ACCORD flat-rate stay report

Study of the cloud's microphysics sensitivity and atmospheric precipitation by taking into account the atmospheric aerosols impact using the 1D MUSC model.

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Aim of my scientific visit was to analyze the 1D HARMONIE-AROME cy46h1 model version sensitivity of aerosol interaction on atmospheric precipitation and cloud microphysics. HARMONIE-AROME model cy46h1 included changes of Daniel Martin in microphysics ICE3 and radiation scheme.

Information of aerosols mass mixing ratio used in the research comes from two different sources:
- monthly climatological data - Tegen climatology [1]
- CAMS global near-real time (NRT) service - daily analyses and forecasts of reactive trace gases, greenhouse gases and aerosol concentrations [2]

Application of the near-real time aerosol mass mixing ratio into weather numerical models of ACCORD consortium were aimed to improve spatial and horizontal resolution of aerosols distribution but also take into account their impact on cloud microphysics.

New HARMONIE-AROME model branch was compiled on local laptops on linux system. At first attempt were used containers prepared by Eoin Whelan [3]. Due to some problems with running test cases on local computers model was compiled by using different configuration file prepared for some linux systems (eg. Debian, Ubuntu, Fedora). Model sensitivity studies and boundary data extraction were conducted at ECMWF supercomputer. Additionally, the new model branch was compiled on a polish supercomputer, however some problems occurred during the running the test cases.

In the report are presented MUSC experiment setups for the two days. Source code used in the study comes from Daniel's branch based on code version cy46h1, MUSC input data were obtained from 3D real experiments of HARMONIE-AROME model. Data extracted from 3D real experiments for MUSC experiment included atmospheric forcing, surface and constant surface properties, and aerosol distribution from CAMS.

1) Day 1 - 19 April 2021, during this day sky was clear and aerosol concentration was low
2) Day 2 – 23 February 2021, Saharan dust intrusion to Finland, cloudy and rainy day

The first case study was used to compare the differences in aerosol vertical distribution in different data sources and their impact on the radiation exchange processes by using HARMONIE-AROME model with two radiation schemes:

- radiation scheme from IFS cycle 25 (Foucault-Morcrette) – default configuration
- radiation scheme ACRANEB2, operationally used ALARO model.

For two model configurations were prepared three different initial conditions:

- aerosols are not present in the atmosphere (shortcut no aerosols)
- aerosols distribution is calculated by using monthly climatological data - Tegen aerosol optical depth at 550 nm (AOD550) of 6 aerosol species (shortcut Tegen)
- aerosols distribution is calculated by using near-real time mass mixing ration (MMR) of 14 aerosol species using the new aerosol inherent properties from ECMWF (shortcut n.r.t. MMR) [4].

In the study were used six different control experiments – two different model configurations and three types of initial data. The same control experiments were prepared for the date 23 February 2021.

For the two selected days were also tested new process of aerosol interaction on atmospheric precipitation and cloud microphysics introduced in HARMONIE-AROME model with use of near-real time MMR database and radiation scheme from IFS cycle 25 (Foucault-Morcrette).

New variables in the atmospheric namelist were added in section NAMNRTAER. Detailed description of new variables and their sensitivity tests are presented in Section 2. Day 1 (19 April 2021) was used to check the correctness of the results for the period where the influence of clouds and aerosol spatial distribution was negligible on the longwave and shortwave radiation fluxes. The day 2, during which occurred Saharan dust intrusion was studied in detail due to the significant role of the dust in ice nucleation within clouds. For this case the parametrization of ice nuclei was switched on.

1. Comparison of impact of different sources of aerosol mass mixing ration on radiation exchange in cy46h1.

First case studies were aimed to compare the impact of aerosol vertical distribution on the radiation exchange process by using radiation scheme from IFS cycle 25 (Foucault-Morcrette) and ACRANEB2. Six control experiments were analyzed:

- atmosphere without aerosols and radiation scheme from IFS cycle 25 (shortcut **ez**)
- Tegen aerosol optical depth and radiation scheme from IFS cycle 25 (shortcut **et**)
- near-real time mass mixing ration (MMR) and radiation scheme from IFS cycle 25 (shortcut **en**)
- atmosphere without aerosols and radiation scheme ACRANEB2 (shortcut **az**)
- Tegen aerosol optical depth and radiation scheme ACRANEB2 (shortcut **at**)
- near-real time mass mixing ration (MMR) and radiation scheme ACRANEB2 (shortcut **an**)

Figures 1 and 2 presents differences in net shortwave and longwave radiation between no aerosols and Tegen, no aerosols and near-real time MMR and near-real time MMR and Tegen for two different model configurations. The simulation started at 6 UTC and the length of forecasts was equal to 3 hours. Comparison of results by using two different model configurations for three different initial conditions have shown similar results. Significantly greater values of mass mixing ratio were obtained for Tegen climatological in comparison with near-real time databases, which in result affected on reduction of net shortwave radiation.

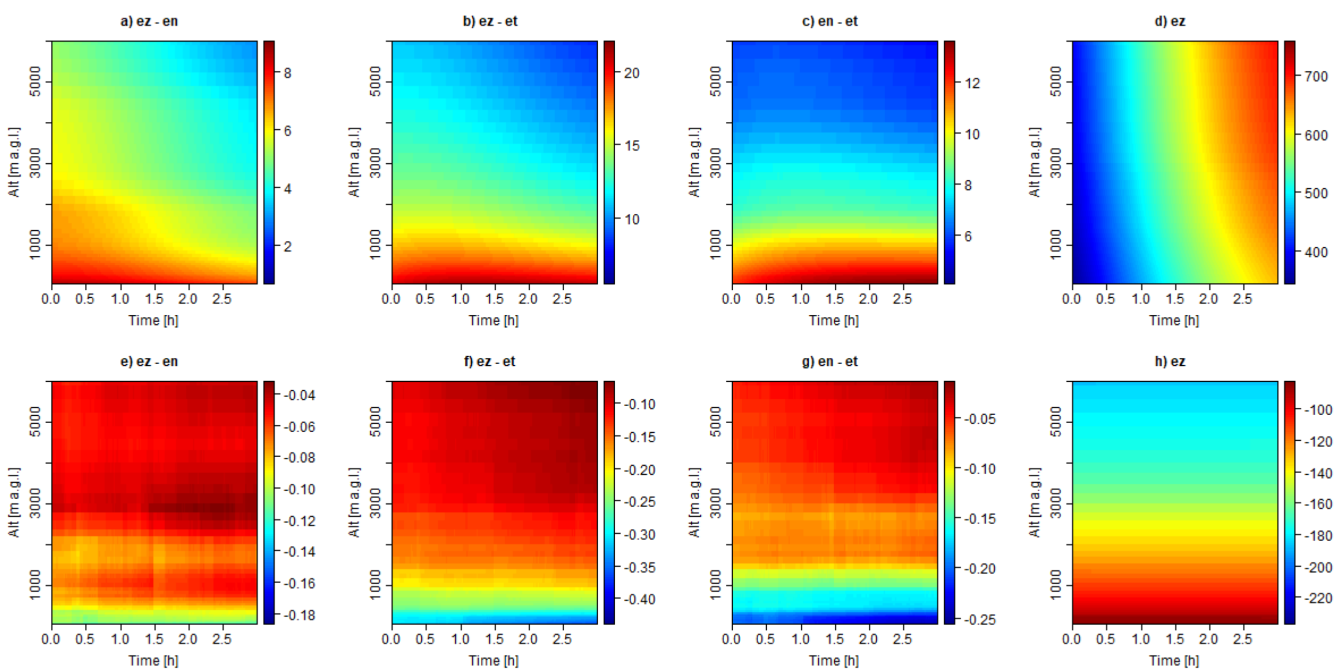

Figure 1. Difference of net shortwave (upper row) and longwave (lower row) radiation fluxes between no aerosols and n.r.t. MMR (first column), no aerosols and Tegen (second column) n.r.t. MMR and Tegen (third column) by using radiation scheme from IFS cycle 25 at 19.04.2021. At figures d) and h) are presented respectively net shortwave and longwave radiation fluxes with no aerosols by using radiation scheme from IFS cycle 25 at 19.04.2021

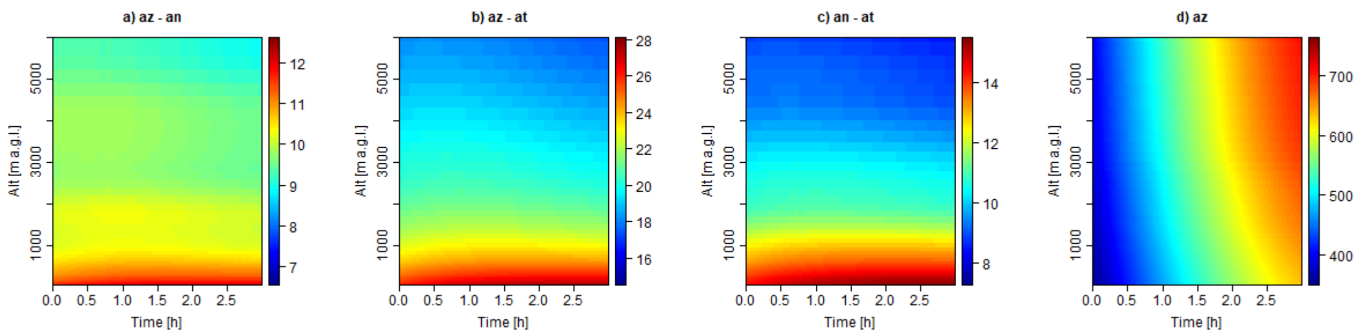

Figure 2. Difference of net shortwave radiation fluxes between a) no aerosols and n.r.t. MMR and b) no aerosols and Tegen c) n.r.t. MMR and Tegen by using radiation scheme ACRANEB2 at 19.04.2021. At figure d) is presented net shortwave radiation flux with no aerosols by using radiation scheme ACRANEB2 at 19.04.2021.

Differences between two radiation schemes for three different initial conditions were negligible, for the net shortwave flux maximum difference was equal to 10 $W \cdot m^{-2}$ above 8000 m a.g.l. for conditions without aerosols (Fig. 3 c). Model results with initial conditions including aerosols in the atmosphere were similar, absolute differences in layer up to 1000 m a.g.l. did not exceed 3 $W \cdot m^{-2}$.

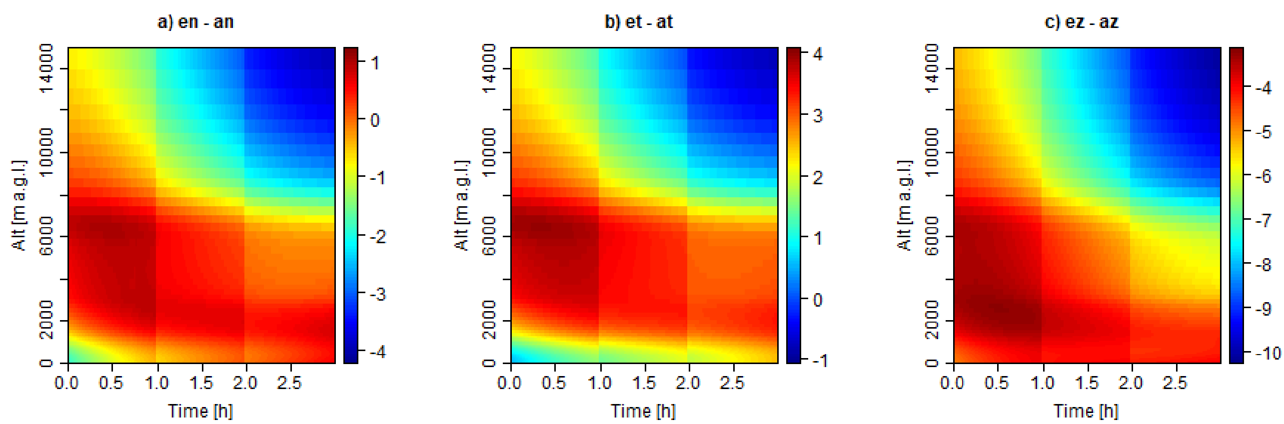

Figure 3. Difference of net shortwave radiation fluxes between model with radiation scheme from IFS cycle 25 and ACRANEB2 for case with a) n.r.t. MMR, b) Tegen and c) no aerosols at 19.04.2021.

2. Studies of aerosol impact on microphysics and radiation exchange during the cloudless day

For the first case study period (19.04.2021) were tested new variables in the atmospheric namelist in section NAMNRTAER provided by Daniel Martin. These variables control the use of near real time aerosols in the HARMONIE-AROME model in radiation and microphysics schemes. In the all tested configurations were used near-real time MMR database and radiation scheme from IFS cycle 25 (Foucault-Morcrette).

- LCAMS_NRT: switch on the use of CAMS aerosols in HARMONIE-AROME
- LAEPHY: To activate the use of near real time aerosols in the microphysics
- LAERAD: To activate the use of n.r.t. in the radiation scheme
- LAERDROP: Permits to use CDNC from n.r.t. aerosols to calculate the effective radius in the radiation scheme.
- LAEREM: Switch on the parametrization for the removal of aerosols
- CCNMIN: Minimum number concentration of Cloud Condensation Nuclei (CCN) inside the cloud
- CLDROPMIN: Minimum CDNC inside the cloud.

- SSMIN: Supersaturation at surface level (default value 0.05%)
- SSMAX: Supersaturation over 100 m height (default value 0.08%)
- LMOCA_NRT: In case of getting the aerosol fields from MOCAGE (still not in use).
- LAEIFN: To activate Ice nuclei
- LAERDRDEP: Activates the aerosol deposition
- LAECCN2CLDR: By default (LAECCN2CLDR=FALSE) we have CDNC=CCN. From the aerosol MMR the CCN is calculated, and it is considered equivalent to CDNC. Due to all the processes, there is no direct relationship between CDNC and CCN, but it was found a formula to get CDNC from CCN (It mainly avoids a high number of CDNC when the number of CCN is too high), that can be used if this switch is activated.

Default values:
LCAMS_NRT=.TRUE.,
LMOCA_NRT=.FALSE.,
LAEPHY=.TRUE.,
LAECCN2CLDR=.FALSE.,
LAEIFN=.FALSE.,
LAERAD=.TRUE.,
LAERDROP=.TRUE.,
LAEREM=.TRUE.,
LAERDRDEP=.FALSE.,
CCNMIN='10.0E6',
SSMIN='0.05E-2',
SSMAX='0.08E-2',
CLDROPMIN='10.0E6',

In aim to analyze effect of different configurations on 1D model forecast, were created 10 possible configurations listed below (named as **nrt0**, **nrt1**, **nrt2**…**nrt10**). Comparison of obtained results have shown that forecast results are almost the same for selected case (not shown in the report). In analysis were used net radiation fluxes (variables PFRSO, PFRTH), specific cloud ice and liquid water content (variables PQI, PQL) and liquid water path and ice water path (variables LWP and IWP). As reference was used default model configuration named as **nrt0.**

In all cases the variable LCAMS_NRT was set to TRUE.

Configuration 1
LAERDRDEP=.TRUE.,

Configuration 2
LAEREM=.FALSE.,

Configuration 3
SSMIN=0.02E-2,

Configuration 4
SSMAX=0.2E-2,
SSMIN=0.02E-2,

Configuration 5
CCNMIN=1.0E6,
CLDROPMIN=10.0E6,

Configuration 6

CCNMIN=10.0E6,
CLDROPMIN=30.0E6,

Configuration 7
CCNMIN=1.0E6,
CLDROPMIN=30.0E6,

Configuration 8
CCNMIN=1.0E6,
CLDROPMIN=30.0E6,
LAECCN2CLDR=.TRUE.,

Configuration 9
LAEPHY=.FALSE.,

Configuration 10
LAEIFN=.TRUE.,

3. Studies of aerosol impact on microphysics and radiation exchange during the cloudy day with Saharan dust advection - 23 February 2021

In aim to analyze impact of aerosol mass mixing ratio on cloud microphysics and radiation was selected period when Saharan dust was transported over Finland. For the day 23 February 2021 were prepared initial and boundary data for 1D HARMONIE-AROME model. As part of the analysis, 6 control experiments were studied:
- atmosphere without aerosols and radiation scheme from IFS cycle 25 (shortcut **ez**)
- Tegen aerosol optical depth and radiation scheme from IFS cycle 25 (shortcut **et**)
- near-real time mass mixing ration (MMR) and radiation scheme from IFS cycle 25 (shortcut **en**)
- atmosphere without aerosols and radiation scheme ACRANEB2 (shortcut **az**)
- Tegen aerosol optical depth and radiation scheme ACRANEB2 (shortcut **at**)
- near-real time mass mixing ration (MMR) and radiation scheme ACRANEB2 (shortcut **an**)

Study of 6 basic configurations

At Figures 4-6 are presented differences of longwave and shortwave net fluxes, and liquid water content between three different initial conditions for two radiation schemes on 23 February 2021. At the first columns from the right side are presented spatial distribution of selected variables for conditions without aerosols in the atmosphere for both model configurations.

Analysis of shortwave fluxes presented at Figure 4 has shown that differences in lower troposphere up to 5000 m a.g.l. between conditions without aerosols and with use of n.r.t. MMR database are greater for radiation scheme ACRANEB2 than for IFS cy25.

Introducing the aerosols in the boundary conditions affected on cloud microphysics, the thin layer of liquid water content can be observed at altitude close to 1000 m a.g.l. for experiment with n.r.t. MMR for both model configurations (Figure 6). Increased concentration of liquid water content around 1000 m a.g.l. for conditions with use of n.r.t. MMR database may be caused by local peak of mass mixing ratio of hydrophilic organic matter, sea salt with diameter 0.5-5μm close to this level (Figure 7).
Direct effect of increased liquid water content is noticeable on differences net longwave radiation fluxes for model configuration with IFS cy25 radiation scheme (Fig 5 e)

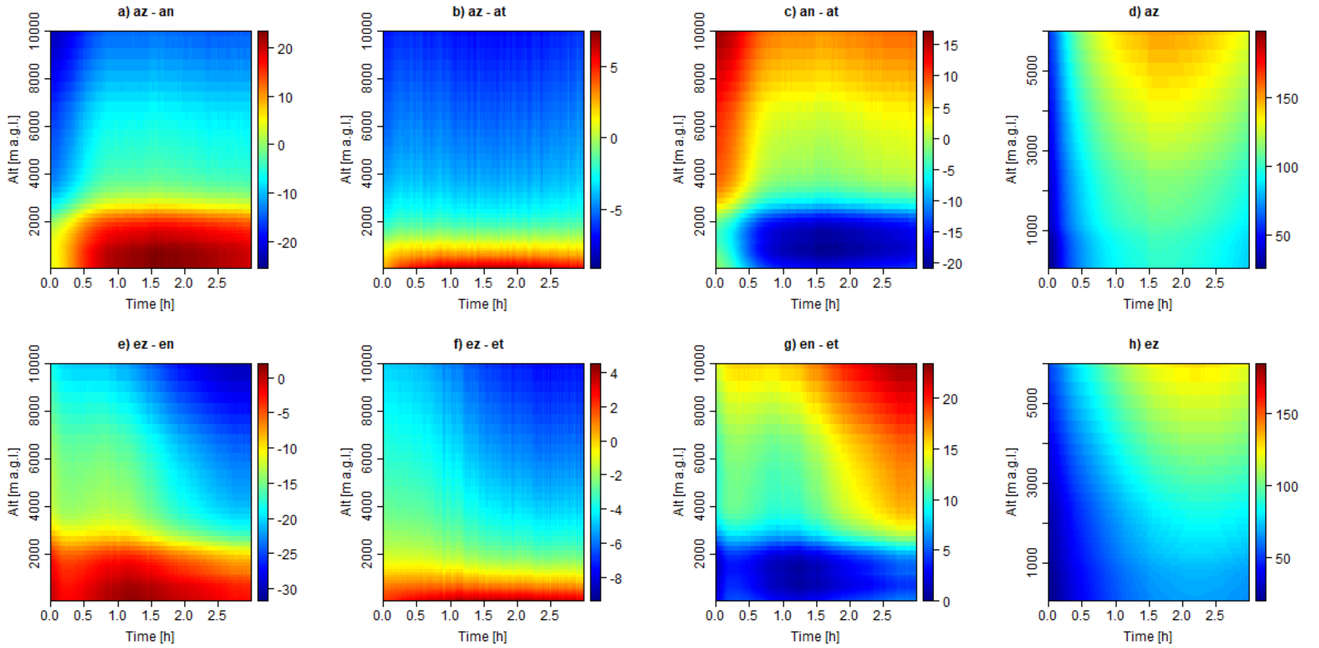

Figure 4. Difference of net shortwave radiation fluxes between no aerosols and n.r.t. MMR, no aerosols and Tegen, n.r.t. MMR and Tegen by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021. At figures d) and h) are presented net shortwave radiation fluxes with no aerosols by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021.

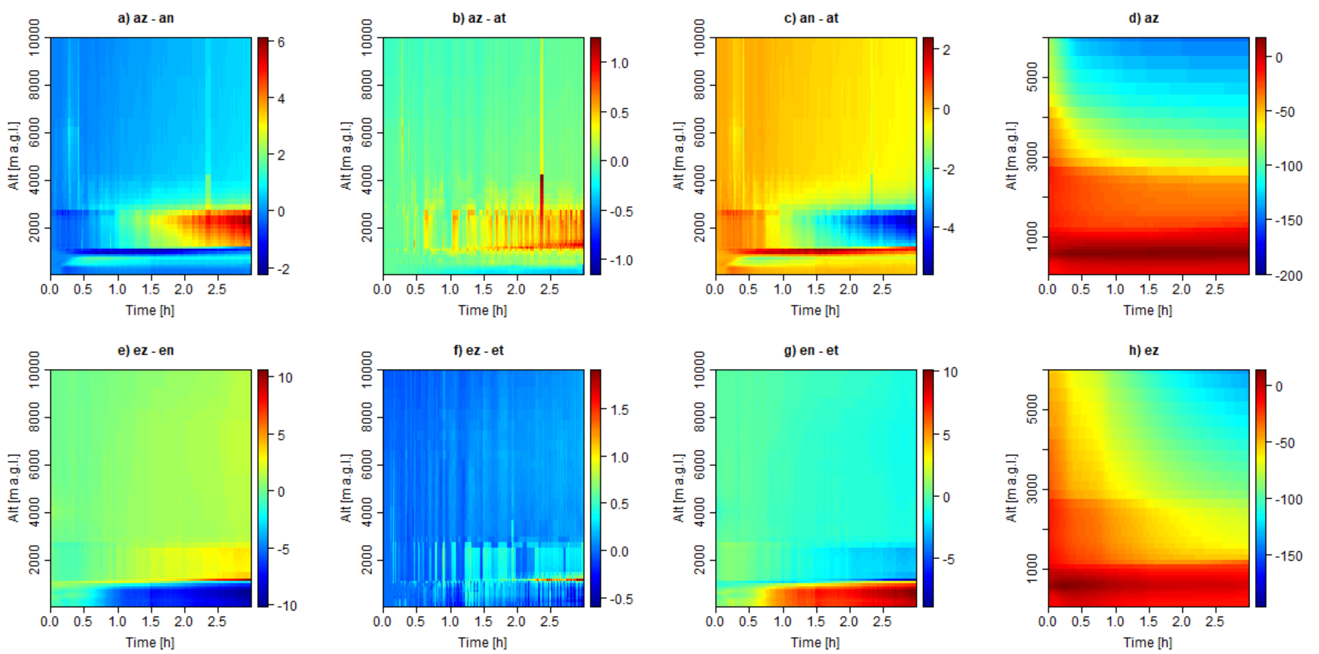

Figure 5. Difference of net longwave radiation fluxes between no aerosols and n.r.t. MMR, no aerosols and Tegen, n.r.t. MMR and Tegen by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021. At figures d) and h) are presented net longwave radiation fluxes with no aerosols by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021.

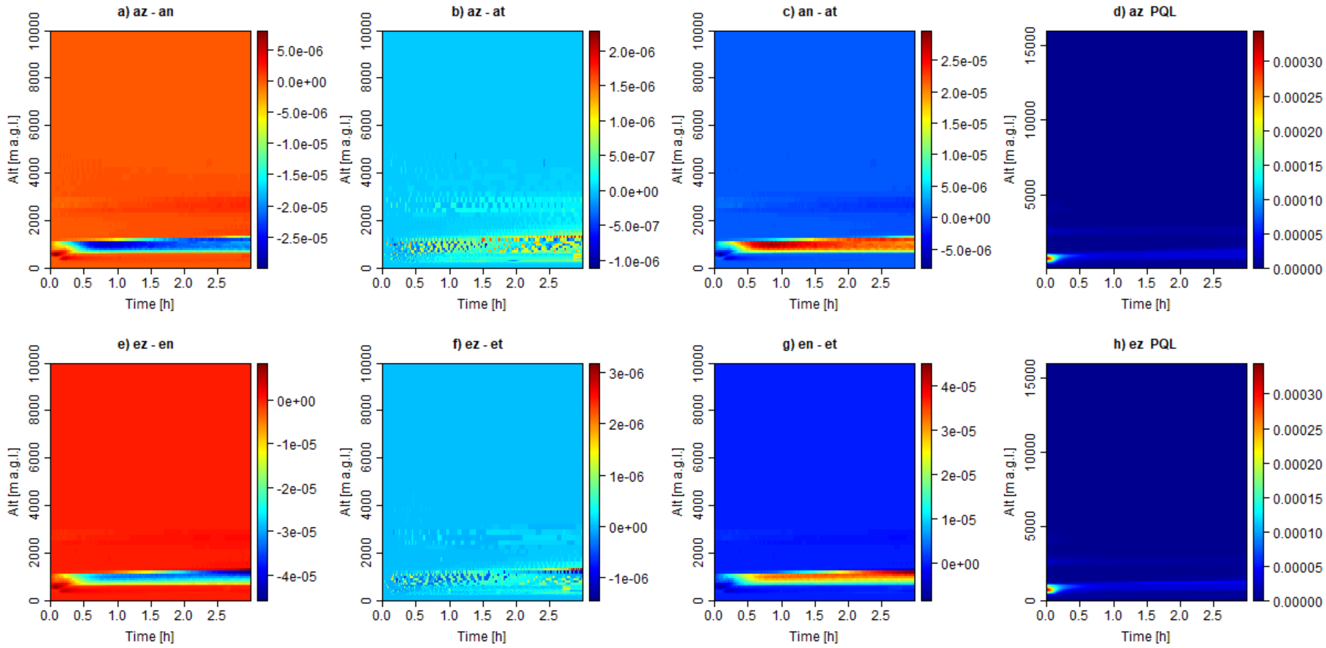

Figure 6. Difference of liquid water content between no aerosols and n.r.t. MMR, no aerosols and Tegen, n.r.t. MMR and Tegen by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021. At figures d) and h) are presented liquid water content with no aerosols by using radiation scheme ACRANEB2 (upper row) and IFS cycle 25 (lower row) at 23.02.2021.

- **Study of model sensitivity –10 configurations**

Model configuration with radiation scheme from IFS cycle 25 and near-real time aerosol data was further investigated to estimate sensitivity of cloud microphysics on aerosols introduced by Daniel Martin. Configurations from 1 to 10 presented in section 2 were studied in detail.

Below are presented comparison of results for the day when occurred advection of Saharan dust over Finland (23 February 2021) presented at Figure 7 b). It's worth to mention that maximum value of mass mixing ratio in layer up to 5000 m a.g.l. of dust particles (with optical diameter in range from 0.9 to 20 μm) during this day was two orders of magnitude greater than any of the other aerosol species. Dust particles influences only on the ice formation, due to this fact parametrization using Ice nuclei was switched on (configuration 10).

The strongest differences in radiation budget between results from reference model were observed for configuration 4 (SSMAX=0.2E-2 (default 0.10E-2)) and configuration 10 (LAEIFN=.TRUE.,) (Figures 8 and 9). Increased value of supersaturation over 100 m height caused increase the Cloud Condensation Nuclei and the Cloud Droplet Number Concentration (Figure 10). For the configuration 10 activation of ice nuclei caused sudden change of specific cloud ice water content during the first 30 minutes of the forecast (Fig 11), after the half an hour of the forecast, Ice Water Path stabilized (Figure 12).

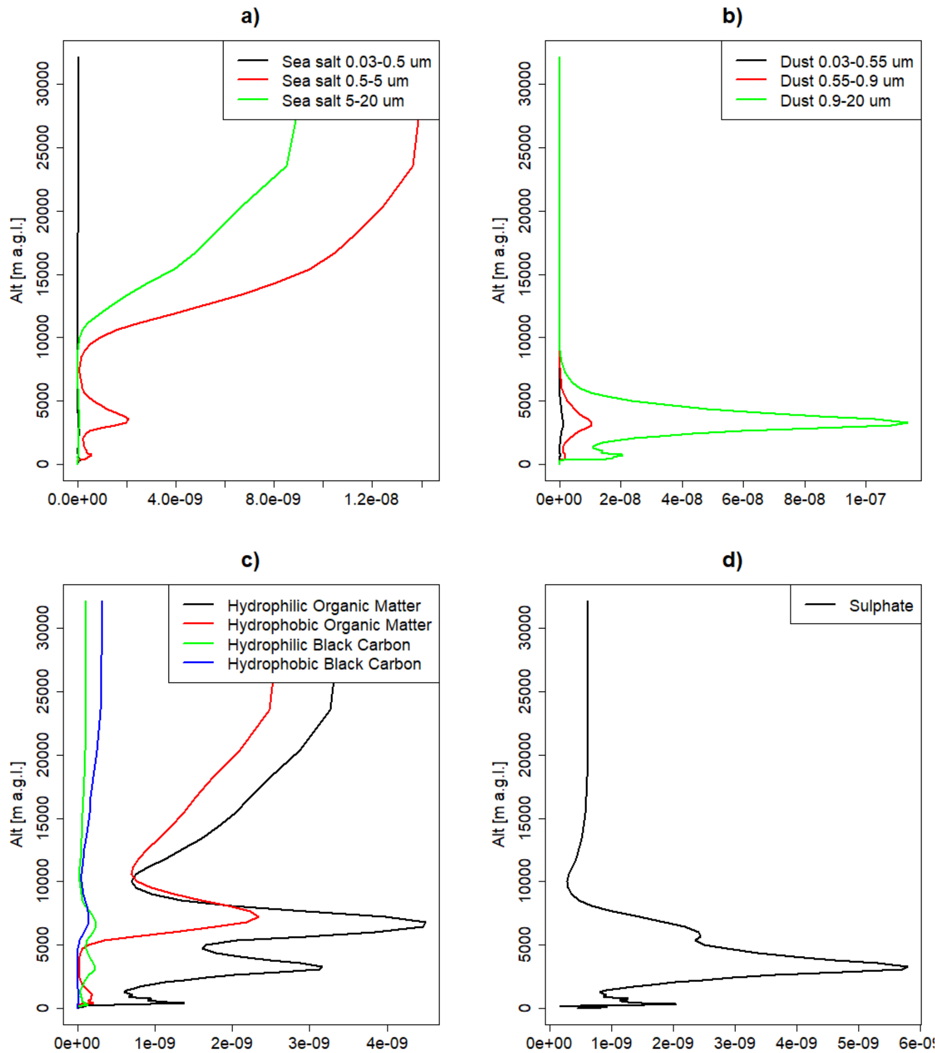

Figure 7. Mass mixing ration vertical profile of a) sea salt b) dust c) organic matter and black carbon d) sulphate on 23 February 2021 (unit kg/kg).

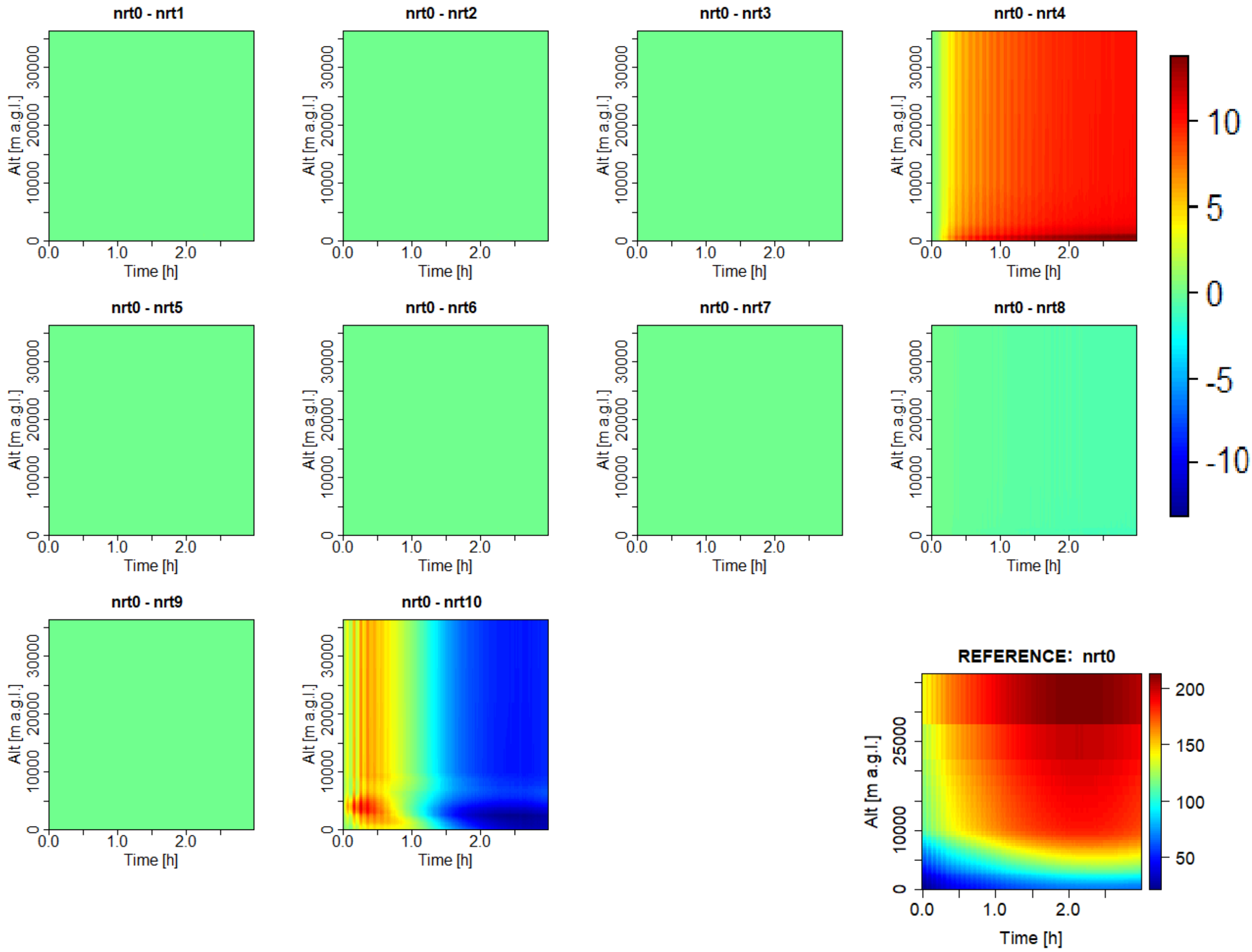

Figure 8. Difference of shortwave radiation fluxes between reference model configuration (nrt0) and 10 different configurations (named as nrt1…nrt10) described in detail in section 2 at 23.02.2021. At right bottom plot is presented shortwave radiation fluxes for reference model configuration (nrt0) at 23.02.2021.

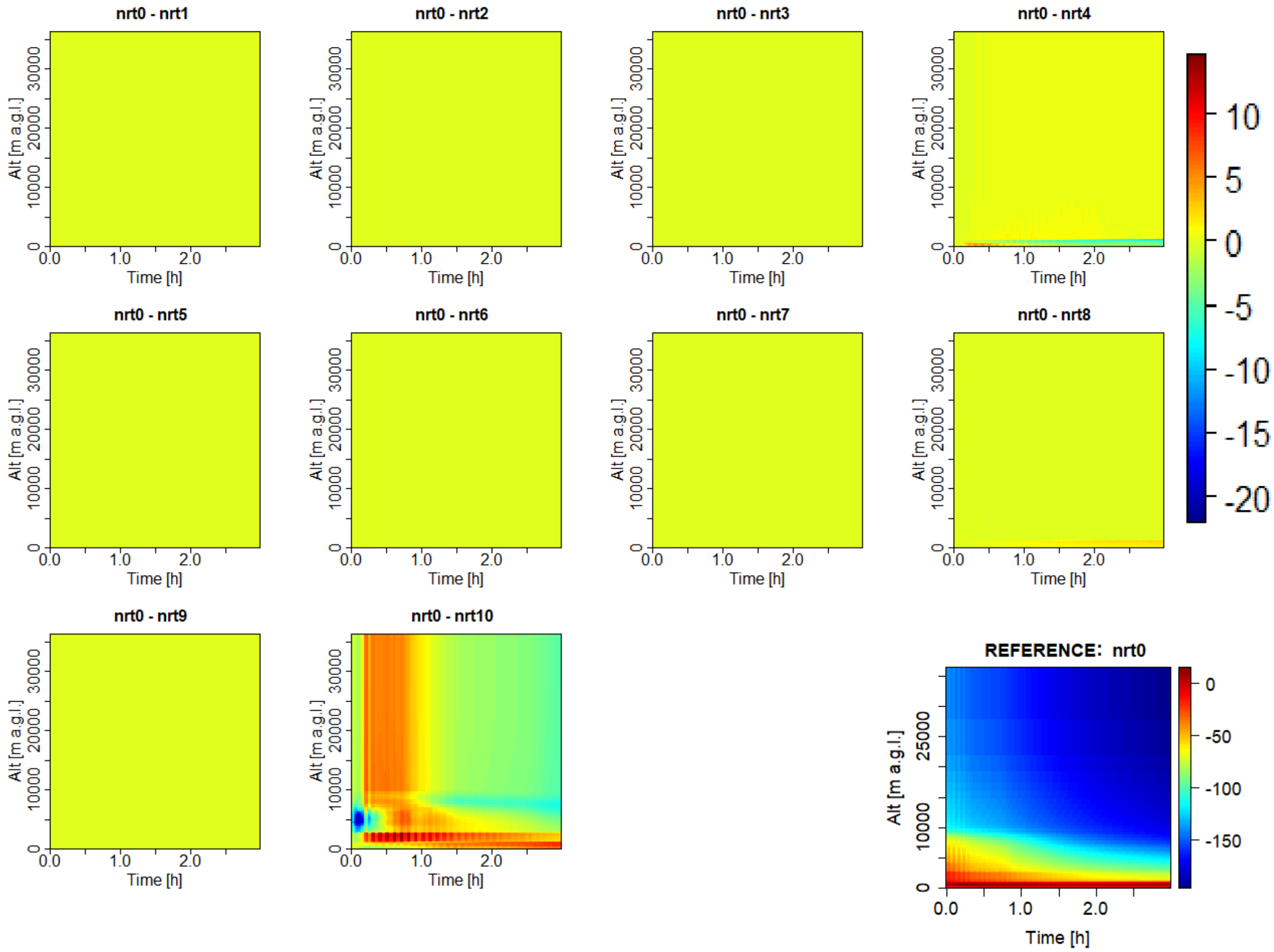

Figure 9. Difference of longwave radiation fluxes between reference model configuration (nrt0) and 10 different configurations (named as nrt1…nrt10) described in detail in section 2 at 23.02.2021. At right bottom plot is presented longwave radiation fluxes for reference model configuration (nrt0) at 23.02.2021.

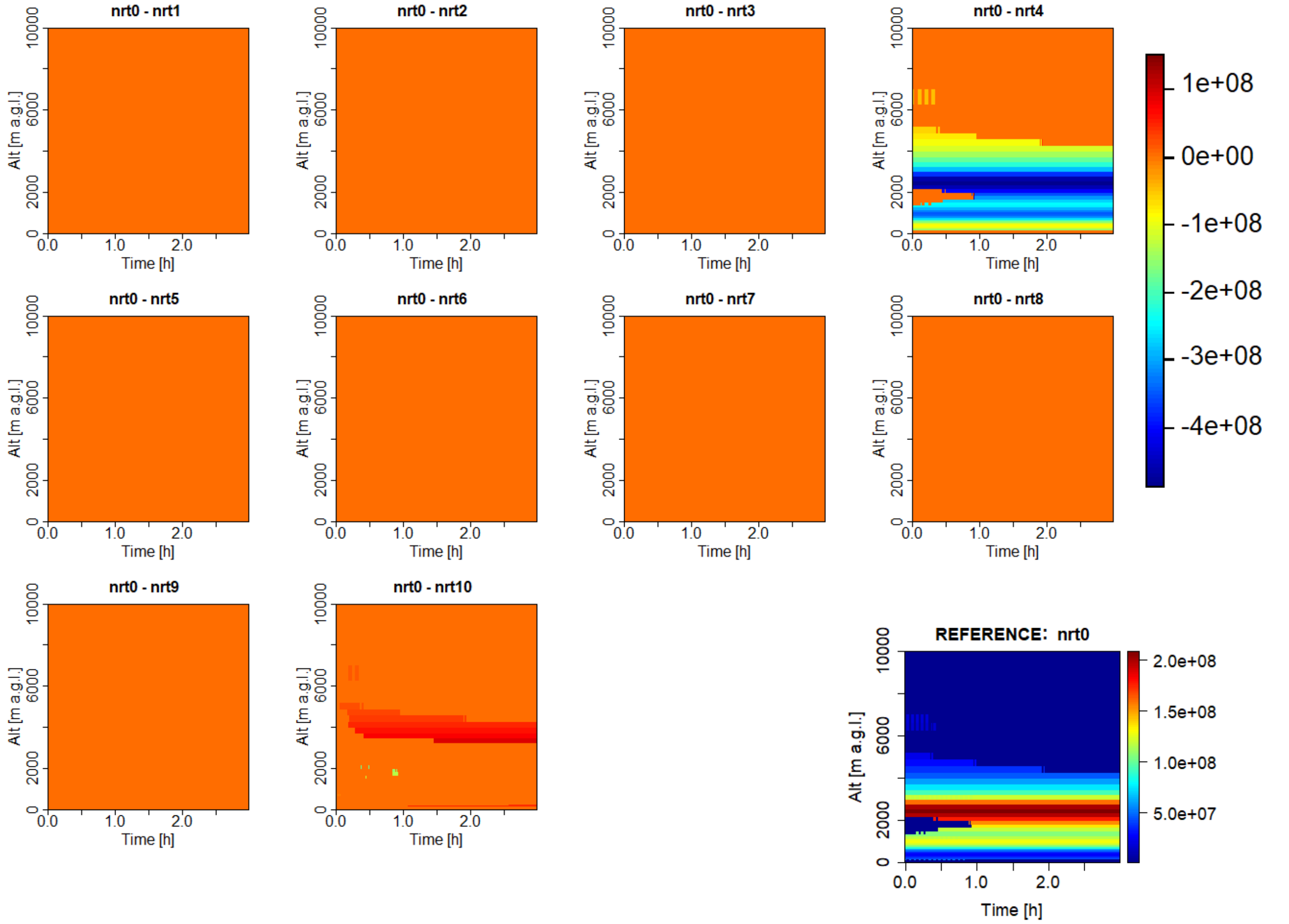

Figure 10. Difference of Cloud Condensation Nuclei between reference model configuration (nrt0) and 10 different configurations (named as nrt1…nrt10) described in detail in section 2 at 23.02.2021. At right bottom plot is presented Cloud Condensation Nuclei for reference model configuration (nrt0) at 23.02.2021.

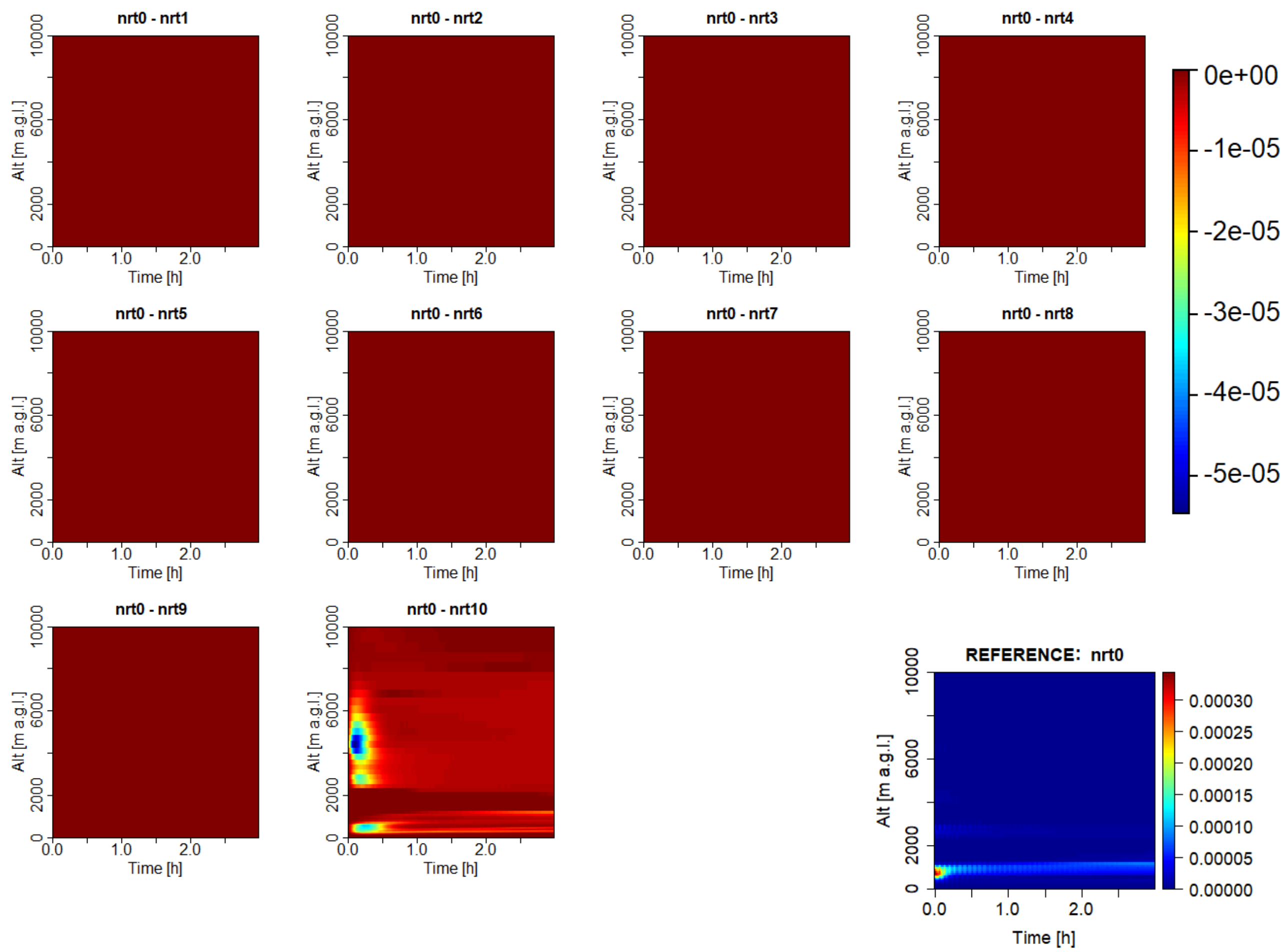

Figure 11. Difference of specific cloud ice water content between reference model configuration (nrt0) and 10 different configurations (named as nrt1…nrt10) described in detail in section 2 at 23.02.2021. At right bottom plot is presented Cloud Condensation Nuclei for reference model configuration (nrt0) at 23.02.2021.

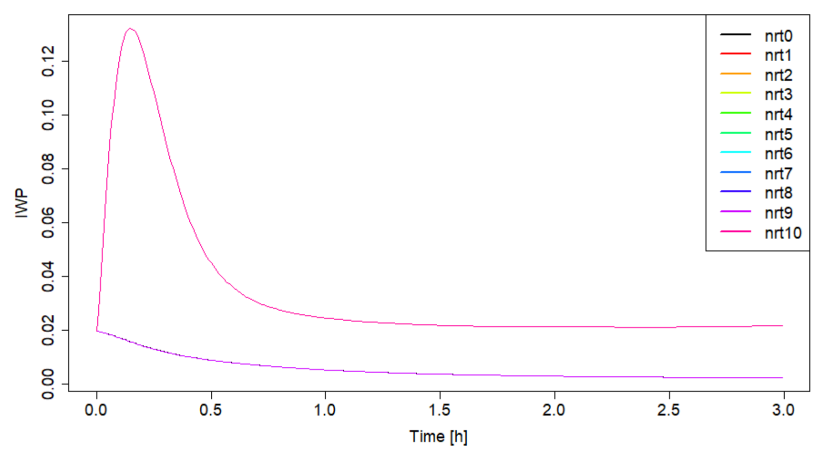

Figure 12. Time course of Ice Water Path for reference model configuration (nrt0) and 10 different configurations (named as nrt1…nrt10) at 23.02.2021.

4. Plotting tool for lfa files

In aim to analyze obtained results were prepared two scripts (Shell script and R script). The first script was used to extract data from lfa files by using DDH toolbox available at:
https://www.umr-cnrm.fr/gmapdoc/spip.php?article19&lang=en

The script extract selected variables from each lfa file separately to the text files. The name of text files consists of name of variable and order of output lfa file. The Shell script also creates file which contain list of model variables available in the output file and list of altitude model levels.

Model output saved to the text files were read to R environment by using RStudio. In aim to plot 2D results function image2D available in package plot3D in R was used. In the plotting script was included fact that dimensions of analyzed variables may differs (dimension of PFRTH and PQI differs by 1; variables LWP IWP CWP are one dimensional).

Instruction to the plotting system and scripts with example results are available at HIRLAM wiki page.

4. Comparison of aerosol concentration with SILAM model

Vertical profiles of dust concentration at 23.02.2021 used in MUSC simulation obtained from CAMS/IFS-chemical model were compared with forecast of SILAM model. SILAM model is global-to-meso-scale dispersion model developed by Finnish Meteorological Institute. Dust particles in SILAM model are divided into four bins based on the aerosol optical depth: 0.01-1µm, 1-2.5µm, 2.5-10µm, 10-30µm. Mass extinction for selected groups of dust particles equals respectively 2496.6 m^2/kg, 826.98 m^2/kg, 239.72 m^2/kg and 66.794 m^2/kg. In CAMS/IFS-chemical model dust particles are divided into three groups: 0.03-0.05µm, 0.55-0.9µm and 0.9-20µm. Mass extinction (m^2/kg) for selected groups equal respectively 2500 m^2/kg,1000 m^2/kg and 400 m^2/kg. Due to the fact that vertical resolution (28 vertical levels in SILAM and 65 vertical levels in HARMONIE-AROME model) and units of aerosol concentration in both models are different some calculations were necessary. Dust concentrations in SILAM model are saved in fields cnc_dust_m_30, cnc_dust_m1_50, cnc_dust_m6_0, cnc_dust_m20, the units are kg/m^3. In HARMONIE-AROME model dust concentrations are provided in fields ZZIAERM-4, ZZIAERM-5 and ZZIAERM-6, where the units are kg/kg.

In aim to compare results from both models to model HARMONIE-AROME additional fields representing dust were added to the source code by Laura Rontu. Comparison of both models were done by conversion of kg/m^3 into optical density (1/m). Dust optical density for SILAM model was obtained by multiplying dust concentration (e.g. filed cnc_dust_m_30; unit kg/m^3) by mass extinction (unit m^2/kg).

Spatial concentration of dust particles for models SILAM and CAMS/IFS-chemical for selected case differed therefore at figure 13 is presented vertical plots of dust optical density from MUSC and SILAM models for two locations: Harmaja (60.109 N, 24.951 E) and Tampere (61.493 N, 23.785 E). Range of the maximum values are close which confirms correctness of calculations. It is worth to mention that maximum height of dust optical density is different for both models (ca. 3000 m a.g.l. for CAMS/IFS and 6000 m a.g.l. for SILAM).

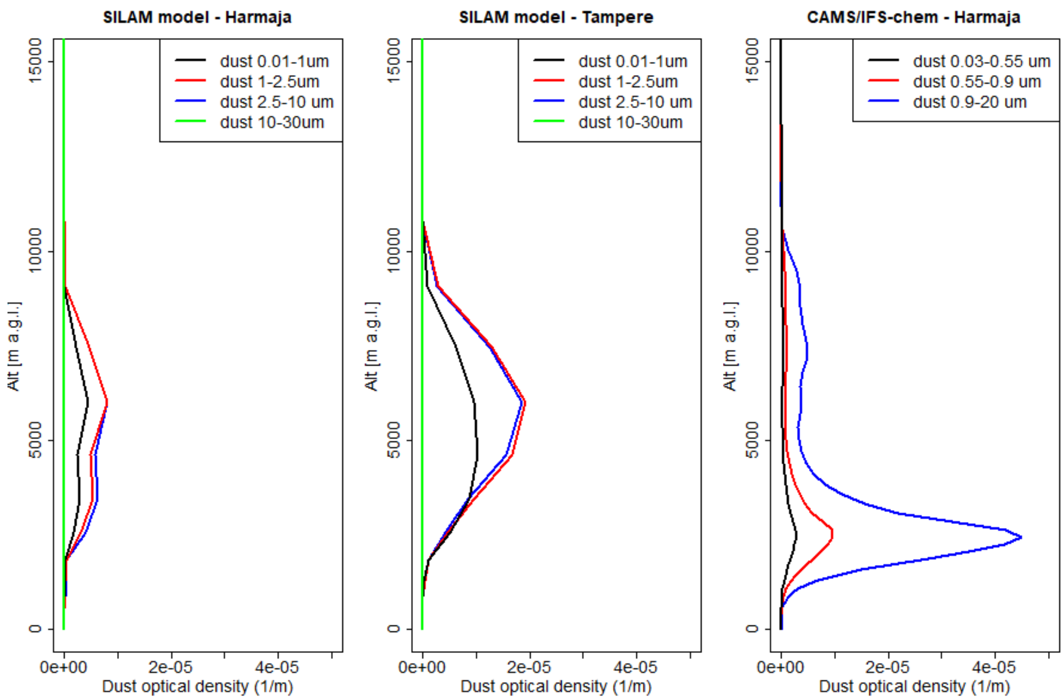

Figure 13. Aerosol density at 9 UTC 23.02.2021 for two locations Harmaja (60.109 N, 24.951 E) and Tampere (61.493 N, 23.785 E) from SILAM and CAMS/IFS-chemical models.

In aim to obtain dust aerosol optical depth (AOD), dust concentrations from SILAM model were converted to mass of dust [kg/m2]. For this purpose, dust concentration (e.g. filed cnc_dust_m_30; unit kg/m3) were multiplied by dp/dg which can be expressed as:

$$dp/g = -(da \cdot ps + db)/g$$

where:
da – layer increment of 'A' coefficients
db – layer increment of 'A' coefficients
ps – atmospheric pressure at the ground level [Pa]
g – gravity acceleration [9.81 m/s]

After conversion of dust from kg/m^3 to kg/m^2 each bin was multiplied by mass extinction separately and then summed for all vertical levels. Total dust AOD was obtained by summing values of four bins into one field. At figure 14 is presented total AOD for all four dust bins at 9 UTC 23.02.2021 from SILAM model.

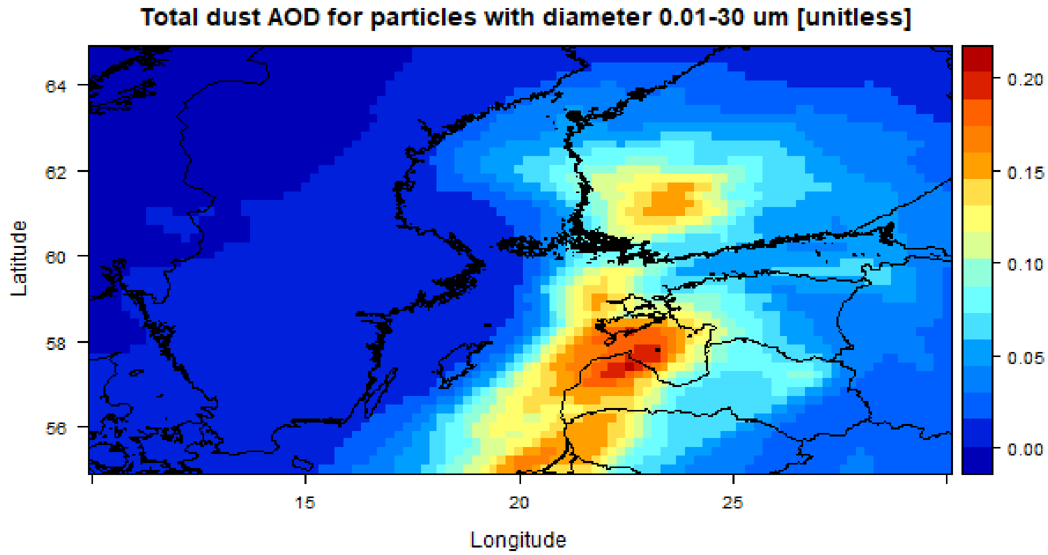

Figure 14. Total AOD for all four dust bins at 9 UTC 23.02.2021 from SILAM model.

[1] Tegen, I., Hoorig, P., Chin, M., Fung, I., Jacob, D., and Penner, J.: Contribution of different aerosol species to the global aerosol extinction optical thickness: Estimates from model results, J. Geophys. Res., 102, 23895–23915, 1997.

[2] http://atmosphere.copernicus.eu, CAMS

[3] https://hirlam.org/trac/wiki/Meetings/Physics/MUSCWW21

[4] Bozzo, A.; Benedetti, A.; Flemming, J.; Kipling, Z.; Remy, S. An aerosol climatology for global models based on the tropospheric aerosol scheme in the Integrated Forecasting System of ECMWF. Geoscientific Model Development 2020, 13, 1007-1034, doi:10.5194/gmd-13-1007-2020.