of error

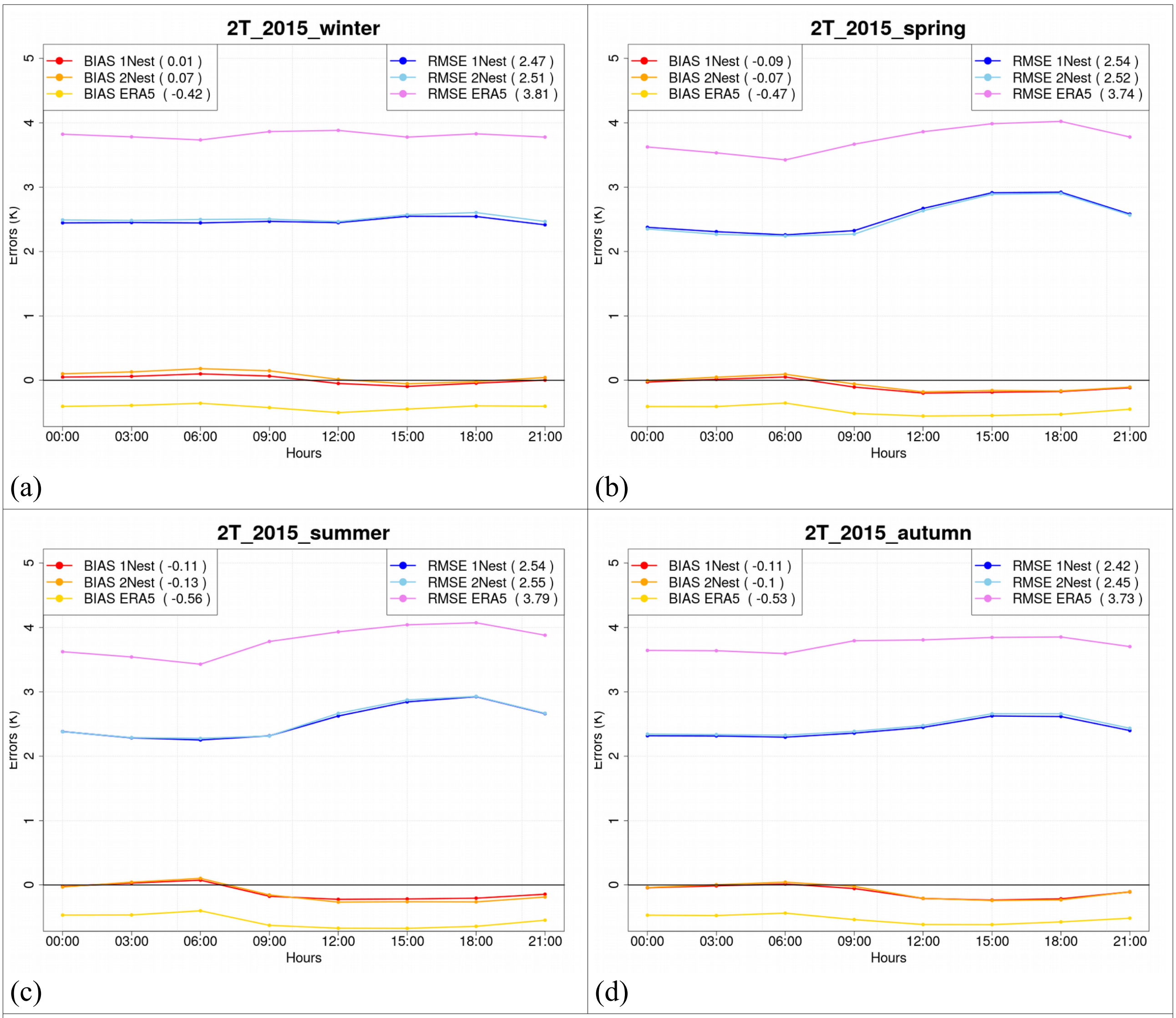

Figure 3. RMSE of tempearature at 2m in SPHERA-1step (labelled "1Nest"), SPHERA-2step (labelled "2Nest") and ERA5 averaged on the day hours for the (a) winter, (b) spring, (c) summer, (d) autumn months 2015

In conclusion, the experiment clearly identified that the 1step nesting modality overcomes the traditional mode for the specific SPHERA environment. Some additional activity is required to pinpoint if the reason sites in the different application of the convection scheme, in the different soil evolution, in some border effect, etc..

2. Definition of the deep soil temperature for SPHERA

The second relevant question tackled regarded the definition of the deep soil temperature to apply in a long term simulation, as a regional reanalysis dataset. In literature, this issue is very marginally treated, mainly for the lack of deep soil observations to validate the results. Nevertheless, the large soil inertia has the potential to trigger differences at the surface level and in the atmosphere on a long time scale. In general, the deep soil temperature in the regional reanalysis is interpolated from

the deepest temperature of the driver model. However, the deepest soil level in ERA5 is located at 1.954m of depth, while the lowest one in COSMO goes down up to 14.58m. Therefore, the direct interpolation of the deepest temperature of ERA5 in SPHERA would cause an error in the amplitude of the seasonal temperature variation (which is dumped by depth) and in the temporal shift of the surface temperature signal (which is delayed by depth).
In order to provide a different field to the COSMO-2I deep temperature, three different parametrizations of the deep soil temperature have been considered. They all are based on the simplified analytic solution of the heat transfer equation in soil (assuming sinusoidal yearly wave of temperature and the mean homogeneity).
The considered parametrizations were:

1. the simplified analytic solution of the temperature wave in which the thermal diffusivity is parametrized by the amplitude method (Evett, 2002)
2. the simplified analytic solution of the temperature wave in which the thermal diffusivity is parametrized by the phase method (Verhoef et al. 1996)
3. the three-yearly running mean of the shallower temperature, with a time delay defined from the simplified analytic solution in which the thermal diffusivity is parametrized by the phase method.

The third option is based on the hypothesis that the amplitude of the annual thermal wave is very small at 14.58m, thus the temperature can be approximated by a multi-year running mean delayed by a proper lag due to soil inertia.
These three methods were compared against observations on specific sites over Europe having soil measurements at a depth larger than 0.5m (Cardington, Fauga-Mauzac, Lindenberg, San Pietro Capofiume and Potsdam). Figure 4 reports the time series reconstructed by the three parametrizations at the depth of 12m against Potsdam data (Potsdam has the deepest soil measurement, the only one really comparable with the 14.58m of depth required in COSMO). Compared to the observations, the analytic solution using the amplitude method shows a correct annual amplitude but with a wrong phase, the analytic solution using the phase method underestimates the wave amplitude and shows a inter-annual trend non-coherent with real data and finally the moving average method underestimates the wave amplitude but the inter-annual trend is coherent with measurements. RMSE and correlation index indicated that the last option better approximates the real time series.
Therefore, the latter parametrization was applied to reconstruct the deep soil temperature for SPHERA. This field resulted quite constant along time: very small seasonal variability and inter-annual variability of 0.5K/year in specific areas.
In order to evaluate the effects of the use of this parametrized deep temperature in SPHERA, two parallel simulations have been run for one year (2015), plus six months of initialization used to spin-up the model soil fields. The first configuration interpolated the deep soil temperature from the ERA5 deepest soil level (1.945m) at the initialization (01/07/2014) and kept this value constant along the model integration. This option corresponds to the one applied in the previous experiment (section 1) and is coherent with the general use in regional reanalysis. The second configuration used the parametrized deep soil temperature, with daily update.

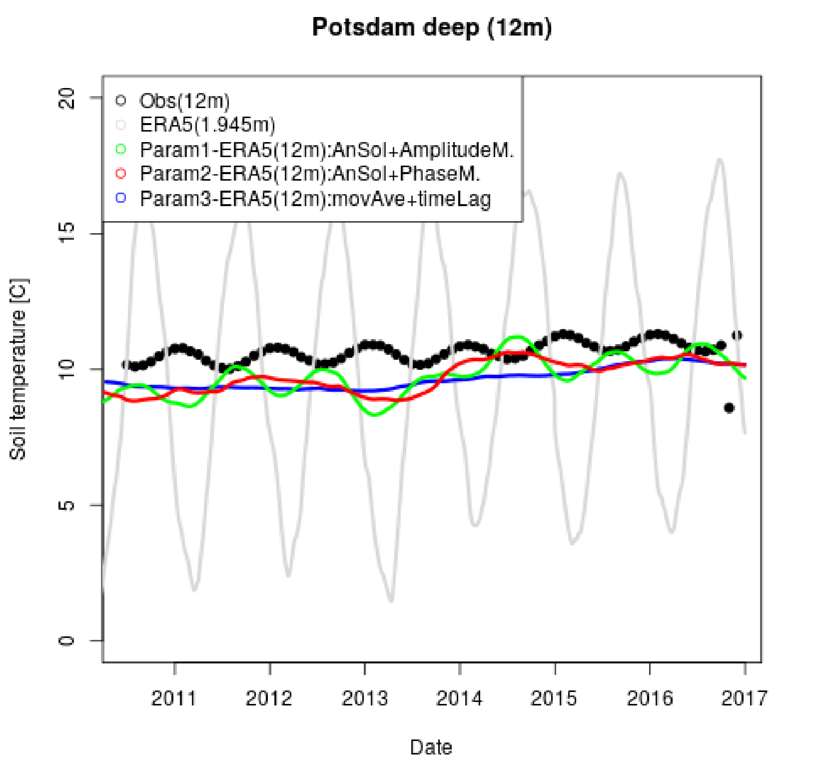

Figure 4. Time series of the soil temperature at 12m of depth observed at Potsdam and reconstructed by the three parametrizations. In grey is plotted the time series of ERA5 at its deepest soil level (1.945m)

Over the Italian domain the main differences between this reconstructed temperature and the one interpolated from ERA5 on the day in which the integration was initialized, are (Figure 5):

- the reconstructed field is colder of 1-3K in the Po Valley
- the reconstructed field is warmer of 1-3K over the Alps

These divergences are due to the large amplitude of the annual thermal wave in ERA5, which is absent in the parametrized field. Therefore, in July 2014, the interpolation from ERA5 can show a wide difference to the the moving mean (e.g. Figure 4). Different regions present different behaviour because of the associated delay depends on the soil features.

The parallel simulations are currently running and the results will be available at approximately the end of July 2018.

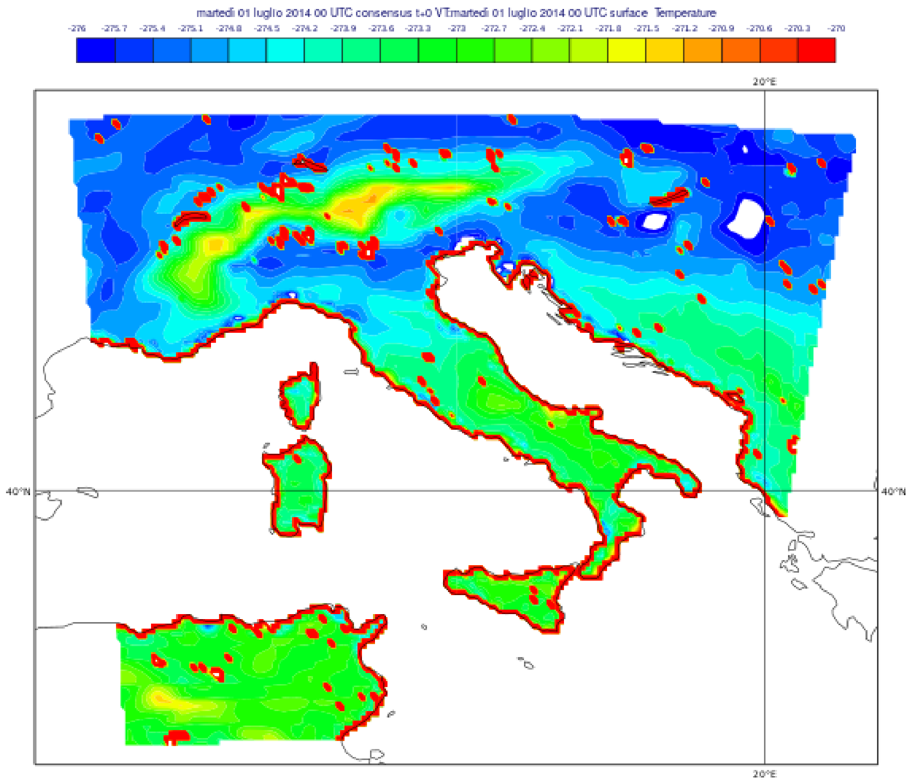

Figure 5. Difference of deep soil temperature between the parametrized field using the delayed moving average and the interpolation from ERA5 deepest temperature.

<u>Conclusions</u>

The configuration of SPHERA up to know is in large part defined (Table 1). Two main points required specific experimentations: the definition of the modality of nest of SPHERA in ERA5 and the definition of the deep soil temperature to provide as bottom boundary condition to SPHERA. The first issue was tackled by comparing over one year two parallel simulations of SPHERA in two different nesting modalities. It resulted that the direct nest of COSMO (at 2.2km of resolution) into ERA5 (at 31km of horizontal resolution) improved the scores of temperature at 2m and of precipitation with respect to a traditional 2steps nest (passing through an intermediate resolution COSMO run). The second issue is currently under definition. Two parallel simulations of SPHERA using two different deep soil temperatures (interpolation from ERA5 deepest temperature and a parametrization using a delayed moving average) are run over one year. As soon as this latter experiment is concluded (approximately end of July 2018), the operational production will start.

References

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Marsigli C., A. Montani, and T. Paccagnella 2014: Provision of boundary conditions for a convection-permitting ensemble: comparison of two different approaches. Nonlinear Processes in Geophysics,21, 393–403, 2014

Verhoef A., Hurk Van Den B.J.J.M., Jacobs A.F.G., Heusinkveld B.G. 1996: Thermal soil properties for vineyard (EFEDA-I) and savanna (HAPEX-Sahel) sites. Agricultural and Forest Meteorology, 78: 1–18.

Warner, T. T., Peterson, R. A., and Treadon, R. E.: A tutorial on lateral boundary conditions as a basic and potentially serious limitation to regional numerical weather prediction, B. Am. Meteorol.Soc., 78, 2599–2617, 1997.

List of publications/reports from the project with complete references

Poster with title "SPHERA: High rEsolution ReAnalysis over Italy. Plan and setup" (Ines Cerenzia , Tiziana Paccagnella, Andrea Montani, Arpae-Emilia Romagna, HydroMeteoClimate Service, Bologna, Italy) presented at the 5th International Conference on Reanalysis

Summary of plans for the continuation of the project

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The latter of the two extensive experiments performed during SPHERA special project is currently ongoing. As soon as this experiment is concluded (approximately end of July 2018), the final configuration of COSMO will be defined. The beginning of the operational production is estimated for September 2018. Within the subsequent months of 2018, it will be possible to simulate approximately 4 to 5 years of reanalysis. The remaining years will be accomplished in 2019 if the needed resources will be allocated.