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A methodology towards the hierarchy of COSMO parameter calibration tests via the domain sensitivity over the Mediterranean area

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1 Abstract

The goal of this work is to estimate systematically the sensitivity of COSMO model over a large number of expected high impact parameters, using objective criteria for their selection. The proposed methodology is based on the relative average values of certain meteorological fields over a considered model domain and time period. Its main advantages are its economy as well as its flexibility, due to its *ab initio* character, as observations do not enter into the decision process. In this way, the calibration procedure is considered as a separate independent stage of the model optimization according to the computational resources available to the user and in reference to the available observations. Another important feature of the method deals with the selection of the proper domain in case of nesting by employing the similarities of the parameter sensitivities between the wider and the internal domain. Twelve parameters were examined over the wider Mediterranean area for a period of 62 dates from February, June, and December of 2013 and a horizontal grid of 0.0625° ($\sim 7\,Km$). The validity of the method is demonstrated via the resulting sensitivities of this domain compared with those of internal domains over the areas of Greece, Italy, Israel and Switzerland leading to a distinct hierarchy regarding the parameter choice as well as the dominant interaction terms of the parameter combinations.

2 Introduction

Numerical weather prediction (NWP) models are tools of exceptional complexity both from the computational perspective regarding the applied numerical schemes as well as the physical processes included along with their approximations. From the operational standpoint, the physical processes are implemented by means of parameters that are either user defined or hardcoded into the model software (default values herein). However, the optimization of the model performance depends significantly on these parameter values. The process of finding the default parameter values is generally addressed as model tuning (Skamarock 2004; Duan et al., 2006). The more physical processes are included in the NWP model, the larger is the number of parameters expected to be tuned to control and optimize its performance. This feature leads usually to a task of employing complicated methodologies of relatively high computational cost (Annan and Hargreaves 2007). This is also the case for COSMO, a state of the art non-hydrostatic local NWP model developed and supported by the synonymous COSMO consortium (COnsortium for Small-scale Modeling, www.cosmo-model.org) consisting of the national meteorological services of Germany, Greece, Israel, Italy, Poland, Romania, Russia and Switzerland. In our previous works (Khain et al., 2015, 2017; Voudouri et al., 2016, 2017, 2018, 2019), there have been performed extensive efforts to increase the performance of COSMO model over the area of Switzerland and Northern Italy through the choice of an optimum set of tunable model physics parameters. The optimization process was based on the use of an objective calibration procedure that has been applied for a regional climate model (RCM) (Bellprat et al., 2012a and 2012b). This calibration methodology relies on a meta-model (MM) that approximates the parameter space, using a multi-variate quadratic regression in an N-dimensional model (Neelin et al., 2010 and 2010a; Box and Behnken, 1960; Mayers et al., 2009) where the dimension N of the model is the number of the parameters that are chosen to be optimized. The number of simulations required to create the quadratic polynomial necessary to construct the MM for calibrating N parameters varies from a minimum of 2N+N(N-1)/2 to a maximum of 2N+2N(N-1) plus a simulation standing for the default parameter values combination. In principle, the first step is to perform the runs of COSMO model with the default parameter values for the time period and domain under consideration and then repeat the process, first by changing one parameter at a time to its maximum and minimum limits values and then changing two parameters at a time to account for the interaction between these parameters. Although the approach is rather straightforward, its computational cost rises practically in analogy to N^2 providing significant constraints in its realization if the number of the parameters rises, especially when relatively large domains are considered along with fine grid spacing.

In the present approach, a strategy is developed on how to decrease the computational cost of the above process by providing realistic options towards the truncation both of the number N of the parameters chosen as well as the choice of the interaction terms. The key concept of this mechanism is the relative sensitivity of the minimum and maximum parameter values with respect to their default values in reference to certain meteorological fields that are considered as the most important ones from the operational perspective of the user (e.g. cloud cover, precipitation, 2m temperature etc.). In this work and in analogy to the work of Dierer et al (Dierer et al., 2009), this sensitivity is defined as the ratio of the difference of the average area values of the considered meteorological fields between their limit parameter values and their default ones over the total period of the model runs. A direct insight regarding the relative sensitivity among the parameters is visualized in the form of spider-graphs. Another feature of the methodology is the possibility to use the parameter sensitivities to relate meteorological similarities among internal domains in reference to the wider area of the model run and potentially attribute criteria for their optimum position and extent in case of the application of nesting techniques to further increase the local model performance. Towards this direction, the relative sensitivities of domains over the areas of Greece, Italy, Israel and Switzerland are presented in reference to the domain of the Mediterranean.

3 Model setup

3.1 Configuration

In this work. Version 5.0 of COSMO model was used that forms the reference version of the current operational applications of the model. Extensive physical parametrizations, as well as refined numerical schemes are induced in the model making it particularly applicable for the current study, since it is mainly designed to be applied operationally in the Meso-β and Meso-γ scales (Steppeler et al., 2003; Baldauf et al., 2011; Gebhardt et al., 2011; Schättler et al., 2013; Collaud Coen, 2014). The model runs were performed for 48hr periods starting at 00 UTC over the wider Mediterranean area (Fig. 1), the domain used operationally by the Hellenic National Meteorological Service (HNMS), on a 0.0625° ($\sim 7\,Km$) horizontal grid spacing, 649x393 grid points with 60 vertical levels and a 30 second integration time step.

This configuration has also been used for research purposes that highlight the value of the model towards the further understanding of storm surges (Calafat et al., 2014), cloud schemes (Avgoustoglou and Tzeferi, 2015), tornadoes (Avgoustoglou et al., 2018) and non-adiabatic atmospheric processes (Kouroutzoglou et al., 2018). The model was initialized from 6-hour analysis of the ECMWF operational model (www.ecmwf.int/en/forecasts/datasets/set-i) over a 0.150° ($\sim 15\,Km$) horizontal grid, while the outputs were produced in 3-hour time intervals. The model runs were performed at ECMWF's High Performance Computing Facility (www.ecmwf.int/en/computing/our-facilities/supercomputer) and are equivalent of approximately 6 years of model runs.

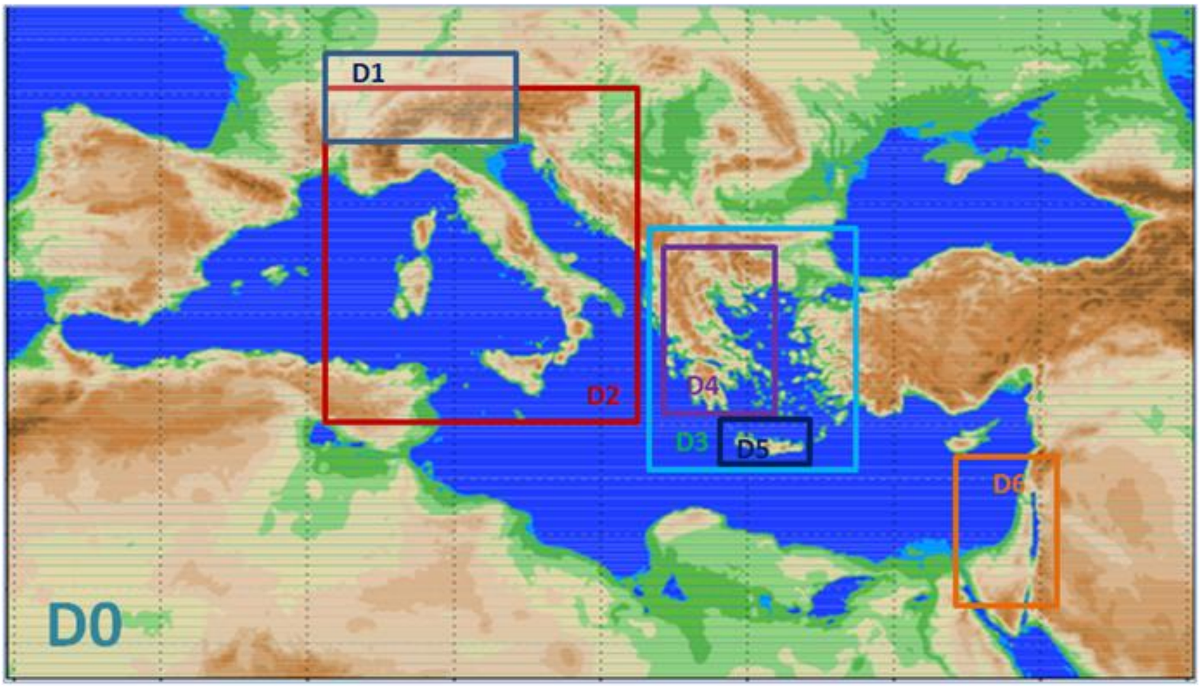

Figure 1: Domain of model runs over the wider Mediterranean area (D0) along with specific test domain for areas around: Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (mainly) (D4), Crete (D5), and Israel (D6).

3.2 Parameter selection and model tests

A set of twelve parameters was selected (Table 1) that practically envelops the most significant physical processes of COSMO model over a general domain selection (Schättler et al 2013).

PARAMETER	INTERPRETATION	TEST VALUES
a_stab	stability correction factor of horizontal length scale	**0.0** , 0.5, 1.0
crsmin	minimum stomatal resistance	50, **150**, 300
c_soil	surface area index of evaporative soil	0, **1**, 2
entr_sc	mean entrainment rate for shallow convection	$5 \cdot 10^{-5}, \mathbf{3 \cdot 10^{-4}}, 2 \cdot 10^{-3}$
mu_rain	shape parameter of the rain drop size distribution	0, **1**, 2
q_crit	critical value for normalized oversaturation	1.6, 2.8, **4.0**
rain_n0_factor	factor to reduce the evaporation of raindrops	0.02, **1.0**, 5.0
rat_sea	ratio of laminar scaling factors for heat over sea	1, **20**, 100
rlam_heat	scaling factor of the laminar boundary layer for heat	0.1, **1.0**, 2.0
tkmmin tkhmax	minimal value of diffusion coefficients for heat and momentum (kept equal)	0.1,**0.4**, 1.0
tur_len	asymptotic maximal turbulent length scale (m)	100, **150**, 1000
v0snow	factor in the terminal velocity for snow	10, **20**, 30

Table 1: List of the 12 parameters of tested sensitivity based on their code names (first column), interpretation (second column) and test values range (third column). The default values are denoted with bold italic characters.

However, the application of a MM for the calibration of COSMO model over such a large number of parameters is prohibitive, especially when a domain with the complexities and size of the Mediterranean should be considered. In our previous works (Voudouri et al., 2017 and 2018), the reduction of the parameters was decided mainly on heuristic arguments based on the works of Bellprat et al (Bellprat et al. 2012a, Bellprat et al. 2012b) as well as the climatological and meteorological characteristics of the considered domain of Switzerland and Northern Italy. The choice of the parameters to be tuned was an essential task and a considerable effort was given regarding their selection since there are numerous parameters in COSMO model specifically related to sub-grid scale turbulence, surface layer parametrization, grid-scale clouds, precipitation, moist and shallow convection, radiation, the soil scheme etc. (Doms et al., 2011, Gebhardt et al., 2011).

Therefore, the consensus regarding the selection of parameters turns out to be the most crucial task to control the number of the model simulations and the consequent computational cost. In the present work and under this motivation, the domain parameter sensitivity (DPS) is introduced as the key term. DPS is considered that leads to the desired most convenient parameter choice in an objective manner via a consequent imposed hierarchy over the resulting DPS of the considered parameters.

For a model field F the domain parameter sensitivity DPS_F is defined as ,

$$DPS_F = \frac{< F >_{TEST} - < F >_{DEFAULT}}{< F >_{DEFAULT}} \cdot 100 \tag{1}$$

where $< F >_{DEFAULT}$ stands for the temporal domain areal average of F for the default parameter values, while $< F >_{TEST}$ stands for the test run where one of the parameters has been set equal to its limit values given in Table 1, while the other parameters are kept with their default values (Avgoustoglou et al., 2016). Although, there is no constraint on the model fields attributed for consideration, the applicability of the method is presented upon the choice of rather common meteorological features related with cloud cover,precipitation and temperature (Table 2).

0-24 hr period accumulated precipitation (kg m^{-2})	TOTPREC
0-24 hr periods accumulated grid-scale snow (kg m^{-2})	SNOW_GSP
Low cloud cover (%) average of 3hr time steps 03-24 hs	CLCL
Medium cloud cover (%) average of 3hr time steps 03-24 hs	CLCM
High cloud cover (%) average of 3hr time steps 03-24 hs	CLCH
Total cloud cover (%) average of 3hr time steps 03-24 hs	CLCT
Maximum 2m temperature (^oC) for 0-24 hr periods	TMAX2m
Minimum 2m (^oC) temperature 0-24 hr periods	TMIN2

Table 2: List of the examined meteorological fields. Their encoded names in COSMO model are given in the second column.

Regarding TMAX2m and TMIN2m the denominator of (1) changes very little relative to the absolute temperature and it was considered more convenient to define DPS simply as,

$$DPS_{\begin{bmatrix} TMIN2m \\ TMAX2m \end{bmatrix}} = \begin{bmatrix} TMIN2m \\ TMAX2m \end{bmatrix}_{TEST} - \begin{bmatrix} TMIN2m \\ TMAX2m \end{bmatrix}_{DEFAULT} \tag{2}$$

For the sake of seasonal coverage, the model tests were performed over a total of 62 days in continuous periods of 20, 20 and 22 days over February, June and December 2013 respectively. Periods from spring and autumn were not included in order to avoid any complexities due to the transitional nature of these seasons.

4 Methodology

4.1 Elemental application over one meteorological field

In order to present the essence of the method, we focus on a single meteorological field, the precipitation (TOTPREC) for the domain of the Mediterranean (D0). After completion of the tests, the resulting DPSs are presented in a standard column graph at the upper part of Fig. 2, from which it is obvious that for D0 the parameters are divided practically in three groups with respect to their sensitivities. According to the magnitude of the DPSs, the first group includes the two most sensitive parameters rat_sea and rlam_heat, the second group includes the five less sensitive parameters c_soil, entr_sc, v0_snow, rain_n0_factor and crsmin while in the third group the five least sensitive remaining parameters are included. Although this preponderance regarding the sensitivities of rat_sea and rlam_heat is directly visible from this graph, it has also been supported by previous works especially regarding rat_sea and rlam_heat parameters (Dierer et al., 2009; Kouroutzoglou et al., 2018) directly from physical arguments regarding mainly non adiabatic atmospheric processes. Of particular importance to our approach is the presentation of DPSs in the form of a spider-graph as given in the lower part of Fig. 2. In this graph the DPSs are given as bullets, the positive ones over and the negative ones under the red polygon of “no sensitivity”. The line that connects the dots defines the domain parameter sensitivity polygon (DPSP). It is drawn to address visually a geometrical morphology to the DPSs that is considered to be important over the next stages of the procedure. The limit parameter values are given as the extensions of the parameter names addressed in the tables and figures of the present work. In case the goal is to optimize the model performance with respect to TOTPREC using a MM, there is also the demand to consider tests with pair parameter combinations (Voudouri et al., 2017 and 2018), an essential task that becomes more and more complicated as the number of sensitive parameters is rising. This requirement is accounted by the creation of the domain parameter sensitivity priority board (DPSPB) presented in Table 3 where the absolute differences of the different parameter pair limit values are given in descending order. It can be easily shown that for N parameters, the number of pairs is 2N(N-1). So in the present case (12 parameters) the number of pairs is 264. Due to the large number of parameter pairs, only the first 20 are given in Table 3. As also shown in Fig. 2, the largest differences correspond to the most sensitive parameters (shaded rows) while there are also large differences between these parameters and those of very low sensitivity. Additionally, in the third column of Table 3, the relative sensitivity of the pairs of the DPSs is addressed by attributing the value -1 if the sensitivities have opposite signs and 1 if the signs are the same. In principle, the couples of the parameters with the highest DPS differences and with opposite sign sensitivities should be considered as the most appropriate choices in the optimization process via the use of a MM (highlighted rows in Table 3). According to the above analysis, upon the application of a model optimization technique, the initial choice of 12 parameters regarding D0 can be truncated from two to seven most sensitive ones and in case of the use of a MM the dominant parameter pairs are the ones addressed with the highlighted rows in Table 3.

4.2 Extension of the methodology over several meteorological fields

Although the precipitation has a standalone value regarding the optimization of model performance (Dierer et al., 2009), in principle, it is necessary to account for the model calibration with respect to more meteorological fields. In that case the parameter selection method can be readily generalized. Under this requirement, the meteorological fields of grid-point snow (SNOWGSP), minimum 2m temperature (TMIN2m), maximum 2m temperature

(TMAX2m), high, medium and low cloud cover (CLCH, CLCM, CLCL respectively) are also included modifying the method accordingly.

TOTPREC		
rat_sea_ 1 - rlam_ heat_0.1	28.389	-1
rat_sea_100 - rlam_heat_2.0	25.164	-1
c_soil_0 - rat_sea_100	25.023	-1
entr_sc_5E-5 - rat_sea_100	24.617	-1
c_soil_0 - rlam_heat_0.1	23.195	-1
entr_sc_5E - 5-rlam_heat_0.1	22.789	-1
rat_sea_100 - v0snow_10	22.743	-1
rlam_heat_0.1 - v0snow_10	20.915	-1
rain_n0_factor_5.0 - rat_sea_100	20.732	-1
crsmin_300 - rat_sea_100	20.686	-1
mu_rain_0 - rat_sea_100	20.029	-1
rat_sea_100 -tur_len_1000	19.872	-1
rat_sea_100 - tur_len_100	19.599	-1
rat_sea_100 - tkhmin_tkmmin_1	19.592	-1
a_stab_0.5 - rat_sea_100	18.910	1
rain_n0_factor_5.0 - rlam_heat_0.1	18.904	-1
a_stab_1.0 - rat_sea_100	18.862	1
crsmin_300 - rlam_heat_0.1	18.858	-1
rat_sea_100 - tkhmin_tkmmin_0.1	18.792	1
q_crit_2.8 - rat_sea_100	18.463	1
...	...	...

Table 3: DPSPB for TOTPREC, i.e. the absolute values, in descending order, of DPS differences of temporal area 24-hour means for pairs of different parameter combinations for precipitation (TOTPREC) over the wider Mediterranean area D0 and over the 62-day period. The highest 20 values of the total of 264 combinations are displayed (second column) along with the corresponding parameter pair (first) column and their relative sensitivity signs (third column) denoted with -1 if they are opposite and 1 they are the same.

The corresponding DPSs are given in Table 4 and are shown in Fig. 3 where the spider graphs are referenced with respect to TOTPREC as it is given in the lower part graph of Fig. 2 and placed again in the head of Fig. 3. From the DPSs given in Table 4, it can be noticed that the most sensitive parameters (in gray shade) are essentially the same with those assessed from Table 3 with the inclusion of the minimal value of diffusion coefficients for heat and momentum (tkhmin & tkmmin) which have a significant impact in middle and low cloud cover, a feature that was the central point of a previous work (Avgoustoglou and Tzeferi, 2015). Moreover, towards the selection of the dominant interaction terms, a compiled DPSPB for all the meteorological fields is given in Table 5 as an extension to Table 3 and in reference to Fig. 3. Although the content of this table is considerably broad, the hierarchical display of the DPSs differences for several meteorological fields in adjacent places provides the framework to place consistent quantitative criteria on the interaction terms that should be considered.

5 Discussion of the relative sensitivity of different domains

As a sequel to the previous analysis regarding the establishment of a parameter ranking for model tuning of a particular domain, there is the possibility to use the DPSs for inducing similarities among different internal areas of the wider domain. These similarities may provide a valuable insight regarding the application of nesting techniques. In Figs. 4-10 the spider graphs for domains D0 to D6 are presented for the meteorological fields of precipitation (TOTPREC) (Fig. 4), grid-point snow (SNOWGSP) (Fig. 5), high, medium, low cloud cover (CLCH, CLCM, CLCL respectively) (Figs. 6, 7, 8), minimum (TMIN2m) (Fig. 9) and maximum 2m temperature (TMAX2m) (Fig. 10).

PARAM	TOTPREC	SNOW_GSP	CLCH	CLCM	CLCL	TMAX2m	TMIN2m
a_stab_0.5	0.1511	-0.2403	0.1904	0.3191	0.1767	0.0003	-0.0341
a_stab_1.0	0.1988	-0.4219	0.3066	0.3665	0.2914	-0.0022	-0.0853
crsmin_300	-16.255	0.0182	0.2097	0.6191	0.1221	0.0818	0.0014
crsmin_50	25.727	0.0595	0.3373	10.707	0.1045	-0.1294	-0.0046
c_soil_0	-59.616	-30.841	0.3787	55.408	0.1548	0.2641	0.0644
c_soil_2.0	3.05	15.448	0.2361	29.961	0.0753	-0.1242	-0.031
entr_sc_2E-3	23.585	0.9937	22.646	62.603	15.248	0.0027	0.0031
entr_sc_5E-5	-55.557	0.7613	87.764	14.055	4.354	-0.0242	0.0006
mu_rain_0	-0.9676	0.2466	0.0088	0.409	0.0441	-0.0036	-0.0017
mu_rain_2	0.6006	-0.0872	0.0074	0.2646	0.0282	0.0025	0.001
q_crit_1.6	1.144	-13.807	0.8898	12.745	0.5128	-0.0161	-0.0061
q_crit_2.8	0.5978	-0.5607	0.4207	0.4144	0.3494	-0.0088	-0.0035
rain_n0_factor_0.02	38.139	-0.7431	0.0045	14.879	0.1475	0.0176	0.0073
rain_n0_factor_5.0	-16.706	0.3933	0.0193	0.6899	0.0723	-0.0063	-0.0037
rat_sea_1	-111.563	0.0619	10.611	31.985	22.331	-0.1486	-0.1196
rat_sea_100	190.612	0.0206	16.945	31.229	2.493	0.1323	0.0923
rlam_heat_0.1	172.325	0.3037	15.349	31.584	23.333	0.1309	0.0633
rlam_heat_2.0	-61.031	-0.2522	0.5916	18.652	11.356	-0.076	-0.0264
tkhmin_tkmmin_0.1	0.2694	13.823	0.68	56.307	12.637	-0.0726	-0.0646
tkhmin_tkmmin_1.0	-0.5307	-21.134	10.701	95.062	21.172	0.133	0.129
tur_len_100	-0.5381	0.3148	0.4474	0.7197	1.178	0.0045	0.0069
tur_len_1000	-0.8106	-21.356	17.747	-2.316	12.931	0.1205	-0.0749
v0snow_10	-36.822	-27.122	0.4876	0.0536	10.252	0.0037	0.0023

Table 4: DPSs for min and max parameter values for precipitation (TOTPREC), grid-point snow (SNOWGSP), minimum 2m temperature (TMIN2m), maximum 2m temperature (TMAX2m), high, medium and low cloud cover (CLCH, CLCM, CLCL respectively) over the wider Mediterranean area D0 and over the 62-day period.

In addition to the wider area of the Mediterranean D0 where the corresponding spider-graph is placed on the top of the figures, D1 refers to an area around Switzerland; D2 refers to an area around Italy, D3 to an area around Greece, D4 to an area constrained mainly to continental Greece, D5 to the area of Crete and D6 to an area around Israel as shown in Fig. 1. All graphs are scaled with respect to the most sensitive parameter of the specific meteorological field and particular domain to provide a better perspective of the analogies and similarities of the DPSs among the domains. For TOTPREC all domains show comparable DPSs and similar corresponding polygons (DPDPs) with the exception of D1 that exhibits considerably lower DPSs from the other areas. In addition, the areas of Italy (D2) and Greece (D3, D4) are very close in DPSs. An interesting aspect with this analysis are the close similarities between D5 (Crete) and D6 (Israel) which most probably addresses climatic characteristics between the two areas directly from the model parameters. This is also highlighted in Fig. 5 regarding SNOWGSP although this parameter might have certain spurious features due to the small number of events for the particular time sampling of 62 days including 20 days in summer. The situation is similar with the rest of the meteorological fields although for low cloud-cover (CLCL) the domains associated with the areas of Greece (D3, D4, D5) and Israel D5 denote sensitivity for several parameters however in good analogy with the reference domain D0.

TOTPREC			SNOW_GSP			CLCL			CLCM			CLCH			TMAX2m			TMIN2M		
P08MIN-P09MIN	28.389	-1	P03MIN-P10MIN	4.466	-1	P04MAX-P10MAX	15.766	-1	P04MIN-P08MIN	6.587	-1	P04MIN-P10MAX	9.846	-1	P03MIN-P08MIN	0.413	-1	P08MIN-P10MAX	0.249	-1
P08MAX-P09MAX	25.164	-1	P03MAX-P12MIN	4.257	0	P09MIN-P10MAX	12.664	-1	P04MIN-P10MAX	6.471	-1	P04MIN-P08MIN	9.837	-1	P02MIN-P03MIN	0.393	-1	P01MAX-P10MAX	0.214	-1
P03MIN-P08MAX	25.023	-1	P10MIN-P12MIN	4.094	-1	P08MAX-P10MAX	12.629	-1	P04MIN-P11MAX	5.647	-1	P04MIN-P09MAX	9.368	-1	P03MIN-P09MAX	0.340	-1	P10MAX-P11MAX	0.204	-1
P04MIN-P08MAX	24.617	-1	P03MIN-P04MAX	4.078	-1	P03MAX-P10MAX	12.502	-1	P04MIN-P09MAX	5.490	-1	P04MIN-P11MIN	9.223	-1	P03MIN-P10MIN	0.337	-1	P03MIN-P08MIN	0.184	-1
P03MIN-P09MIN	23.195	-1	P03MIN-P04MIN	3.845	-1	P03MIN-P04MAX	11.801	-1	P04MIN-P06MIN	4.867	-1	P03MIN-P04MIN	9.155	-1	P03MIN-P04MIN	0.288	-1	P08MIN-P09MIN	0.183	-1
P04MIN-P09MIN	22.789	-1	P04MAX-P12MIN	3.706	-1	P03MIN-P10MIN	11.172	-1	P04MIN-P06MAX	4.703	-1	P02MAX-P04MIN	8.986	-1	P08MIN-P10MAX	0.282	-1	P01MAX-P08MAX	0.177	-1
P08MAX-P12MIN	22.743	-1	P03MAX-P11MAX	3.681	-1	P06MIN-P10MAX	10.780	-1	P04MIN-P12MAX	4.685	-1	P04MIN-P12MAX	8.859	-1	P08MIN-P09MIN	0.280	-1	P08MAX-P11MAX	0.167	-1
P09MIN-P12MIN	20.915	-1	P03MAX-P10MAX	3.658	-1	P02MIN-P10MAX	10.577	-1	P01MAX-P04MIN	4.645	-1	P04MIN-P07MAX	8.795	-1	P03MIN-P06MIN	0.280	-1	P01MIN-P10MAX	0.163	-1
P07MAX-P08MAX	20.732	-1	P10MIN-P11MAX	3.518	-1	P07MAX-P10MAX	10.196	-1	P08MAX-P10MAX	4.610	-1	P04MIN-P05MIN	8.785	-1	P03MIN-P06MAX	0.273	-1	P03MAX-P10MAX	0.160	-1
P02MAX-P08MAX	20.686	-1	P03MIN-P07MAX	3.477	-1	P06MAX-P10MAX	9.920	-1	P08MIN-P09MIN	4.566	-1	P04MIN-P05MAX	8.783	-1	P03MIN-P07MAX	0.270	-1	P08MAX-P10MIN	0.157	-1
P05MIN-P08MAX	20.029	-1	P04MIN-P12MIN	3.473	-1	P05MIN-P10MAX	9.915	-1	P01MIN-P04MIN	4.531	-1	P04MIN-P07MIN	8.772	1	P08MIN-P11MAX	0.269	-1	P09MAX-P10MAX	0.155	-1
P08MAX-P11MAX	19.872	-1	P03MIN-P11MIN	3.399	-1	P10MAX-P12MIN	9.560	-1	P03MIN-P04MIN	4.509	-1	P01MIN-P04MIN	8.586	1	P03MIN-P05MIN	0.268	-1	P01MAX-P03MIN	0.149	-1
P08MAX-P11MIN	19.599	-1	P03MIN-P09MIN	3.388	-1	P10MAX-P12MAX	9.477	1	P04MIN-P07MIN	4.501	-1	P03MAX-P04MIN	8.540	1	P03MIN-P12MAX	0.266	-1	P01MAX-P09MIN	0.148	-1
P08MAX-P10MAX	19.592	-1	P03MIN-P05MIN	3.331	-1	P04MAX-P08MIN	9.459	-1	P02MIN-P04MIN	4.458	-1	P01MAX-P04MIN	8.469	1	P01MAX-P03MIN	0.266	-1	P03MIN-P11MAX	0.139	-1
P01MIN-P08MAX	18.910	1	P03MIN-P08MIN	3.146	-1	P05MAX-P10MAX	9.241	1	P09MIN-P10MAX	4.450	-1	P02MIN-P04MIN	8.439	1	P01MIN-P03MIN	0.264	0	P09MIN-P11MAX	0.138	-1
P07MAX-P09MIN	18.904	-1	P02MIN-P03MIN	3.143	-1	P01MIN-P10MAX	9.187	1	P04MIN-P05MAX	4.382	-1	P04MIN-P06MAX	8.355	1	P02MIN-P10MAX	0.262	-1	P06MIN-P10MAX	0.135	-1
P01MAX-P08MAX	18.862	1	P04MAX-P11MAX	3.130	-1	P01MAX-P10MAX	9.140	1	P04MIN-P05MIN	4.310	1	P04MIN-P12MIN	8.288	1	P02MIN-P08MAX	0.261	-1	P02MIN-P10MAX	0.134	-1
P02MAX-P09MIN	18.858	-1	P04MAX-P10MAX	3.107	-1	P02MAX-P10MAX	8.887	1	P04MIN-P07MAX	4.282	1	P04MIN-P10MIN	8.096	1	P03MIN-P05MAX	0.261	1	P07MAX-P10MAX	0.133	-1
P08MAX-P10MIN	18.792	1	P07MAX-P12MIN	3.105	-1	P08MIN-P10MIN	8.830	-1	P03MAX-P04MIN	4.279	1	P04MIN-P06MIN	7.886	1	P03MIN-P04MAX	0.261	1	P06MAX-P10MAX	0.133	-1
P06MAX-P08MAX	18.463	1	P03MIN-P08MAX	3.105	-1	P10MAX-P11MIN	8.786	1	P02MAX-P04MIN	4.232	1	P04MIN-P09MIN	7.241	1	P02MIN-P09MIN	0.260	-1	P05MIN-P10MAX	0.131	-1
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Table 5: Three-column groups of the DPS differences absolute values for different parameter pair combinations regarding precipitation (TOTPREC), grid-point snow (SNOWGSP), minimum 2m temperature (TMIN2m), maximum 2m temperature (TMAX2m), high, medium and low cloud cover (CLCH, CLCM, CLCL respectively) over the wider Mediterranean area D0. The highest 20 values of the total of the 264 combinations are displayed (second) column along with the corresponding parameter pair (first) column and their relative sensitivities (third column) denoted with -1 if it is of the opposite and 1 if it is of the same sign. Due to space constraints, we correspond, P01 → a_stab, P02 → crssmin, P03 → c_soil, P04 → entr_sc, P05 → mu_rain, P06 → q_crit, P07 → rain_n0_factor, P08 → rat_sea, P09 → rlam_heat, P10 → tkhmin (together with tkmmin), P11 → tur_len , P12 → v0snow.

6 Conclusions

In the present study, a method was given aimed to restrict consistently the number of parameters chosen for COSMO model optimization especially via the use of a MM. The criteria were based on parameter sensitivities with additional insight of their relative values via spider-graphs. The method was developed analytically for the meteorological field of precipitation and was generalized to more meteorological fields where an internal consistency regarding the parameter choice was displayed. A decision process with respect to the interaction terms was also provided based on the differences of parameter sensitivities as well as their relative sign via the domain sensitivity priority boards. Finally, it was shown that the domain sensitivity spider graphs provide an important direct visual insight to certain similarities among them. These similarities might turn out to be important on the domain choice for the application of nesting techniques. This methodology is currently utilized in the development of CALMO-MAX project of COSMO (http://www.cosmo-model.org/content/tasks/priorityProjects/calmoMax/).

7 Acknowledgments

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www.cosmo-model.org/content/model/documentation/newsLetters/newsLetter19/cnl19_05.pdf

9 Appendix for Figs. 2 to 10

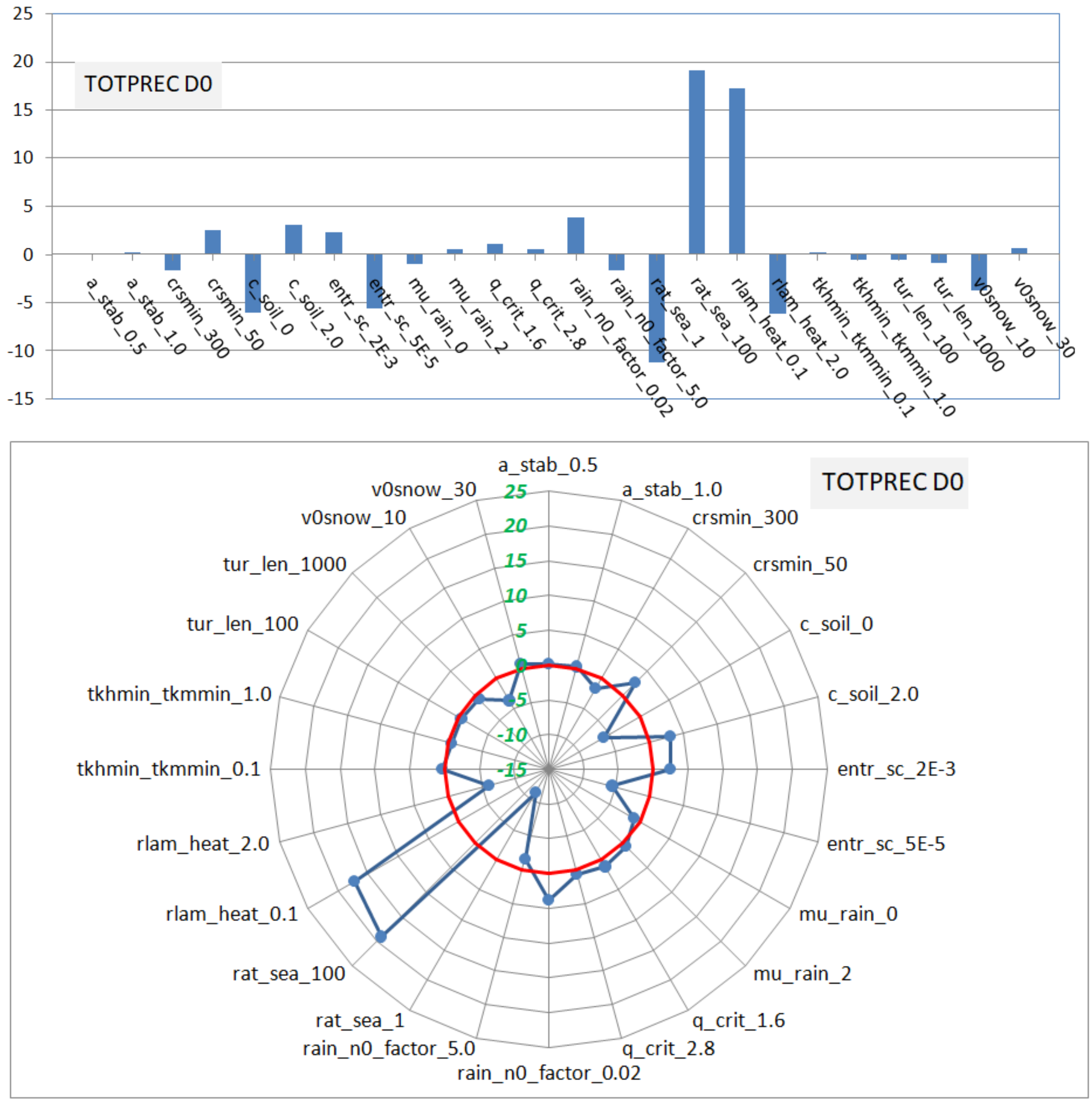

Figure 2: : DPSs for 24-hour precipitation (TOTPREC) over the wider Mediterranean area D0 in standard column form and in the form of spider-graph.

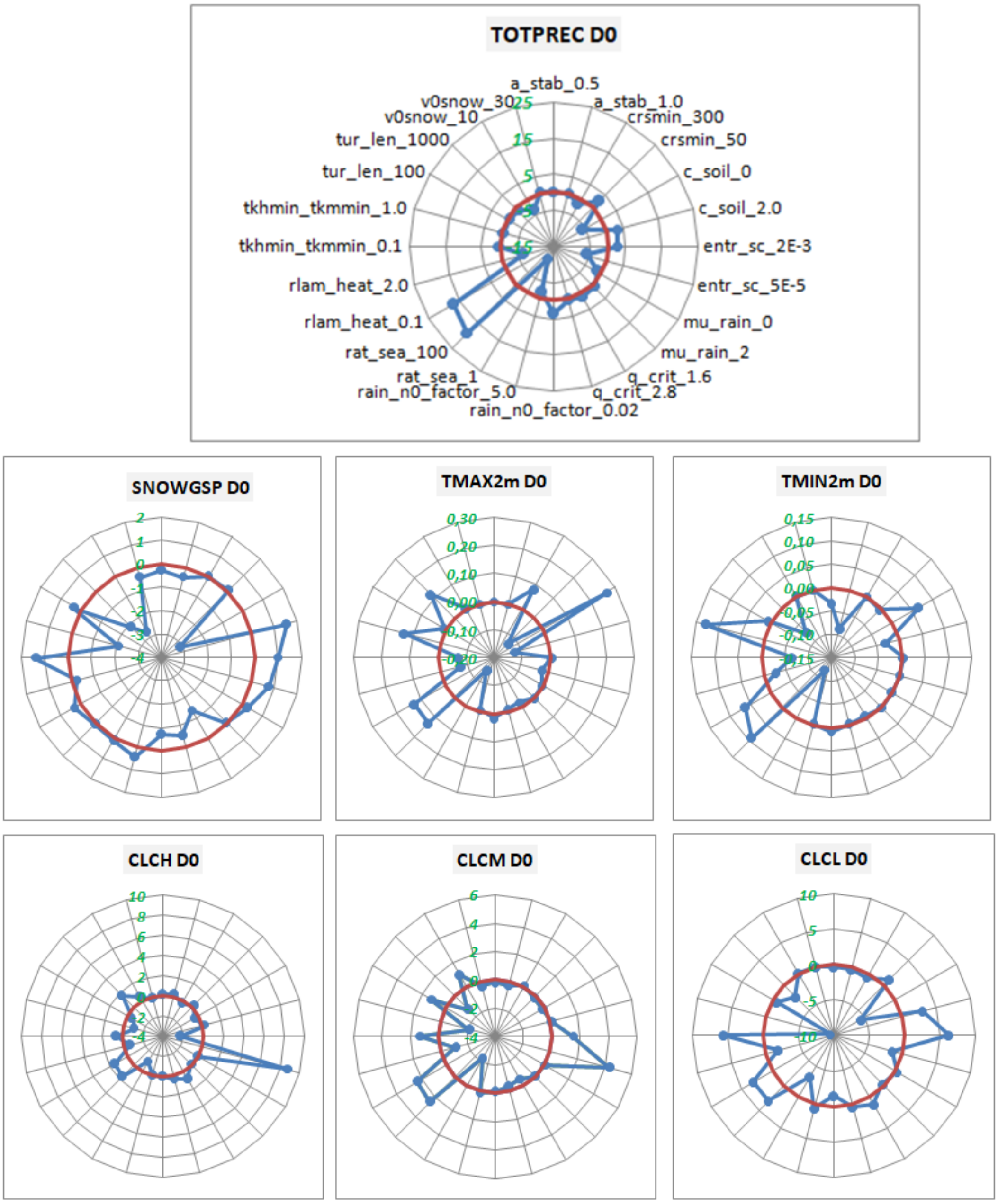

Figure 3: : DPS spider-graphs for temporal area 24-hour means of precipitation (TOTPREC), grid-point snow (SNOWGSP), minimum 2m temperature (TMIN2m), maximum 2m temperature (TMAX2m), high, medium and low cloud cover (CLCH, CLCM, CLCL respectively) over the wider Mediterranean area D0 and over the 62-day period.

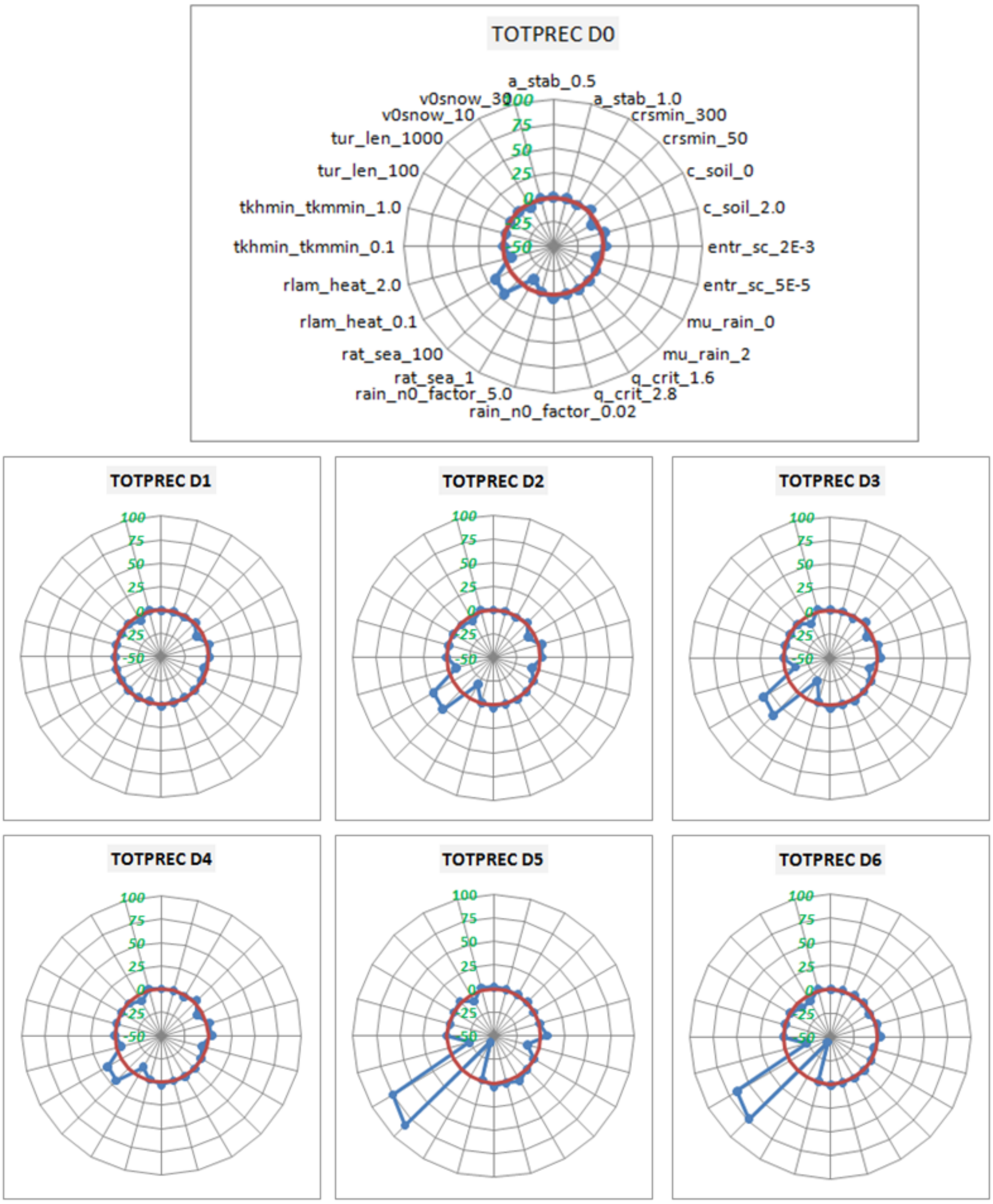

Figure 4: : DPS spider-graphs for temporal area 24-hour means of precipitation (TOTPREC), over the wider Mediterranean area D0, Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

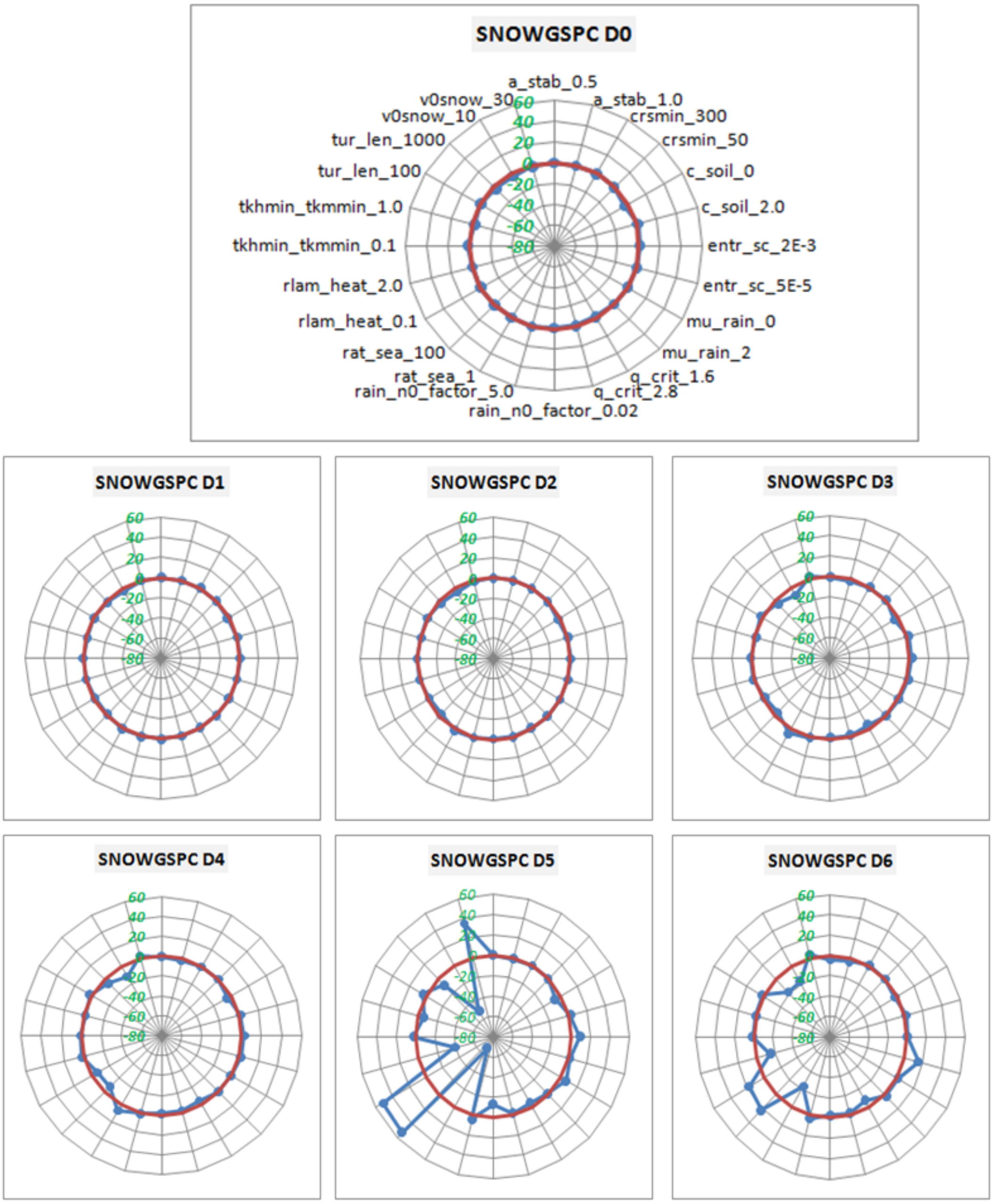

Figure 5: : DPS spider-graphs for temporal area 24-hour means of grid point snow(SNOWGSP), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

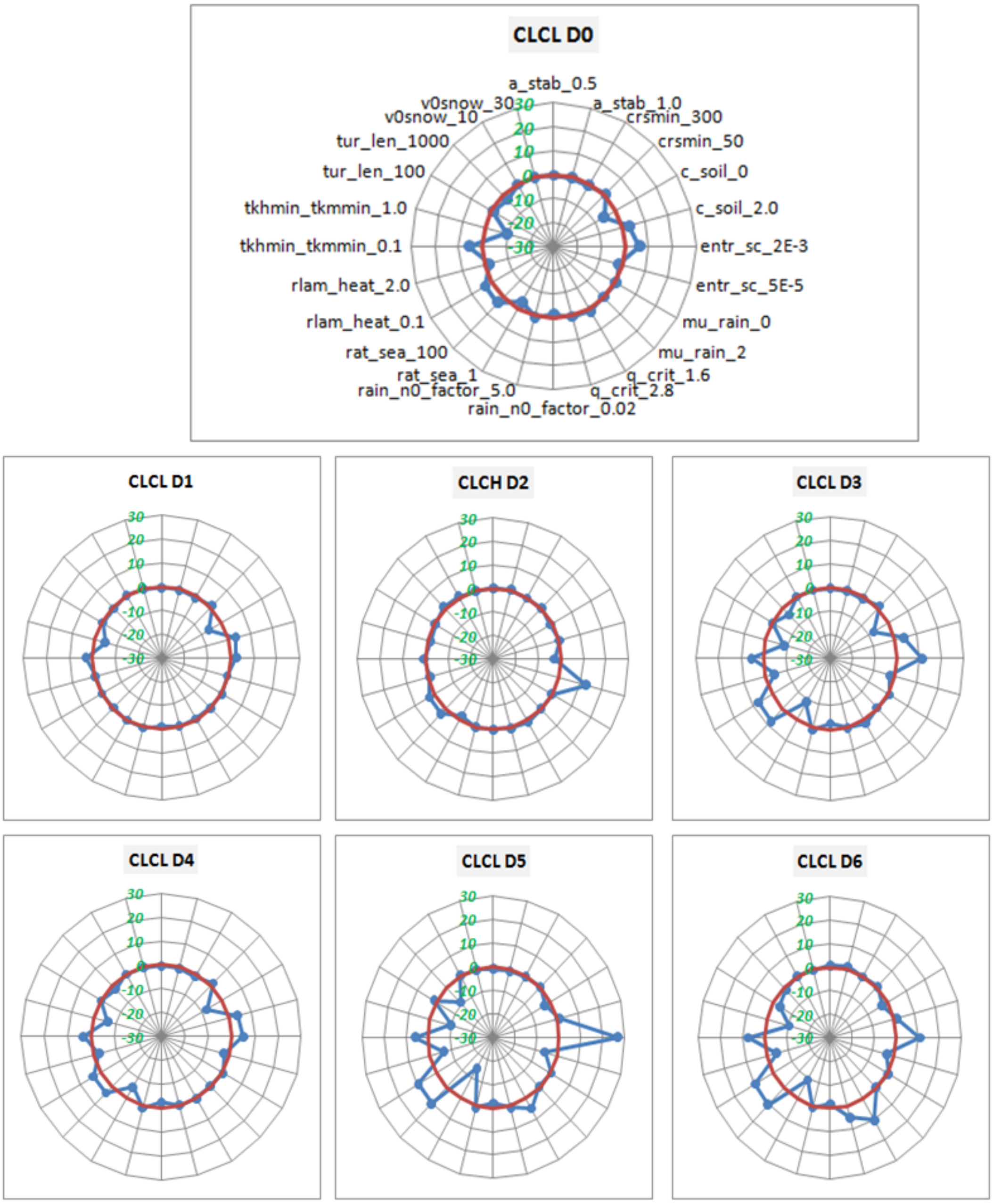

Figure 6: : DPS spider-graphs for temporal area 24-hour means, in 3-hour intervals, for low cloud cover (CLCL), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

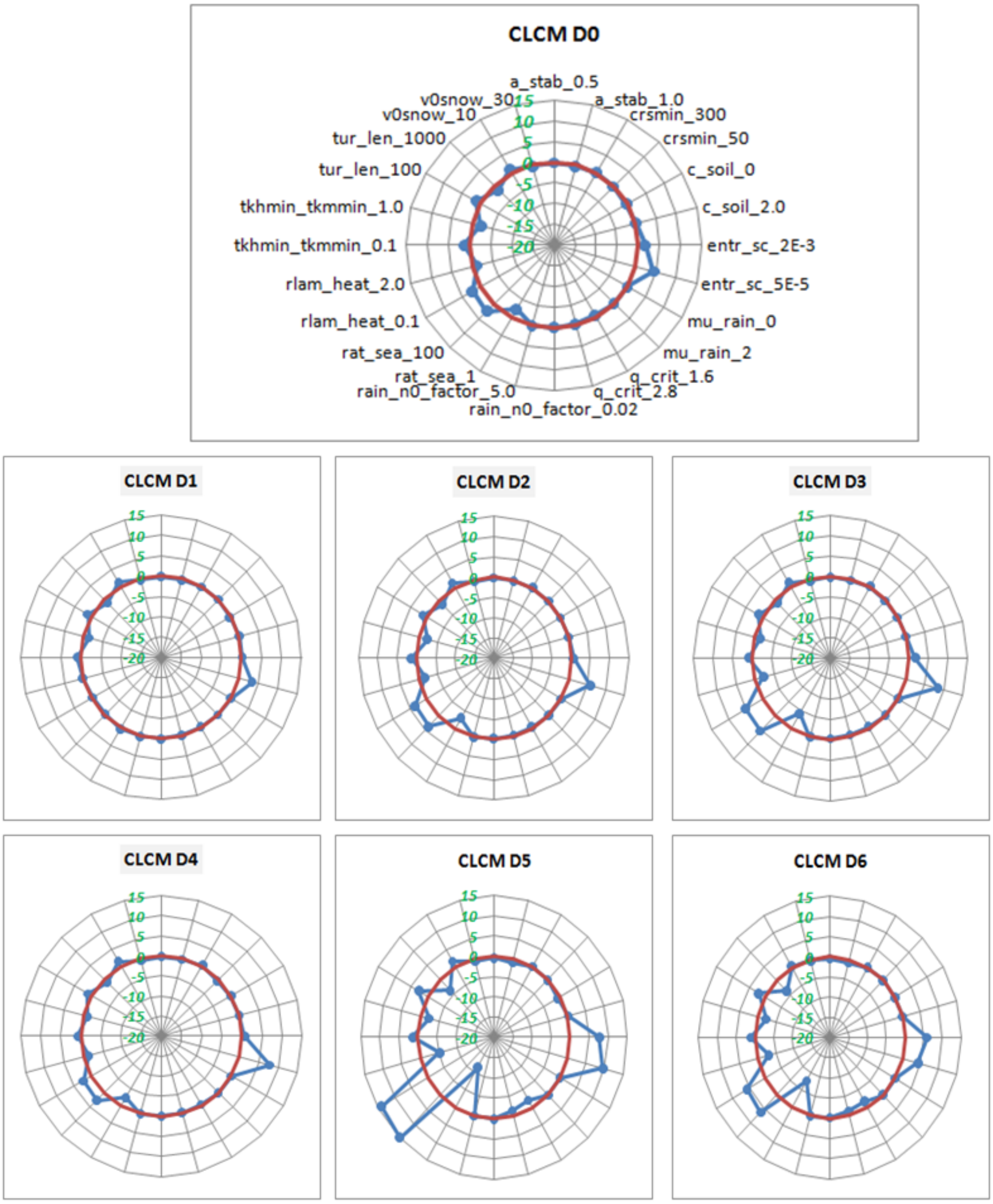

Figure 7: :DPS spider-graphs for temporal area 24-hour means, in 3-hour intervals, for medium cloud cover (CLCM), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

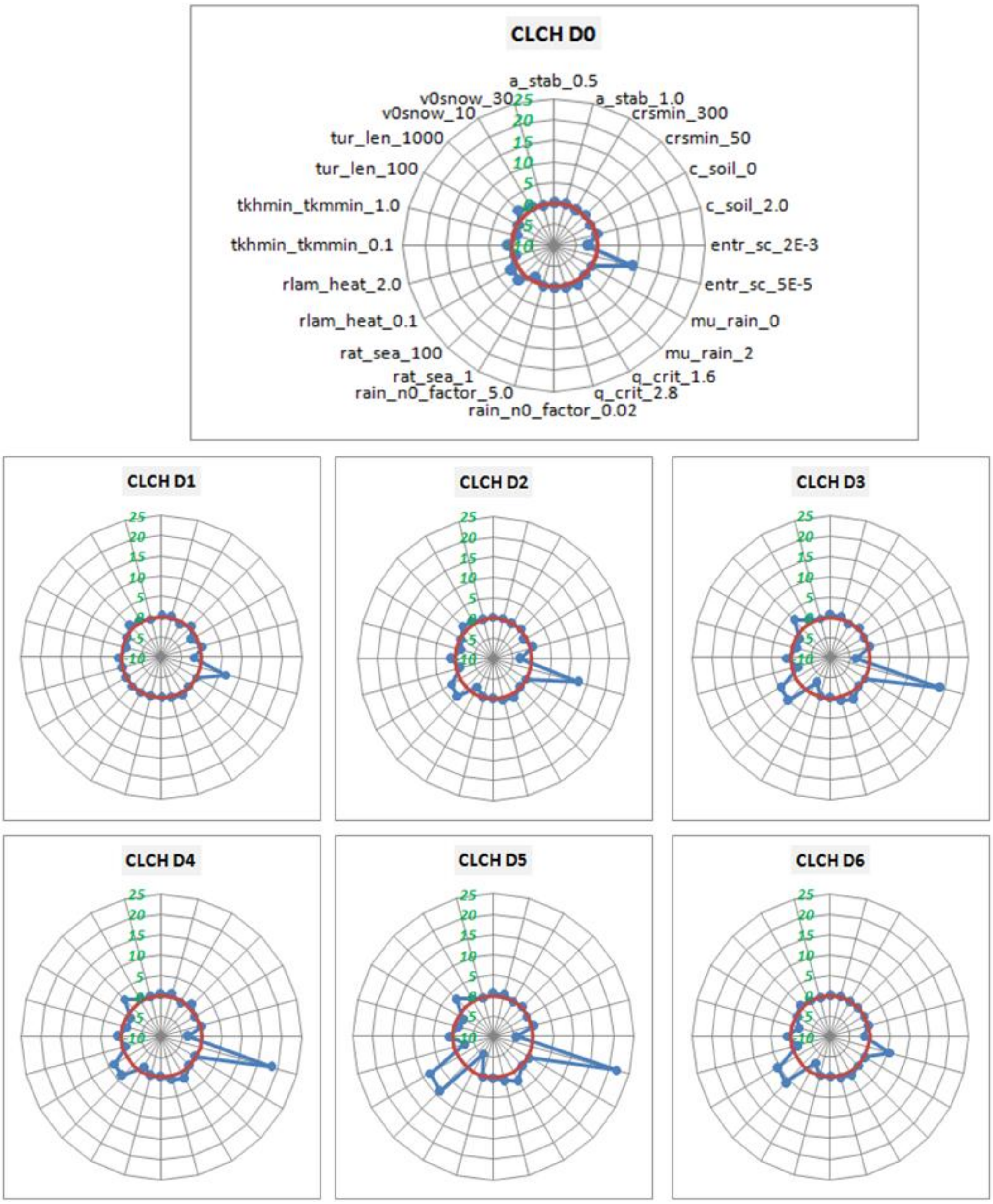

Figure 8: : DPS spider-graphs for temporal area 24-hour means, in 3-hour intervals, for high cloud cover (CLCM), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

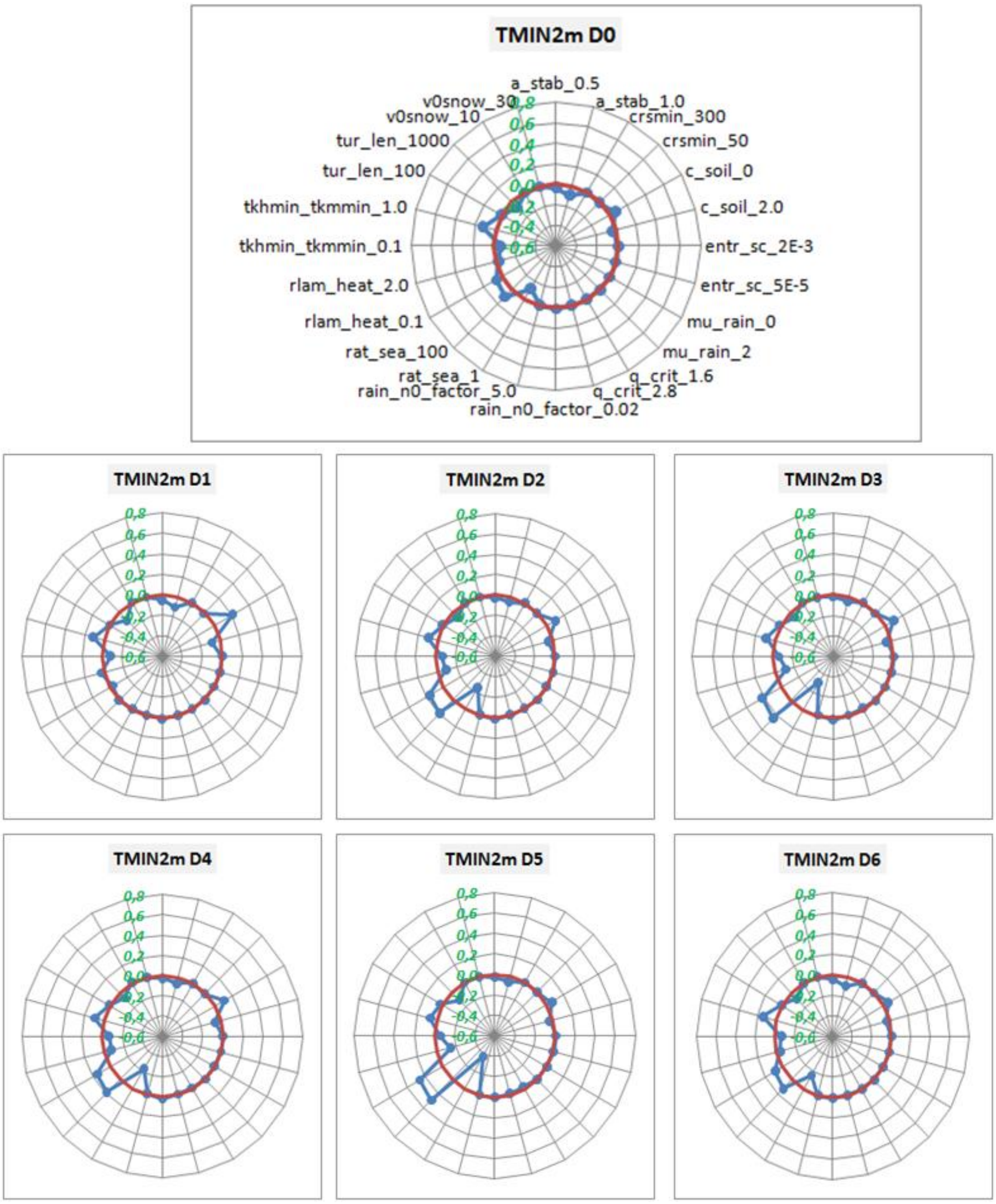

Figure 9: : DPS spider-graphs for temporal area 24-hour means, for minimum 2m-Temperature (Tmin2m), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

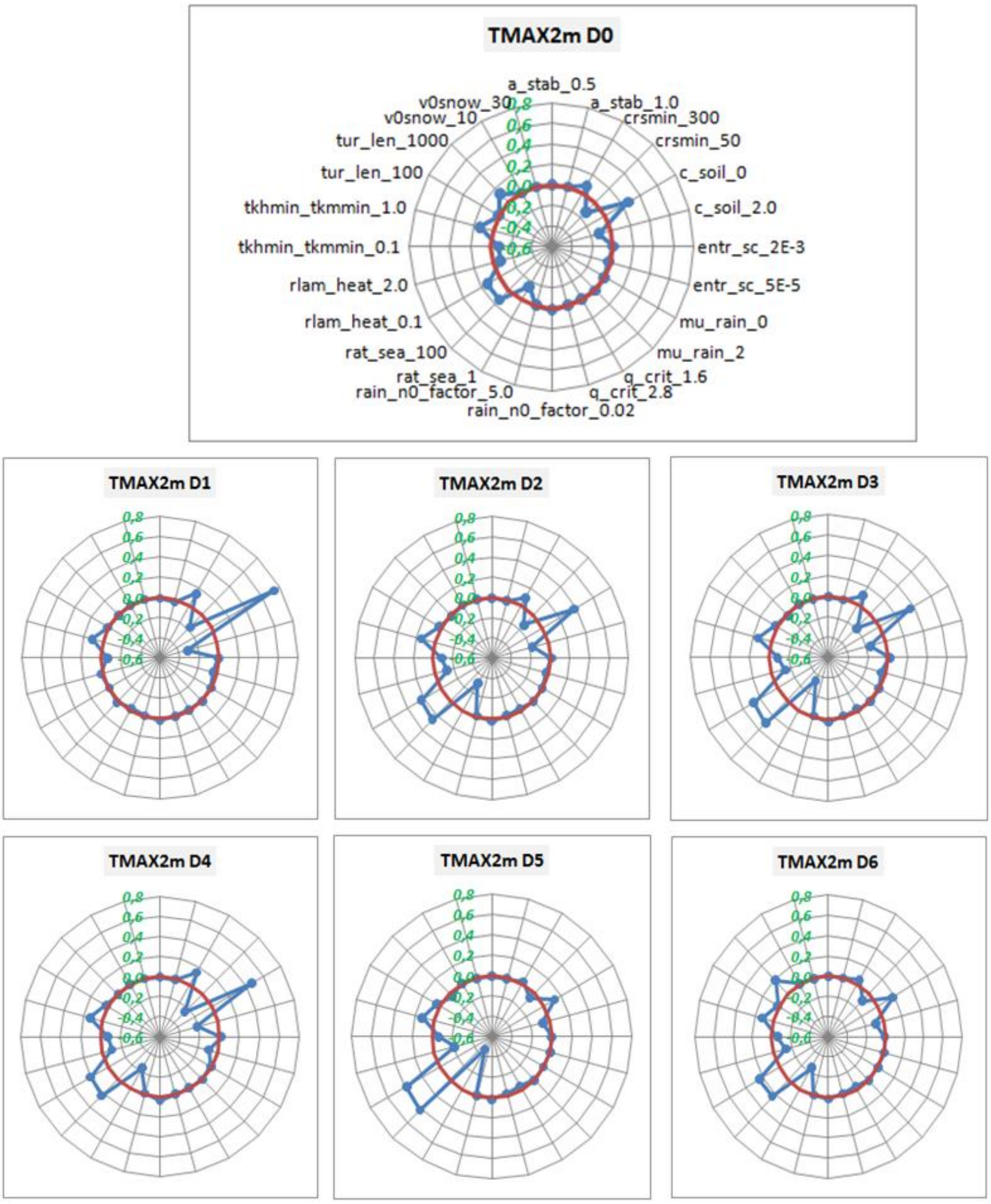

Figure 10: :DPS spider-graphs for temporal area 24-hour means, for minimum 2m-Temperature (Tmin2m), over the wider Mediterranean area (D0), Switzerland (D1), Italy (D2), Greece (D3), Continental Greece (D4), Crete (D5) and Israel (D6) over the 62-day period.

List of COSMO Newsletters and Technical Reports

(available for download from the COSMO Website: www.cosmo-model.org)

COSMO Newsletters

No. 1: February 2001.

No. 2: February 2002.

No. 3: February 2003.

No. 4: February 2004.

No. 5: April 2005.

No. 6: July 2006.

No. 7: April 2008; Proceedings from the 8th COSMO General Meeting in Bucharest, 2006.

No. 8: September 2008; Proceedings from the 9th COSMO General Meeting in Athens, 2007.

No. 9: December 2008.

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No. 16: July 2016.

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No. 18: November 2018.

No. 19: October 2019.

COSMO Technical Reports

No. 1: Dmitrii Mironov and Matthias Raschendorfer (2001):
Evaluation of Empirical Parameters of the New LM Surface-Layer Parameterization Scheme. Results from Numerical Experiments Including the Soil Moisture Analysis.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_1

No. 2: Reinhold Schrodin and Erdmann Heise (2001):
The Multi-Layer Version of the DWD Soil Model TERRA_LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_2

No. 3: Günther Doms (2001):
A Scheme for Monotonic Numerical Diffusion in the LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_3

No. 4: Hans-Joachim Herzog, Ursula Schubert, Gerd Vogel, Adelheid Fiedler and Roswitha Kirchner (2002):
LLM ‾ the High-Resolving Nonhydrostatic Simulation Model in the DWD-Project LITFASS. Part I: Modelling Technique and Simulation Method.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_4

No. 5: Jean-Marie Bettems (2002):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_5

No. 6: Heinz-Werner Bitzer and Jürgen Steppeler (2004):
Documentation of the Z-Coordinate Dynamical Core of LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_6

No. 7: Hans-Joachim Herzog, Almut Gassmann (2005):
Lorenz- and Charney-Phillips vertical grid experimentation using a compressible nonhydrostatic toy-model relevant to the fast-mode part of the 'Lokal-Modell'.
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No. 8: Chiara Marsigli, Andrea Montani, Tiziana Paccagnella, Davide Sacchetti, André Walser, Marco Arpagaus, Thomas Schumann (2005):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_8

No. 9: Erdmann Heise, Bodo Ritter, Reinhold Schrodin (2006):
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No. 10: M.D. Tsyrulnikov (2007):
Is the particle filtering approach appropriate for meso-scale data assimilation ?
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_10

No. 11: Dmitrii V. Mironov (2008):
Parameterization of Lakes in Numerical Weather Prediction. Description of a Lake Model.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_11

No. 12: Adriano Raspanti (2009):
COSMO Priority Project "VERification System Unified Survey" (VERSUS): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_12

No. 13: Chiara Marsigli (2009):
COSMO Priority Project "Short Range Ensemble Prediction System" (SREPS): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_13

No. 14: Michael Baldauf (2009):
COSMO Priority Project "Further Developments of the Runge-Kutta Time Integration Scheme" (RK): Final Report.
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No. 15: Silke Dierer (2009):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_15

No. 16: Pierre Eckert (2009):
COSMO Priority Project "INTERP": Final Report.
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Description of some convective indices implemented in the COSMO model.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_17

No. 18: Daniel Leuenberger (2010):
Statistical analysis of high-resolution COSMO Ensemble forecasts in view of Data Assimilation.
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No. 19: A. Montani, D. Cesari, C. Marsigli, T. Paccagnella (2010):
Seven years of activity in the field of mesoscale ensemble forecasting by the COSMO–LEPS system: main achievements and open challenges.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_19

No. 20: A. Roches, O. Fuhrer (2012):
Tracer module in the COSMO model.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_20

No. 21: Michael Baldauf (2013):
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No. 22: C. Marsigli, T. Diomede, A. Montani, T. Paccagnella, P. Louka, F. Gofa, A. Corigliano (2013):
The CONSENS Priority Project.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_22

No. 23: M. Baldauf, O. Fuhrer, M. J. Kurowski, G. de Morsier, M. Müllner, Z. P. Piotrowski, B. Rosa, P. L. Vitagliano, D. Wójcik, M. Ziemiański (2013):
The COSMO Priority Project 'Conservative Dynamical Core' Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_23

No. 24: A. K. Miltenberger, A. Roches, S. Pfahl, H. Wernli (2014):
Online Trajectory Module in COSMO: a short user guide.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_24

No. 25: P. Khain, I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini (2015):
The Proof of the Parameters Calibration Method: CALMO Progress Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_25

No. 26: D. Mironov, E. Machulskaya, B. Szintai, M. Raschendorfer, V. Perov, M. Chumakov, E. Avgoustoglou (2015):
The COSMO Priority Project 'UTCS' Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_26

No. 27: J-M. Bettems (2015):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_27

No. 28: Ulrich Blahak (2016):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_28

No. 29: M. Tsyrulnikov and D. Gayfulin (2016):
A Stochastic Pattern Generator for ensemble applications.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_29

No. 30: D. Mironov and E. Machulskaya (2017):
A Turbulence Kinetic Energy – Scalar Variance Turbulence Parameterization Scheme.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_30

No. 31: P. Khain, I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini, P. Kaufmann (2017):
CALMO - Progress Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_31

No. 32: A. Voudouri, P. Khain, I. Carmona, E. Avgoustoglou, J.M. Bettems, F. Grazzini, O. Bellprat, P. Kaufmann and E. Bucchignani (2017):
Calibration of COSMO Model, Priority Project CALMO Final report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_32

No. 33: N. Vela (2017):
VAST 2.0 - User Manual.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_33

No. 34: C. Marsigli, D. Alferov, M. Arpagaus, E. Astakhova, R. Bonanno, G. Duniec, C. Gebhardt, W. Interewicz, N. Loglisci, A. Mazur, V. Maurer, A. Montani, A. Walser (2018):
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COSMO Technical Reports

Issues of the COSMO Technical Reports series are published by the *COnsortium for Small-scale MOdelling* at non-regular intervals. COSMO is a European group for numerical weather prediction with participating meteorological services from Germany (DWD, AWGeophys), Greece (HNMS), Italy (ITAF-ReMet, ARPAE, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA), Russia (RHM) and Israel (IMS). The general goal is to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO. This system is initially based on the COSMO-Model (previously known as LM) of DWD with its corresponding data assimilation system.

The Technical Reports are intended

- for scientific contributions and a documentation of research activities,
- to present and discuss results obtained from the model system,
- to present and discuss verification results and interpretation methods,
- for a documentation of technical changes to the model system,
- to give an overview of new components of the model system.

The purpose of these reports is to communicate results, changes and progress related to the LM model system relatively fast within the COSMO consortium, and also to inform other NWP groups on our current research activities. In this way the discussion on a specific topic can be stimulated at an early stage. In order to publish a report very soon after the completion of the manuscript, we have decided to omit a thorough reviewing procedure and only a rough check is done by the editors and a third reviewer. We apologize for typographical and other errors or inconsistencies which may still be present.

At present, the Technical Reports are available for download from the COSMO web site (www.cosmo-model.org). If required, the member meteorological centres can produce hard-copies by their own for distribution within their service. All members of the consortium will be informed about new issues by email.

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