4 Operational Applications

The LM is operated in five centres of the COSMO members (ARPA-SIM, DWD, HNMS, IMGW, MeteoSwiss). Following a 1-year preoperational trial from October 1998 to November 1999, the model became operational at DWD in December 1999. At MeteoSwiss the LM was integrated in a preoperational mode two times a day since July 2000. The model became fully operational in February 2001. In Italy the model runs operational twice a day at ARPA-SIM. The HNMS in Greece integrates the LM once a day in parallel to their old operational system. IMGW integrated the LM twice a day since October 2001 in a preoperational mode and switched to an operational schedule when they officially joined the COSMO group in July 2002. Figure 5 shows the integration domains of the model runs at the COSMO meteorological centres.

ARPA-SIM, HNMS and IMGW use interpolated boundary conditions from forecasts of the global model GME of DWD. Only a subset of GME data covering the respective LM-domain of a COSMO meteorological centre are transmitted from DWD via the Internet. HNMS and IMGW start the LM from interpolated GME analyses. In this case it is possible to smooth the initial fields using the digital filtering scheme of Lynch et al. (1997). At DWD, a comprehensive data assimilation system for LM has been installed, comprising the LM nudging analysis for atmospheric fields, a sea surface temperature (SST) analysis, a snow depth analysis and the soil moisture analysis according to Hess (2001). A data assimilation system based on the LM nudging scheme is now also used at MeteoSwiss (since November 2001) and at ARPA-SIM (since October 2003). Since September 2003, MeteoSwiss uses lateral boundaries from interpolated IFS-forecasts.

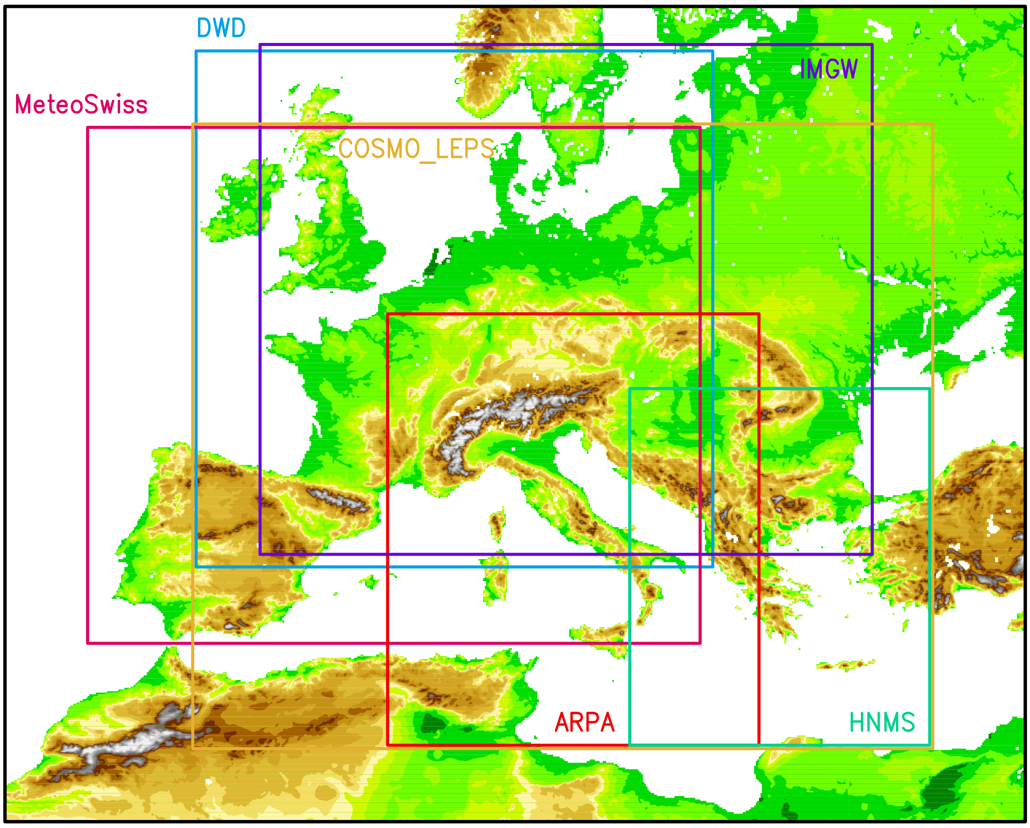

Figure 5: LM integration domains used at DWD, MeteoSwiss, ARPA-SIM, HNMS, IMGW and for the COSMO-LEPS

ARPA-SIM installed the COSMO-LEPS (Limited Area Ensemble Prediction System) based on LM and ECMWF ensemble forecasts at the ECMWF computing centre. 5 operational LM runs are performed (10 km grid spacing, 32 levels) starting at 12 UTC on initial and boundary conditions for 5 representative members of an ECMWF-EPS superensemble.

In addition, the national weather service of Italy, UGM in Rome, runs the LM at the ECMWF computing centre for the same domain as ARPA-SIM and also for a bigger domain comparable to the COSMO-LEPS domain. The lateral boundaries for these runs are taken from the IFS.

The following sections give a brief overview on the configurations of the operational LM systems in the COSMO meteorological centres. MeteoSwiss, ARPA-SIM and UGM have renamed the model within their services: the LM application in Switzerland is called ***aLMo*** (Alpine Model), the LM application in Italy is called ***LAMI*** (Limited Area Model Italy).

4.1 ARPA-SIM (Bologna)

Basic Set-Up of LM

The regional meteorological service ARPA-SIM in Bologna operates the LM (as LAMI) at 7 km grid spacing. The rotated lat-lon coordinates of the lower left and the upper right corner of the integration domain are $(\lambda = -5°, \varphi = -24.0°)$ and $(\lambda = 9.5625°, \varphi = -7.0625°)$, respectively. See Figure 5 for this model domain. The main features of the model set-up are summarized in Table 7.

Table 7: **Configuration of the LAMI at ARPA-SIM**

Domain Size	234 x 272 gridpoints
Horizontal Grid Spacing	0.0625° ($\sim$ 7 km)
Number of Layers	35, base-state pressure based hybrid
Time Step and Integration Scheme	40 sec, 3 time-level split-explicit
Forecast Range	72 h
Initial Time of Model Runs	00 UTC and 12 UTC
Lateral Boundary Conditions	Interpolated from GME at 1-h intervals
Initial State	Nudging data assimilation cycle, no initialization
External Analyses	None
Special Features	Use of filtered topography, new TKE scheme, new surface-layer scheme, cloud-ice scheme
Model Version Running	lm_f90 3.5
Hardware	IBM SP pwr4 (using 32 of 512 processors)

Changes in the last year

The most important changes in the last year were the introduction of an operational data assimilation suite (see below) and the treatment of cloud ice in the LM.

Data assimilation

Since October 2003 the assimilation suite has become the main operational suite and the run initialized directly from GME is not performed anymore. As during the experimental period, the assimilation suite includes two 12-h cycles with AOF-file provided by UGM Rome with SYNOPs, AIREPs, TEMPs and PILOTs. Two forecasts up to 72 hours, at 00 and 12 UTC, are performed daily starting from the analyses provided by the assimilation cycles. Figure 6 illustrates the scheme of the assimilation suite.

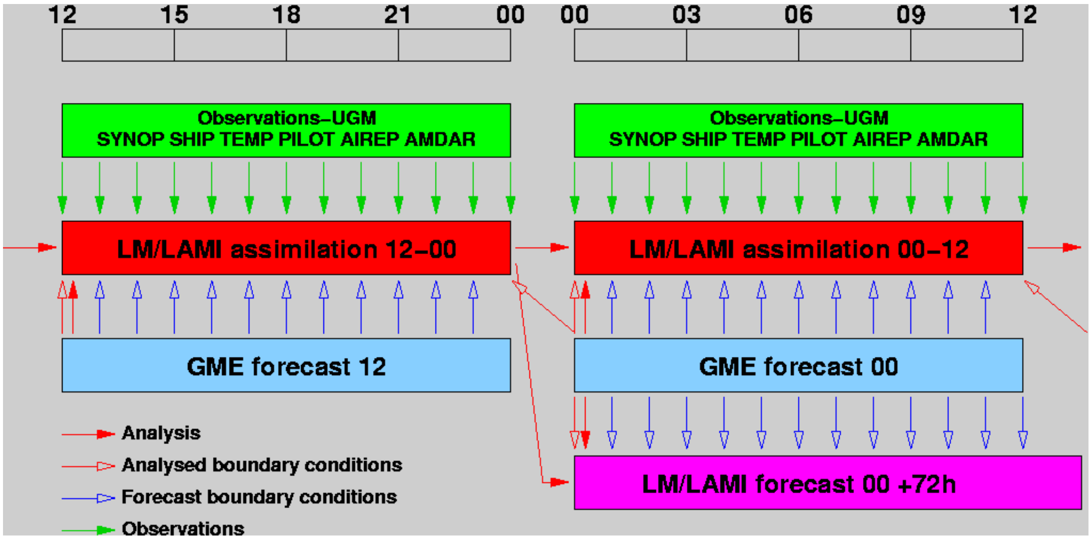

Figure 6: The assimilation suite at ARPA-SIM

Computer system
Since autumn 2003, an experimental backup suite is being set up at ARPA on a cluster of i386 computers with a total of 32 processors INTEL Xeon 2.4Ghz, connected by Gigabit ethernet network and running the Linux/GNU operating system. The setup is the same as the one on IBM at Cineca and the suite is controlled by ECMWF SMS software.

4.2 DWD (Offenbach)

Basic Set-Up of LM
The LM runs operationally at DWD using a 7 km grid spacing and 35 vertical levels. The rotated lat-lon coordinates of the lower left and the upper right corner of the integration domain are ($\lambda = -12.5°, \varphi = -17.0°$) and ($\lambda = 7.75°, \varphi = 3.25°$), respectively. See Figure 5 for this model domain. The main features of the model set-up are summarized in Table 8.

Changes in the last year
These are the main changes in the operational setup in the last year:

- The computation of the maximal wind gusts: now also the convective gusts created by downdrafts are considered for determining the maximal gusts in the LM.
- The parameterization of moist convection: to avoid convective drizzle, new thresholds for the minimal moisture convergence and the minimal vertical motion were set in the Tiedtke convection scheme.
- The introduction of cloud ice in GME and LM.

Data Assimilation
At DWD, a comprehensive data assimilation system for LM has been installed. Besides the analysis by observational nudging, three external analyses are run: a sea surface temperature

Table 8: **Configuration of the LM at DWD**

Domain Size	325 x 325 gridpoints
Horizontal Grid Spacing	0.0625° ($\sim$ 7 km)
Number of Layers	35, base-state pressure based hybrid
Time Step and Integration Scheme	40 sec, 3 time-level split-explicit
Forecast Range	48 h
Initial Time of Model Runs	00 UTC, 12 UTC, 18 UTC
Lateral Boundary Conditions	Interpolated from GME at 1-h intervals
Initial State	Nudging data assimilation cycle, no initialization
External Analyses	Sea surface temperature (00 UTC) Snow depth (00, 06, 12, 18 UTC) Variational soil moisture analysis (00 UTC)
Special Features	Use of filtered topography, new TKE-scheme new surface-layer scheme, cloud-ice scheme
Model Version Running	lm_f90 3.1
Hardware	IBM SP3 (using 165 of 1280 processors)

(SST) analysis (00 UTC), a snow depth analysis (00, 06, 12 and 18 UTC) and a variational soil moisture analysis (00 UTC).

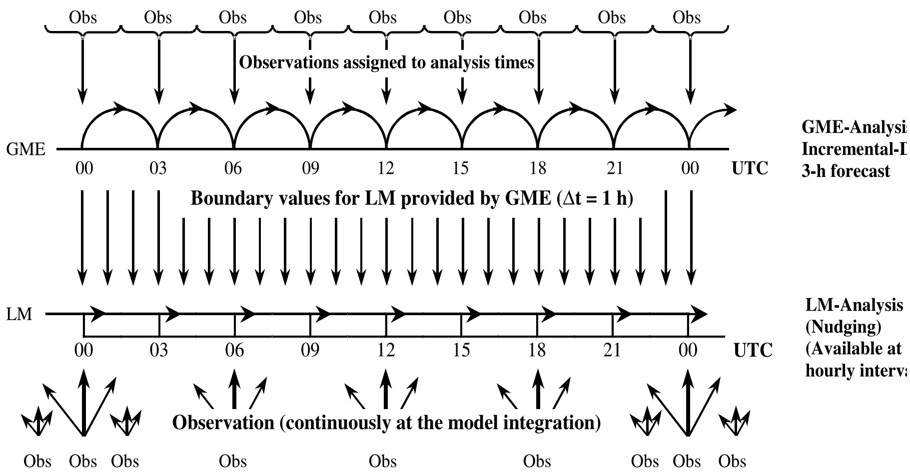

Figure 7: 4-D data assimilation for GME and LM

The data assimilations for the models GME and LM proceed as parallel streams which are coupled only via the boundary data. (see Fig. 7). The GME analysis is based on a 3-D multivariate optimum interpolation (OI) of deviations of observations from 3-h forecasts (first guess), generating an intermittent assimilation cycle with 3-h analysis frequency. All observations within a time window of $\pm$ 1.5 hours are considered as instantaneous, i.e. to be valid at analysis time.

The 3-h GME forecasts to produce the first guess are used to generate boundary data at 1-h intervals for the LM assimilation cycle. The nudging scheme produces a continuous analysis stream, where data are assimilated at the time they are observed - but using a time-weighting function to spread the information in time. For practical reasons, 3-hour LM assimilation runs are done. LM analysis files are written every hour.

Operational Schedule
The operational schedule is structured by data assimilation for GME and LM every three hours, i.e. for 00, 03, 06, 09, 12, 15, 18 and 21 UTC. The data cut-off time for the 00 UTC and 12 UTC model runs of both GME and LM is 2 h 14 min. Based on this analyses, GME performs a 174-h forecast, and LM performs a 48-h forecast. Another 48-h prediction of both models is performed starting at 18 UTC with a data cut-off time of 4 hours. Besides the forecast models, a wave prediction suite comprising a global and a local sea state model (GSM and LSM) is run operationally.

4.3 HNMS (Athens)

Basic Set-Up of LM
The national meteorological service of Greece, HNMS in Athens, operates the LM in a pre-operational mode at 14 km grid spacing. The rotated lat-lon coordinates of the lower left and of the upper right corner of the integration domain are ($\lambda = 4.5°, \varphi = -24.0°$) and ($\lambda = 16.25°, \varphi = -10.0°$), respectively. See Figure 5 for this model domain.

Since August 2002, HNMS has utilized its computational resources at ECMWF and operates the LM at the IBM SP on a daily basis at 00 and 12 UTC. The domain is the same as in the one used for the local operation but the grid spacing has been reduced to 7 km. In addition to their regular operational use at the National Meteorological Center, the results were used for the partial support of the first Olympic test event that was held in August 2002 at the Saronic Gulf, South of the Athens Metropolitan area. Table 9 shows the main features of both model set-ups for the greek runs.

Table 9: **Configuration of the LM at HNMS and at ECMWF**

Domain Size	95 x 113 grid points	189 x 225 gridpoints
Horizontal Grid Spacing	0.125° (∼ 14 km)	0.0625° (∼ 7 km)
Number of Layers	35, base-state pressure based hybrid	
Time Step	80 sec	30 sec
Integration Scheme	3 time-level split-explicit	
Forecast Range	48 h	48 h
Initial Time of Model Runs	00 UTC	00, 12 UTC
Lateral Boundary Conditions	Interpolated from GME at 1-h intervals	
Initial State	Interpolated from GME	
External Analyses	None	
Special Features	Use of filtered topography	
Model Version Running	lm_f90 3.5	
Hardware	HP	IBM SP

Figure 8 shows the results for 10 meter winds for a sample of dates where strong winds were prevailing over almost all of Greece and in particular over the sea area.

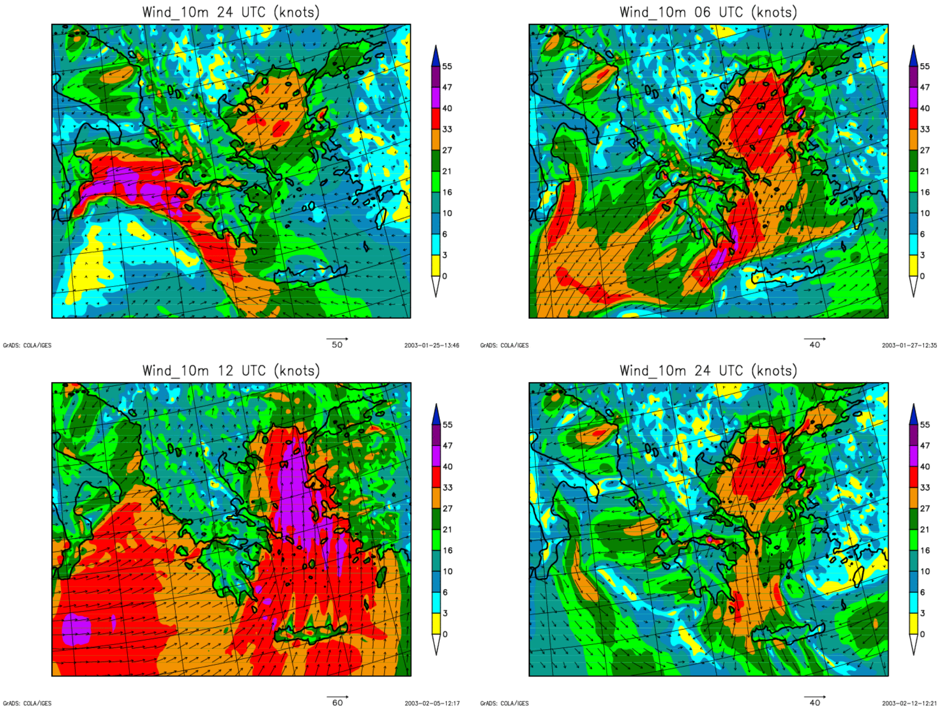

Figure 8: Forecast products used at HNMS, Athens

4.4 IMGW (Warsaw)

Basic Set-Up of LM

The national meteorological service of Poland, IMGW in Warsaw, operates the LM in an operational mode at 14 km grid spacing twice a day (00 UTC and 12 UTC). The rotated lat-lon coordinates of the lower left and of the upper right corner of the integration domain are ($\lambda = -10.0°, \varphi = -16.5°$) and ($\lambda = 14.0°, \varphi = 3.5°$), respectively. See Figure 5 for this model domain. The main features of the model set-up are summarized in Table 10.

Table 10: **Configuration of the LM at IMGW**

Domain Size	193 x 161 gridpoints
Horizontal Grid Spacing	0.125° (~ 14 km)
Number of Layers	35, base-state pressure based hybrid
Time Step and Integration Scheme	80 sec, 3 time-level split-explicit
Forecast Range	72 h
Initial Time of Model Runs	00 UTC and 12 UTC
Lateral Boundary Conditions	Interpolated from GME at 1-h intervals
Initial State	Interpolated from GME
External Analyses	None
Special Features	Use of filtered topography, new TKE-scheme new surface-layer scheme, cloud-ice scheme
Model Version Running	lm_f90 3.5
Hardware	SGI 3800 (using 88 of 100 processors)

The results of the LM forecasts are provided to the Weather Offices and to the RADAR and HYDRO units of IMGW (also for verification). Figure 9 shows some of these forecast products.

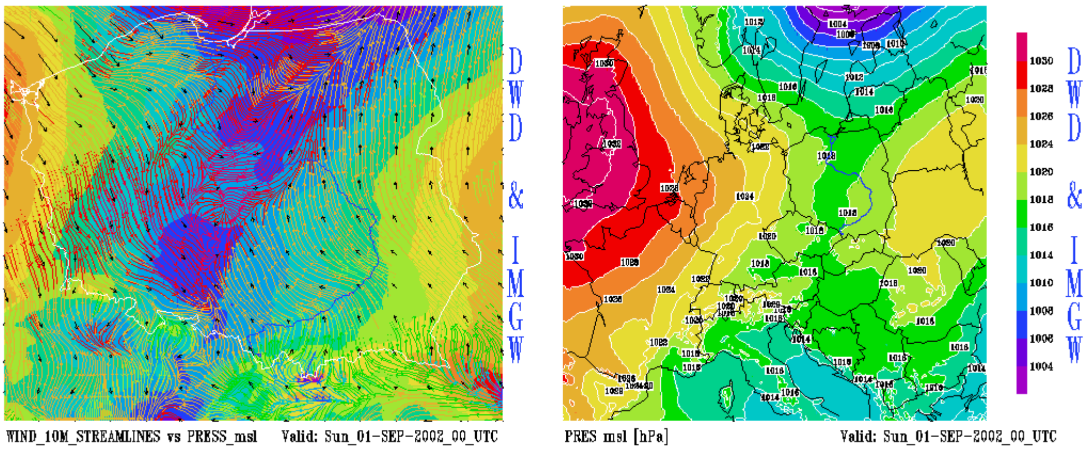

Figure 9: Forecast products used at IMGW, Warsaw

In addition to the operational runs with dx=14 km the LM also runs with a resolution of 7 km, but only for a forecast range of 30 hours.

4.5 MeteoSwiss (Zürich)

The Alpine Model (aLMo) is the operational 7km version of the LM at MeteoSwiss. The model is computed on a NEC SX-5 operated by the Swiss Centre for Scientific Computing (CSCS) in Manno (Tessin). During the operational forecasting slots the SX-5 enters near-dedicated mode: 14 CPUs are then reserved for the model integration and 1 CPU is left for the interpolation of the lateral boundary fields provided by the driving global model. From the global model (Integrated Forecast System, IFS, from ECMWF) only frames are used. The operational suite is controlled by the LM Package. This is a set of shell scripts running on SGI Origin 3000.

Basic Set-Up of aLMo

The aLMo domain extends from 35.11 N, 9.33 E (lower left) to 57.03 N, 23.41 E (upper right). This domain is covered by a grid of 385×325 points with a horizontal resolution of 7 km (see Figure 5). The borders are placed over sea in order to reduce negative interferences generated in the transition zone of the orographies of the driving model (IFS) and aLMo. The main features of the model set-up are summarized in Table 11.

Vertical Coordinates

In operational mode the model runs with 45 levels vertically distributed as shown in Fig. 10.

Hardware and Communications

The computational work of the aLMo suite is managed by 3 systems:

- SUN Enterprise 3000	at MeteoSwiss	(dissemination)
- SGI Origin 3000	at CSCS	(control, pre- and postprocessing, trajectories)
- NEC SX5	at CSCS	(IFS2LM, aLMo, LPDM)

Table 11: **Configuration of the aLMo at MeteoSwiss**

Domain Size	385 x 325 gridpoints
Horizontal Grid Spacing	0.0625° (∼ 7 km)
Number of Layers	45, base-state pressure based hybrid
Time Step and Integration Scheme	40 sec, 3 time-level split-explicit
Forecast Range	72 h
Initial Time of Model Runs	00 UTC and 12 UTC
Lateral Boundary Conditions	Interpolated from IFS at 3-h intervals
Initial State	Nudging data assimilation cycle, no initialization
External Analyses	Merging of LM-DWD snow analysis
Special Features	Use of filtered topography
Model Version Running	lm_f90 3.5+
Hardware	NEC SX5 (using 14 of 16 processors)

Figure 11 shows the present configuration of hardware and communication used for the operational application of aLMo.

Data Flow
All the operational processes are illustrated in the flow diagram of Figure 12. The format of the different products is shown by the different colours of the connections.

LM Package
The operational suite is driven by "LM Package", a software developed at Meteo Swiss. It has a modular structure and is composed by 50 shell scripts. It can be executed in three different modes: operational, test and personal mode. In operational mode preprocessing, aLMo and postprocessing are running concurrently; warnings and exits are transmitted to the permanently on-duty operators, who have the possibility to do manual interventions.

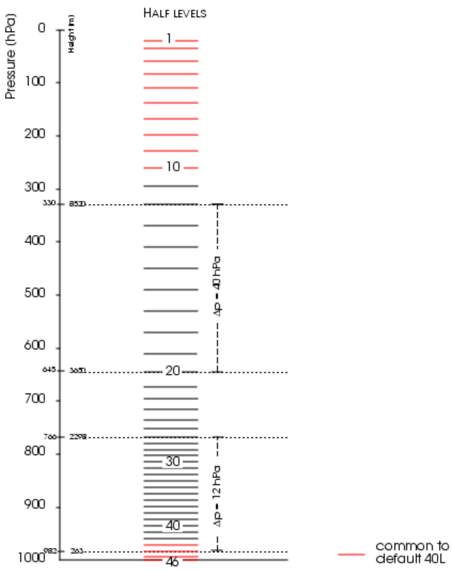

Figure 10: Vertical distribution of levels used at MeteoSwiss

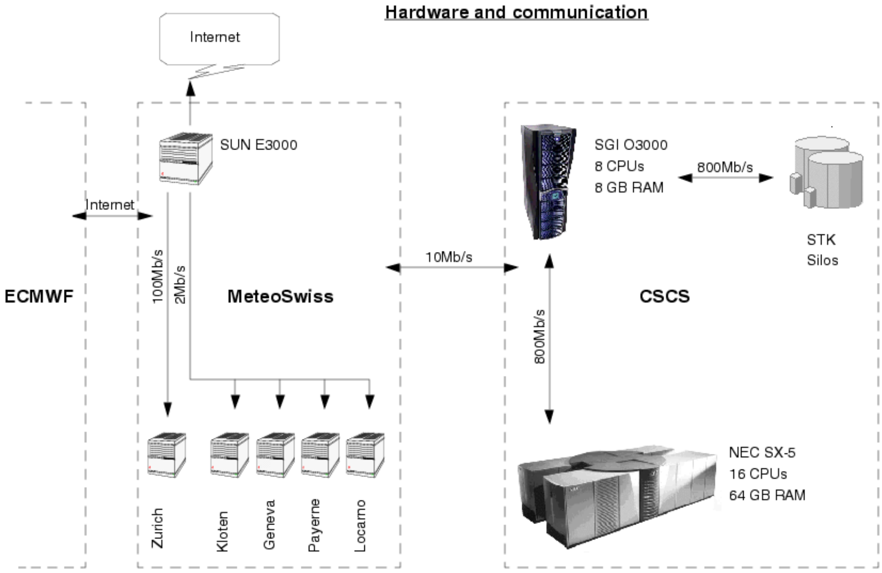

Figure 11: Present configuration of hardware and communications at MeteoSwiss

Products
- 2-D plots: produced by MetView every 3 or 6 hours
- Animations: Hourly loops produced with IDL and AVS
- Tables and extracts of the model output in different formats
- Trajectories
- Concentrations calculated by the LPDM module

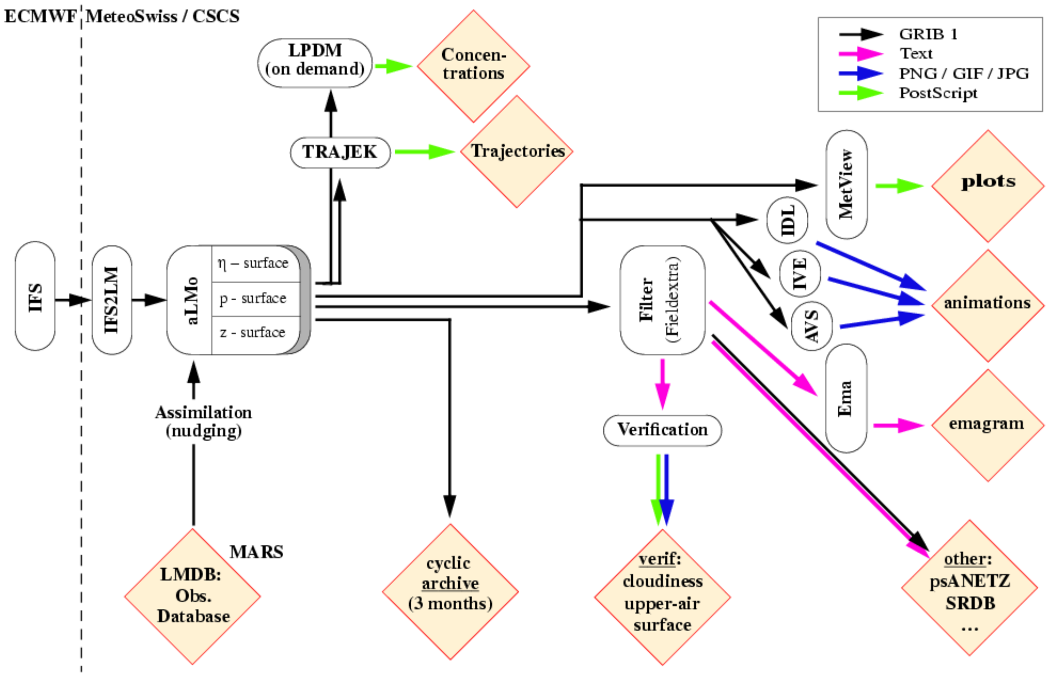

Figure 12: Dataflow of the current operational system at MeteoSwiss

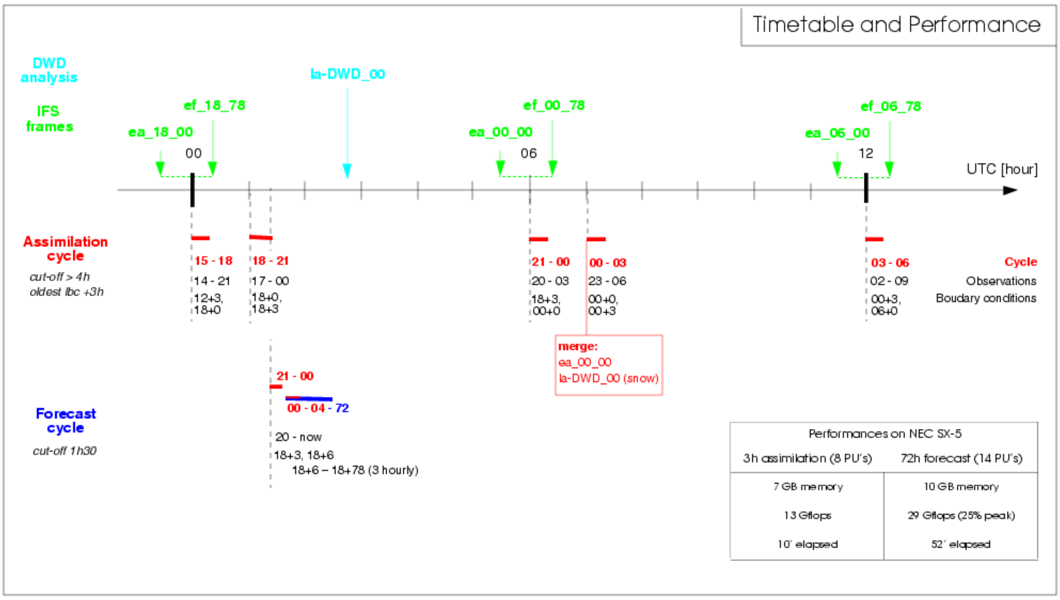

Figure 13: Time table of the aLMo assimilation cycle at MeteoSwiss

Assimilation Cycle

The data assimilation at MeteoSwiss is implemented with 3-hour assimilation runs. aLMo files are written every hour. The cut off time is at least 4 hours. The observations are taken from the aLMo data base, basically a copy of the ECMWF message/report data base. At the beginning of the 00-03 UTC and 12-15 UTC assimilation runs the soil parameters are updated from the IFS analysis. In a similar way the LM snow analysis from DWD is merged into aLMo initial conditions. The schedule for half a day is displayed in Fig. 13.

Time Table

The analysis used by the main 72h forecasts is produced just ahead of the main runs (aLMo forecast) with a 3h run of aLMo in assimilation mode with the IFS frames from 6h earlier (18 or 06 UTC). The boundary conditions in the frames are updated every 3 hours. During the main forecast runs assimilation continues during the first 4 hours. The postprocessing is divided into a time critical and a non time critical part. During the first part the crucial products for Meteo Swiss internal clients (mainly forecasters) are generated and disseminated. During the second part the remaining products for internal and external clients are created. Archiving and statistics take place at the very end of the task. The concurrent processes of the operational production are illustrated in Fig. 14.

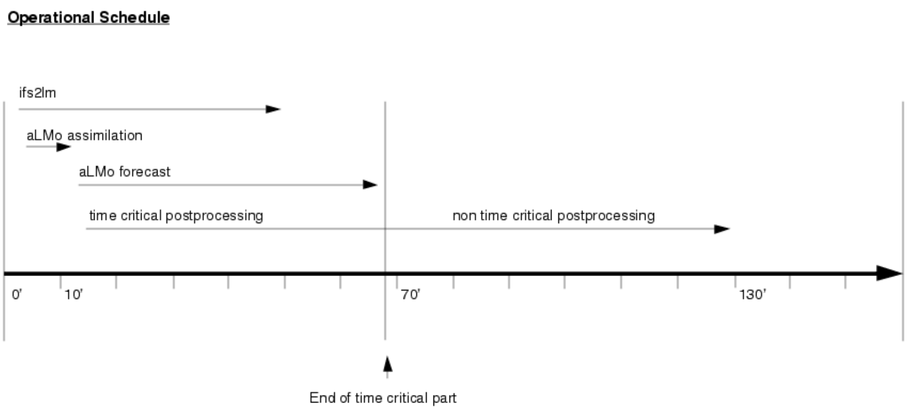

Figure 14: Time table of the operational suite at MeteoSwiss

Verification
The output of the Model undergoes four different types of verification:

- Surface verification: The surface parameters are compared to measurements taken by synoptical and automatic stations.
- Upper air verification: verification of the model against measured radiosonde ascents;
- Cloud verification: verification of the model cloudiness based on METEOSAT visible images.
- Radar verification: verification of the precipitation against swiss radar network measurements.

4.6 COSMO Limited-Area Ensemble Prediction System

The COSMO limited area ensemble prediction system (COSMO-LEPS) based on LM and ECMWF ensemble forecasts has been installed at ECMWF by our colleagues at ARPA-SIM in Bologna (Montani et al., 2003) The system is ready for a quasi-operational trial since November 2002, using 120-h forecasts of 5 LM runs starting at 12 UTC on initial and boundary conditions for 5 representative members of an ECMWF-EPS superensemble. Supervision and scheduling of the suite is done by ARPA-SIM. COSMO-LEPS probability products (derived and processed by the group in Bologna) are ready at about 7.30 GMT. The dissemination to COSMO centres is by GRIB-files.

Basic Set–Up of COSMO–LEPS
Within COSMO–LEPS framework, LM runs operationally at ECMWF using a 10 km grid spacing and 32 vertical layers. The rotated lon–lat coordinates of the lower left and upper right corner of the integration domain are ($\lambda = -12.5^o$, $\varphi = -16.0^o$) and ($\lambda = 14.95^o$, $\varphi = 11.13^o$), respectively. The main features of the model set–up are summarised in Table 12.

Table 12: **Configuration of COSMO–LEPS, run at ECMWF by ARPA-SIM**

Domain size	306 × 258 gridpoints
Horizontal grid spacing	0.09^o (∼ 10 km)
Number of layers	32, basic-state presure based hybrid
Time Step and Integration Scheme	60 sec, 3 time–level split–explicit
Forecast Range	120 h
Initial Time of Model Runs	12 UTC
Lateral Boundary Conditions	Interpolated from EPS members at 6-h intervals
Initial State	Interpolated from EPS members' analyses
Special Features	Use of filtered topography
Model version running	lm_f90 3.5 (since 1/10/2003)
Hardware	IBM p690 clusters (using 84 processors)

Changes in the last year
Since 1/9/2003, a 10–member suite is being experimented. In addition to the 5 LM integrations with the operational convection scheme ("Tiedke runs"), 5 more runs are performed using the recently–implemented Kain–Fritsche convection scheme ("KF runs"). In order to

minimize modifications to the operational suite and to test properly the impact of the new scheme, the 5 KF integrations use the same boundary and initial conditions as the Tiedke runs. Rainfall probability maps using the 10–member suite are being produced and disseminated in addition to the operational ones. The skill of the KF runs as well as the usefulness of a 10–member suite will be evaluated during 2004.

Two test suites started on 1/10/2003 to assess the impact of the clustering–selection technique when either the most recent EPS or the two most recent EPSs are used to select the representative members (when compared to the operational suite when 3 successive EPS sets are employed). The verification will be performed **only** on EPS runs by assessing the performance of the "reduced" EPS, that is the 5–member EPS obtained after the clustering–selection technique.

COSMOE-LEPS Products
A number of probabilistic products have been added in 2003 and some thresholds values and cumulation periods have been changed. At present, the following products are available.

- Probability of 24-h precipitation amount exceeding 1, 20, 50, 100 and 150 mm thresholds.
- Probability of 72-h precipitation amount exceeding 50, 100, 150 and 250 mm thresholds.
- Probability of maximum 2m-temperature above 20, 30, 35 and 40 Celsius thresholds.
- Probability of minimum 2m-temperature below 5, 0, -5 and -10 Celsius thresholds.
- Probability of maximum 10m wind speed above 10, 15, 20 and 25 m/s thresholds.
- Probability of maximum CAPE (in 24 hours) exceeding 2000., 2500., 3000. and 3500. J/kg thresholds.
- Probability of minimum SHOWALTER INDEX (in 24 hours) below 0, -2, -4 and -6 thresholds.
- Probability of minimum 'height of 0 °C isotherm' (HZEROCL) over 24 hours below 1500, 1000, 700 and 300 m thresholds.
- Mean sea level pressure and accumulated precipitation from 5 deterministic LM runs (every 24 hours).
- Geopotential at 700 hPa and temperature at 850 hPa from 5 deterministic LM runs (every 24 hours).