Parameterization of orographic effects on surface radiation in AROME

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1. Introduction:

Complex topography has a significant influence on radiation fluxes at the earth's surface. As a consequence, parameters like slope aspect, slope angle, sky view factor and shadowing do also have a big impact on, for instance temperature fields, local circulation, formation of clouds or triggering of convection in such areas.
With increasing spatial resolution of weather forecast models these effects gain also importance for numerical modelling. For a better representation of these topographic influences and thus to improve the model performance in complex topography, an according radiation parameterization scheme has been introduced to the High Resolution Limited Area Model AROME during my stay at Meteo France in autumn 2014.

2. Motivation:

A verification of the operational AROME forecasts in Austria has shown that sometimes a strong difference between the model forecast and station observations appears in small Alpine valleys like the Enns-valley or the Inn-valley. This strong positive BIAS of about 2 - 3 °C especially occurs around the time of sunrise (see Fig.1). A further investigation of this problem has shown that the different radiation conditions of model and reality caused by orographic shadowing effects are resonsible for this model BIAS. In other words, the station lies in reality much longer in the shadow than it is simulated in the model. This fact is caused by supposed flat and effectively homogeneous grid boxes in the radiation parameterizations and no influence of surrounding grid cells. This problem is not new and has already been described by Müller and Scherer (2005) in a paper some years ago. To improve the performance of numerical models in complex topography they designed a unified radiation parameterization scheme based on high resolution topography data. This method has also been used and adapted to the HIRLAM (High Resolution Limited Area Model) model by Senkova et al. (2007).
During my stay at Meteo France in autumn 2014 I have adapted this scheme to the AROME model (cy 41). In the following I shortly describe the steps and work that has to be done to use the scheme in every other setup and at every other domain of the AROME model.

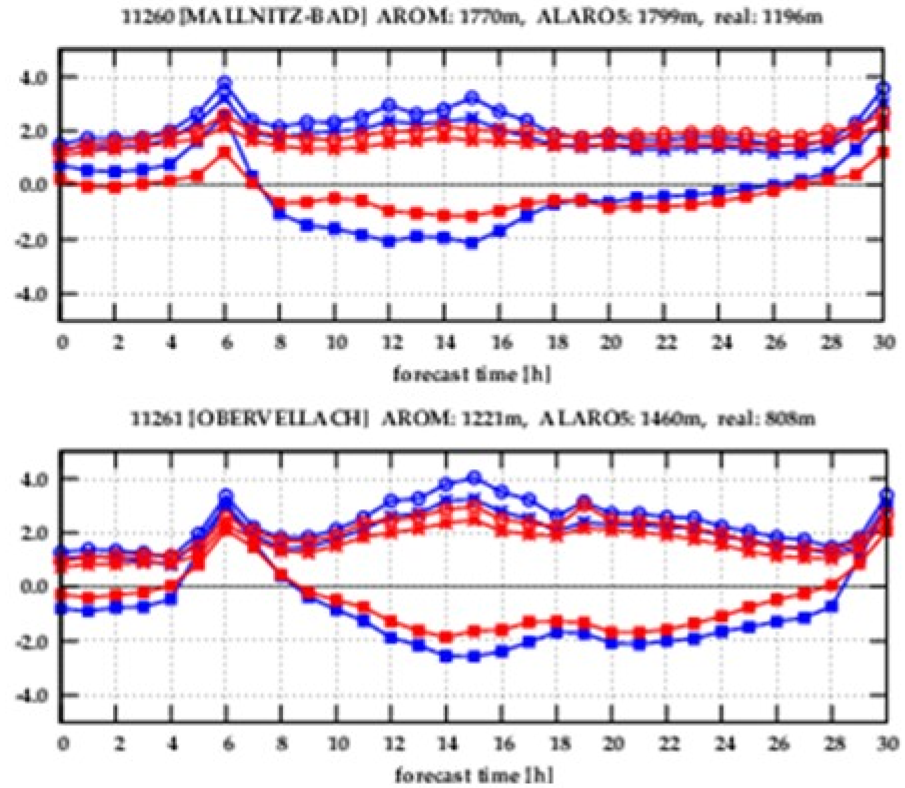


Fig. 1: BIAS, MAE and RMSE for AROME (blue) and ALARO (red) at the valley stations of Mallnitz and Obervellach in Austria for summer 2013. A positive BIAS means higher temperatures in the model than observed.

3. Methodology:

3.1. Used method:

The formulation of the basic equations for the present radiation parameterization, accounting for the orographic effects on radiation, follows the approach of Müller and Scherer (2005). They formulated a unified method to parameterize the radiation effects due to different slope angles and directions, relief shadows (for SWR) and restricted sky view (SWR and LWR).

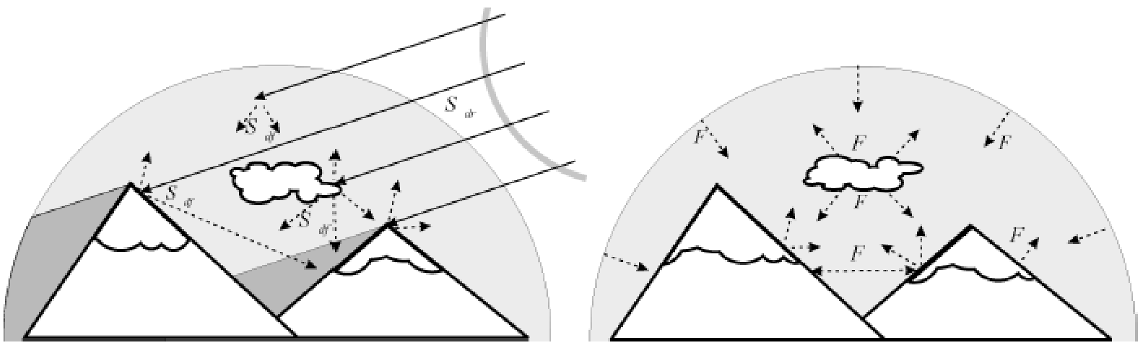


Fig. 2: Solar (short-wave, left) and terrestrial (long-wave, right) radiation fluxes over mountainous terrain.

Figure 2 shows the main SWR and LWR fluxes modified by orographic features. Direct solar radiation is absorbed and scattered by atmospheric gases, aerosol and cloud particles and is

reflected by clouds and the earth's surface. Part of the scattered and reflected radiation reaches the surface as diffuse radiation. Surrounding mountains and hills create shadows and obscure parts of the sky visible at a given location. LWR is emitted and absorbed by atmospheric gases, aerosol and cloud particles. Long-wave emission by sloping surfaces may significantly influence the surroundings and reduce radiative cooling especially in valley bottoms.
The orographic correction of the surface radiation fluxes is based on three quantities : the slope parameter δsl, the shadow fraction δsh and the sky-view factor δsv.

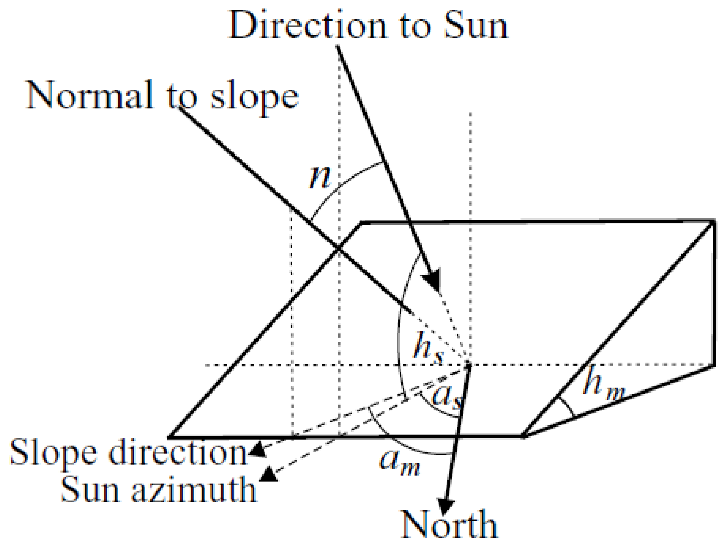


Fig. 3: Definition of the angles used in eqs 1 and 2.

The slope parameter δsl is used to modify the downwelling direct solar flux and can be formulated as

$$\begin{aligned}\delta sl &= \cos(n)/\cos(hm) \\ &= \sin(hs)[1 + \tan(hm)/\tan(hs)\cos(as - am)].\end{aligned} \qquad \text{eq. 1}$$

The meaning of the relevant parameters can be extracted from Figure 3.

The treatment of shadows is done by introducing a shadow fraction δsh. It is defined with values between 0 (shadowed) and 1 (clear).
Accordingly, the direct solar flux arriving at a slope is defined as

$$S{\downarrow}dr,1 = \delta sl\, \delta sh\, S{\downarrow}dr,0 \qquad \text{eq. 2}$$

where $S{\downarrow}dr,0$ is the unmodified down-welling direct solar radiation.

For the calculation of diffuse solar radiation and long-wave up-welling radiation flux the sky view factor δsv is important. It is defined by integration of the horizon angle $hh(\theta)$,

$$\delta_{sv} = 1 - \frac{1}{2\pi}\int_0^{2\pi} \sin[h_h(\theta)]\, d\theta. \qquad \text{eq. 3}$$

The values of δsv vary from 0 (no sky seen) to 1 (whole sky visible). Accordingly the diffuse short wave radiation is defined as

$S{\downarrow}df,1 = \delta sv\, S{\downarrow}df,0 + \alpha e(1 - \delta sv)S{\downarrow},e,$ eq. 4

where αe is the average surface albedo and $S{\downarrow}e$ the average downwelling global radiation over the surrounding surfaces.

The long-wave radiation budget is also depending on the sky view factor and can be described by eq. 5,

$F{\downarrow} = \delta sv F{\downarrow}0 + (1 - \delta sv)F{\uparrow}0,e,$ eq. 5

$F{\uparrow}0,e$ can be calculated with the Stefan-Boltzmann law ($F{\uparrow}0,e = e\sigma\, Ts^4$) with e being the average surface emissivity and Ts the average surface temperature of the surrounding terrain.

The three parameters δsl, δsh and δsv have to be calculated before the model integration (see chapter 3 preprocessing) by the use of a high resolution orography dataset.

3.2. High resolution orography data:

During the last years different detailed global data on surface elevation have become available. The resolution of these data lies generally between 30m and 1km, but local data sets exist with even higher horizontal resolution. For the present study we have used orography data from the Shuttle Radar Topography Mission (SRTM, Rodriguez et al., 2005) with a horizontal resolution of three arc-seconds (about 90m in middle Europe). SRTM digital raster elevation covers the globe between latitudes 60°N and 56°C. The data are given in regular latitude-longitude grid. The domain for the test study is centred in Austria and comprises the area shown in Fig. 4.
Of course, any other high resolution dataset (e.g. GTOPO30 (USGS, 1998), Hydro1K (USGS, 2003), ASTER (NASA, 2001), etc.) and any other domain can be used for the present parameterization scheme.

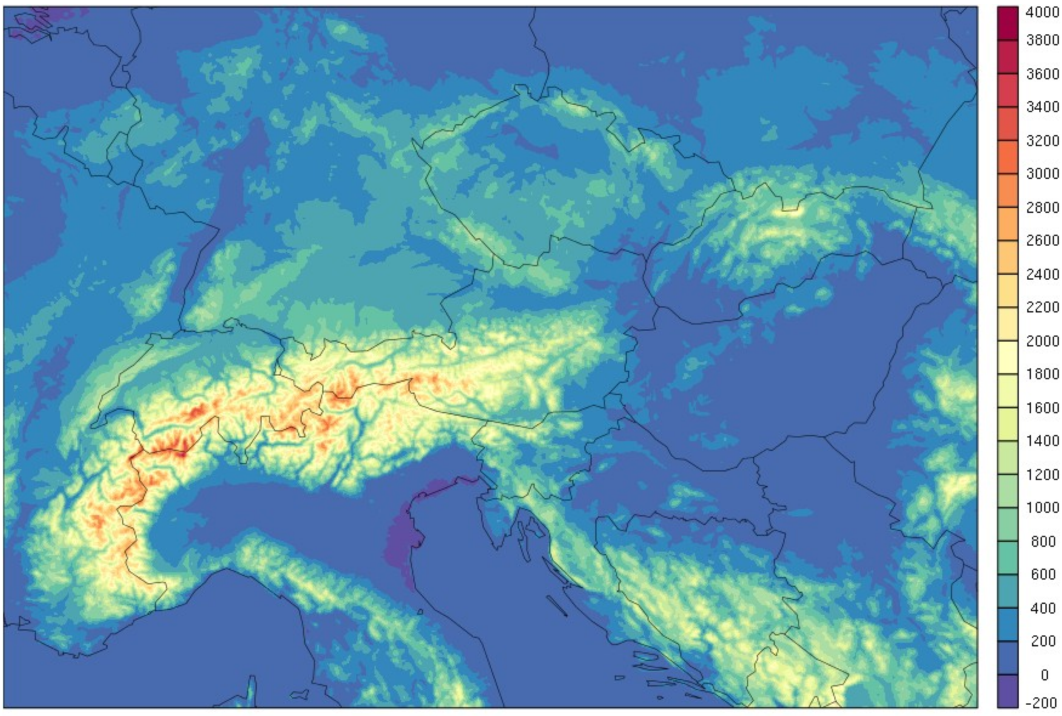


Fig. 4 : Topography [m] of the operational AROME domain in Austria that has been used as test site.

3.3. Preprocessing:

Before starting with the implementation of the radiation scheme in AROME, the method for computing the orographic parameters mentioned above is shortly described.
At the moment δsl, δsh and δsv are calculated in a two-step concept. The first step - calculation of slope, aspect and local horizon - is done outside the numerical model with scripts provided by the HIRLAM community (thanks to Laura Rontu)! The second step - adaptation from the high resolution SRTM dataset to the model resolution of 2.5km and some additional computations - is performed inside PGD together with the other surfex physiographic parameters.
After downloading the SRTM dataset, merging the tiles into one big file and cutting it to the model domain, the full resolution slope elevation and direction angles can be calculated easily by using the GDAL tools (Geospatial Data Abstraction Library, GDAL 2014). Gdaldem slope and gdaldem aspect are the relevant shell commands.
The sky view factor is depending on the local horizon in each direction and can be derived by introducing the concept of slope sections. With this concept we avoid additional preprocessing and storage of large amounts of time-dependent data while still retaining essential details of the orography. This concept has been developed by the HIRLAM community and is described in a paper (Senkova et al., 2007). At each high-resolution orography source data point, a local horizon angle is calculated for a defined number of sectors. At the moment 8 sectors are used, which implies a width of 45° for each sector centred at the main geographical directions (N, NE, E, SE, S, SW, W, NW). The local horizon angle is calculated by scanning in a circle around the location. In this study we restricted the radius of the circle to 9 km (100 grid-points of 90m in each direction), scanning with a resolution of 1°. The local horizon angle is determined by the elevation difference between the central and surrounding points. Each angle is weighted according to its squared distance from the central point. Thus the closest obstacles, which are able to obscure the largest area, get more weight than the remote ones. At each point, the sectorial local horizon angles are defined by the weighted average of the 1° values. The sky view factor is then obtained by integration over the local horizon angles, determined by the nearby orography (eq. 3). In this case the integral is replaced by the summation over the local horizon values in all 8 sectors. The output fields of this preprocessing are shown in Table 1.

Parameter	Type	Unit	Range	Missing values
Slope angle	Integer	1/100 °	0 - 9000	-9999
Aspect angle	Integer	°	0 - 359	-9999
Local horizontal angle*	Integer	1/100 °	0 - 9000	-9999
Sky view factor	Integer	1/10 %	0 - 1000	-9999

Table 1: Output fields of preprocessing scripts. * Local horizon consists of 8 fields, because of 8 sectors.

This procedure is at the moment done outside the numerical model by the HIRLAM scripts, but it is planned that this step should also be included into PGD in the near future.
The retrieved fields have to be subsequently converted to a binary format which can be read by PGD (.dir file and respective header .hdr file).

3.4. PGD:

The idea behind the present approach is to include all necessary fields into the physiographic fields so that they have to be calculated only once before the actual model integration. This saves time and computational resources. A list of all PGD routines within SURFEX that have been adapted to calculate the additional orographic fields is provided in the appendix.
The main routine dealing with the orographic fields is pgd_orography.F90. The parameters themselves and the temporary fields are defined in the modules modd_pgdwork.F90 and modd_surf_atm_sson.F90. Within the SURFEX routines average1_orography.F90 and average2_orography.F90 the fields mentioned in Table 1 are converted to the AROME grid size of 2.5km. For the slope angles a simple average over all SRTM points in each AROME grid square is applied resulting in a mean slope angle. In case of aspect the horizon is subdiveded into the 8 sectors mentioned before and the numbers of the small scale grid points in a certain direction are counted. Afterwards these numbers are divided by the total number of small scale grid-points in each AROME square resulting in a relative fraction of each sector. Additionally, for all 8 sectors a mean slope at each AROME square is defined. The sky view factor on the AROME scale is obtained as a simple average of the fine-resolution sky view factor values. For the calculation of the shadow factor, minimum and maximum values of the local horizon are found in each sector. Direction-dependent coefficients A_i and B_i are determined so as to fulfil a linear relationship

$$\delta_{sh,i} = A_i \sin(h_s) + B_i , \qquad \text{eq. 6}$$

assuming that $\delta_{sh,i} = 1$ when the sun is higher than the maximum local horizon in the sector and $\delta_{sh,i} = 0$ when the sun is below the minimum local horizon in this direction. Between the minimum and maximum values, $\delta_{sh,i}$ is assumed to increase from zero to $1 - b_{cr}$, where b_{cr} is taken to be $1/N$ and N is the number of SRTM points inside a AROME grid-square. Over the sea no orographic factors are calculated – they are set to default.
Hence, the output of PGD comprises 34 additional fields (see Table 2) in case of 8 directional sectors.

Parameter	Type	Unit	Range	Missing values
Mean slope	Real	°	0.00 - 90.00	1.0E20
Fraction of aspect in sector*	Real	Relative number	0.00 - 1.00	1.0E20
Mean slope in sector*	Real	°	0.00 - 90.00	1.0E20
Mean sky view factor	Real	%	0.00 - 100.00	1.0E20
A factor*	Real	no unit	Depending on topography and resolution	1.0E20
B factor*	Real	no unit		1.0E20

Table 2: Additional orographic fields in the output of PGD. * paramaters consists of 8 fields, because of 8 direction sectors defined.

Whether the new orographic fields should be calculated or not can be defined by the switch LSHA_ZS in the PGD namelist NAM_ZS (routine read_nam_pgd_orography.F90). In this namelist also the names of the input SRTM files and the number of sectors has to be set. In the following you can see the respective extraction of the PGD namelist.

```
&NAM_ZS
  YZS='srtm',
```

```
YFILETYPE='DIRECT',
LSHA_ZS=.TRUE.,
YFILETYPE_SHA='DIRECT',
YFRAC_SHA=8,
YSLO='srtm_slo',
YASP='srtm_asp',
YSVF='srtm_svf',
YLHA='srtm_lh',
```

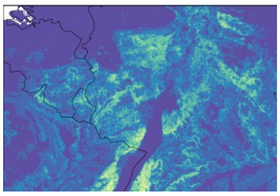
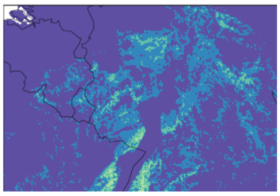
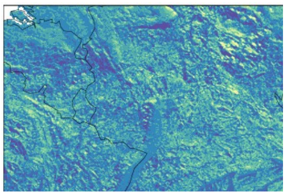
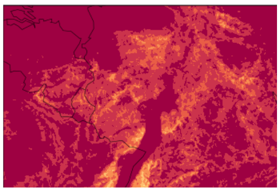



Fig. 5 : Mean slope [°], mean slope in direction S [°], fraction of aspect in direction S [rel. num.], mean sky view factor [%], A and B factor in direction S [no dimension].

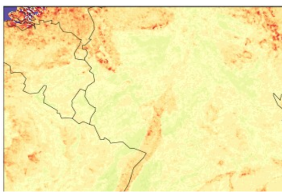
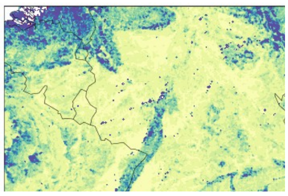
Due to the high horizontal resolution of the SRTM data (90m) the computation of the necessary fields in PGD takes some time.

Figure 5 shows plots of all calculated fields for the test domain in central Europe. Remark, only the sector South (157.5° – 202.5°) is depicted.
The writing of the new fields to the PGD output file is controlled by the routine writesurf_sson.F90. All the steps presented before must be done only once before the actual model run (like the other physiographic fields too).

3.5. SURFEX:

If the respective orographic fields are included in the PGD output file (lfi format), we can start with the real model integration. Therefore the new arrays have to be read from the lfi file, which is done by the routine read _sson.F90. The reading of the new fields can again be regulated by a namelist switch. The switch LSHAD has been placed into the namelist NAM_SSOn (module modn_sson.F90) which has to be added to the surfex namelist of both, the 927 which configurates the boundary conditions for AROME, and the 001 which is doing the actual model integration.

The subroutine that is doing the main calculations of the new radiation parameterization scheme is called HLORORAD and has been inserted to the routine coupling_surf_atmn.F90, which generally performs the physical evolution of the surface schemes. In coupling_surf_atmn.F90 most of the needed parameters are already included, only the netto longwave radiation (PLWNETM) has to be integrated which also requires small adaptations in the routines apl_arome.F90, aplpar.F90, aro_ground_param.h and aro_ground_param.F90. The complete subroutine HLORORAD is given in the appendix. In HLORORAD a local azimuth angle has been defined, because PAZIM, which comes from aro_ground_param.F90, is defined counterclockwise with start from south, while the parameters in the preprocessing scripts were calculated in a way with azimuth defined clockwise from north.
Additionally to the main namelist switch LSHAD, the 3 switches LDSL, LDSH and LDSV have been introduced. With these switches the 3 basic orographic effects of the surface radiation flux can be regulated separately. LDSL is responsible for the slope effect, LDSH describes the shadow effect

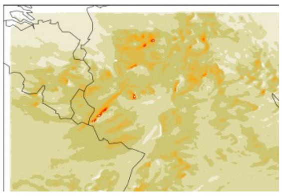
and LDSV the effect of reduced sky view in mountainous areas. An example for the 001 surfex namelist considering all 3 effects is shown in the following.

```
&NAM_SSOn
 LSHAD=.TRUE.,
 LDSL=.TRUE.,
 LDSH=.TRUE.,
 LDSV=.TRUE.,
```

The 3 additional switches were created only for testing the radiation scheme, for operational purposes all 3 should be TRUE. Remark, they only have an impact if the general switch LSHAD is set to TRUE. In the 927 surfex namelist only the switch LSHAD is available.

4. First Results

At the time of writing this report only some very first tests with the new orographic radiation parameterization scheme have been made. In Fig. 6 the temperature difference (lowest model level) between AROME runs with the new radiation scheme and different switch settings and an operational AROME run is shown. As a first test case we have selected March 12th 2014 which was characterized by clear sky conditions over the whole Austrian AROME domain. The picture shows the 00 UTC run for a leadtime of 12 hours.



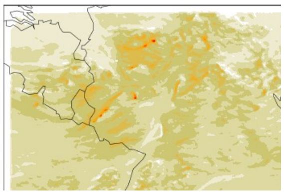


Fig. 6 : 2m temperature difference (AROME with new radiation parameterization - AROME operational) in [°C] for different switch settings at March 12th 2014 12 UTC (00 UTC run). The left upper panel shows the effect of shadowing (LDSH=TRUE), the upper right the slope effect (LDSL=TRUE), lower left the influence of restricted sky view (LDSV=TRUE) and the lower right panel shows the effect of the whole orographic radiation parameterizations (all switches TRUE).

The upper left figure shows that the influence of the shadow (LDSH=.TRUE.) is only visible along the Alpine arc, but also here quite weak. The cooling (blue colours) in the valleys due to shadows lies around -0.1°C - -0.3°C. The upper right panel shows very good the influence of the topography because sun exposed slopes are warmed and slopes away from the sun are cooled. The magnitude of this slope effect is between -1.0°C and + 0.7°C compared to the standard AROME run. The strongest influence seems to come from the restricted sky view (lower left panel) which causes a general warming in the domain. Strongest warming occurs in small Alpine valleys with a magnitude up to 1.5°C. Interestingly a temperature increase is also present in rather flat areas like southern Germany or Hungary. This effect has to be further investigated in more tests, maybe the choice of the influence radius when calculating the local horizont plays a major role in this context. The difference between the complete orographic shadowing parameterization (all switches set to TRUE) and the operational AROME run is illustrated in the lower right panel of Fig. 6. Strongest temperature increase can be observed in the valleys and at the southern facing slopes in the Alps where the scheme simulates a heating of 0.5°C – 0.9°C. On the other hand the temperatures at the northern edges of the Apennin and the Alps are up to 1.0°C lower than in the reference AROME run. In general this seems to be very reasonable, but of course more testing and tuning has to be done in future.

5. Outlook

Since first tests look quite promising, intensive testing is planned in the near future. Not only the direct effect on the temperature fields, but also secondary influences on for example the formation of clouds, onset of convection, changes in the local wind system or effects on the development and dissolving of elevated fog due to the new radiation parameterization scheme should be investigated. Test cases will be selected for all seasons and not only for clear sky days, but also for partly clouded or overcast days. A paper summarizing the output of some test cases should be submitted in 2015.

6. Acknowledgments

At the end of this report I want to thank all the people that have contributed to this interesting work and study. First of all I want to thank Christoph Wittmann for enabling my stay at Meteo France which has been financed by LACE (Limited Area Modelling Central Europe). Special thanks go to Yann Seity for an excellent and competent supervision in Toulouse and for answering thousands of my questions via email. Also Alexandre Mary for technical support and for providing his Python library for plotting should be mentioned at this point. Last but not least I want to thank Laura Rontu for providing the scripts for preprocessing and helping me in many questions with a lot of enthusiasm.

7. References

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USGS, 2003: Hydro1k elevation derivative database, available at http://edcdaac.usgs.gov/gtopo30/hydro/readme.html.

8. Appendix

Appendix A: List of AROME routines which have been adapted

arpifs/phys_dmn/apl_arome.F90

arpifs/phys_dmn/aplpar.F90

mse/interface/aro_ground_param.h

mse/programs/driver_off_omp.F90

mse/programs/offline.F90

mse/externals/aro_ground_param.F90

surfex/SURFEX/default_sso.F90

surfex/SURFEX/dealloc_surf_atmn.F90

surfex/SURFEX/pgd_orography.F90

surfex/SURFEX/writesurf_sson.F90

surfex/SURFEX/zoom_pgd_orography.F90

surfex/SURFEX/coupling_surf_atmn.F90

surfex/SURFEX/average2_orography.F90

surfex/SURFEX/modn_sson.F90

surfex/SURFEX/read_namelists_surfn.F90

surfex/SURFEX/modd_surf_atm_sson.F90

surfex/SURFEX/init_surf_atmn.F90

surfex/SURFEX/read_nam_pgd_gauss_index.F90

surfex/SURFEX/read_sson.F90

surfex/SURFEX/modd_pgdwork.F90

surfex/SURFEX/pt_by_pt_treatment.F90

surfex/SURFEX/read_direct.F90

surfex/SURFEX/read_nam_pgd_orography.F90

surfex/SURFEX/treat_bathyfield.F90

surfex/SURFEX/treat_field.F90

surfex/SURFEX/write_pgd_surf_atmn.F90

surfex/SURFEX/average1_orography.F90

Appendix B: Source Code of the HLORORAD subroutine in coupling_surf_atmn.F90

```
SUBROUTINE HLORORAD(PDIR_SWL,PSCA_SWL,PLWL,PLWNETL)

!

IMPLICIT NONE
```

```
!
!IN - OUT VARIABLES
REAL, DIMENSION(KI,KSW), INTENT(INOUT) :: PDIR_SWL !direct short wave radiation
REAL, DIMENSION(KI,KSW), INTENT(INOUT) :: PSCA_SWL !diffuse short wave radiation
REAL, DIMENSION(KI), INTENT(INOUT)     :: PLWL     !downwelling long wave radiation
REAL, DIMENSION(KI), INTENT(INOUT)     :: PLWNETL  !net long wave radiation

!FROM MAIN ROUTINE COUPL_SURF_ATMN.F90
!REAL, DIMENSION(KI,KSW)         :: PSCA_ALB    !diffuse albedo
!REAL, DIMENSION(KI)             :: PZENITH     !zenith angle
!REAL, DIMENSION(KI)             :: PAZIM       !azimuth angle from south, counterclockwise

!NAMELIST SETTINGS
!INTEGER                         :: NFRAC_SHA   !number of sections (e.g. 8)
!LOGICAL                         :: LDSV, LDSH, LDSL !switch for sky view factor, shadow factor, slope factor

!VARIABLES FROM PGD FILE
!REAL, DIMENSION(KI)             :: XAVG_SLO    !average slope
!REAL, DIMENSION(KI,NFRAC_SHA)   :: RSLOPE      !mean slope in section
!REAL, DIMENSION(KI,NFRAC_SHA)   :: FRASP       !fraction of subgrid pixels in section
!REAL, DIMENSION(KI)             :: XAVG_SVF    !average sky view factor
!REAL, DIMENSION(KI,NFRAC_SHA)   :: XSHA        !factor A for shadow calculation, see paper of Senkova
!REAL, DIMENSION(KI,NFRAC_SHA)   :: XSHB        !factor B for shadow calculation

!LOCAL VARIABLES
INTEGER                          :: SI, SK, SL        !loop variables
INTEGER                          :: SLI, IAZI         !counter for definition of section
INTEGER, DIMENSION(NFRAC_SHA)    :: TAB               !center points of the sectors
REAL                             :: PI_SEC1, PI_SEC2, RIND !for calculation of center point in each sector
REAL                             :: SCOS, SSIN        !cos and sin of zenith angle
REAL                             :: LAZIM             !local azimuth angle (from north clockwise)
```

```
REAL                    :: SSWDIR, SSWDIF       !direct and diffuse short wave radiation
REAL                    :: DSLOPFRAC, ALFRAC     !number of sectors, sum over all secotrs
REAL                    :: DSL1, ALB1          !slope factor in section, albedo
REAL                    :: DSLOP               !slope factor
REAL                    :: DSHAD               !shadow factor
REAL, DIMENSION(KI,KSW)      :: DSV, DSL, DSH       !sky view, slope and shadow factor (for output)
LOGICAL                  :: LFOUND              !logical switch for definition of section
REAL                    :: SLWUP               !longwave upward radiation
REAL                    :: SLWDN               !longwave downward radiation


PI_SEC1 = XPI/REAL(NFRAC_SHA)
PI_SEC2 = PI_SEC1 * 2.

DO SK=1,NFRAC_SHA                              !calculating the center of the sectors
  RIND = REAL(SK - 1.)
  TAB(SK) = NINT(1000. * (RIND * PI_SEC2 + PI_SEC1))
END DO

DO SL=1,KI                              !loop over grid points
!only if all orographic shadowing parameters are available
  IF((XAVG_SLO(SL)<XUNDEF).AND.(XAVG_SVF(SL)<XUNDEF).AND.(FRASP(SL,1)<XUNDEF).AND. &
   (RSLOPE(SL,1)<XUNDEF).AND.(XSHA(SL,1)<XUNDEF).AND.(XSHB(SL,1)<XUNDEF))THEN

   DO SI=1,KSW                              !loop over spectral bands
     DSV(SL,SI) = 1.
     DSL(SL,SI) = 1.
     DSH(SL,SI) = 1.

     IF ((PDIR_SWL(SL,SI) >= 0.) .AND. (PSCA_SWL(SL,SI) >= 0.) .AND. &
       (PDIR_SWL(SL,SI) < 2000.) .AND. (PSCA_SWL(SL,SI) < 2000.))THEN !only if there is radiation (no
default)
```

```
        SCOS = MIN(MAX(COS(PZENITH(SL)),1.E-12),1.0-1.E-12)   !cos of solar zenith angle
        LAZIM = XPI-PAZIM(SL)
        IF(LAZIM < 0.)LAZIM=LAZIM+2*XPI
        SSWDIR = PDIR_SWL(SL,SI)
        SSWDIF = PSCA_SWL(SL,SI)!
!-------------------------------------------------------------------------
! 1. DIFFUSE AND REFLECTED SOLAR RADIATION
!-------------------------------------------------------------------------
!
        IF (LDSV == .TRUE.)THEN
          ALB1 = PSCA_ALB(SL,SI)
          IF ((ALB1 >= 0.07) .AND. (ALB1 <= 1.0))THEN
            IF (XAVG_SVF(SL) > 0.1) DSV(SL,SI) = XAVG_SVF(SL) / 100.
            SSWDIF = DSV(SL,SI) * SSWDIF + ALB1 * (1.0 - DSV(SL,SI)) * (SSWDIR + SSWDIF)
          END IF
        END IF
!
!-------------------------------------------------------------------------
! 2. CORRECTION OF SOLAR DIRECT RADIATION FLUX
!-------------------------------------------------------------------------
!
! SLOPE CORRECTION

        SSIN = SQRT(1.0 - SCOS * SCOS)                    !sinus of solar zenith angle
        ALFRAC = 0.
        DSLOPFRAC = 0.

        IF (LDSL == .TRUE.)THEN
          DO SK=1,NFRAC_SHA                               !loop over sections
            DSL1 = 1.0 + TAN(RSLOPE(SL,SK) * XPI / 180.) * SSIN / SCOS &
```

```
      * COS(LAZIM - XPI / 4.0 * REAL((SK - 1.)))
      ALFRAC = ALFRAC + FRASP(SL,SK)
    IF (DSL1 > 0.) DSLOPFRAC = DSLOPFRAC + DSL1 * FRASP(SL,SK)
    END DO
  END IF

  DSL(SL,SI) = DSLOPFRAC + 1 - ALFRAC

! CAST SHADOW, DETERMINE THE VALUE OF SHADOW MASK

  DSHAD = 1.0

  IF (LDSH == .TRUE.)THEN
!       IF (SCOS < 0.34)THEN                   !do only if zenith angle > 70 deg
    DSHAD = XSHA(SL,1) * SCOS + XSHB(SL,1)
    LFOUND = .FALSE.
    SLI = 2
    IAZI = NINT(LAZIM * 1000.)
    DO WHILE(.NOT. LFOUND .AND. SLI <= NFRAC_SHA)
      IF ((IAZI >= TAB(SLI - 1)) .AND. (IAZI < TAB(SLI)))THEN
      DSHAD = XSHA(SL,SLI) * SCOS + XSHB(SL,SLI)
      LFOUND = .TRUE.
      END IF
      SLI = SLI + 1
    END DO

    IF (DSHAD > 0.001) DSH(SL,SI) = DSHAD
    IF (DSHAD > 1.000) DSH(SL,SI) = 1.0
    IF (DSHAD < 0.000) DSH(SL,SI) = 0.0
!      END IF
  END IF
```

```
            SSWDIR = SSWDIR * DSL(SL,SI) * DSH(SL,SI)!
!--------------------------------------------------------------------------
! 3. GLOBAL AND NET SOLAR RADIATION
!--------------------------------------------------------------------------
!
            PSCA_SWL(SL,SI) = SSWDIF
            PDIR_SWL(SL,SI) = SSWDIR

        END IF
!
!--------------------------------------------------------------------------
! 4. LONGWAVE RADIATION
!--------------------------------------------------------------------------
!
        IF ((PLWL(SL) >= 0.) .AND. (PLWL(SL) < 2000.) .AND. &
            (PLWNETL(SL) > -2000.) .AND. (PLWNETL(SL) < 2000.))THEN !only if there is radiation (no default)
            IF (LDSV == .TRUE.)THEN
                SLWDN = PLWL(SL)
                SLWUP = PLWL(SL)-PLWNETL(SL)
                SLWDN = DSV(SL,SI) * SLWDN + (1.0 - DSV(SL,SI)) * SLWUP

                PLWNETL(SL) = SLWDN - SLWUP
                PLWL(SL) = SLWDN
            END IF
        END IF
!--------------------------------------------------------------------------
! 5. DIAGNOSTIC OUTPUT OF APPLIED FACTORS
!--------------------------------------------------------------------------
!
        DSL(SL,SI) = DSL(SL,SI) * SCOS
```

```
        IF (SCOS < 0.001) DSH(SL,SI) = 0.

     END DO
   END IF
END DO

END SUBROUTINE HLORORAD
```