

COSMO Priority Project: Testing and Tuning of Revised Cloud Radiation Coupling T²(RC)² Phase 2: Project Plan

Version 4.0, 26.07.2017

Project duration: 09.2017 – 09.2019

Project leader: Harel Muskatel

Summary

This is an extension of the **Testing and Tuning of Revised Cloud Radiation Coupling – T²(RC)²** priority project. Prior to the first phase (09.2015 – 09.2017) of this project, in the Revised Cloud Radiation Coupling (RC)² priority task, new parametrizations for water droplets (Hu and Stamnes, 1992) and ice particles (Fu, 2007) were implemented as well as new optical properties for these species that were calculated based on state of the art data and adapted to COSMO spectral bands. Now, after choosing the most sensitive tuning parameters that were introduced in the new cloud-radiation scheme, we started the process of systematic calibration using the CALMO method. The parameter tuning is conducted on the ECMWF computers testing the new COSMO radiation scheme in COSMO-DE domain as well as on COSMO-IS domain. Our first goal in this phase of the project is to implement the mentioned new cloud droplets and ice particles optical properties in the ICON RRTM scheme. The calculation of the optical properties of ice and droplets for the ICON spectral bands was already done (Ulrich Blahak, Harel Muskatel) and also the ice particles properties were even partially implemented in ICON radiation scheme (Simon Gruber - KIT). We wish to complete the implementation and testing the new ICON scheme against observational data and to retune the model in order to sustain model performance.

In the first phase of the project we successfully implemented the CAMS-ECMWF prognostic aerosols in COSMO radiation scheme. The int2Im code was designed to read and interpolate (both in time and space) the CAMS 3D mixing-ratio fields. The five aerosols species: sea salt, mineral dust, black carbon, organic matter and sulphate are sub-divided to eleven tracers because sea salt and dust have three size bins while black carbon and organic matter have both hydrophobic and hydrophilic types. A beta version of COSMO 5.1 with the new radiation scheme using CAMS aerosols input was tested in Israel domain for 30 test cases in different weather situations and showed similar or better results for radiation fluxes compared to the Tegen climatology (1997). Furthermore, the introduction of the new radiation scheme including the CAMS aerosols to a semi operational COSMO 5.1 in June 2017 improved the average Tmax forecast for 15 Israeli stations compared to the operational Israeli COSMO V5.1, until 24.7.2017. Preliminary results show that the average negative bias of 0.9K was reduced to 0.8K and the RMSE was reduced from 1.6K to 1.4K. The negative bias reduction is consistent with the reduction of the optical depth in the CAMS compared to the Tanre climatology. In dust storm cases it performed much better than all other

aerosols climatologies. Better results in CAMS aerosols testing were also obtained during comparison with the aerosol/radiation measurements at the Moscow State University and Lindenberg Observatories with the application of the accurate radiative scheme (Tarasova and Fomin, 2007, Chubarova et al. 2017). We note here that overestimation of ~5% was obtained by the COSMO radiation algorithm. In addition, testing Kinne aerosol climatology against the measurements at both observatories provides similar or better results than the standard Tegen climatology in radiation simulations. However, aerosol at these sites belongs to the same continental type. Therefore it should be useful to continue its testing for different aerosol types. For example, over desert (dust aerosol), over pristine Arctic area (arctic aerosol) and to examine their temperature response. Similar procedure of evaluating the temperature effect of aerosol has been done for continental type of aerosol in the first stage of the project.

In the analysis of the aerosol – cloud interaction two sequential steps for these developments are suggested: First, we wish to couple the prognostic/new climatology aerosols content with cloud microphysics. Aerosols number concentration, aerosols type and size distribution can tremendously affect the clouds microphysics and dynamics (see Rosenfeld, 2008). So far COSMO model aerosols number concentration input for the microphysics is taken to be a fixed number which is a tuning parameter. Of course this input is in many cases non-realistic. The Tanre climatology is known to have high aerosols overestimation and the Tegen climatology can be both under-estimated (i.e. dust events) or overestimated (i.e. due to wash out events) (Kinne et al. 2013). Instead of using a monthly climatological averages a more realistic input can be taken from CAMS which is initiated using a very complex data assimilation system and is driven with IFS model. Giving the model a realistic aerosols content can hopefully improve significantly COSMO forecast in general and especially improve precipitation forecast or even better distinguish between different types of precipitation (rain, graupel, snow, etc.), i.e. mineral dust mixing ratios from CAMS can be used for more accurate ice nuclei concentration, while sea salt can be used for cloud condensation nuclei (CCN) concentration. We plan to test the implementation of new input aerosol for the improvement of cloud reproducing against observational data.

The second natural outcome from the CAMS implementation is using ICON-ART prognostic aerosols input. While COSMO-ART is not running on operational basis in all COSMO-users site, ICON-ART is running globally twice a day and it is possible to use ICON-ART aerosols input operationally. As for now, ICON-ART has only two aerosols species namely mineral dust and volcanic ash, but it will expand to other species in the future. It is straightforward to use ICON-ART input since COSMO-ART is already implemented in COSMO radiation scheme.

Cumulus clouds, which are sub-grid for COSMO, play an important role in radiation transfer. In order to describe their effect on radiation one has to estimate their cloud cover, liquid water content and droplets effective radius. In the operational COSMO version these three components are parameterized in a simplistic way, causing a big uncertainty in radiation transfer on sub-grid scale. At the first stage of T²(RC)² project, we have parameterized the liquid water content and droplets effective radius using Hebrew University Cloud Model (HUCM) and System for Atmospheric Modelling with

bin microphysics (SAM-SBM) large-eddy simulation to simulate shallow cumulus ensembles. The new parameterization, as well as other components of the new cloud radiation coupling scheme, are being tested nowadays on ECMWF computers. In this second phase of T²(RC)², we propose to analyse the possibility to improve the parameterization of the cloud cover of shallow cumulus and to test cloud cover and radiation response against observational data .

Apart from these new tasks, few tasks from the first phase remained unfinished: the testing and tuning of the new radiation scheme using the CALMO methodology (task 1.3), testing the Monte-Carlo Spectral Integration (MCSI) method (task 5.3), full implementation of the Kinne climatology (task 6.1) and radiation verification under cloudy skies conditions against observational data from Moscow State University (MSU) and Lindenberg observatories (task 6.4). After implementing new Kinne aerosol climatology in COSMO and its testing in conditions with continental aerosols we propose to continue testing and evaluating temperature effect for other type of aerosol (dust, pristine arctic, etc.), including clear and cloudy skies conditions.

The last mission in this project will be the integration of all new features, which were developed in the last couple of years, into the radiation scheme. All of these developments were performed on offline COSMO 5.1 version and should be implemented in the most updated COSMO version. Special care should be given to the blocking structure coding demands.

Motivation

Radiation is the main source of the Earth's energy, and it is strongly coupled to other elements of NWP models especially the heating and cooling rates. On the other hand, precise line by line calculation of extinction of radiation in the atmosphere due to different scatterers and absorbers is computationally costly. Wise parameterizations of the cloud hydrometeors and aerosols optical properties and also a smart computational algorithm are key aspects of a fast and accurate operational radiation transfer model. In the (RC)² - Revised Cloud Radiation Coupling priority task, re-computation of optical properties (optical thickness, single scattering albedo, asymmetry factor and delta-transmission function) of water droplets and ice was done using state of the art geometric ray-scattering calculations. In the same PT, the Tegen (Tegen et al., 1997) aerosols climatology was implemented in the COSMO radiation scheme in addition to the default option of the older Tanre climatology (Tanre et al., 1984). In the first phase of the T²(RC)² newer climatology developed by Kinne (Kinne et al., 2013) was implemented and the prognostic aerosols by ECMWF- CAMS model was implemented and tested. All of these new features not only have high impact on the radiation fluxes but also they indirectly effect the dynamics through surface temperature biases cloud formation, evaporation and so on. Aerosols have two impacts on radiation: direct by absorbing and scattering radiation, and indirect by influence on cloud microphysical properties as the droplet concentration and effective radius. The differences between pristine, marine, polluted and continental environments were treated in numerous researches (see for example a review on the topic by Rosenfeld et al., 2008).

The motivation for the implementation of state of the art optical properties for the ice and water hydrometeors in ICON model is obvious. The ICON-COSMO shared physical packages are long ago a standard routine in DWD. Nevertheless the impact on RRTM scores and the entire model scores should be carefully tested in order to maintain the parametric balance that was achieved over the last couple of development years.

Actions proposed

1. Implementation and testing of new ice and water droplets optical properties in ICON-RRTM (Task 7)
2. Implementation and testing of ICON-ART prognostic aerosols in COSMO radiation scheme (Task 8)
3. Implementation and testing of CAMS prognostic aerosols in COSMO microphysical scheme (Task 9)
4. SAM LES utilization for parameterization of sub-grid scale shallow cumulus cloud cover and its testing (Task 10)
5. Updating the COSMO latest version (written in block structure) with (RC)² and T²(RC)² developments (Task 11)

Description of individual tasks

Task L: Project leadership

Estimated resources: 0.1 FTE per year

Task 7: Implementation and testing of new ice and water droplets optical properties in ICON-RRTM

New parameterizations (fits) for the optical parameters of water droplets (based on Hu and Stamnes, 1993) and for ice particles (based on Fu, 2007) in the ICON- radiation scheme (RRTM) have been constructed. Compared to existing parameterizations, the effective size range is extended so that these are also applicable for larger hydrometeor categories like snow, graupel and rain.

For the ice phase particles, raw data of single particle scattering parameters optical properties (single scattering albedo, asymmetry factor, extinction coefficients and forward scattering fraction) have been provided by Quiang Fu of University of Washington (Fu, 1996; Fu et al., 1998; Fu, 2007). Particles are assumed as randomly oriented needles of length L and diameter D with effective aspect ratio (AR) that decreases from 1 at small sizes to 0.22 at sizes > 500 μm. The optical properties are calculated as function of AR or the generalized effective size $D_{ge}(= 2 \cdot R_{eff})$ and for each of the 30 spectral band of ICON-RRTM separately with a wise and complex spectral integration (to be published). We used a rational non-linear ansatz (a

polynomial function of some order divided by another polynomial of a different order) so each spectral band optical properties are defined by only a few coefficients. At each grid point the model diagnoses AR and D_{ge} using the microphysical parametrization of ice water content.

For the liquid hydrometeors the method was similar but using the more common effective radius which is motivated by the large size approximation limit for the extinction coefficient. Also here the effective radius is diagnosed from LWC, mass-size relation constants and the gamma size distribution parameters. The single particle data were taken from Hu and Stamnes (1992).

Therefore we propose the following subtasks:

7.1 Implementation of Fu's ice particles optical properties in ICON-RRTM model. The single particle data needs ramping to the 30 wavelength bands. The parametrizations depend on both AR and D_{ge} hence those need to be calculated and diagnosed based on the microphysical gamma distribution factors.

7.2 Implementation of Hu and Stamnes water droplets optical properties in ICON-RRTM model. The single particle data needs ramping to the 30 wavelength bands. The parametrizations depend on effective radius and hence need to be calculated and diagnosed based on the microphysical gamma distribution factors.

7.3 The new cloud-radiation coupling will be tested against observational data using ICON-LAM. The exact setup will be determined at a later stage by the RHM based on computational resources available. The possibilities are e.g. ICON-DE 2.2 km, ICON-RU 2.2 km, or even ICON-ETR 2.2 km on Eastern Russia region. A Comparison with the previous scheme will be performed.

Deliverables:

(09.2018, 0.05 FTE, Harel Muskatel 0.05, Simon Gruber) Implementation of Fu's ice particles optical properties in ICON-RRTM

(09.2018, 0.2 FTE, Harel Muskatel 0.1, Martin Kohler 0.1) Implementation of Hu and Stamnes water droplets optical properties in ICON-RRTM

(09.2019, 0.2 FTE, Harel Muskatel 0.1, Pavel Khain 0.1, Natalia Chubarova 0.1, Marina Shatunova 0.1) Case studies and documentation of the effects

Pavel Khain 0.1 FTE, Harel Muskatel 0.25 FTE, Martin Kohler 0.1 FTE, Natalia Chubarova 0.1 FTE, Marina Shatunova 0.1 FTE

Estimated resources: 0.65 FTE

Status: Already started. Ice particle optical properties for the ICON bands were calculated (Harel Muskatel and Ulrich Blahak) and partially implemented in ICON-RRTM.

Task 8: Implementation and testing of ICON-ART prognostic aerosols in COSMO radiation scheme

ICON-ART is a global ICON NWP model coupled with the ART modules developed at KIT which deals with aerosols and reactive gases in the atmosphere. In the regional

COSMO-ART, the radiation scheme includes the aerosols-radiation feedback. In this sub-task we would like to repeat the procedure done with CAMS prognostic aerosols and couple ICON-ART aerosols to COSMO radiation scheme. The sub-tasks suggested are as follows:

8.1 Adaptation of INT2LM code to allow the time and space interpolation of ICON-ART aerosols fields onto COSMO grid. As in CAMS case, we will not use COSMO dynamics to simulate advection or removal of aerosols by wash out, etc. The code will allow hybrid aerosols options, i.e. Tegen climatology and ICON-ART aerosols mixture due to the fact that not all species are available on ICON-ART in operational mode.

8.2 Implementation of ICON-ART aerosols into the radiation code using either the prognostic optical depth forecast like in COSMO-ART or the aerosols number concentration like was done with CAMS. The preferred method will be chosen later.

8.3 Comparative testing of the model output against observational data (T2m, global radiation, rain) using ICON-ART for the same 30 test cases performed with the COSMO-CAMS experiment against 10 radiation measurements stations in Israel. More studies will be performed in Russia against Moscow State University radiation measurements.

Deliverables:

(09.2018, 0.15 FTE, Harel Muskatel 0.1, Uli Blahak 0.05, Daniel Rieger 0.05)
Implementation of ICON-ART aerosols fields into INT2LM code

(09.2018, 0.15 FTE, Harel Muskatel 0.1, Daniel Rieger 0.05) Implementation of
ICON-ART aerosols fields into COSMO radiation scheme

(09.2019, 0.25 FTE, Harel Muskatel 0.1, Gdaly Rivin 0.05, Alexander Kirsanov 0.1,)
Case studies, documentation of effects

FTEs altogether: Harel Muskatel 0.3, Uli Blahak 0.05, Daniel Rieger 0.1, Gdaly Rivin 0.05, Alexander Kirsanov 0.1

Estimated resources: 0.6 FTE

Status: Not yet done.

Task 9: Implementation and testing of CAMS prognostic aerosols in COSMO microphysical scheme

CAMS aerosol fields model (Morcrette et al., 2009; <http://www.gmes-atmosphere.eu/>) includes prognostic variables for the mass of sea salt, dust, organic matter, black carbon and sulfate aerosols, interactive with both the dynamics and the physics of the IFS model. Implementation of these fields into the radiation model of COSMO has been completed, and the new model has been successfully tested under real circumstances and compared with the current methods. Further model tuning is needed to make it the state of the art radiation scheme that includes more realistic input for radiation forecast compared to the fixed monthly climatological averages. The current nucleation schemes, both for water droplets and for ice, use fixed aerosols number concentration and later define cloud number concentrations for these hydrometeors. Second option (implemented but not fully tested) is using the climatological value, i.e. Tegen

climatology, and use it as input for cloud droplet activation formula described by Segal and Khain (2006) (SK). That formula defines the droplet number concentration based on aerosols concentration, vertical velocity at cloud base and effective updraft speed. Now it is possible to explicitly use the 3D mixing ratios given by the CAMS model as an input for the SK parameterization. Even more so, we can now implement the CAMS initial number concentrations of the different aerosols in the currently available water and ice nucleation schemes. Special care will be given to the chemical and hydrophobic/hydrophilic nature of different species of aerosols which are not treated in COSMO current microphysical schemes but now can be distinguished by their type. Luckily, the adaptations needed in the INT2LM code were done in the first phase of the project. The aerosols fields are interpolated to COSMO grid both in space and time up to 5 days lead time. Since the CAMS tracers are fully treated under the IFS model framework including advection, removal by precipitation (scavenging) and so on, we do not wish to include those processes in the COSMO model. Although discrepancy between the aerosols and the COSMO dynamics/clouds are possible, using COSMO model to simulate advection of these aerosols will cause severe and unrealistic non-continuities.

Therefore we propose the following subtasks:

9.1 Implementation of CAMS prognostic aerosols in the water droplets nucleation schemes including to the SK method to define cloud number concentration. This will affect not only cloud formation but also effective radius diagnosis for grid and sub-grid scale clouds in the radiation scheme.

9.2 Implementation of CAMS prognostic aerosols in the Philips (Phillips et al., 2008) heterogeneous ice nucleation scheme instead of the currently fixed aerosols number concentration and lookup tables. The same will be done with the Meyers (Meyers et al., 1992) heterogeneous ice nucleation scheme available in COSMO.

9.3 Testing the new aerosols-microphysical scheme against measurements. The domains that we wish to use are COSMO-IS and COSMO-DE domains. We already have rain verification system based on rain gauge corrected radar data for the Israel domain that was applied to testing the previous implementations. To compare cloud water and cloud ice coverage we can use MODIS satellite products or/and the Lindenberg observatory CloudNet products. Testing radiation fields and cloud products using different approaches against observational data.

Deliverables:

(09.2019, 0.5 FTE, Harel Muskatel 0.2 (0.1 per year), Pavel Khain 0.2 (0.1 per year), Uli Blahak 0.1 (0.05 per year)) Implementation of CAMS aerosols fields into COSMO cloud water droplets nucleation schemes

(09.2019, 0.5 FTE, Harel Muskatel 0.2 (0.1 per year), Pavel Khain 0.2 (0.1 per year)) Implementation of CAMS aerosols fields into COSMO cloud ice nucleation schemes

(09.2019, 0.4 FTE, Harel Muskatel 0.1, Pavel Khain 0.1, Alexey Poliukhov 0.1, Natalia Chubarova 0.05, Marina Shatunova 0.05) Case studies, documentation of effects

FTEs altogether: Harel Muskatel 0.5, Pavel Khain 0.5, Uli Blahak 0.1, Alexey Poliukhov 0.1, Natalia Chubarova 0.05, Marina Shatunova 0.05

Estimated resources: 1.3 FTEs

Status: Not yet done.

Task 10: SAM LES utilization for parameterization of sub-grid scale shallow cumulus cloud cover

In this task we plan to analyse the possibility to improve the parameterization of the cloud cover of shallow cumulus. In the default COSMO version, the total cloud cover (CLC) depends on two parts. The sub-grid scale cloud cover (CLC_SGS) is a function of a mixed-phase generalized relative humidity RH_g and of other parameters, and the so-called convective cloud cover (CLC_CON) is assumed to be proportional to shallow cumulus cloud depth (TOP_CON-BAS_CON). Other two alternative schemes are available: an alternative scheme based also on RH_g and a statistical scheme. The three approaches were not yet comprehensively tested. Recently, a new shallow cumulus parameterization was developed by Boeing et al. (2012) which suggests more robust estimation of shallow cumulus cloud cover. We plan to introduce this new parameterization into the COSMO radiation scheme.

We plan to investigate these parameterizations of shallow cumulus in three sub-tasks:

10.1 Set-up COSMO idealized simulation of BOMEX conditions and compare the cloud cover with that of SAM LES simulation. Check the components of Boeing et al. parameterization (updraft fraction, convective velocity scale, entrainment rate, etc.) which influence the estimation of cloud cover against SAM LES simulation. Based on this analysis, recommend (or not) the use of cloud cover diagnostics of Boeing et al. within the COSMO radiation scheme.

10.2 In the grey zone of convection (resolutions from 500m to 5km), shallow convection parameterization tends to transform humidity from the lower atmosphere upwards, reducing the possibility of grid scale precipitation. Therefore one needs a proper mechanism of shutting down shallow convection parameterization when there is a potential for the development of grid-scale convection. We will analyse the various options of shutting down shallow convection parameterization, focusing on Boeing et al. parameterization. Obviously, when the grid scale convection is initiated, the cloud cover in the grid box is no more parameterized, but set to 1. Proper shutting down the shallow convection parameterization may have a benefit on precipitation forecast, as well as on cloud cover diagnostics used by the radiation scheme.

10.3 The sub-grid scale CLC parameterization schemes needs to be tested against measurements with a resolution of hundreds of meters or less and to be compared to currently available schemes. The usual way to evaluate the CLC is by human eye. We wish to investigate a new way of CLC measurements using the instruments available at the Ashalim solar thermal power station run by BrightSource Company and its partners. At this site, about 100 PV radiation measurement tools are spread over an area of 2 km in diameter. This area is approximately the size of COSMO 2.8 km grid box and presumably can provide the clouds cover measurements with a ca.100 m resolution over the entire cell. Another method that we wish to investigate as a verification tool is satellites measurements such as MODIS. The recommendations of this work are highly relevant both for COSMO and ICON models. It would also be

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useful to provide verification of cloud amount using fish-eye camera measurements and of its effects on radiation fields.

Deliverables:

(09.2018, 0.2 FTE, Pavel Khain 0.2) Check Boeing parametrization components using SAM LES simulations with BOMEX setup, implementation of the new parametrization in COSMO CLC scheme

(09.2018, 0.1 FTE, Pavel Khain 0.1) New shallow convection shutdown scheme development

(09.2019, 0.2 FTE, Pavel Khain 0.1, Harel Muskatel 0.1, Alexey Poliukhov 0.1, Natalia Chubarova 0.1) SGS cloud cover schemes verifications against ground base and satellite observations including fish-eye camera verification and testing radiation response

FTEs altogether: Pavel Khain 0.4, Harel Muskatel 0.1, Alexey Poliukhov 0.1, Natalia Chubarova 0.1

Estimated resources: 0.7 FTE

Status: Not yet done.

Task 11: Updating the COSMO latest version with $(RC)^2$ and $T^2(RC)^2$ developments

The new cloud-radiation coupling scheme has been developed using COSMO 5.1-beta version. The new scheme includes new hydrometeors to the cloud-radiation interaction, fundamental revision of the optical properties of hydrometeors, revised sub-grid scale clouds properties and their influence on the radiation, different aerosol climatological and prognostic fields, etc. These developments result in tens of thousands of new code lines, definition of tens of new fields, partially organized in container classes.

However, since the time the version 5.1-beta was released, the official COSMO code was significantly changed and redesigned. The changes include the transformation of the model physics to blocking structure. Bringing the new cloud-radiation coupling scheme developed within the version 5.1-beta to the latest COSMO version in blocking structure is an important and worthy goal that will be beneficial for both the COSMO and the ICON developers and users.

Deliverables:

(09.2019, 0.5 FTE, Pavel Khain 0.1 1st year 0.2 2nd year, Uli Blahak 0.05 2nd year, Alexey Poliukhov 0.05, Marina Shatunova 0.05) Updating the latest COSMO version with the $(RC)^2$ and $T^2(RC)^2$ developments

FTEs altogether: Pavel Khain 0.3, Uli Blahak 0.05, Alexey Poliukhov 0.05, Marina Shatunova 0.05

Estimated resources: 0.45 FTE

Status: Not yet done.

Risks

1. The usual risks of scientific developments are that the planned developments and tasks do not work out as originally anticipated.
2. Both COSMO and ICON are calibrated to perform best under the previous radiation schemes. Re-tuning for operational use is needed.
3. In task 10, we propose to analyze cloud cover using the operational and the Boeing et al. shallow convection parameterizations. As the cloud cover has a major impact on the heating rates in the model, changes of its diagnostics are risky and will not necessarily lead to improvements in the overall model performance.

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Project Plan

Task	Contributing scientist(s)	FTE-years	FTE per person	Start	Deliverables	Date of delivery	Preceding tasks
1.3	Pavel Khain (IMS)	0.1	P-0.1	01.09.2017	Automatic parameter tuning performed on ECMWF computers	31.08.2018	
5.3	Harel Muskatel (IMS)	0.05	H-0.05	01.09.2017	The MCSI method tested	31.08.2018	
6.3	Alexei Poliukhov (RHM) Natalia Chubarova (RHM) Marina Shatunova (RHM) Gdaly Rivin (RHM)	0.3	A-0.1 N-0.1 M-0.05 G-0.05	01.09.2017	Results of intercomparison of aerosol COSMO simulations with the accurate experimental measurements and accurate modelling in clear sky conditions with dust, pristine and other types of aerosols and their influence on meteorological forecast	31.08.2018	
6.4	Alexei Poliukhov (RHM) Natalia Chubarova (RHM) Marina Shatunova (RHM) Gdaly Rivin (RHM)	0.3	A-0.1 N-0.1 M-0.05 G-0.05	01.09.2017	Results of intercomparison of different aerosol COSMO simulations with the accurate experimental measurements in cloudy conditions	31.08.2018	
7.1	Simon Gruber (KIT) Harel Muskatel (IMS)	0.05	H-0.05	01.09.2017	Fu's ice particles optical properties implemented into ICON-RRTM	31.08.2018	
7.2	Harel Muskatel (IMS)	0.2	H-0.1 M-0.1	01.09.2017	Hu and Stamnes water droplets optical properties	31.08.2018	

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Task	Contributing scientist(s)	FTE-years	FTE per person	Start	Deliverables	Date of delivery	Preceding tasks
	Martin Kohler (DWD)				implemented into ICON-RRTM		
7.3	Harel Muskatel (IMS) Pavel Khain (IMS) Marina Shatunova (RHM) Natalia Chubarova (RHM)	0.4	H-0.1 P-0.1 M-0.1 N-0.1	01.09.2018	Results from case studies and documentation of the effects	31.08.2019	7.1,7.2
8.1	Ulrich Blahak (DWD) Harel Muskatel (IMS) Daniel Rieger (DWD)	0.2	U -0.05 H-0.1 D-0.05	01.09.2017	ICON-ART aerosols fields implemented into INT2LM code	31.08.2018	
8.2	Harel Muskatel (IMS) Daniel Rieger (DWD)	0.15	H-0.1 D-0.05	01.09.2017	ICON-ART aerosols fields implemented into COSMO radiation scheme	31.08.2018	
8.3	Harel Muskatel (IMS) Alexander Kirsanov (RHM) Gdalii Rivin (RHM)	0.25	H-0.1 A-0.1 G-0.05	01.09.2018	Results from case studies and documentation of the effects	31.08.2019	8.1,8.2
9.1	Ulrich Blahak (DWD)	0.5	U-0.05 per year	01.09.2017	CAMS aerosols fields implemented into COSMO cloud water droplets nucleation schemes	31.08.2019	

COSMO Priority Project: Testing and Tuning of Revised Cloud Radiation Coupling (T²(RC)²) phase 2
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Task	Contributing scientist(s)	FTE-years	FTE per person	Start	Deliverables	Date of delivery	Preceding tasks
	Harel Muskatel (IMS) PavelKhain (IMS)		H-0.1 per year P-0.1 per year				
9.2	Harel Muskatel (IMS) PavelKhain (IMS)	0.4	H-0.1 per year P-0.1 per year	01.09.2017	CAMS aerosols fields implemented into COSMO cloud ice nucleation schemes.	31.08.2019	
9.3	Harel Muskatel (IMS) Pavel Khain (IMS) Alexey Poliukhov (RHM) Natalia Chubarova (RHM) Marina Shatunova (RHM)	0.4	H-0.1 P-0.1 A – 0.1 N – 0.05 M – 0.05	01.09.2018	Results from case studies and documentation of the effects	31.08.2019	9.1,9.2
10.1	Pavel Khain (IMS)	0.2	P-0.2	01.09.2017	Boeing parameterization components using SAM LES simulations with BOMEX setup checked New parametrization implemented into COSMO CLC scheme	31.08.2018	
10.2	Pavel Khain (IMS)	0.1	P-0.1	01.09.2017	New shallow convection shutdown scheme developed	31.08.2018	
10.3	Harel Muskatel (IMS) Pavel Khain (IMS)	0.4	P-0.1 H-0.1 A-0.1 N-0.1	01.09.2018	SGS cloud cover schemes verified against ground based and satellite observations, its radiation feedback tested	31.08.2019	10.1

COSMO Priority Project: Testing and Tuning of Revised Cloud Radiation Coupling (T²(RC)²) phase 2
Project Plan

Task	Contributing scientist(s)	FTE-years	FTE per person	Start	Deliverables	Date of delivery	Preceding tasks
	Alexey Poliukhov, (RHM) Natalia Chubarova (RHM)						
11.1	Pavel Khain (IMS) Ulrich Blahak (DWD) Alexey Poliukhov (HMC) Marina Shatunova (HMC)	0.45	P-0.1 1 st , 0.2 2 nd U-0.05 2 nd A -0.05 2 nd M-0.05 2 nd	01.09.2017	The latest COSMO version updated with the (RC) ² and T ² (RC) ² developments	31.08.2019	
L	Harel Muskatel (IMS)	0.2	H-0.2 (0.1 per year)	01.09.2017	Project leadership	31.08.2019	
All		4.65		01.09.2017		31.08.2019	

Estimated resources (in FTE per year) needed for COSMO-year 2017-2018:

Ulrich Blahak	0.1 FTE
Daniel Rieger	0.1 FTE
Martin Kohler	0.1 FTE
Pavel Khain	0.7 FTE
Harel Muskatel	0.7 FTE
Alexey Poliukhov	0.2 FTE
Natalia Chubarova	0.2 FTE
Marina Shatunova	0.1 FTE
Gdaly Rivin	0.1 FTE

Total: 2.3 FTE

Estimated resources (in FTE per year) needed for COSMO-year 2018-2019:

Ulrich Blahak	0.1 FTE
Pavel Khain	0.7 FTE
Harel Muskatel	0.7 FTE
Alexey Poliukhov	0.25 FTE
Natalia Chubarova	0.25 FTE
Marina Shatunova	0.2 FTE
Gdaly Rivin	0.05 FTE
Alexander Kirsanov	0.1 FTE

Total: **2.35 FTE**