Numerical Weather Prediction at MeteoSwiss

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1. Current operational configuration

1.1 System run schedule and forecast ranges

The actual short-range forecasting system of MeteoSwiss is the alpine Model aLMo, the Swiss implementation of the non-hydrostatic Local Model developed by COSMO (the Consortium for Small-Scale Modelling currently composed of the national weather services of Germany, Switzerland, Italy, Greece and Poland – see cosmo-model.cscs.ch). It is operational at MeteoSwiss since April 2001, with IFS frames as lateral boundary conditions provided by the ECMWF BC special project.

A continuous assimilation cycle has been implemented, currently ingesting conventional observations only. A main assimilation suite has been defined with a cut-off time larger than 4 hours, implemented with 3-hour assimilation runs; an additional short cut-off suite is also calculated to provide initial conditions for the operational forecasts and for other near-real time requirements. Two daily 72 hours forecasts are calculated, based on the 00 and the 12 UTC analyses, with a 90 minutes cut-off time. The time critical forecast products are available in about 70 minutes.

A sophisticated set of scripts controls the whole operational suite, and allows for a very high reliability of the system, with less than 2% of the forecasts requiring manual intervention. This same environment is also used to run parallel suites, to validate proposed modifications to the system, and to facilitate experimentation by the modelling group.

The computing resources and expertise are provided by the Swiss National Supercomputing Centre (CSCS, see www.cscs.ch). aLMo is calculated on a single node 16 processors NEC SX-5, and achieves a sustained performance of 29 GFlops, or more than 25% of the peak performance of the machine. Pre- and post-processing needs are covered by a 8 processors SGI O3200 front-end platform; a large multi-terabytes long term storage is used for archiving purposes, and a 100 MBit/s link connects the MeteoSwiss main building with the CSCS (on the other side of the Alps!).

1.2 Data assimilation, objective analysis and initialization

Data assimilation with aLMo is based on the nudging or Newtonian relaxation method, where the atmospheric fields are forced towards direct observations at the observation time. Balance terms are also included: (1) hydrostatic temperature increments balancing near-surface pressure analysis increments, (2) geostrophic wind increments balancing near-surface pressure analysis increments, (3) upper-air pressure increments balancing total analysis increments hydrostatically. A simple quality control using observation increments thresholds is in action.

Currently, only conventional observations are assimilated: synop/ship/buoys (surface pressure, 2m humidity, 10m wind for stations below 100 m above msl), temp/pilot (wind, temperature and humidity profiles) and airep/amdar (wind, temperature). Typical 24 h assimilation at MeteoSwiss ingests about 180 vertical soundings, about 7000 upper-air observations and about 25000 surface observations. Assimilation of wind profiler data and GPS derived integrated water vapour, as well as a radar based 2-dimension latent heat nudging scheme are being developed.

The snow analysis made by the German Weather Service is used in aLMo; it is based on a simple weighted averaging of observed values. Effort is currently under way to derive a new snow analysis from MSG satellites combined with dense observations (see chapter 3). All other surface and soil model fields are obtained by interpolating IFS analysis. These fields are updated twice daily by direct insertion in the assimilation cycle. Finally, the ozone and vegetation fields are based on climatic values.

In addition to the MARS retrieving system, the full ECMWF decoding, quality control and database software have been installed on our front end machine. The cut-off time for the main assimilation cycle is at least 4 hours, and the oldest lateral boundary conditions are 3 hours old. Based on this main cycle, additional short cut-off cycles (90 minutes) are calculated to produce the initial conditions for the operational forecasts.

1.3 Model

A thorough description of the Local Model itself can be found on the COSMO web site. aLMo is a primitive equation model, non-hydrostatic, fully compressible, with no scale approximations. The prognostic variables are the pressure perturbation, the cartesian wind components, the temperature, the specific humidity, the liquid water content, cloud ice, rain and snow. There are options for additional prognostic variables (e.g. turbulent kinetic energy) which are currently not used at MeteoSwiss.

The model equations are formulated on a rotated latitude/longitude Arakawa C-grid, with generalized terrain-following height coordinate and Lorenz vertical staggering. Finite difference second order spatial discretization is applied, and time integration is based on a 3 time levels split explicit method. Fourth order linear horizontal diffusion with an orographic limiter is in action. Rayleigh-damping is applied in the upper layers.

At MeteoSwiss aLMo is calculated on a 385x325 mesh, with a 1/16° mesh size (about 7 km), on a domain covering most of Western Europe (see aLMo in Figure 1). In the vertical a 45 layers configuration is used; the vertical resolution in the lowest 2 km of the atmosphere is about 100 m. The main time step is 40 seconds.

2. Plans of MeteoSwiss for future high resolution

The development of a high resolution model has started in 2005. The motivation is to get an automatic generation of local forecast products in complex topography being used for general forecast purposes and contributing to the security of the Swiss population by the generation of warnings/alarms e.g. in case of incidents in nuclear power plants, floods, or avalanches. It will also allow MeteoSwiss to develop and maintain its key competence in Alpine meteorology.

The new model called aLMo2 will get its boundary conditions from the actual aLMo, have a mesh size about 1/50°~2.2km and its domain of 480 x 350 grid points with 60 levels will be centered on the Alps. In addition to the current forecast, it will produce 8 times a day 18 hours forecasts. It is planned to be pre-operational in 2007 and operational in 2008.

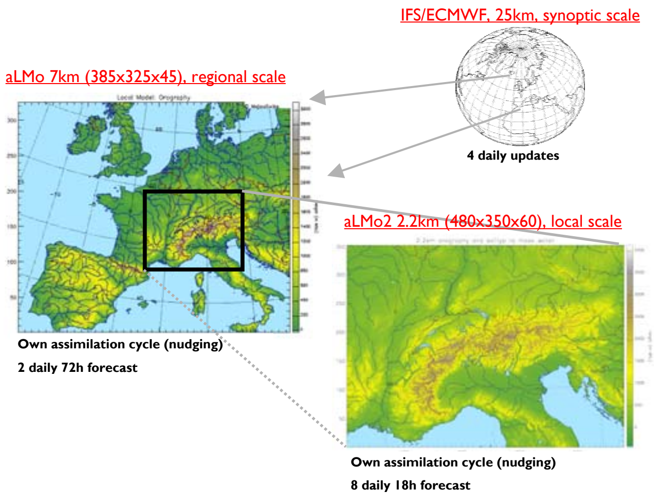

Figure 1 future NWP system of MeteoSwiss

The probable setup will be based on a new numerical kernel, 2-timelevel 3rd order Runge-Kutta, with a main time step of about 15 seconds. It will use improved physics with e.g. new schemes for graupel, 3-d turbulence and shallow convection (the deep convection being resolved), as well as with implementation of the topographic effects on radiation (see 4). New types of measurement will be used for assimilation: radar data (using the latent heat nudging), wind profiler, VAD, SODAR, GPS data (using tomographic methods) and satellite data for snow analysis (see 3).

3. Snow cover mapping in the Alps using multi-temporal satellite data

To improve the snow analysis used in aLMo, satellite data will be combined with the measurements of a maximum of conventional climate stations. Until recently only polar-orbiting satellites, which monitor the surface with low temporal frequencies, possessed the necessary spectral channels to separate snow and clouds. This gap has been closed by a new geostationary satellite, Meteosat-8, launched in 2002 by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). It caries the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI), which has an unprecedented combination of high temporal frequency (15 minutes) and spectral resolution (12 spectral channels). The spatial resolution is rather coarse, about 5 km over central Europe, but this is still higher than the resolution of the actual aLMo. The spectral and temporal capabilities of SEVIRI can be used to avoid a regularly encountered problem in remote sensing of snow, which is the confusion of snow and clouds. This can occur when clouds, which have a similar visible reflectance as snow, also have the same Brightness Temperature (BT) and phase (i.e. ice clouds). Such clouds may not be detected by traditional methods that have been used for remote sensing of snow and clouds. The problem is illustrated by Figure 2, which displays an RGB image of Europe, made from several SEVIRI channels. Snow is red in this image and many clouds are white, but some clouds appear in the same colour as snow.

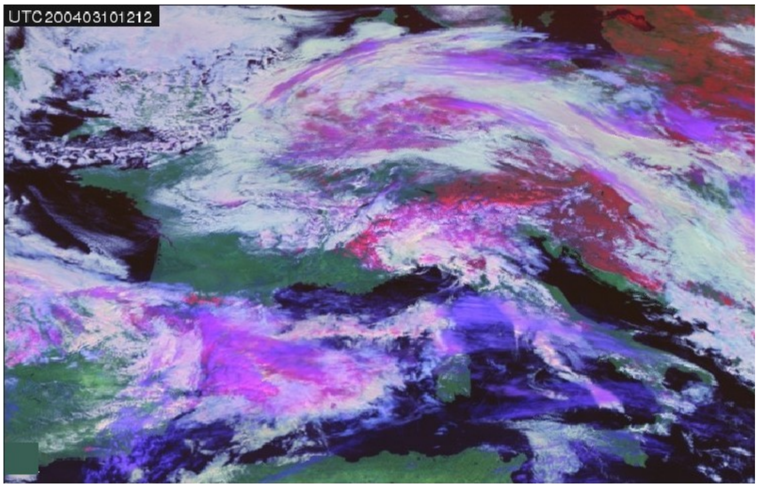

Figure 2 RGB image of Europe, made from SEVIRI channel 1 (0.64 µm), channel 3 (1.6 µm) and a combination of channels 4 (3.9 µm), 9 (10.8 µm) and 11 (13.4 µm). The scene was acquired on March 10th, 2004, around 12:12 UTC

Here we use two improvements for the detection of such clouds, one spectral and one temporal. The first uses the 3.9 µm - 10.8 µm brightness temperature difference, which is a well-known feature for detecting clouds, in combination with the 13.4 µm brightness temperature. This combination of three channels detects more clouds, including many ice clouds, than any other known spectral feature. Over water clouds, the latter feature has high values and appears bright, whereas unclouded regions appear dark. Unfortunately, clouds with high ice content appear as dark as unclouded areas. The combination of $BT_{3.9}$, $BT_{10.8}$ and $BT_{13.4}$ clearly reveals many ice clouds that are not detectable with $BT_{3.9}$ - $BT_{10.8}$ alone.

The second improvement involves the high temporal frequency of SEVIRI. The temporal behaviour of many clouds often makes them recognisable to the human eye: at a time scale of minutes to hours the surface is virtually static, whereas many clouds are dynamic at these time scales. We can simply quantify this dynamic behaviour with the standard deviation in time of a pixel, and then use this to detect clouds. This is possible in each of the SEVIRI channels, and by combining the temporal information from all single channels; many clouds can be detected. Not all clouds have a high temporal variability and can be detected in this way, so the temporal information should always be used in combination with the spectral information. Cloud obscurance can be reduced by combining a series of snow maps into one composite snow map. Figure 3 (left part) displays such a composite map for a three-day period. Relatively small areas were covered by clouds during this entire period and for most of the surface the snow cover could be retrieved. Apart from the above-mentioned low-resolution channels, SEVIRI also contains one high resolution visible channel. In this channel, clouds can be masked by combining its temporal information, which does not detect all cloud cover, with the down-scaled low-resolution cloud mask. Figure 3 (right part) shows that nearly all clouds are detected in this way and that only very few cloudy pixels were missed (visible as very small isolated patches of snow).

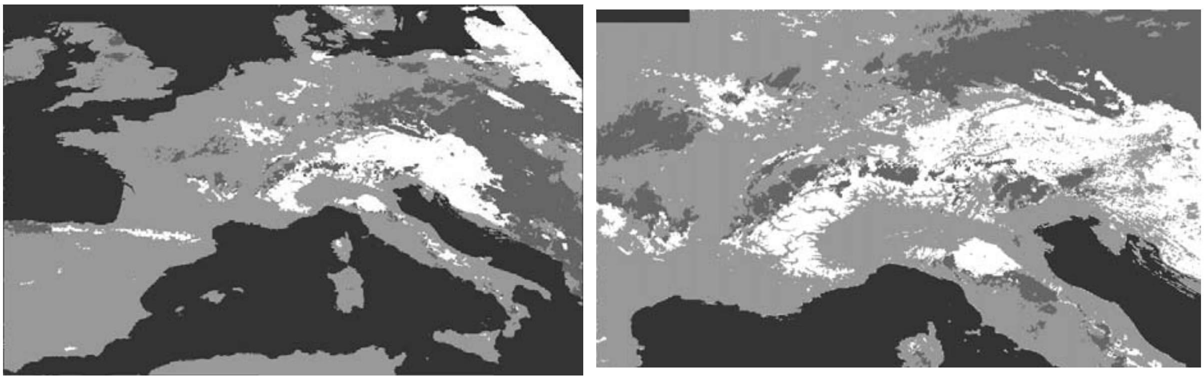

Figure 3 Composite snow map for the period March 8th till March 10th 2004. (left) low and (right) high resolution channel

4. Gridscale parameterization of topographic effects on radiation

At the grid spacing of aLMo2, slope aspect, slope angle or slope inclination, sky view as well as shadowing significantly modify radiation fluxes at the earth's surface. The radiation scheme implemented in the aLMo (Ritter and Geleyn, 1992) computes the surface radiation components on horizontal surfaces and doesn't take into account topographic effects. Before considering a wide reformulation of this scheme in a complex topography environment, a concept based on correction factors for the surface radiation components can give us a simpler way to include this effect in the model.

4.1 The parameterization

The parameterization scheme proposed by Müller and Scherrer (2005) offers a simple approach to compute and introduce topographic effects on radiation in NWP models. It has been implemented into the aLMo and the sensitivity of the model to the introduced radiation corrections has been studied.

This parameterization scheme computes for each model grid cell correction factors for the surface radiation components based on the sunshine conditions and on the model topography. In order to save computing resources all the correction factors are computed prior to the model integration. For each time step of the radiation scheme a correction factor for the direct solar radiation is calculated considering the sunshine conditions (sun elevation and azimuth angle), the slope angle, the slope aspect as well as the possible shadow conditions depending on the horizon (shadow mask). The diffuse downward solar component and the downward thermal component are corrected using the sky view factor. Here also the effect of surrounding grid points is introduced. The correction for the thermal downward radiation has been modified in order to take account also average vertical temperature differences of the adjacent grid points in a chosen horizontal length scale.

4.2 Results

At 7 km grid mesh the effects on the surface temperature of the implemented parameterization scheme in the Swiss alpine region are generally below 1 K (Figure 4). Nevertheless in some few grid points the effect can be higher if the small radiation balance change can modify significantly the snow amount conditions or the turbulence exchange coefficients (in winter with strong temperature inversion, warm air from above can be transported down). These indirect effects are reduced during the summer day case study, where we observe in some grid points from the late morning to the afternoon some interesting indirect changes in the total cloud cover, which influence significantly the surface temperature.

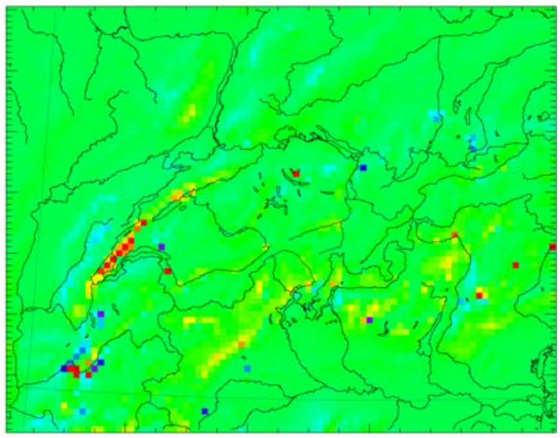

Figure 4 11.12.2004 00 UTC +9h, aLMo 7 km, surface temperature difference between aLMo with and without radiation correction.

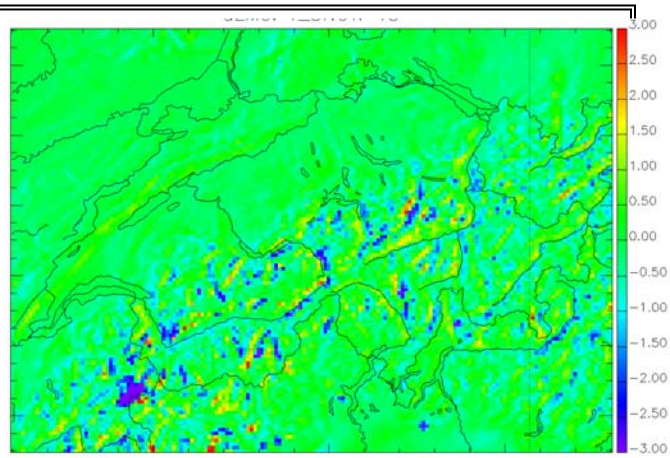

Figure 5 7.8.2003 00 UTC +9h, aLMo 2.2 km, surface temperature difference between aLMo with and without radiation correction.

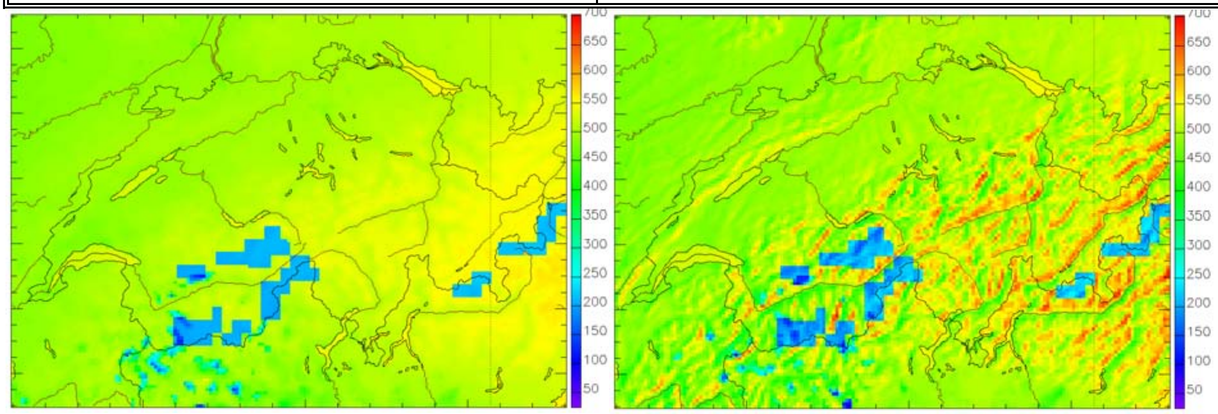

Figure 6 7.8.2003 00 UTC +8h, aLMo 2.2 km, net shortwave radiation, left uncorrected aLMo run, right corrected aLMo run.

By decreasing the grid mesh down to 2 km the effects of the radiation changes become more important. The impact on the net shortwave radiation can be on the order of magnitude up to 200 W/m2 (Figure 6). In the morning and in the evening significant shadowing effects take place. The surface temperature changes in Swiss alpine region is generally below 2 K, but many grid-points have bigger changes up to 3-4 K, even in summer days (Figure 5). Changes in the cloud cover have been also observed either in winter by the high resolution run or in summer. The thermal differences at the surface can generate also some significant changes in the thermal circulations.

4.3 Conclusions

The impact of the topographic effects (shadowing, slope angle, slope aspect and sky view) is substantial at high resolution. Some significant indirect impacts (feedbacks) can be seen even at 7 km horizontal resolution: they are related to snow melt, stability (turbulence) and low clouds. The effect on clouds is more pronounced at 2.2 km and have to be further investigated.

5. References

Müller D. M. and Scherrer D. (2005): A grid- and subgrid-scale Radiation Parameterization of Topographic Effects for mesoscale weather forecast models. *Mon. Wea. Rev.*, **133**, 1431-1442.

Ritter B. and Geleyn J.-F. (1992): A comprehensive Radiation Scheme for numerical weather prediction models with potential applications in climate simulations. *Mon. Wea.Rev.,* **120**, 303-325.