On the Seasonal Sensitivity of ICON Model

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1 Introduction

Over the last few years, the local version of ICON model (Zängl etal, 2015, Prill etal, 2020) has gradually undertaken COSMO model on the operational mode of the Consortium Members. In addition to the complexities of installing the model to many different computer architectures as well as data assimilation issues, such an endeavour is quite challenging regarding the proper choice of the many model parameter values in order for the model to have the optimum performance. An important step towards this direction is to estimate the sensitivity of ICON model in reference to these parameters. Such an effort is addressed within the framework of the replacement of the currently operational COSMO-LEPS with its successor ICON-LEPS. The impact for the minimum and maximum values for many of the parameters turned out to be important in reference to their default values and to their seasonal dependence with respect to the considered meteorological fields.

2 Work Overview

The sensitivity of ICON model was gauged over a large number (24) of parameters towards the establishment of ICON-LEPS in place of the currently operational COSMO-LEPS where model parameter perturbations are applied. The consequent list of the parameters considered of interest for the corresponding perturbations in ICON-LEPS (Table 1)has been decided and ranked according to their estimated significance by ICON experts, (Schlemmer etal, 2022) and in close reference to COSMO model (Avgoustoglou etal, 2020). All the parameters were tested over a domain covering the wider area of Greece and Italy (Figure 1 of the appendix) for a total period of four months i.e., January, April, July and October 2020 using the ICON model installed by the IsraeliMe teorological Service (IMS) at the European Center for Medium-Range Weather Forecasts (ECMWF) super-computing system and using computational resources provided gratis by the Hellenic National Meteorological Service (HNMS).
The ICON model was forced by the ECMWF operational forecast in 3-hour intervals and was performed on a 6.5 km horizontal grid for a total of approximately 6000 runs. The model sensitivities are presented for 16 surface fields over the areal average of the whole period as well as for January, April, July and October separately, at the last lead time hour (132^{nd}) where sensitivity is expected to be on its climax.

3 Analysis

The parameters under consideration cover almost all aspects regarding the tuning of a numerical weather prediction model, i.e., turbulence, convection, terra, sub-scale orography, grid-scale micro-physics and cloud cover.

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PARAMETER (meaning) relevance: high[**H**]/medium[**M**]	MIN, **DEFAULT**, MAX
P01: **a_hshr** (scale for the separated horizontal shear mode) [**M**]	0.1, **0.0**, 2.0
P02: **alpha0** (lower bound of velocity-dependent *Charnock* param) [**H**]	0.0123, **0.0123**, 0.0335
P03: **alpha1** (scaling for the molecular roughness of water waves) [**H**]	0.1, **0.5**, 0.9
P04: **a_stab** (stability correction of turbulent length scale factor) [**M**]	0.0, **0.0**, 1.0
P05: **capdcfac_et** (extratropics CAPE diurnal cycle correction) [**H**]	0.0, **0.5**, 1.25
P06: **c_diff** (length scale factor for vertical diffusion of TKE) [**H**]	0.1, **0.2**, 0.4
P07: **c_soil** (evaporating fraction of soil) [**H**]	0.75, **1.0**, 1.25
P08: **cwimax_ml** (scaling for maximum interception storage) [**H**]	$0.5\text{x}10^{-7}$, $\mathbf{1.0x10^{-6}}$, $0.5\text{x}10^{-4}$
P09: **entrorg** (entrainment convection scheme valid for dx=20km) [**H**]	0.00175, **0.00195**, 0.00215
P10: **gkwake** (low level wake drag constant for blocking) [**H**]	1.0 , **1.5**, 2.0
P11: **q_crit** (normalised supersaturation critical value) [**H**]	1.6, **2.0**, 4.0
P12: **qexc** (test parcel ascent excess grid-scale QV fraction) [**M**]	0.0075, **0.0125**, 0.0175
P13: **rain_n0_factor** (raindrop size distribution change) [**H**]	0.02 , **0.1**, 0.5
P14: **rdepths** (maximum allowed shallow convection depth) [**H**]	15000, **20000**, 25000
P15: **rhebc_land** (RH threshold for onset of evaporation below cloud base over land) [**M**]	0.70, **0.75**, 0.80
P16: **rhebc_ocean** (ibid over ocean) [**H**]	0.80, **0.85**, 0.90
P17: **rlam_heat_rat_sea** (scaling of laminar boundary layer for heat and latent and heat fluxes over water (constant product)) [**H**]	(0.25,28.0), **(1.0,7.0)**, (4.0,1.75)
P18: **rprcon** (precipitation coefficient conversion of cloud water) [**H**]	0.00125, **0.0014**, 0.00165
P19: **texc** (excess value for temperature used in test parcel ascent) [**M**]	0.075, **0.125**, 0.175
P20: **tkhmin_tkmmin** (common scaling for minimum vertical diffusion for heat-moisture and momentum) [**H**]	0.55 , **0.75**, 0.95
P21: **box_liq** (box width for liquid cloud diagnostic) [**H**]	0.03, **0.05**, 0.07
P22: **box_liq_asy** (liquid cloud diagnostic asymmetry factor) [**H**]	2.0 , **3.5**, 4.0
P23: **tur_len** (asymptotic maximal turbulent distance (m)) [**H**]	250, **300**, 350
P24: **zvz0i** (terminal fall velocity of ice) [**H**]	0.85 , **1.25**, 1.45

Table 1: List of the 24 parameters (P01-P24) of the tested sensitivity based on their code names, interpretation and relevance (first column) as well as their test range (second column). The default values are denoted with bold characters as well as their recommended relevance, [**H**] and [**M**] standing for high and medium respectively.

These are presented in Table 1 while in Table 2, their categorization is displayed. For every day of the considered period, forty eight 132 hour runs were performed corresponding to the minimum and maximum of the 24 examined parameters, as well as one run with the default model values (Table 1). The min/max parameter (P) sensitivity ($S_{\langle V \rangle P}$) for sixteen meteorological fields (Table 3) was evaluated according to the formula,

$$S_{\langle V \rangle P}\,(\%) = 100 \cdot \left(\frac{\langle V \rangle_P}{\langle V \rangle_D} - 1 \right) \qquad (1)$$

where $\langle V \rangle$ stands for the area average of the meteorological field V over a considered period with respect to its value for the default parameter set D over the same period.

Parameter categories	Corresponding parameters
Turbulence	P01, P02, P03, P04, P06, P11, P17, P20, P23
Convection	P05, P09, P12, P14, P15, P16, P18, P19
Terra	P07, P08
Sub-Scale Orography	P10
Grid-Scale Micro-Physics	P13, P24
Cloud Cover	P21, P22

Table 2: Categorization of the parameters encoded in Table 1.

The sensitivities of the examined meteorological fields are displayed in Figures 2 to 5 of the appendix. In all figures, the parameter minimum and maximum values are placed on the horizontal axis while the corresponding sensitivities on the vertical axis. In order to have a reference regarding the actual values of the fields, the default area average value of the four month period is shown.
The sensitivities for January, April, July, October as well as the whole four month period (JAJO) are displayed respectively with blue, red, orange and black colors regarding the maximum parameter values and their corresponding lighter shades (not shown explicitly) for the minimum values. From these graphs, it is relatively straightforward to infer heuristically the parameters of the greatest sensitivity and especially the most sensitive ones for every meteorological field considered. This feature is summarized in Table 3.From this tabulation, it is important to see that these parameters are practically almost half of the 24 parameters considered overall. Even more interesting is to note that the most sensitive parameters, designated with bold characters, belong to a considerably smaller subset consisting of five parameters. Consequently, a set between five to ten parameters looks like a pragmatic and flexible choice where perturbation or optimization techniques may be applied to improve the model performance.

More specifically, regarding cloudiness (Figure 2), the most sensitive parameters for total (clct), medium (clcm) and low (clcl) cloud cover are those of P21 (box width for liquid cloud diagnostic) and P22 (liquid cloud diagnostic asymmetry factor) while for high cloud cover (clch) is clearly P24 (the terminal fall velocity of ice). Some differences with respect to seasonal sensitivity are displayed mainly for summer.

Averaged Meteorological Fields	**Sensitive parameters**
T2m: 2m Temperature ^oK	P07, P21, **P22**
Tmax2m : 2m-Temperature ^oK	P07, P21, **P22**, P23
T_min2m : Min 2m-Temperature ^oK	P17, **P20**
Td_2m : Dew point 2m-Temperature ^oK	**P03**, P07, P22, P23
tot_prec : Accumulated Precipitation (kg m^{-2})	P03, P17, **P22**
pmsl : Mean sea level Pressure (hPa)	P10, P21, **P22**
u10m : 10 m wind speed u component (m s^{-1})	P10, **P22**, P23
v10m : 10 m wind speed v component (m s^{-1})	P02, P10, **P22**
gust10m : Wind gust 10 m above ground (m s^{-1})	**P10**, P22, P23
clcl : Low cloud cover (1-100%)	P03, P21, **P22**
clcm : Medium cloud cover (1-100%)	P09, P14, P21, **P22**
clch : High cloud cover (1-100%)	P09, P18, P22, **P24**
clct : Total cloud cover (1-100%)	P03, P21, **P22**
tqv : Column integrated water vapor (kg m^{-2})	**P03**, P20, P22
tqi : Total column integrated cloud ice (kg m^{-2})	P18, P22, **P24**
tqc : Total column integrated cloud water (kg m^{-2})	P11, **P22**, P23

Table 3: List of the area-averaged meteorological fields over the 132^{nd} lead time and the corresponding parameters that display great sensitivity as it can be inferred from Figures 2 to 5. The most sensitive parameter for every field is addressed with bold faced characters.

With respect to temperature (Figure 3), there are several parameters that display significant sensitivity. Nevertheless, P03 (scaling for the molecular roughness of water waves) shows the greatest sensitivity for dew-point temperature (Td2m), P20 (common scaling for minimum vertical diffusion for heat-moisture and momentum) for minimum 2m-temperature (Tmin2m) and P22 (liquid cloud diagnostic asymmetry factor) for 2m-temperature (T2m) as well as maximum 2m-temperature (Tmax2m). It can also be mentioned that there several differences in seasonal sensitivity, most of them of different magnitude but of the same sign.

The same remarks hold for the fields related to atmospheric water (Figure 4), where P22 (liquid cloud diagnostic asymmetry factor) is the most sensitive parameter regarding accumulated precipitation (tot_prec) as well as total column integrated cloud water (tqc), P03 (scaling for the molecular roughness of water waves) for total column integrated vapour (tqv) and P24 (the terminal fall velocity of ice) for total column integrated cloud ice (tqi) as expected in relevance to the same sensitivity for high cloud cover.

Referring to mean sea-level pressure (pmsl) (Figure 5, upper graph), extensive sensitivity is displayed for many parameters, however, P22 (liquid cloud diagnostic asymmetry factor) is again the most sensitive parameter. There is also extensive seasonal sensitivity for several parameters of opposite sign. The situation is practically the same for zonal (u10m) and meridional (v10m) wind components (Figure 5, bottom and upper bottom graphs). An interesting feature is related to the 10m-gust wind (gust10m) where the sensitivity is constrained essentially to P10 (low level wake drag constant for blocking) parameter.

4 Conclusions and Outlook

The impact of the minimum and maximum values for most of the parameters turned out to be important for the considered meteorological fields, in reference to their default values and to their seasonal dependence . The sensitivity was quite versatile justifying the choice to examine directly a very large number of parameters, probably one of the largest ever in a NWP model. Consequently, the advancement towards ICON-LEPS will be a formidable operational but also research challenge for the years to come that might have also some impact to ICON model overall. Due to the inclusion of a large and complicated marine area in the desired integration domain for the proposed ICON-LEPS, the project will contribute to the understanding of the behaviour of the ICON model over the Mediterranean Sea.

References

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Appendix for figures 1 to 5

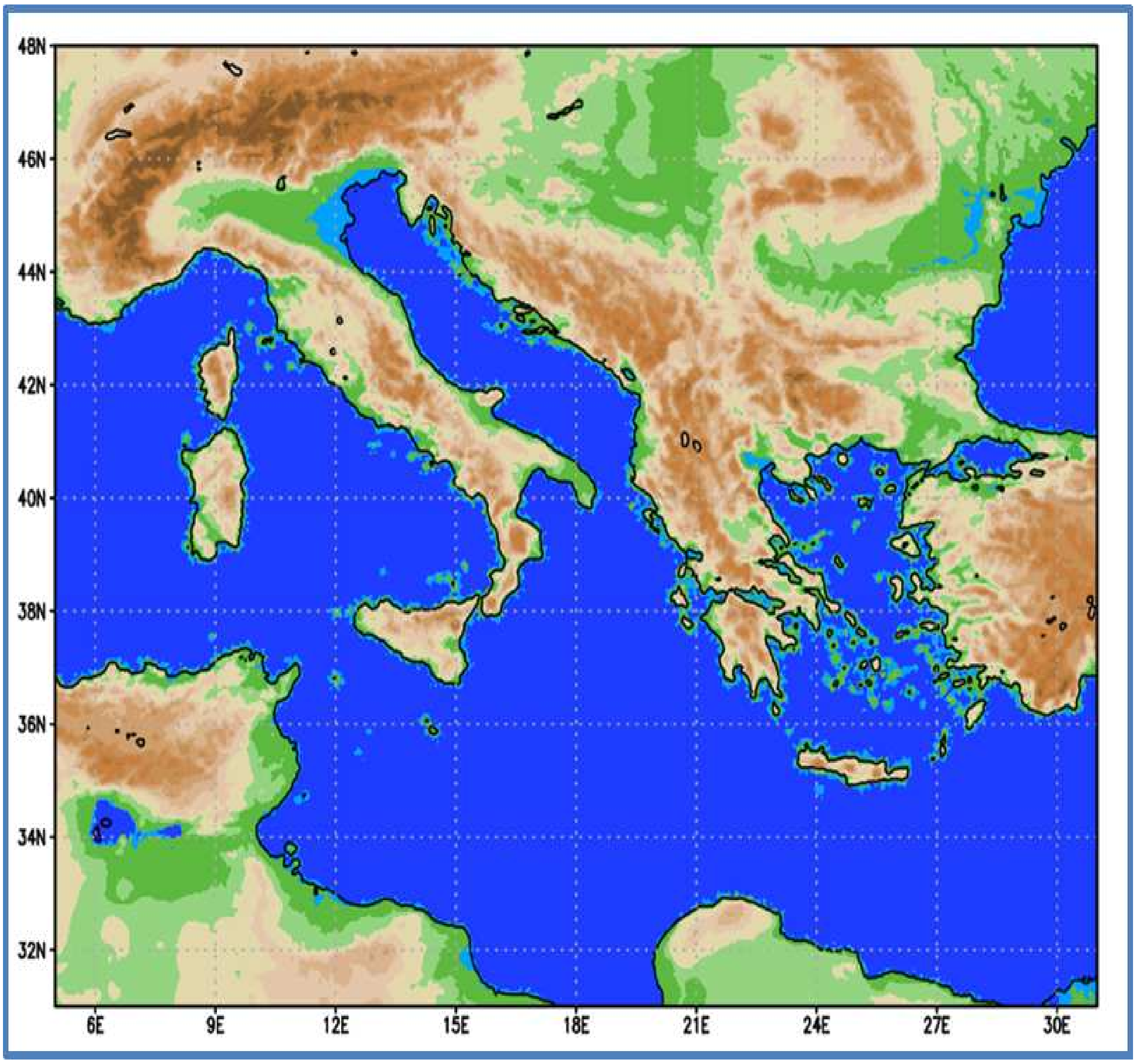

Figure 1: ICON model integration domain covering the wider area of central Mediterranean.

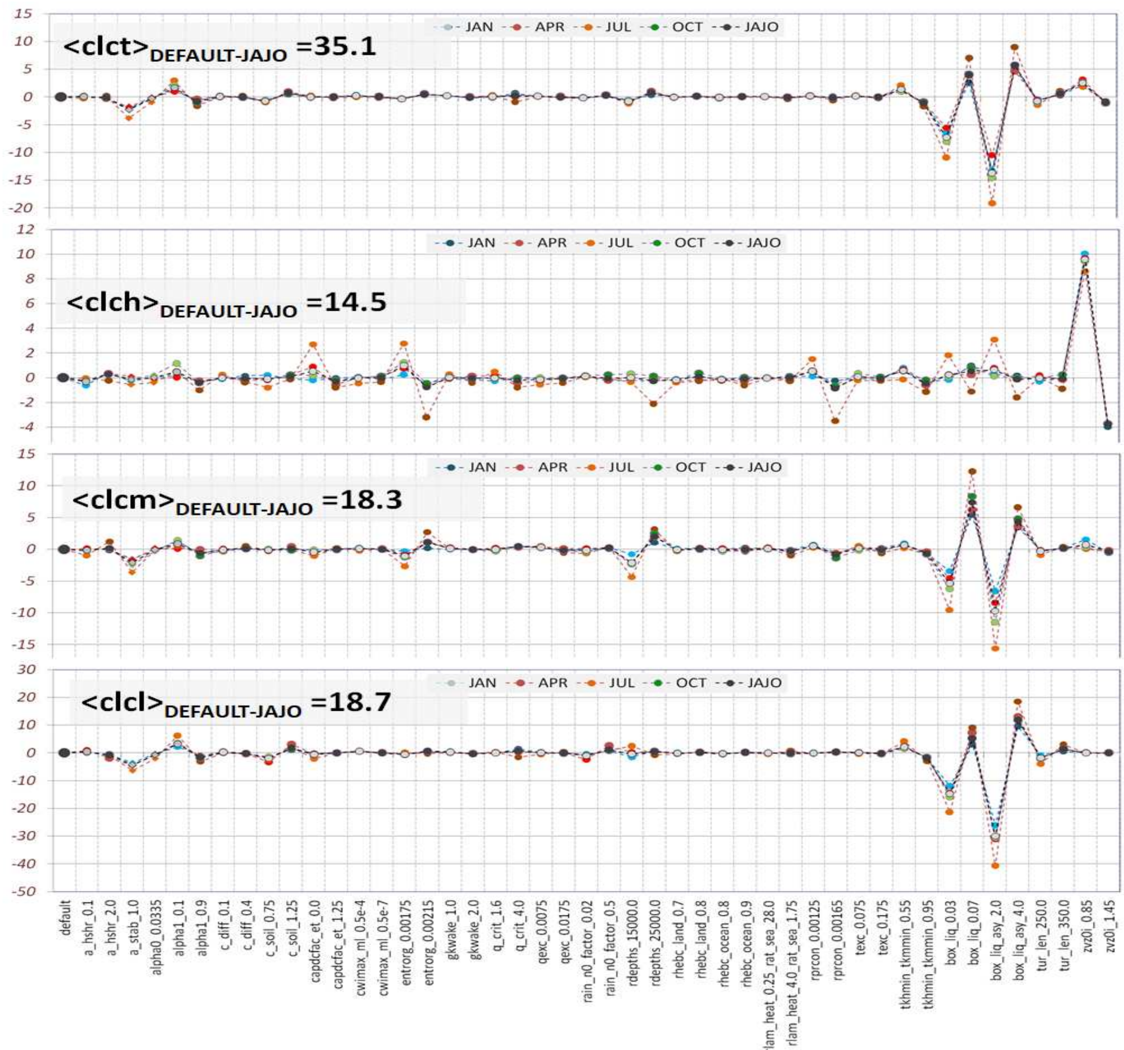

Figure 2: Area average sensitivity for total (clct), high (clch), medium (clcm) and low (clcl) cloud cover (top to bottom) for the 132^{nd} hour of the model run. The time periods for January, April, July, October as well as thewh ole four months are displayed respectively with blue, red, orange and black colors regarding the maximum parameter values and their corresponding lighter shades (not shown explicitly) for the minimum values. The corresponding cloud cover area average values (in %) for the the default run and for the whole period are also shown (i.e, $\langle clct\rangle_{DEFAULT-JAJO}$, $\langle clch\rangle_{DEFAULT-JAJO}$, $\langle clcm\rangle_{DEFAULT-JAJO}$ and $\langle clcl\rangle_{DEFAULT-JAJO}$).

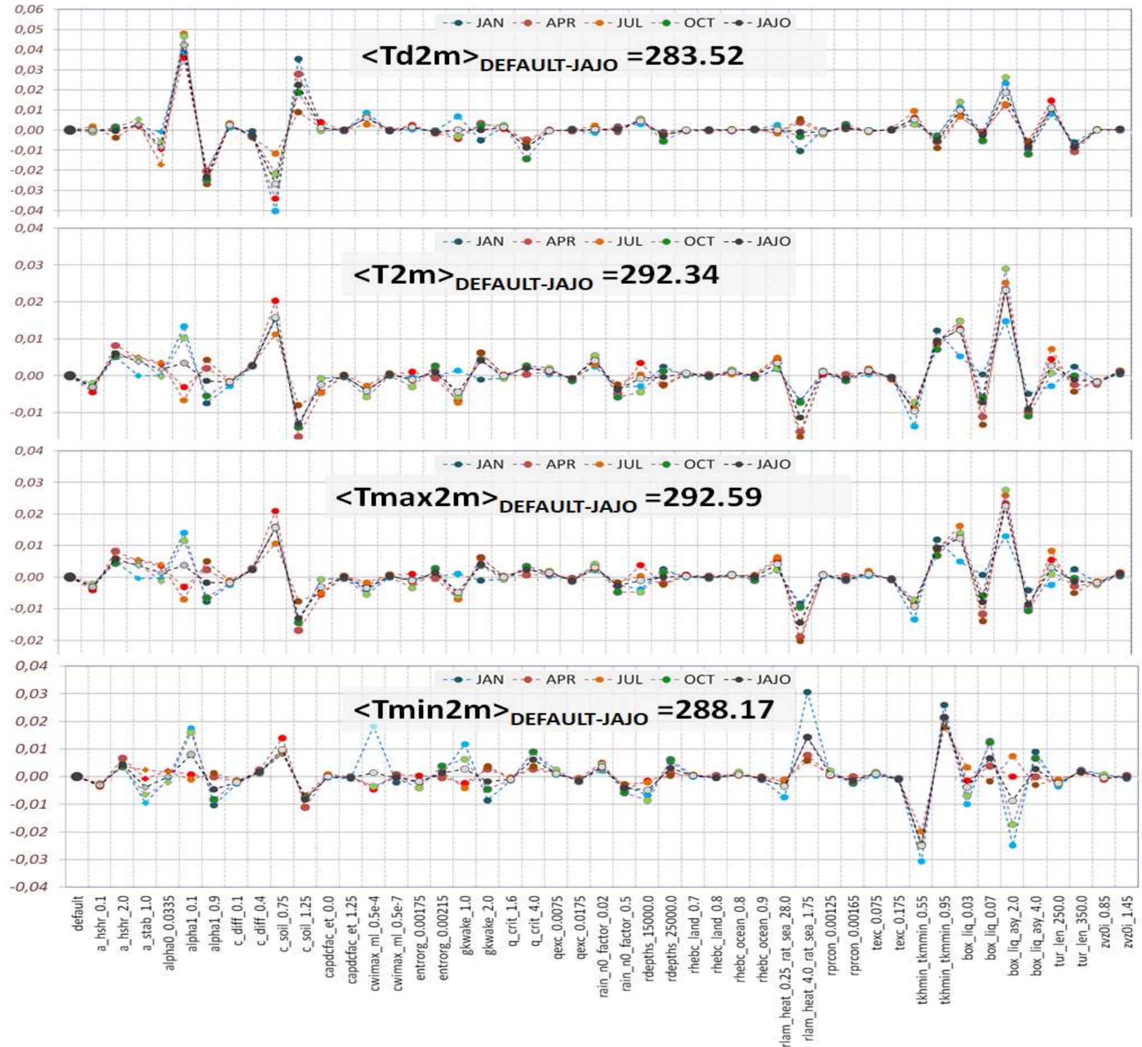

Figure 3: Area average sensitivity for dew point (Td2m), 2-meter (T2m), maximum (Tmax2m) and minimum (Tmin2m) temperature(top to bottom)for the 132^{nd} hour of the model run. The time periods for January, April, July, October as well as the whole four months are displayed respectively with blue, red, orange and black colors regarding the maximum parameter values and their corresponding lighter shades (not shown explicitly) for the minimum values. The corresponding area average values (in ^{o}K) for the the default run and for the whole period are also shown (i.e, $\langle Td2m \rangle_{DEFAULT-JAJO}$, $\langle T2m \rangle_{DEFAULT-JAJO}$, $\langle Tmax2m \rangle_{DEFAULT-JAJO}$ and $\langle Tmin2m \rangle_{DEFAULT-JAJO}$).

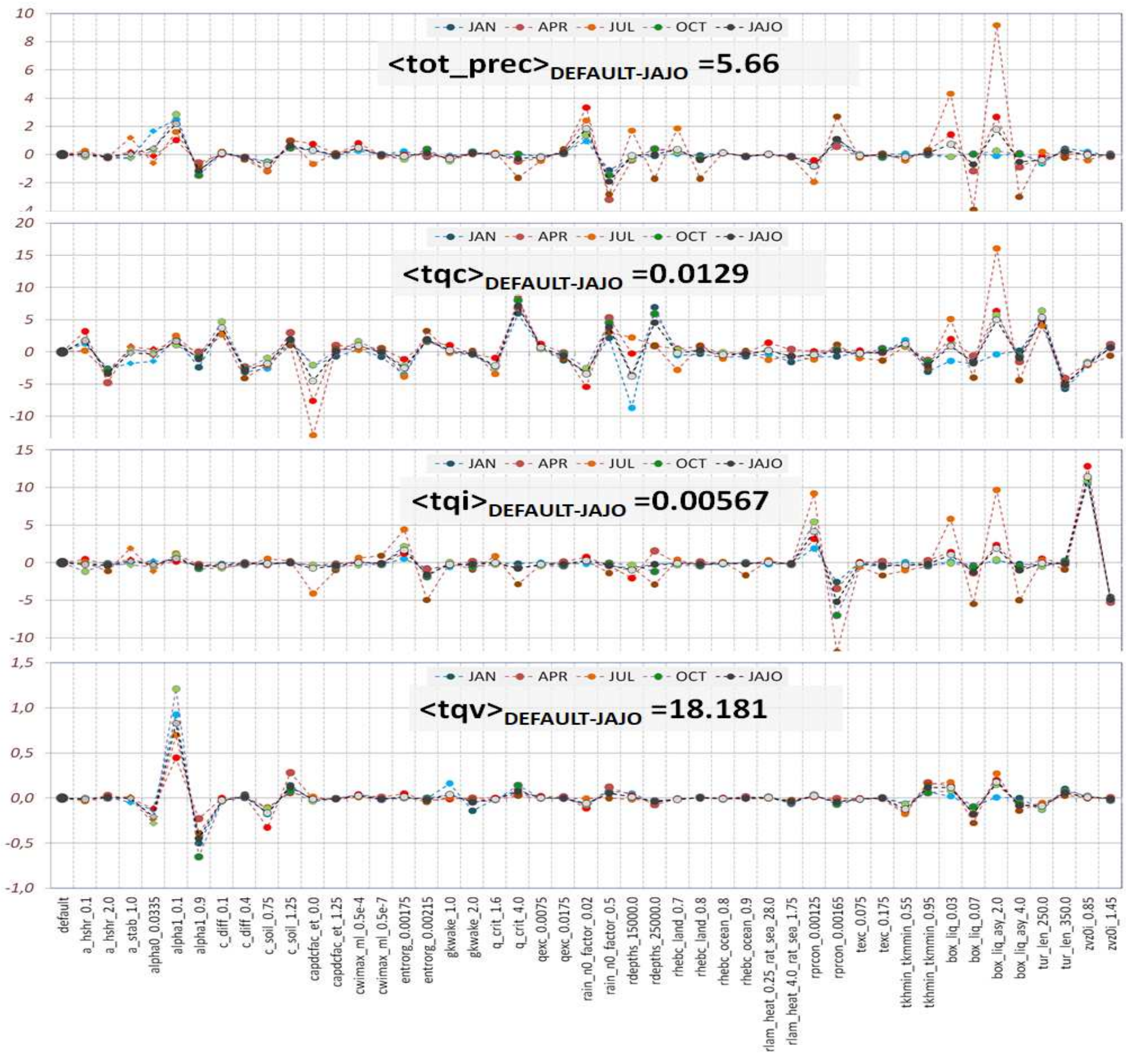

Figure 4: Area average sensitivity for accumulated precipitation (tot_prec), total column: cloud water (tqc), ice (tqi) and vapour (tqv) from top to bottom for the 132^{nd} hour of the model run. The time periods for January, April, July, October as well as the whole four months are displayed respectively with blue, red, orange and black colors regarding the maximum parameter values and their corresponding lighter shades (not shown explicitly) for the minimum values. The corresponding area average values (in kg m^{-2}) for the the default run and for the whole period are also shown (i.e, $\langle tot_prec \rangle_{DEFAULT-JAJO}$, $\langle tqc \rangle_{DEFAULT-JAJO}$, $\langle tqi \rangle_{DEFAULT-JAJO}$ and $\langle tqv \rangle_{DEFAULT-JAJO}$).

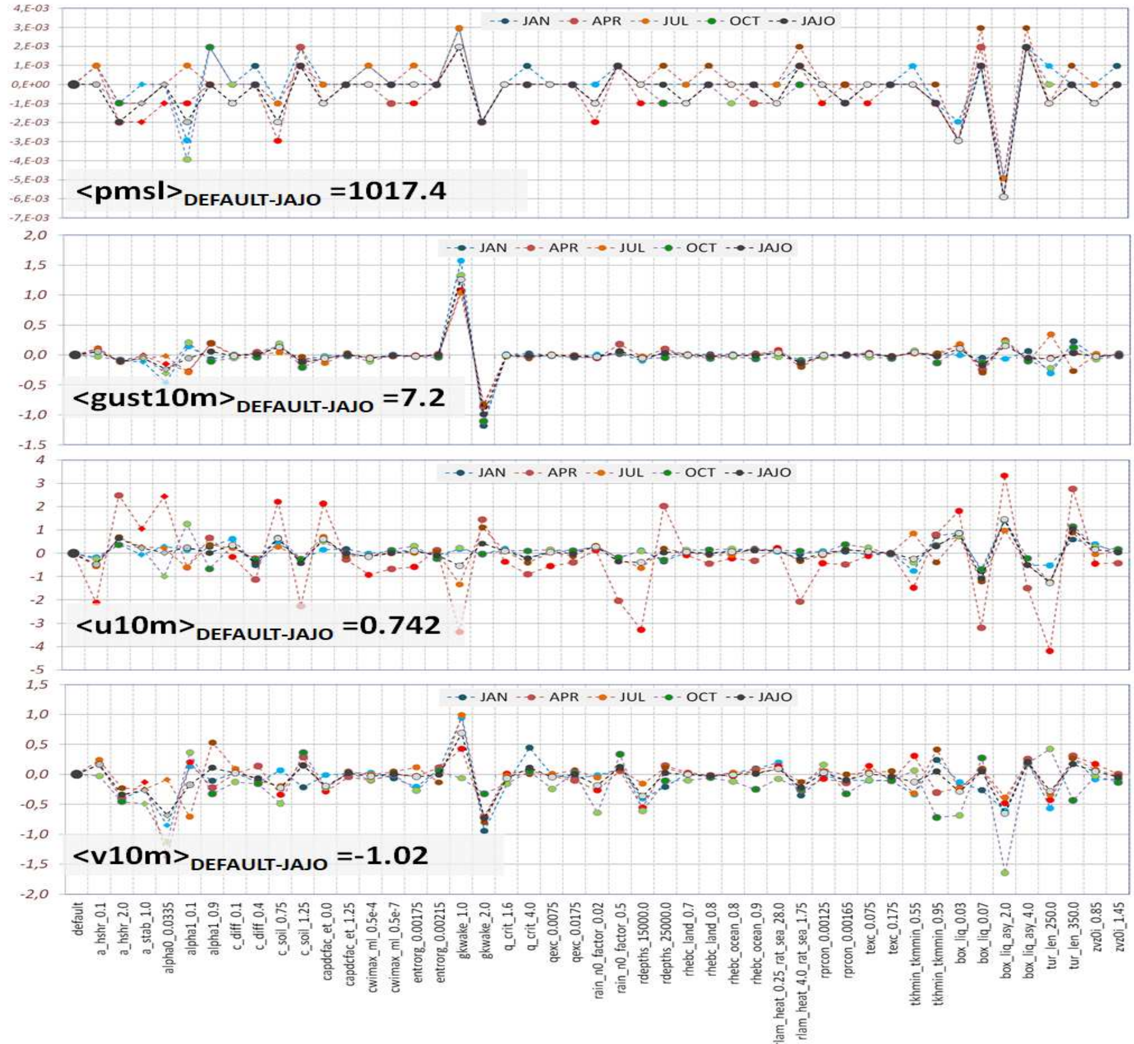

Figure 5: Area average sensitivity for mean-sea level pressure (pmsl), 10m: gust (gust10m), zonal (u10m) and meridional (v10m) wind from top to bottom for the 132^{nd} hour of the model run. The time periods for January, April, July, October as well as the whole four months are displayed respectively with blue, red, orange and black colors regarding the maximum parameter values and their corresponding lighter shades (not shown explicitly) for the minimum values. The corresponding area average values (in hPa and m s^{-1}) for the the default run and for the whole period are also shown (i.e, $\langle pmsl\rangle_{DEFAULT-JAJO}$, $\langle gust10m\rangle_{DEFAULT-JAJO}$, $\langle u10m\rangle_{DEFAULT-JAJO}$ and $\langle v10m\rangle_{DEFAULT-JAJO}$).