Stay report

Desert dusts aerosols and microphysics interaction in AROME:

Initialization of ice freezing nuclei in LIMA scheme.

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Content:

Introduction:

The present work aims to investigate the desert dust aerosol interaction with microphysics in AROME. In order to tackle this study, the following plan had been set up:

- Activation of dusts module in AROME based on CY46T1_bf.02 and validation comparing to CY43T2_bf.09;

- Separation of dusts modes and recovering of number concentrations for only two modes: coarse and medium;

- Running AROME with LIMA and initialization of ice freezing nuclei (IFN) by dusts concentrations (only the two recovered modes from the previous step);

- Perform several sensitivity tests on a particular case study over Southern Algeria (severe situation with dusts and convection);

- Running AROME_Dust with LIMA at the same time (Not yet completed);

This report is devoted to the description of all those tasks, encountered issues and main results.

1- About dusts in LIMA:

The impact of aerosols on climate and the mechanism of its interactions have been widely discussed. In microphysics, aerosols could act as cloud condensation nuclei (CCN) and/or as ice freezing nuclei (IFN). LIMA (Liquid Ice Multiple Aerosols) is a two moment microphysical scheme, with several aerosols modes (Tab.01) of cloud condensation nuclei and ice freezing nuclei that are considered individually (B. Vié et al.,2016). For size distribution, a log-normal approach is used by LIMA (eq.01).

Tab.01: Aerosols classification and properties in LIMA scheme (Source : T.Hoarau, 2018)

Class	Types and modes	Ơ	r_m (µm)
CCN	Sea salt	1.9	0.4
	Sulfate	1.6	0.25
	Organics & black carbon (hydrophilic)	1.6	0.1
IFN (coated)	Organics & black carbon (hydrophobic)	1.6	0.1
IFN	Dust	1.9	0.4

$$g(D) = \frac{1}{\sqrt{2\pi}\sigma D} e^{-\left(\frac{\log(\lambda D)}{\sqrt{2}\sigma}\right)^2} \qquad \text{(eq.01)}$$

For AROME_Dust, 3 modes are considered with also a log-normal size distribution (M.Mokhtari et al., 2012) : coarse mode, medium mode and fine mode (Tab.02).

Tab.01: Log-normal parameters of desert dusts size distribution (AMMA) used in AROME_Dust (Source : M.Mokhtari et al., 2012)

Dust mode	Mode 1	Mode 2	Mode 3
Number fraction (%)	97.52	1.95	0.52
Mass fraction (%)	0.08	0.92	99
Geometric standard deviation	1.75	1.76	1.70
Number median diameter (μm)	0.078	0.64	5.0
Mass median diameter (μm)	0.20	1.67	11.6

Basically, CCN and IFN are given constant values during all the process. In this study, since the desert dust aerosols are considered as IFN in LIMA, we'll use AROME dusts outputs to initialize LIMA IFN fields (Fig.01), after that we'll try putting both dusts module and LIMA in AROME in order to get dusts at each timestep for LIMA.

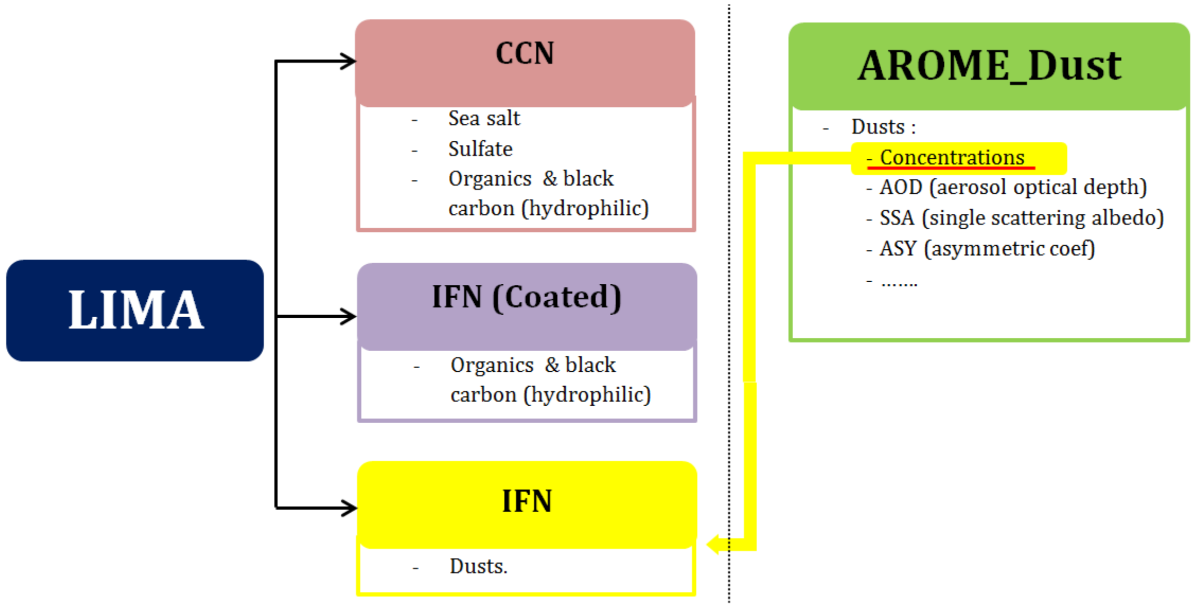

Fig.01: LIMA aerosols types and dust initialization from AROME_Dust.

2- Activation of desert dusts module in CY46T1.bf02:

2-1- Namelist update:

The last validated configuration of AROME_Dust is based on CY43T2_bf.04 (Mokhtari, 2018) and CY43T2_bf.09 (available at Météo Algérie HPC). Thus, the first task was to activate dusts module in AROME based on CY46T1_bf.02, and make sure that it works by comparing the result with CY43T2_bf.09.

The activation of dusts in AROME is done by switching on the dust keys in E001 namelist at the NAMARPHY block as follow (in red):

```
&NAMARPHY
  LRDEPOS=.TRUE.,
  LRDUST=.TRUE.,
```

Then, we need to add the dust related variables at the NAMGFL block, we have 9 passive scalar and 9 diagnostics (Tab.03). We must mentioned that dusts incorporated in rain (DEDSTEM3*R) and clouds (DEDSTEM3*C) are set for deposition process (in case LRDEPOS=TRUE). If not (LRDEPOS=FALSE), YEXT_NL table dimension will be 3, because it contains only the DSTM3* of the three modes.

Tab.03: AROME_Dust passive scalar et diagnostics.

&NAMGFL	
NGFL_EXT	
DSTM33	dusts of mode 3
DSTM32	dusts of mode 2
DSTM31	dusts of mode 1
DEDSTM33R	dusts of mode 3 incorporated in rain
DEDSTM32R	dusts of mode 2 incorporated in rain
DEDSTM31R	dusts of mode 1 incorporated in rain
DEDSTM33C	dusts of mode 3 incorporated in cloud
DEDSTM32C	dusts of mode 2 incorporated in cloud
DEDSTM31C	dusts of mode 1 incorporated in cloud
NGFL_EZDIAG	
ZN_DST	Dust concentration number
ZM_DST	Dust concentration mass
ZRG_DST	Dust mean radius number
ZRGM_DST	Dust mean radius mass
SSA_DST	Single scattering albedo
ASY_DST	Asymmetric coefficient
AOD_DST	Aerosol optical depth
EXT_DST	Extinction coefficient
FLX_DST	Dust flux

The modes order will be controlled in modd_dst_surf.F90 by **JPDUSTORDER**, it is set by default as: JPDUSTORDER = (3,2,1) !(coarse, medium, fine)

For surface uprising process, we need to add to blocks in SURFEX namelist:

```
&NAM_DUST
  LDUST=.TRUE.,              ! key to activate dusts
  LRGFIX_DST=.TRUE.,         ! control dispersion radius variation
  LVARSIG=.FALSE.,           ! control sigma variation
  LSEDIMDUST=.TRUE.,         ! activate sedimentation
  LDEPOS_DST=.TRUE.,         ! activate wet deposition
  NMODE_DST=3,               ! modes number

&NAM_SURF_DST
  CEMISPARAM_DST='AMMA',     ! size distribution used by default (see Tab.02)
  CVERMOD='CMDVER',          ! key to activate the modified DEAD version (Mokhtari et al., 2012)
```

For more details about desert dust module activation, please refer to Mokhtari's stay report about desert dusts in ALADIN (Mokhtari, 2011).

2-2- Validation of results: comparison with CY43T2.bf09:

Aerosol optical depth (AOD) obtained by AROME CY46T1_bf.02 (Fig.03, Fig.06) will be compared to those obtained by CY43T2_bf.02 (Fig.04, Fig.07) and to MSG seviri images (Fig.02, Fig.05).

On June 15th 2017, massive dust storm was observed over Algerian Sahara due to strong southwest winds. The situation was indeed well predicted by both AROME dust CY43T2_bf.09 and CY46T1_bf.02, with small differences in high values areas.

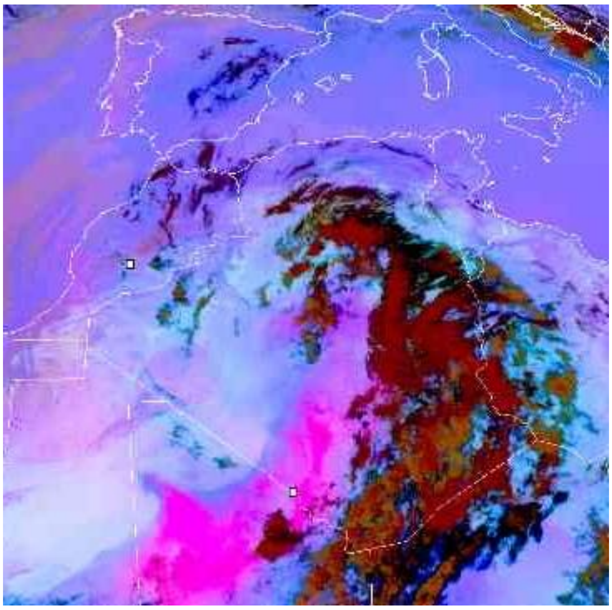

Fig.02: MSG seviri satellite images taken on 15th June 2017, at 06UTC.

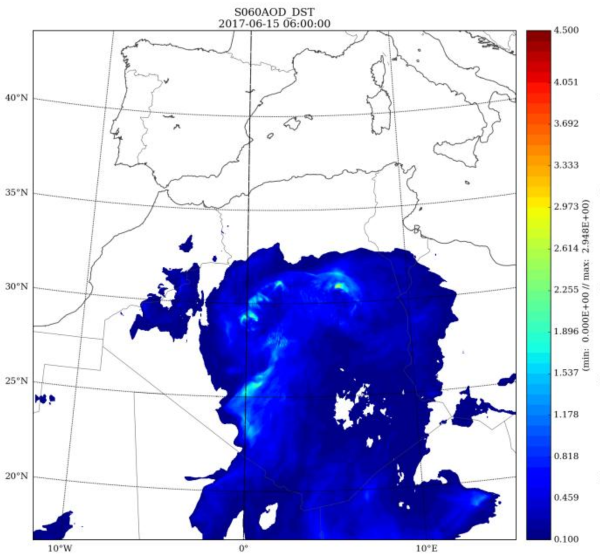

Fig.03: Aerosol optical depth predicted by AROME_Dust (CY43T2_bf.09) on 15th June 2017, at 06UTC.

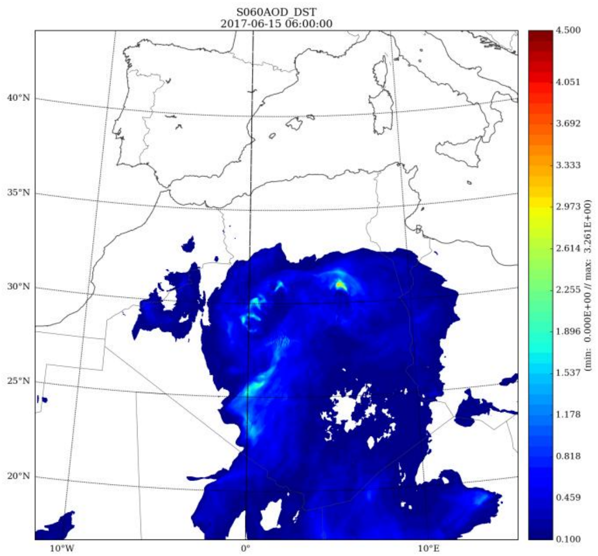

Fig.04: Aerosol optical depth predicted by AROME_Dust (CY46T1_bf.02) on 15th June 2017, at 06UTC.

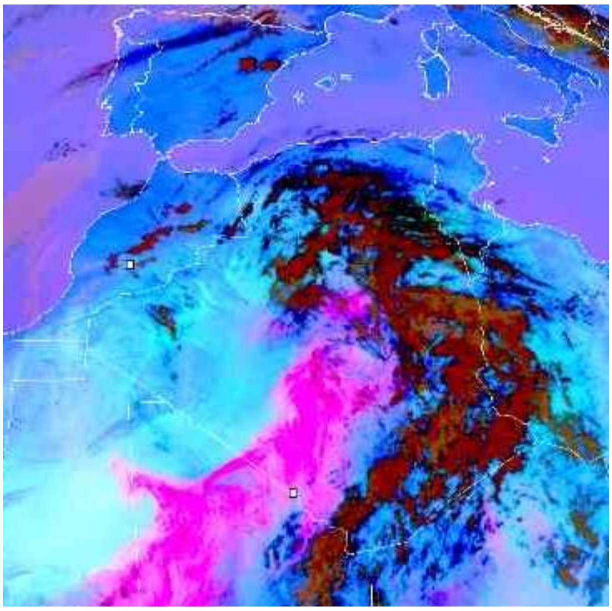

Fig.05: MSG seviri satellite images taken on 15th June 2017, at 06UTC.

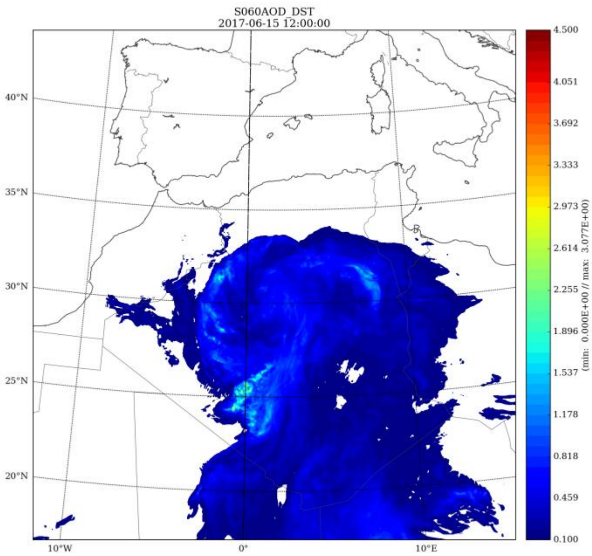

Fig.06: Aerosol optical depth predicted by AROME_Dust (CY46T1_bf.02) on 15th June 2017, at 12UTC.

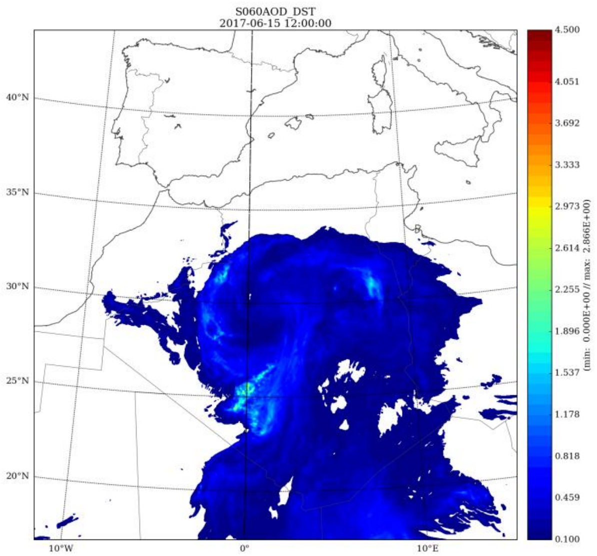

Fig.07: Aerosol optical depth predicted by AROME_Dust (CY46T1_bf.02) on 15th June 2017, at 12UTC.

3- Initialization of LIMA by desert particles from AROME_Dust:

3-1- AROME dusts outputs as IFN for LIMA: How?

As we said before, desert dust aerosols could act like an ice freezing nuclei (IFN) for LIMA. However, only two desert dusts modes will be considered here: coarse and medium, because of their size ability that gave favorable area for ice freezing process. So first thing to do, is to modify the dust routine aro_mnhdust.F90 in a way that only those two modes will be calculated and printed out separately as IFN_F1 and for medium mode and IFN_F2 for coarse mode.

aro_mnhdust.F90

```
*********************************************************************
IF (SIZE(PPEZDIAG, 3) .GE. 4) THEN
PPEZDIAG(:,:,1:4) = 0.
!********************************************************************
!DO IMOD = 1,NMODE_DST ! NMODE_DST!=3 ! PPEZDIAG<25
!PPEZDIAG(:,:,1) = PPEZDIAG(:,:,1) + ZNDST_MOD(:,:,IMOD) ! Nb/m³
!PPEZDIAG(:,:,2) = PPEZDIAG(:,:,2) + ZMDST_MOD(:,:,IMOD) ! Mass(ug)/m3
!PPEZDIAG(:,:,3) = PPEZDIAG(:,:,3) + ZRGDST_MOD(:,:,IMOD) ! RG nb (um)
!PPEZDIAG(:,:,4) = PPEZDIAG(:,:,4) + ZRGMDST_MOD(:,:,IMOD) ! RG m (um)
!ENDDO
!********************************************************************
PPEZDIAG(:,:,1) = ZNDST_MOD(:,:,1)       ! NCon mode grossier (Nb)/m3
PPEZDIAG(:,:,2) = ZNDST_MOD(:,:,2)       ! NCon mode moyen (Nb)/m3
PPEZDIAG(:,:,3) = ZMDST_MOD(:,:,1)      ! MCon mode grossier (ug)/m3
PPEZDIAG(:,:,4) = ZMDST_MOD(:,:,2)      ! MCon mode moyen (ug)/m3
!********************************************************************
```

In order to take those dust aerosols into account as IFN in LIMA processes, we made some modifications in the routine that control aerosols properties (init_aerosol_properties.F90). We've add new case, that we called 'AROME_DUST', in which we put desert dusts properties of coarse and medium modes (Tab.02) : Geometric standard deviation, Number median diameter and fraction of each mode.

init_aerosol_properties.F90

```
******************************************************************************
!!!!!!!!!!!!!!!!
! IFN properties
!!!!!!!!!!!!!!!!
!
IF ( NMOD_IFN .GE. 1 ) THEN
  SELECT CASE (CIFN_SPECIES)
   CASE ('AROME_DUST')
      NSPECIE = 4
      IF (.NOT.(ALLOCATED(XMDIAM_IFN))) ALLOCATE(XMDIAM_IFN(NSPECIE))
      IF (.NOT.(ALLOCATED(XSIGMA_IFN))) ALLOCATE(XSIGMA_IFN(NSPECIE))
      IF (.NOT.(ALLOCATED(XRHO_IFN)))   ALLOCATE(XRHO_IFN(NSPECIE))
      XMDIAM_IFN = (/ 0.64E-6 , 5.E-6 , 0.016E-6 , 0.016E-6 /)
      XSIGMA_IFN = (/ 1.76 , 1.7 , 2.5 , 2.5 /)
      XRHO_IFN   = (/ 2650. , 2650. , 1000. , 1000. /)
*****************************************************************************
*****************************************************************************
CASE ('AROME_DUST')
    XFRAC(1,1)=1
    XFRAC(2,1)=0.
    XFRAC(3,1)=0.
    XFRAC(4,1)=0.
    XFRAC(1,2)=0.
    XFRAC(2,2)=1.
    XFRAC(3,2)=0
    XFRAC(4,2)=0
*****************************************************************************
```

Then, before the simulation we should modify the namelist block NAMLIMA by telling LIMA that we have now two IFN modes:

```
&NAMLIMA
   NMODE_IFN=2,
```

Also modify the namelist block NAMGFL by setting up the medium and coarse modes as **IFN_F1** and **IFN_F2** respectively:

```
&NAMGFL
   YEZDIAG_NL(5)%CNAME='IFN_F1'     ========> dust medium mode (ZN_DST_2)
   YEZDIAG_NL(6)%CNAME='IFN_F2'     ========> dust coarse mode (ZN_DST_1)
```

After that we have to put the new IFN_F1 and IFN_F2 instead of IFN_F:

```
&NAMGFL
   YLIMA_NL(6)%CNAME='N_IFN_F1',
   YLIMA_NL(6)%LPT=.FALSE.,
   YLIMA_NL(6)%NREQIN=1,
   YLIMA_NL(6)%NCOUPLING=0,
   YLIMA_NL(6)%LQM=.TRUE.,
   YLIMA_NL(6)%LSLHD=.TRUE.,
   YLIMA_NL(6)%CNAME='N_IFN_F2',
   YLIMA_NL(6)%LPT=.FALSE.,
   YLIMA_NL(6)%NREQIN=1,
   YLIMA_NL(6)%NCOUPLING=0,
   YLIMA_NL(6)%LQM=.TRUE.,
   YLIMA_NL(6)%LSLHD=.TRUE.,
```

3-2- Simulations and comparison: (15th June, 2017)

In order to test the contribution of the initialization of LIMA by AROME dusts outputs, we have chosen a case study characterized by strong sandstorms and convection in southern Algeria (Fig.08). Actually, it is the same situation chosen previously to validate AROME_Dust on CY46T1_bf.02 (15th June, 2017). During this episode, quite high precipitations amount was observed that reached 30mm/12h at Mertoutek station (north of Tamanrasset).

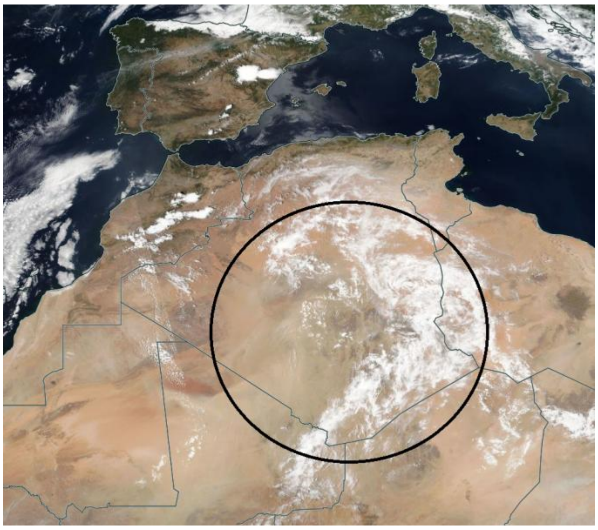

Fig.08: Modis satellite image showing dust-storms with convective activity over Algerian Sahara, on 15th June 2017 (12UTC).

Several simulations of precipitations have been performed by using AROME with different configurations, but we'll be mainly interested by comparing two experiments:

LIMA$^{(ref)}$: AROME CY46T1_bf.02 with LIMA but no dust initialization.

LIMA$^{(init)}$: AROME CY46T1_bf.02 with LIMA and dust initialization.

The results show that we have both increasing and decreasing amounts of accumulated precipitations (ACCPLUIE) between LIMA$^{(ref)}$ and LIMA$^{(init)}$, but in general we have more amounts with LIMA$^{(init)}$. Those differences are not too clear at the beginning of simulations, after 3 hours for example (Fig.09), but it becoming progressively more significant after 06 hours (Fig.10), 12 hours (Fig.11) and 23 hours (Fig.12).

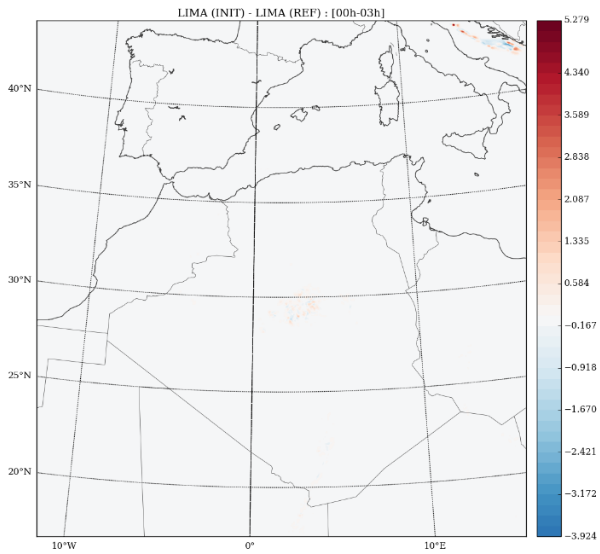

Fig.09: ACCPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ at 03h.

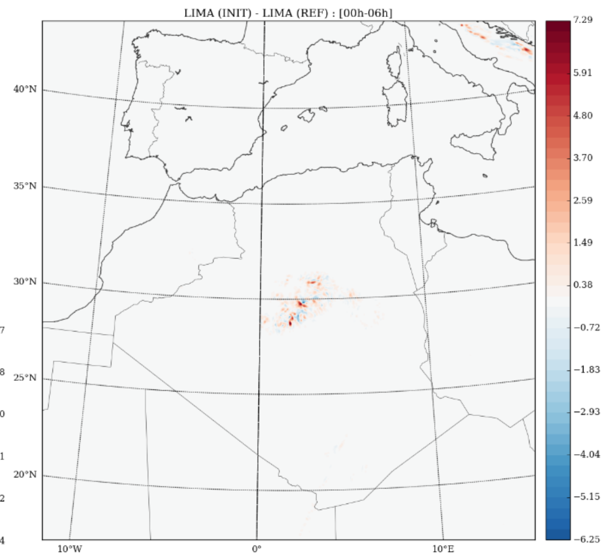

Fig.10: ACCPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ at 06h.

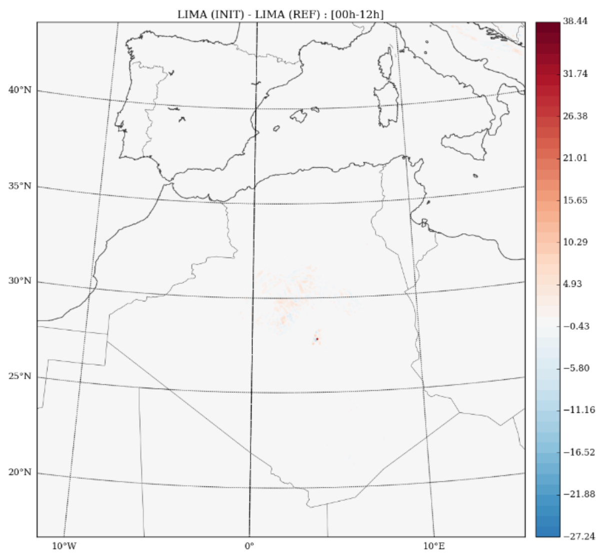

Fig.11: ACCPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ at 12h.

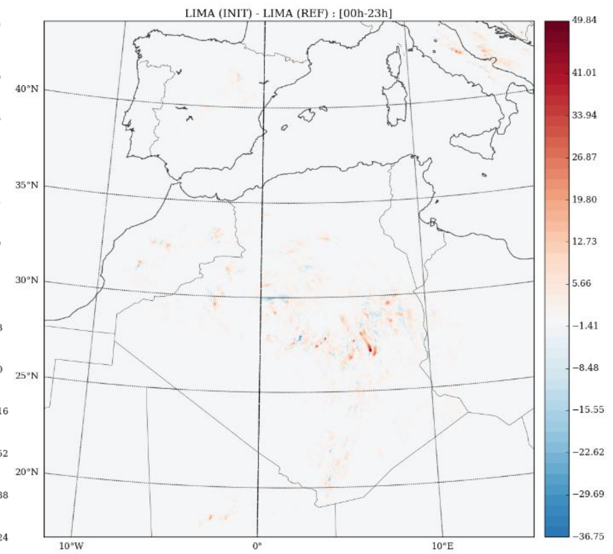

Fig.12: ACCPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ at 23h.

So to check when exactly we get more or less amounts in LIMA$^{(init)}$ comparing to LIMA$^{(ref)}$, we plotted the instantaneous precipitations fields to follow the hourly evolution. Actually the differences start from the beginning (Fig.13), but they are almost unseen, and then it becoming more important for both positive and negative differences (Fig.14 to Fig.20). However, we notice something attractive: LIMA$^{(init)}$ provide usually higher precipitations values until 12h (Fig.13 to Fig.16), but from 13h to 23h (Fig.17 to Fig.20) it provide usually lower precipitations values.

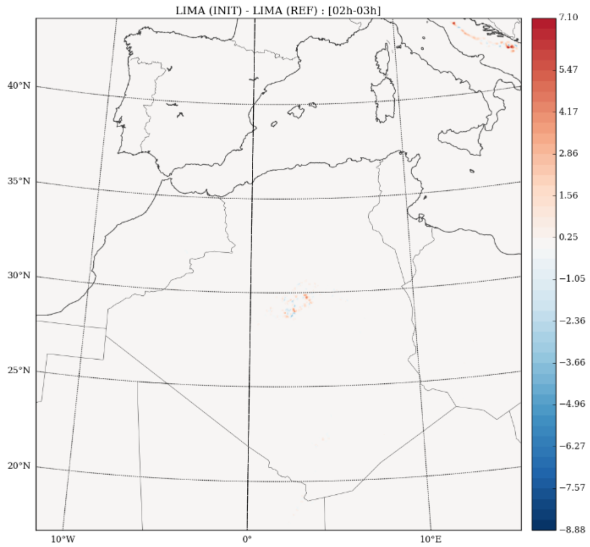

Fig.13: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [02h-03h].

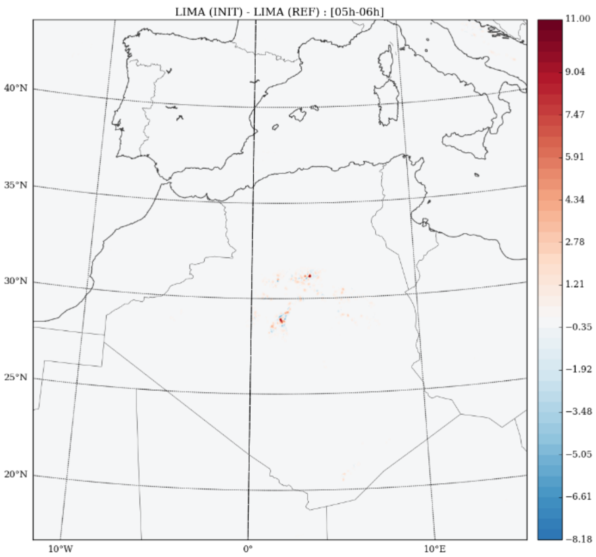

Fig.14: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [05h-06h].

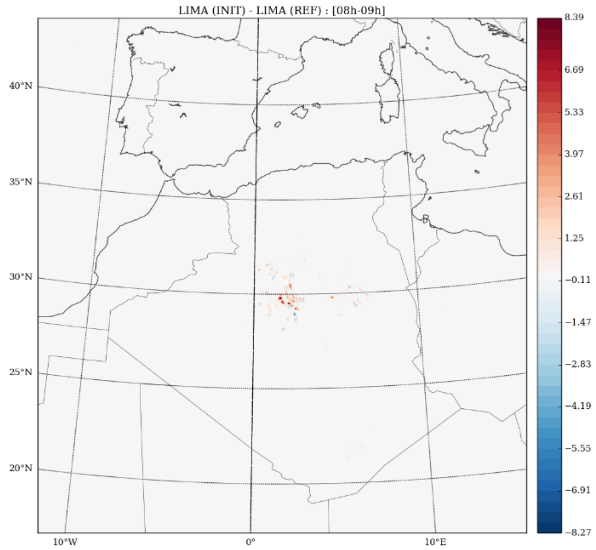

Fig.15: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [08h-09h].

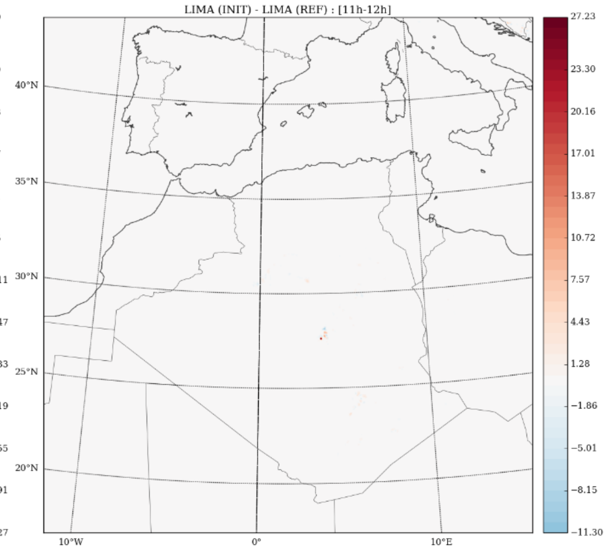

Fig.16: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [11h-12h].

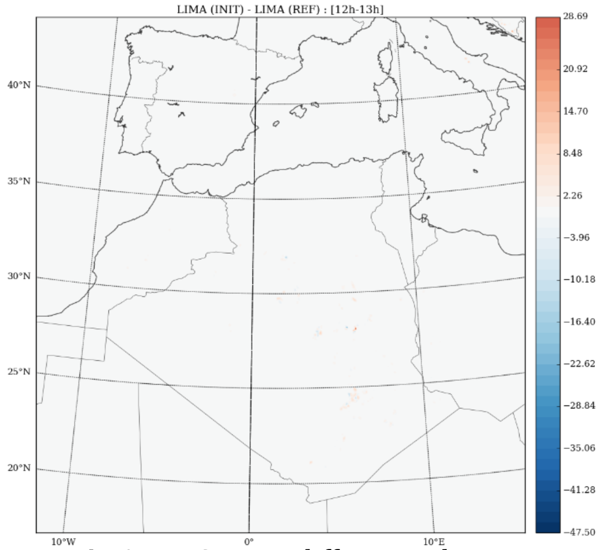

Fig.17: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [02h-03h].

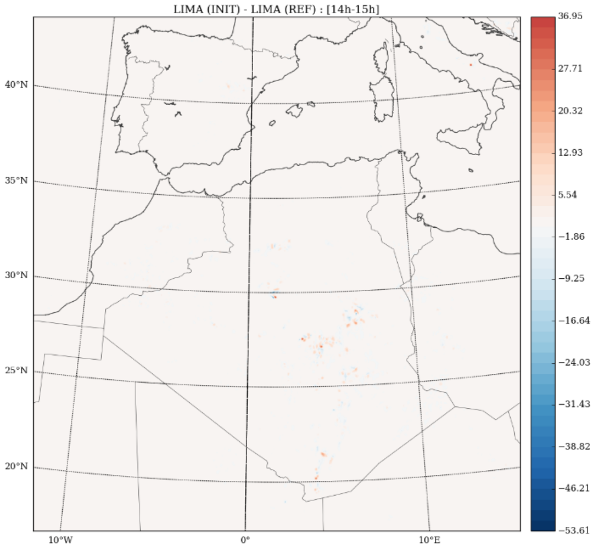

Fig.18: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [05h-06h].

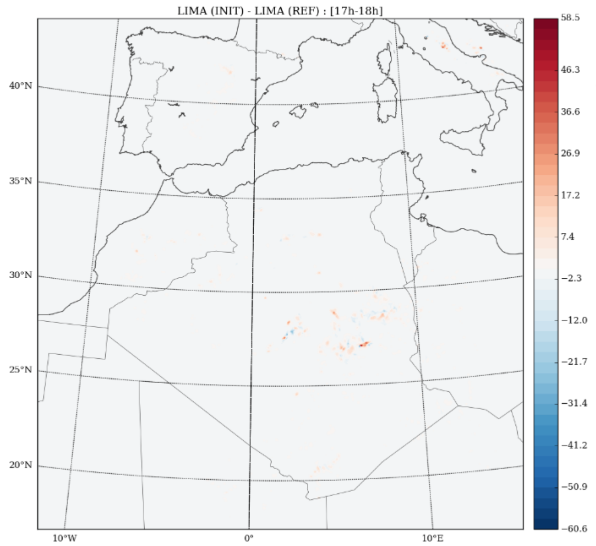

Fig.19: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [08h-09h].

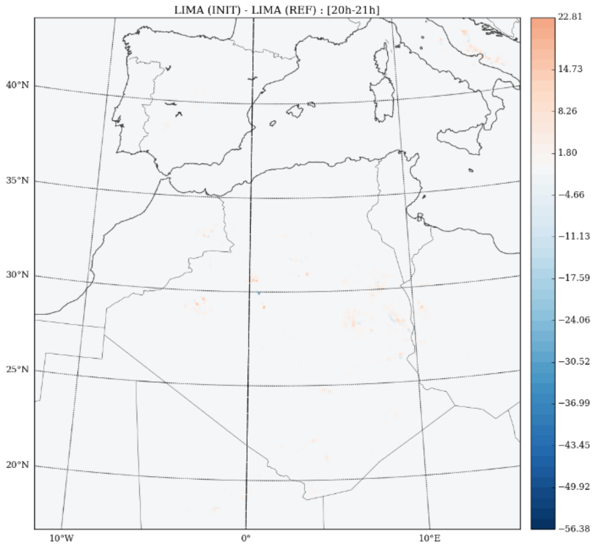

Fig.20: INSPLUIE differences between LIMA$^{(init)}$ and LIMA$^{(ref)}$ [11h-12h].

The differences (LIMA$^{(init)}$-LIMA$^{(ref)}$) were expected to be positive for this situation, because we had an interesting dusts concentration on this day, so it means more IFN injected in LIMA than the standard values (1000L^{-1}). Indeed, we had dominant positive differences, but after 12h, the negative differences take the lead. Part of this could be explained by the fact that IFN fields used from AROME dusts are heterogeneously distributed, so it means that we'll definitely have places with values lower than reference value taken by LIMA$^{(ref)}$.

We'll focus on the area with the maximum convective activity on southern Algeria. The variables calculated in the following part are averaged only over this region and not the whole domain (yellow area in Fig.21).

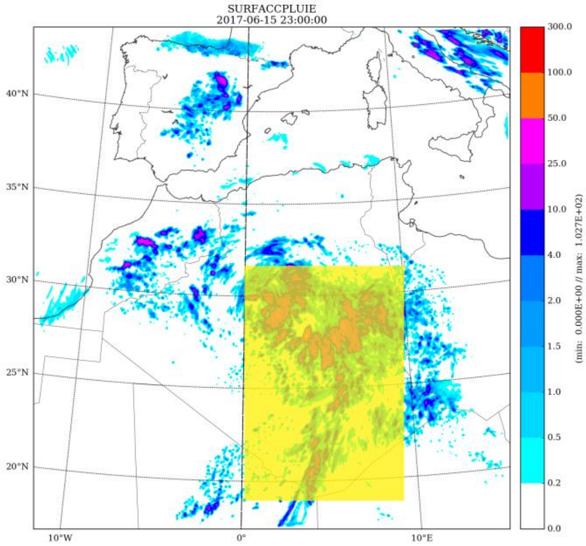

Fig.21: Delimitation of the area with maximum convective activity during this case study.

The vertical profile of IFN taken from AROME dusts (IFN_F1 and IFN_F2) show that during all the process, the values were quite high (Fig.22) comparing to the reference ($1000L^{-1}$). However, we can see in the next hours (Fig.23 to Fig.29) that they decreased progressively since LIMA is consuming them, which means that we have less free IFN available for nucleation.

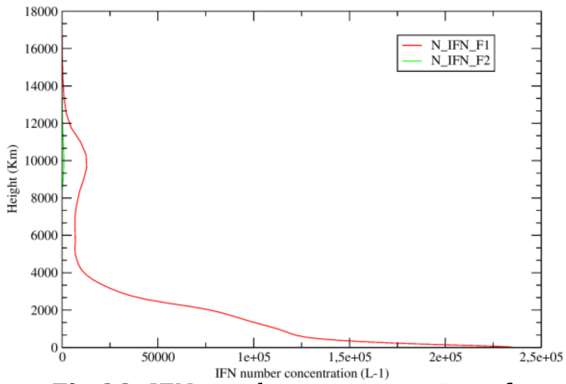

Fig.22: IFN number concentration after 01h of simulation.

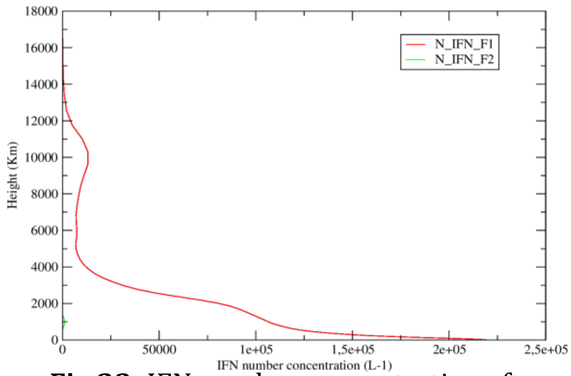

Fig.23: IFN number concentration after 03h of simulation.

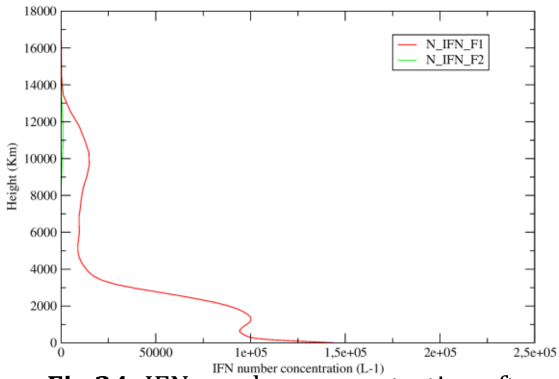

Fig.24: IFN number concentration after 06h of simulation.

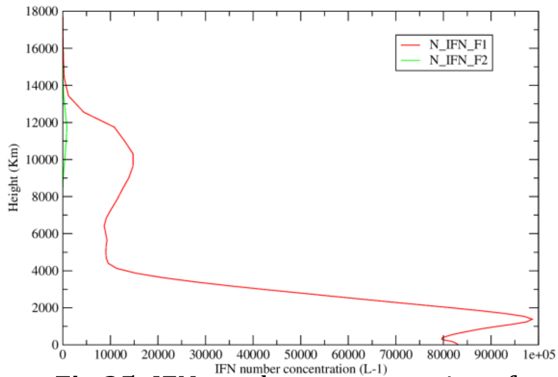

Fig.25: IFN number concentration after 09h of simulation.

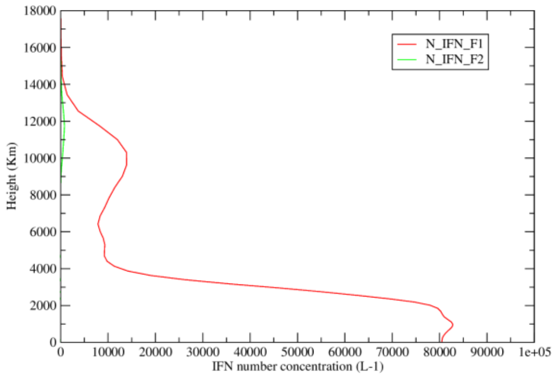

Fig.26: IFN number concentration after 12h of simulation.

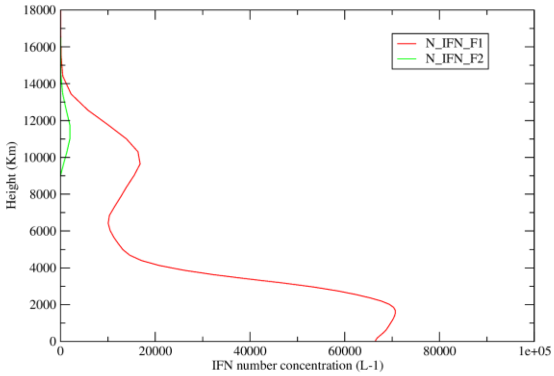

Fig.27: IFN number concentration after 15h of simulation.

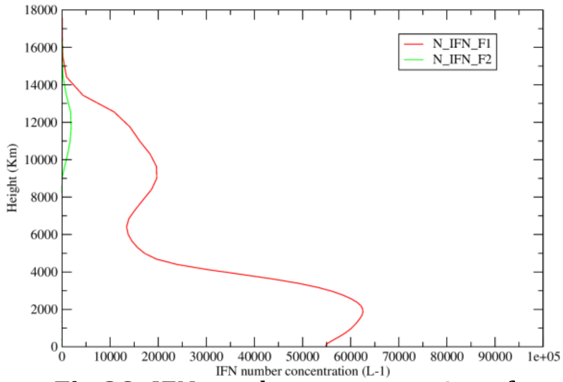

Fig.28: IFN number concentration after 18h of simulation.

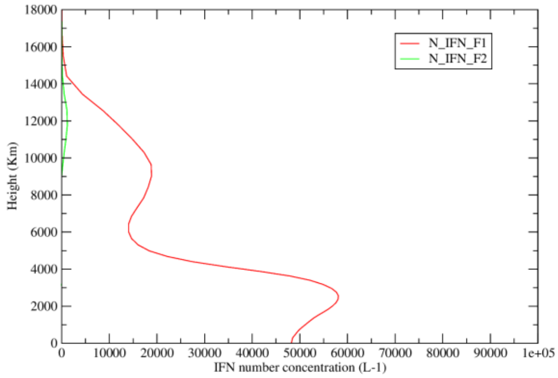

Fig.29: IFN number concentration after 23h of simulation.

We have also plotted some section profiles of pristine ice crystals number (N_ICE) at different latitudes situated inside our high convective activity area. This showed that N_ICE was almost the same at the beginning of the simulation, and then becoming quite different with no particular dominance: sometimes N_ICE are highest for LIMA$^{(init)}$ and sometimes highest for LIMA$^{(ref)}$ (Fig.30, Fig.31 and Fig.32).

To get information about that, we have calculated the hourly means over the 60 levels of number of pristine ice crystals and plotted its evolution (Fig.33). This showed that in general we get more pristine ice crystals formed in LIMA$^{(ref)}$ than in LIMA$^{(init)}$. We have also calculated the same means for: number of rain drops, number of cloud droplets and graupel, but the only information we get is that no significant differences are observed: the values are so close between the two cases (Fig 34, Fig.35 and Fig.36).

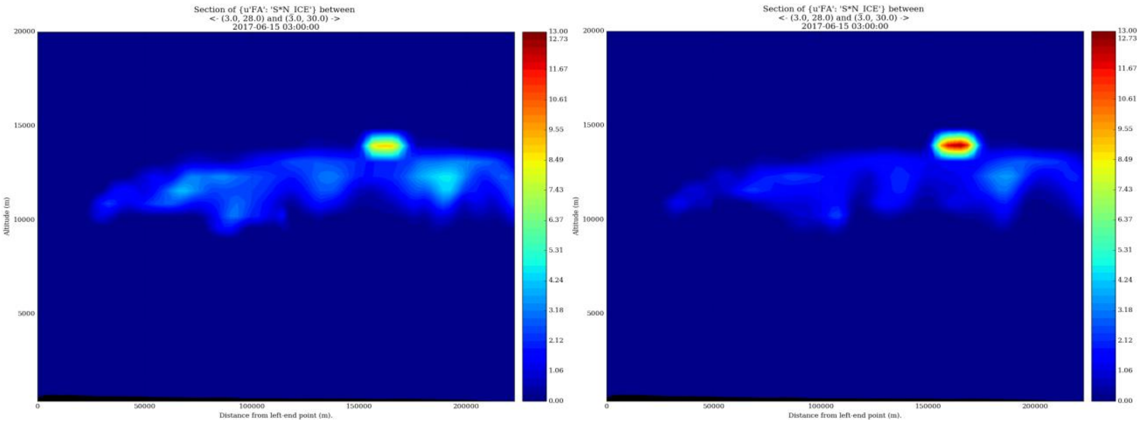

Fig.30: Pristine ice crystals of LIMA$^{(ref)}$ (left) and LIMA$^{(init)}$ (right) and between P1(3°E , 28°N) and P2(3°E , 30°N) at 03h.

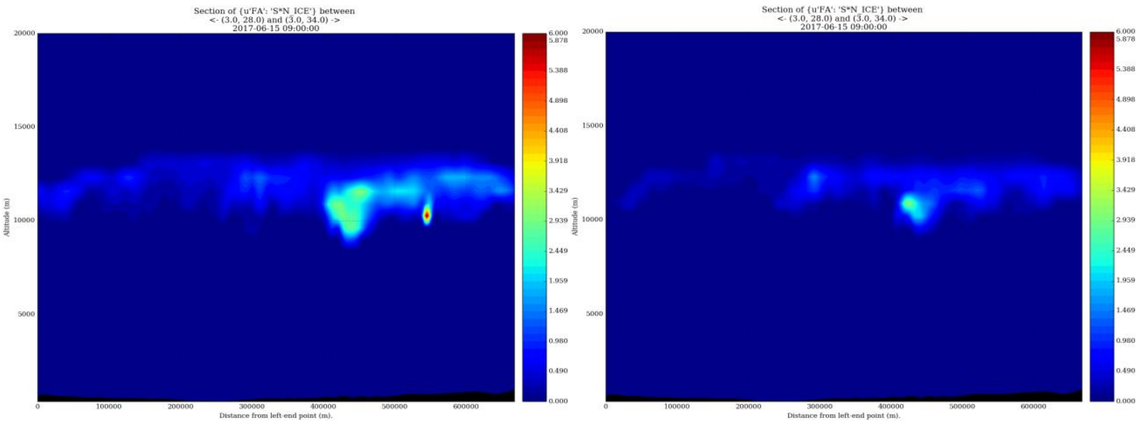

Fig.31: Pristine ice crystals of LIMA$^{(ref)}$ (left) and LIMA$^{(init)}$ (right) and between P1(3°E , 28°N) and P2(3°E , 34°N) at 09h.

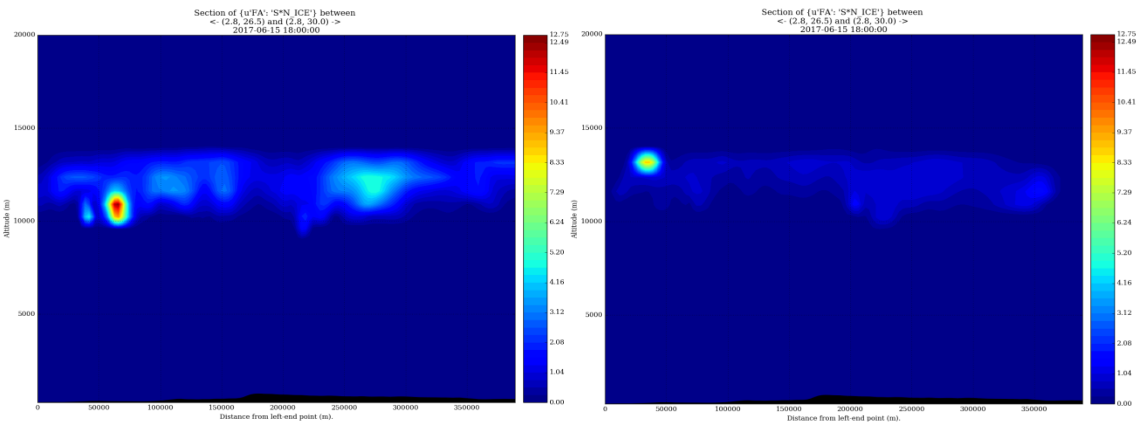

Fig.32: Pristine ice crystals of LIMA$^{(ref)}$ (left) and LIMA$^{(init)}$ (right) and between P1(2.8°E , 26.5°N) and P2(2.8°E , 30°N) at 18h.

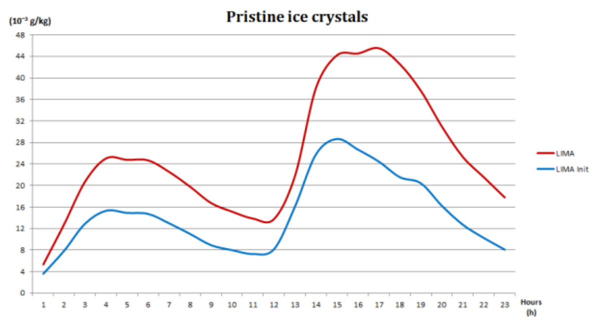

Fig.33: Hourly means of pristine ice crystals over the 60 levels.

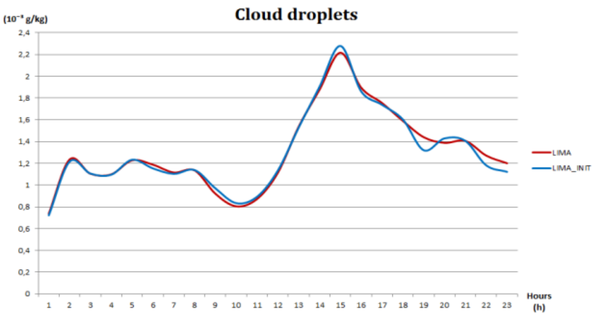

Fig.34: Hourly means of cloud droplets over the 60 levels.

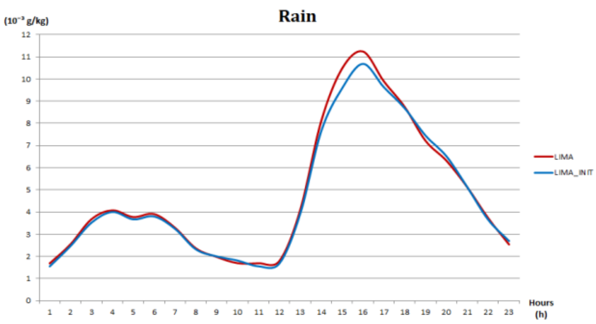

Fig.35: Hourly means of rain drops over the 60 levels.

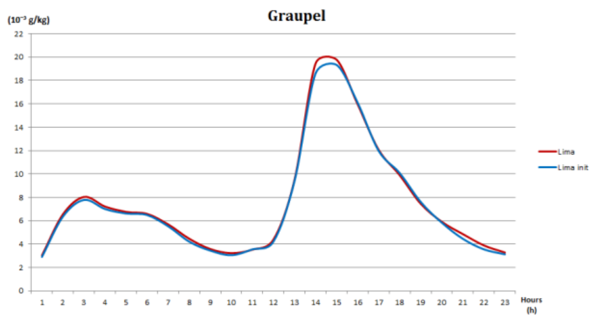

Fig.36: Hourly means of graupel over the 60 levels.

Conclusion and perspective:

The first task in this work was to activate desert aerosol dusts in AROME for CY46T1_bf02 and then validate the outputs by comparing to the last validated configuration (CY43T2_bf.09). The results were good and the desert aerosol cycle was well predicted in CY46T2_bf.02.

In order to recover only the medium and coarse modes of the AROME dusts fields, we made few code changes to calculate only these two modes and get them printed out. Then we used the AROME dusts outputs to initialize the ice freezing nuclei fields (IFN) of LIMA, and tested the contribution of starting with AROME dusts fields as IFN for LIMA. This test was performed on a case study selected carefully: convective activity and sandstorms on southern Algeria (15th June 2017). The results showed that the initialization of IFN in LIMA by dusts aerosols affected the precipitation fields in both directions (negative and positive) : we have more precipitation in the first part of the simulation with LIMA$^{(init)}$ but then less precipitation in the second part (from 13h) comparing to LIMA$^{(ref)}$. This is probably explained by heterogeneous distribution of dusts concentrations, provided by AROME_Dust as IFN for LIMA, and also by the fact that part of those IFNs were consumed during the process.

The next step will be to make the IFN fields even more realistic, by running AROME_Dust with LIMA in the same simulation, to have the dusts at each time-step for LIMA. We started this work but a crash appears at the turbulence routine (aro_turb_mnh.F90): confusion between the variables of LIMA (NLIMA) and dusts (NGFL_EXT). We managed to make it work technically, by switching off the LIMA related variables in the turbulence part, but the outputs was quite weird. Besides, even if the outputs were not okay, we must mention that this experiment (LIMA+Dusts) was expensive (details of computational costs in Appendix). The work will continue in order to resolve the remaining issues.

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I would like to thank Yann Seity for his precious help and guidance during my stay. I would also like to thank Benoit Vié for his beneficial remarks during the meetings we had.

Appendix:

I/ Computational costs:

Config.	Microphysics	Dusts	Elapsed time	Cost (%)	
CY43T2_bf.09	ICE3	No	01:55:49 (1)		
	ICE3	Yes	02:33:51	32,84%	Compared to (1)
CY46T1_bf.02	ICE3	No	01:57:12 (2)		
	ICE3	Yes	02:37:15	34,17%	Compared to (2)
	LIMA (ref)	No	03:42:15 (3)		
	LIMA (init)	No	03:47:19	2,30%	Compared to (3)
	LIMA	Yes	04:24:28	19%	

II/ Packs :

- **CY46T1_bf.02 with dusts (without LIMA):**

/home/gmap/mrpa/abdenoura/pack/cy46t1_DUST_MODE

- **CY46T1_bf.02 with LIMA and dusts initialization:**

/home/gmap/mrpa/abdenoura/pack/cy46t1_LIMA_INIT_DST

- **CY46T1_bf.02 with dusts and LIMA:**

/home/gmap/mrpa/abdenoura/pack/cy46t1_LIMA_DUST_2 (still not working correctly)

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