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'UTCS'
Final Report

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The COSMO Priority Project

'UTCS'

Final Report

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1 Introduction

The PP UTCS was completed in September 2012. The interim reports of the project participants are available at the COSMO web page. A summary of the project results as of September 2012 are given below. Results from the efforts, that are initiated within the framework of the PP UTCS but are completed (or still ongoing) past the official end of the project in September 2012, are reported to COSMO through the Working Group 3a. In what follows, the authors of the respective section are given in parentheses.

2 Development and testing of the TKE-Scalar Variance mixing scheme for the COSMO model (Ekaterina Machulskaya and Dmitrii Mironov)

The TKE-Scalar Variance (TKESV) scheme for the COSMO model is developed. The scheme carries prognostic equations for the turbulence kinetic energy (TKE), the liquid water potential temperature variance, the total water specific humidity variance, and the temperature-humidity covariance. These prognostic second-moment equations include the turbulent diffusion terms (divergence of the velocity-velocity and velocity-scalar triple correlations) that are parameterized through the down-gradient approximations. The other second-order moments, viz., the Reynolds stress and the scalar fluxes, are determined through the algebraic diagnostic expressions. The expressions for the scalar fluxes include non-gradient terms that are parameterized with due regard for the turbulence anisotropy. The formulation for the turbulence length (time) scale accounts for the effect of static stability. Recall that within the framework of the current COSMO-model turbulence scheme (one-equation TKE scheme), the time-rate-of-change and the turbulent diffusion terms are retained in the TKE equation only, whereas all other second-order moments, including scalar variances, are determined from the algebraic diagnostic expressions. The expressions for the scalar fluxes do not include non-gradient terms (among other things, this does not allow for up-gradient scalar transfer), and a Blackadar-type turbulence length scale formulation independent of static stability is used.

The TKESV scheme is tested through single-column numerical experiments. Results of simulations with the TKESV and the TKE schemes are compared with observational and numerical large-eddy simulation (LES) data from dry convective planetary boundary layer (PBL) and from cloudy PBLs (BOMEX and ARM shallow cumulus test cases and DYCOMS-II stratocumulus case). The TKESV scheme clearly outperforms the TKE scheme in dry convective PBL. Vertical profiles of the scalar variances and of the TKE computed with the TKESV scheme show better agreement with data. The PBL is better mixed with respect to potential temperature. An up-gradient heat transfer that is known to occur in the upper part of the dry convectively-mixed layer is well reproduced by the TKESV scheme. This is not possible with the TKE scheme, where the down-gradient formulations for the scalar fluxes are used. For cloudy PBLs, the application of the TKESV scheme leads to a better prediction of the scalar variances and TKE and to slight improvements with respect to the vertical buoyancy flux and the mean temperature and humidity. Both schemes tend to overestimate fractional cloud cover in the cumulus-topped PBL. This error is attributed primarily to the shortcoming of quasi-Gaussian statistical cloud parameterization scheme used by both TKESV and TKE schemes to determine fractional cloudiness (which in term strongly affects the buoyancy flux). A detailed analysis of simulation results suggests that a quasi-Gaussian cloud scheme is unable to accurately describe fractional cloudiness in the cumulus regime even though the characteristics of turbulence (first of all, scalar variances that serve as input to the cloud scheme) may be predicted perfectly. A somewhat more sophisticated cloud scheme that accounts of non-Gaussian effects is required.

The TKESV scheme is implemented into the COSMO model and tested through a series of parallel experiments including the entire COSMO-model data assimilation cycle. Both COSMO-EU and COSMO-DE model configurations operational at DWD are used (the horizontal mesh size of these configurations is ca. 7 km and ca. 2.8 km, respectively). Results from parallel experiments with the TKESV scheme performed to date look promising. Verification of results against observational data indicates improvements as to some scores, e.g. fractional cloud cover and 2m temperature and humidity. Further analysis of the new TKESV scheme performance within COSMO is underway.

Reduced minimum (background) diffusion coefficients of 0.1 m^2/s are used in some parallel experiments. Recall that in the current operational COSMO-model configurations a large value of 1 m^2/s is utilized for both momentum and scalars, which is often detrimental for stably stratified boundary layers and for the inversions capping convective boundary layers (this is a long-standing problem of the COSMO model). It is worth noting that some improvements in terms of verification scores can be achieved by just reducing the minimum diffusion coefficients, without the use of the new TKESV scheme. However, the application of the TKESV scheme and the reduced minimum diffusion coefficients leads to a better overall COSMO-model performance as compared to the model configuration with the reduced coefficients only. Furthermore, minimum diffusion coefficients are insensitive to the mixing regime. That is, a reduction of minimum diffusion coefficients is desirable in stably-stratified parts of the flow, but relatively large diffusion coefficients may be needed in other parts of the flow as a (unphysical) proxy for unaccounted mixing processes. This is impossible to achieve with constant minimum diffusion coefficients. On the contrary, the TKESV scheme is selective in terms of mixing regimes. Importantly, it does not produce excessive unphysical mixing in the stably-stratified PBL and in the capping inversion. A combination of the TKESV scheme and reduced minimum diffusion coefficients is a promising option for the COSMO model.

As the results from the LES study of Mironov and Sullivan (2010) demonstrate, the stably-stratified PBL should be parameterized with due regard for the heterogeneity of the underlying surface (first of all, with respect to the temperature). This can be achieved through the application of a tile approach to compute surface fluxes. The use of tiled surface scheme allows to account for the enhanced mixing in the SBL over heterogeneous surfaces in a physically plausible way (cf. large background diffusivity discussed above), and to prevent the PBL turbulence from dying out entirely as the (grid-box mean) static stability increases. The idea is successfully tested through single-column numerical experiments. The number of tiles should not necessarily be large (otherwise the tiled scheme becomes computationally expensive) but the tiles with the largest difference in terms of thermal inertia should be accounted for. In this regard, the treatment of the sub-grid scale (SGS) water bodies is crucial. As the thermal inertia of water is (much) larger than the inertia of most other land types, the inclusion of SGS water allows to maintain the temperature difference between tiles and hence to account for the enhanced mixing due to surface heterogeneity. The implementation of tile approach into the COSMO model is underway at DWD, where the mosaic approach implemented by Felix Ament is taken as a starting point. A parallel COSMO-EU experiment with a two-tile surface scheme is performed, where a land tile with the land-use type the same as in the operational COSMO model and inland water tile (lake) are considered in each COSMO-model grid box. The surface temperature of the inland-water tile is computed with the lake parameterization scheme FLake. Recall that in the operational COSMO configurations, only the grid boxes with the inland-water fraction in excess of 0.5 are treated as the inland-water-type grid boxes whereas the SGS water bodies with fractional area coverage less than 0.5 are entirely ignored. Results from the parallel experiment indicate some improvements of the COSMO-model performance, e.g. warm bias of the near-surface temperature during summer is slightly reduced.

In summary, the TKESV scheme holds considerable promise in terms of the improvement of the COSMO-model performance. The TKESV scheme is currently not coded as a separate module. Changes associated with the TKESV scheme are implemented into the current COSMO-model TKE scheme developed by Matthias Raschendorfer. Since massive modifications to the current TKE scheme (many of them being of technical and re-organizational order) are prepared by Matthias Raschendorfer and should soon be included into the official COSMO code, modifications associated with the TKESV scheme will be implemented into the COSMO version following the version with Matthias changes. The implementation process will be controlled by the COSMO source code administrator. Every effort will be made to complete the implementation and testing of the tile approach. To this end, the software to generate external-parameter fields (e.g. the field of lake depth) should be modified. This may require considerable effort and take much time. A deadline for the tile approach implementation cannot be set at the time being.

A brief outline of the TKESV scheme, a discussion of the scheme performance in various clear and cloudy boundary-layer regimes as revealed by off-line single-column tests, details of the implementation of the new scheme into COSMO, and some results from numerical experiments with the full-edged COSMO model are given in Machulskaya and Mironov (2013). Documentation of the scheme is in preparation.

3 Comprehensive testing and further development of the current COSMO-model turbulence scheme, including the surface-layer transfer scheme

3.1 Comprehensive testing of the COSMO-model TKE turbulence scheme (Balazs Szintai)

The performance of the COSMO model was evaluated in the Planetary Boundary Layer for different conditions. Next to the mean prognostic variables, the turbulence characteristics of the model were also verified. The following conclusions can be drawn from the experiments.

It has been shown that the COSMO model is able to reproduce the main evolution of the boundary layer in dry convective situations with the operational parameter setting if the external parameters are realistic and if the initial conditions are adequate. However, it has been found that the COSMO model tends to simulate a too moist and too cold PBL, with shallower PBL heights than observed. During stable conditions the operational parameter setting has to be modified significantly (e.g. the minimum diffusion coefficient) to obtain a good model performance.

The reasons for the inadequate temperature and humidity profiles in convective conditions have been investigated with the component testing approach. The budget terms in the TKE equation have been validated separately against LES data and turbulence measurements. The turbulent transport term (third order moment) has been found to be significantly underestimated by the COSMO model. This results in inaccurate TKE profiles and thus missing entrainment fluxes at the top of the PBL. A solution to increase the TKE transport in the PBL was proposed, resulting in a more realistic TKE profile and higher entrainment fluxes.

This modification of the turbulence scheme has also been tested in a parallel experiment over a one-month period. Results show only minor impacts on the operationally verified fields.

The impact of the horizontal resolution on the simulation results has also been studied. It was shown that the three-dimensional structure of the PBL is significantly different in the 1 km simulation than in the 2.2 km run, and the former shows great sensitivity towards the horizontal diffusion. The standard isotropic three-dimensional turbulence scheme was compared to the fourth-order numerical diffusion and to the newly implemented first-order Smagorinsky closure. It can be concluded that without horizontal diffusion the 1 km simulation exhibits unrealistically strong waves in the PBL. Based on these findings, it is recommended to use the three-dimensional turbulent diffusion scheme with horizontal mesh sizes on the order of 1 km, because it is more physically based than the fourth-order numerical filter. For flat convective conditions with very low horizontal wind field deformation the Smagorinsky closure in its classical formulation generates too low mixing, however, the extension of the scheme to include the horizontal shear of vertical wind might be beneficial for these cases.

3.2 Detailed investigation of diurnal cycle of the near surface quantities, revision of the surface-layer transfer formulation (Matthias Raschendorfer)

A final COSMO-SC (single column) version adapted to COSMO version 4.24 has been composed including the recent running developments of Task 2.1 and 2.3 and being ready for component testing.

The new COSMO-SC version includes a couple of bug fixes and extensions and the possibility of forcing with measured surface fluxes, which caused related modifications not only in the SC framework and the turbulence code (MODULE src_turbdiff) but also in that for soil processes (MODULE src_soil_multlay, with particular difficulties in relation to forcing the soil moisture calculation with measured evaporation) and in that for implicit vertical diffusion (MODULE slow_tendencies, which is going to become obsolete due to the development of a new universal code, see Task 2.3).

Some component tests have been performed with COSMO-SC attendant to the current model development.

A revised formulation of the complete transfer resistance in the surface-to-atmosphere transfer scheme has been developed, but not yet implemented. However as a first step, the code structure has been modified in order to allow for an easier implementation of the new formulation. As a second step an adopted profile function for stable stratification has been implemented in the current test version as an option that needs to be tested soon.

Future plans for a pending priority task (ConSAT):

- detailed investigation of the problems with daily cycle of near surface variables using measurements and COSMO-SC;
- implementation and verification of the full revised transfer formulation.

Future plans for later years:

- implementation of a canopy/skin layer.

3.3 Generalization of non-local formulation of the turbulence length scale to account for moist processes (Veniamin Perov and Mikhail Chumakov)

The new formulation for turbulence length scale based on the Bougeault and Lacarrere (BL89) proposal have been developed and implemented in 3-D COSMO model. We use a postulate proposed by BL89 that for each level in the atmosphere turbulence length scale l can be related to the distance that a parcel of originating from this level and having an initial kinetic energy equal to the mean TKE of the layer, can travel upward and downward before being stopped by buoyancy effects. More precisely, if we define l_up and l_down then l must be related to some average value between l_up and l_down. The main advantage of the method is to allow for remote effects of stable zones on the definition of the turbulence length scale. For instance, using l_up, the vertical depth of an unstable layer capped by a strong inversion is automatically selected as the length scale for turbulence.

The non-local length scale algorithm was generalized for cloudy boundary layers, in order to consider the influence of moist processes and phase transition of moisture on the scale of turbulence. The new algorithm uses a turbulent kinetic energy equation in conservative variables for non-precipitating processes. The new algorithm was tested for stratocumulus-capped boundary layers. From the results we can conclude that the new mixing length gives more realistic results, because the reference mixing length formulation gives an anomalously high dissipation inside the cloud, near the inversion.

The new algorithm was implemented in the module TURBDIFF of COSMO. Convective summer cases were analysed. Firstly, we have found a significant difference in change with height of a local (reference scheme) and nonlocal (new scheme) turbulence length scale. The nonlocal l results in a strong damping of turbulence as soon as stable conditions (inversion at the top of convective layer) are encountered, while local l results a monotonic increase with height. The results suggest that boundary layer (BL) with reference length scale underestimates surface temperature T_s and generate a colder and shallow convective mixed layer. The BL scheme with the new length scale yields better T_s and improved vertical profiles of temperature and humidity. Thus, the height of the boundary layer was 20 percent higher, the temperature of convective layer has increased by 1.5-2.0 °C. In conclusion, we assume that the new mixing length algorithm is preferred when the turbulent structure of atmospheric boundary layer is not known in advance.

Proposals for the future work:

- Use the new algorithm for cases with a stable boundary layer. The goal is to reduce a negative bias of T2m (2-4 °C), which is often observed in COSMO-RU in winter;
- Develop a new boundary-layer scheme over mountainous terrain.

3.4 Development of a unified turbulence scheme for COSMO, COSMO-SCM and ICON (Matthias Raschendorfer)

The code of MODULE src_turbdiff has been revised, reorganized and reformulated in large parts in order to achieve a better modularization, as well as a numerically and conceptually better representation of the whole system of 2-nd order equations, including sub grid scale condensation, TKE diffusion and the integration of scale interaction. A special focus was turned on artificial security measures to guarantee realizability, that is to avoid singularities. A further intention was to unify the formulation of implicit vertical diffusion and to gain more flexibility with respect to grid structure, time step organization and so on, in order to use the MODULE also in ICON. Some modifications have also been done in order to allow a better vectorization of the code.

A lot of modifications refer to the solution of second order equations (TKE equation and stability functions) as well as to the description of moist physics. Each of both tasks is now treated as a specific SUBROUTINE that is called from both, the turbulence model (turbdiff) and the scheme for surface-to-atmosphere-transfer (turbtran). In the prior code, for both sub-models these tasks are formulated explicitly, each with specific modifications.

The positive definite solution of TKE equation has been modified, allowing less serious restrictions for realizability. These restrictions can now be selected and modified by NAMELIST-input in order to test their effect in detail, in particular for stable stratification.

Numerics of solving for the stability functions have been changed, introducing a matrix preconditioning and the possibility to better control how far TKE can be apart from equilibrium without generating singularities in the solution.

Since all aspects of moist physics, in particular the calculation of conservative variables and the local saturation adjustment, are treated now in a single SUBROUTINE, these aspects are now treated consistently in turbdiff and turbtran, and - since conservative variables and not the model variables should be interpolated onto the 2m level - are applied even to 2m-diagnostics. This modularization further allows for a better control in case of modifications Thus, the mixed water-ice phase that already exists in an earlier sub version of the code (used by E. Avgoustoglou) can now be implemented here again with less modification effort.

Despite their formulation based on conservative scalar variables, sub grid scale variations of condensation need to be considered in our turbulence scheme as well, not at least because the buoyancy source term for TKE is dependent on it. By means of our statistical saturation adjustment assuming a Gaussian distribution function of local oversaturation this issue has already been implemented before. However, due to condensation coupling the turbulent vertical fluxes of scalar model variables are linear combinations of the respective fluxes in conserved variables and hence have no strict flux gradient representation being a prerequisite of our implicit solution for vertical diffusion. Although analytical inspection showed that we can apply vertical diffusion simply with the flux gradient form as long as a grid scale saturation adjustment is applied at the end of each time step, we invented a general method of gradient correction in order to gain a 3-diagonal linear system for the implicit diffusion equation even in the case of non gradient fluxes. This case had to be treated by an explicit (moist) diffusion correction before. As an alternative it is also possible to apply vertical diffusion to the conserved thermodynamic variables followed by subsequent transformation of the updated variables into the model variables by means of statistical saturation adjustment. So far it is a question of model configuration and numerical accuracy or efficiency what option should be used.

The TKE diffusion is now calculated by means of a common SUBROUTINE for semi-implicit vertical diffusion applicable to all variables to be diffused including passive tracers. This routine contains options as to how to consider explicit tendencies or corrections of vertical gradients, where the latter option enables expressing non gradient fluxes by effective vertical gradients.

This new scheme for semi-implicit vertical diffusion is going to substitute the current code for that purpose being a part of the numerical core in COSMO, where similar code is written explicitly for each diffused variable, in particular for each passive tracer. The lower boundary condition can be chosen by NAMELIST input (either concentration condition or flux condition), and in case of a flux condition, the surface fluxes can be specified. Otherwise the resulting surface flux has an implicit part as well depending on the degree of implicitness.

The current representation of the circulation term, still expressed in terms of a flux divergence, is treated as a gradient correction as well, avoiding an extra explicit formulation for it. Nevertheless, this current representation of the circulation term is going to be changed into a thermal SSO term, what unfortunately had to be delayed again.

All the above mentioned development is present in a still private test version based on COSMO version 4.24. Due to the quite fundamental modifications of the code, it was not yet possible to test the code sufficiently and to provide an optimal parameter setup. Nevertheless, the code is already running and provides reasonable results. But final tuning and consolidation as well as formal adoptions to the official COSMO version may take some more time.

A stability correction of turbulent master length scale according to Deardorff has been implemented into the official code, which might currently be missing.

In order to gain a theoretical framework for a comprehensive and consistent parameterization of sub-grid scale processes, a concept of scale separation has been developed and described in an internal still growing document. This concept takes into account the fact that generally valid closure assumptions cannot exist in principle and that consequently the full generality of sub grid scale processes needs to be split somehow into separated regimes valid for the application of specific closure assumptions. In this sense turbulence is a regime defined by the fundamental closure assumptions allowing a quite consistent solution of the 2-nd order budget equations. Since the separator has been related to the filter operator associated with discretization, a separated treatment of turbulence automatically generates additional interaction terms in the 2-nd order equations for turbulence that formally will make the scheme applicable, if non turbulent sub-grid scale processes are present as well and may be of particular importance when a solution without interaction terms is not possible and thus requires artificial manipulation (like in the strongly stable boundary layer) for the lack of missing physics.

According to the concept of scale separation three scale interaction terms have been introduced into our prognostic TKE equation, representing a transfer of sub grid scale kinetic energy towards turbulent scales by the action of shear generated by related non-turbulent sub-grid scale flow patterns. These are production terms by SSO wakes, convective plumes, and separated horizontal shear eddies. The SSO term is expressed using the SSO tendencies of momentum and the convection term is buoyant convective kinetic energy production derived form the convection scheme (Tiedke and shallow convection). The horizontal shear term is the horizontal shear production with respect to a special non isotropic length scale. All the 3 additional terms are based on an assumed equilibrium of production and scale transfer being treated like a dissipation term. They are implemented in the official code and can be switched on by NAMELIST input. At DWD the SSO source term has been already switched on in the operational code, the others need to be verified. However, these source terms are already used as important predictors of atmospheric turbulence for aviation purpose. Their effect is being tested in more detail by our aviation department using the package TMOS (turbulence model output statistics) developed during an internal DWD project parallel to UTCS.

A crucial problem of an UTCS is the consistent representation of sub-grid scale variation in terms of moist physics. In the framework of a single set of 2-nd order equations this can be tried by means of a statistical saturation adjustment, as we do it in our moist turbulence scheme, at which this procedure requires the existence of saturation equilibrium and the knowledge of the distribution function of oversaturation. However, as far as the whole sub grid scale variability is represented by each of the governing statistical moments, the ice phase and precipitation cannot be neglected, in particular if deep convection is included. Since both of these condensates are known not to be in saturation equilibrium and since the overall distribution functions may be rather arbitrary, attempts in that direction are very likely to fail. Thus some analytical work has been done in order to treat this problem in the framework of scale separation, what is necessary anyway according to the previous arguments. The main result of this analysis is the finding that a modified mass flux approach can be a solution, if simplified averaged budget equations are considered for convective sub-domains. Considering the necessary construction constraints for these sub-domains, estimates of their volume fraction can be provided and the full model microphysics can be applied to these sub domains. In this approach turbulence is assumed to be either a sub grid scale process with respect to the sub domains maintaining lateral mixing, or it provides initial convective sub domains. Thus turbulence and convection would really be interacting and the governing scales of convection would develop by the governing physics. Finally a separation to resolved scales can be formulated for convection as well. The concept has been worked out only in a manuscript yet and an excerpt of it has been compiled as PPT file.

Future plans for related work after the PP UTCS:

- generation of an official well-tested code valid for COSMO, SCM and ICON, ready for operational forecast, containing all the development present in the private test code being active, in particular the new routine for vertical diffusion;
- finding an optimal mode for vertical diffusion with respect to the lower boundary condition, the consideration of explicit tendencies and of moist corrections;
- switching on the implemented scale interaction terms after verification against SYNOP data (operational verification).

Future plans for a medium range prospect:

- reformulation of the current circulation term to be a thermal SSO source term for TKE;
- implementation of SSO/roughness layer terms based on an extended boundary layer approximation in a vertically resolved roughness layer;
- consideration of missing mixing by non-turbulent sub-grid scale motions themselves (in case of SSO wakes and horizontal shear eddes).

Future plans for later years:

- implementation of a scale separated mass-flux convection interacting with turbulence and providing volume fractions of convective sub-domains (final step of a scale separated UTCS).

4 Evaluation of SGS cloud schemes against satellite data and data from measurements in the surface air layer (Euripides Avgoustoglou)

COSMO model uses operationally two sub-grid schemes for stratus clouds. A semi-empirical one based on relative humidity used in the radiation module, denoted as RH scheme, and a parameterizable statistical one used in the turbulence module, denoted as SGSLI scheme. The main objective of the work was to show whether SGSLI could be operationally implemented in the radiation module.

Although the task looked straightforward, several issues needed to be settled as the work was progressing.

The main issues of consideration were:

- the availability of a code version that could properly include the cloud-ice content into the statistical scheme;
- the proper boundary conditions;
- the availability and comparison with real time data;
- the selection of the test cases.

The test version was provided by Matthias Raschendorfer and is based on COSMO version 4.6. Although this version is relatively old, any comparative tests that were made with newer versions did not change the diagnostics.

The domain was centred around the Hellenic geographical area characterized by equal sea and land partitions. This choice gives rise to the strong mixing of continental as well as marine clouds which is one of the most challenging features regarding the operational use of numerical weather prediction models by the Hellenic Meteorological Service.

The choice of the initial and boundary conditions was considered an issue because the main synoptic features are carried by the global model used. Over the first diagnostic tests, GME as well as ECMWF forecasts were used without any important differences between them. However our main evaluations were delivered through GME analysis mode over 3-hour intervals of 36 or 48-hour spans provided by DWD.

The default parameterization of the SGSLI scheme was mainly used, however several other diagnostics were performed either through different parameterization of SGSLI or mixing of SGSLI and RH.

The main strategy regarding the choice of the considered test cases was to have synoptic conditions that favour stratus clouds over the domain under consideration without any significant convection and over the full seasonal span.

Over the fist stages of the project, direct heuristic comparisons of the model total cloud cover with MSG satellite images at the 10.8 and 8.7 micron channels were performed. The main outcome of these comparisons was that the implementation of the SGSLI scheme was realistic but not conclusive. Further comparisons were made regarding 2-meter minimum and maximum daily temperatures as well as daily 2-m temperature variations for about 50 synoptic Hellenic meteorological stations. The revealed feature was that the 2-meter minimum temperature was better simulated when the SGSLI scheme was implemented in the radiation module while the 2-meter maximum temperature was better simulated when the default RH scheme was implemented in the radiation module.

An important boost towards the relative impact of the cloud schemes came from a close comparison of artificial satellite images provided by the model with the real ones provided directly at the Hellenic Meteorological Service by MSG. These comparisons were accomplished via the CineSat software and became possible by the Remote Sensing Division of the Hellenic National Meteorological Service that provided access to the available tools and database structure in order to create the necessary look-up tables and perform the statistics. It became clear from these direct comparisons that the implementation of the SGSLI scheme leads to an underestimation of low cloud cover by the model in contrast to the implementation of the default RH scheme. However, another important feature was that the implementation of the SGSLI scheme leads to a relatively better simulation for medium cloud-cover. Nevertheless, the total cloud cover is better estimated by the default relative humidity scheme, and so are the radiation temperatures in the 10.8, 3.9, 6.2 and 7.3 μm.

Although the SGSLI scheme cannot in its present form replace the RH scheme in the radiation module, it is an important asset to COSMO model that can be used as a reference to support the ongoing research in this crucial area of atmospheric physics.

A further investigation of the cloud schemes associated with different COSMO parameterizations in an updated model version (like changing the default values of vertical turbulent diffusion coefficients) in the fashion of QPF Project could be considered as an extension to the project.

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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 (USAM, ARPA-SIMC, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA) and Russia (RHM). 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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