The COSMO Consortium in 2001-2002

Günther Doms

Deutscher Wetterdienst, PO-Box 100465, 63004 Offenbach am Main, Germany

Phone: +49 69 8062 2729, e-mail: guenther.doms@dwd.de

1. Organizational Structure of COSMO

The *Consortium for Small-Scale Modelling* (COSMO) aims at the improvement, maintenance and further development of a non-hydrostatic limited-area modelling system to be used both for operational and for research applications by the members of COSMO. The emphasis is on high-resolution numerical weather prediction by small-scale modelling. COSMO is initially based on the "Lokal-Modell" (LM) of DWD with its corresponding data assimilation system. At present, the following national, regional and military meteorological services are participating:

DWD	Deutscher Wetterdienst, Offenbach, Germany
HNMS	Hellenic National Meteorological Service, Athens, Greece
IMGW	Institute for Meteorology and Water Management, Warsaw, Poland
MeteoSwiss	Meteo-Schweiz, Zürich, Switzerland
UGM	Ufficio Generale per la Meteorologia, Roma, Italy
ARPA-SMR	Il Servizio Meteorologico Regionale di ARPA, Bologna, Italy
AWGeophys	Amt für Wehrgeophysik, Traben-Trarbach, Germany

All internal and external relationships of COSMO are defined in an Agreement between the national weather services, which was signed by DWD, HNMS, MeteoSwiss and UGM on 3 October 2001. The national weather service IMGW of Poland joined the consortium on 3 July 2002. There is no direct financial funding from or to either member. However, the partners have the responsibility to contribute to the model development by providing staff resources and by making use of national research cooperations. A minimum of 2 scientist working in COSMO research and development areas is required from each member. In general, the group is open for collaboration with other NWP groups, research institutes and universities as well as for new members.

The COSMO's organization consists of a steering committee (composed of representatives from each national weather service), a scientific project manager, work-package coordinators and scientists from the member institutes performing research and development activities in the COSMO working groups. At present, six working groups covering the following areas are active: Data assimilation, numerical aspects, physical aspects, interpretation and application, verification and case studies, reference version and implementation.

COSMOS activities are developed through extensive and continuous contacts among scientists, work-package coordinators, scientific project manager and steering committee members via electronic mail, special meetings and internal mini workshops. Once a year there is a General Meeting of the COSMO group in order to present results, deliverables and progress reports of the working groups and to elaborate a research plan with new projects for the next annual period. Following this meeting, a final work plan for each working group is set up. In 2002, the COSMO General Meeting was held on 25-27 September in Warsaw (Poland). More information about COSMO can be obtained from our web-site *www.cosmo-model.org*.

Table 1: The Lokal-Modell (LM)

Dynamics	
Basic equations:	nonhydrostatic, fully compressible, no scale approximations
Prognostic variables:	horizontal and vertical wind components, temperature, pressure perturbation, specific humidity, cloud water content. - optionally: cloud ice.
Diagnostic variables:	total air density, precipitation fluxes of rain and snow.
Coordinates:	rotated lat/lon coordinates horizontally and a generalized terrain-following height coordinate in the vertical.
Numerics	
Grid structure:	Arakawa C-grid, Lorenz vertical grid staggering.
Spatial discretization:	second order horizontal and vertical differencing.
Time integration:	Leapfrog HE-VI (horizontally explicit, vertically implicit) time-split integration scheme by default; includes extensions proposed by Skamarock and Klemp (1992). Additional options for: - a two-time level Runge-Kutta split explicit scheme (Wicker and Skamarock(1998), - a 3-d semi-implicit scheme (Thomas et al., 2000).
Numerical Smoothing:	4th order linear horizontal diffusion; - option for a monotonic version including an orographic limiter. Rayleigh-damping in upper layers.
Physics	
Clouds and precipitation:	bulk-parameterization including rain and snow; optional: cloud ice scheme.
Convection:	mass-flux convection scheme (Tiedtke, 1989) with moisture convergence closure; option for CAPE-type closure.
Vertical diffusion:	Level 2 diagnostic K-closure. Option for a Level 2.5 scheme with prognostic TKE.
Surface layer	parameterization scheme after Louis (1979); option for a new surface scheme including a laminar-turbulent roughness layer.
Radiation	δ-two stream radiation scheme after Ritter and Geleyn (1992) for short and longwave fluxes; full cloud-radiation feedback.
Soil processes	soil model with 2 soil moisture layers and Penman-Monteith transpiration; snow and interception storage included. optional: a new multi-layer soil model.
Initial and Boundary Conditions	
- initial and boundary data interpolated from GME or EM/DM as driving models. - one way nesting by Davies boundary relaxation scheme. - diabatic or adiabatic digital filtering initialization (DFI) scheme (Lynch et al., 1997). - Nudging analysis scheme.	
Topographical Data Sets	
- Mean orography derived from the GTOPO30 data set (30"x30") from USGS. - Prevailing soil type from the DSM data set (5'x5') of FAO. - Land fraction, vegetation cover, root depth and leaf area index from the CORINE data set. - Roughness length derived from the GTOPO30 and CORINE data sets.	
Code	
- Standard Fortran-90 constructs. - Parallelization by horizontal domain decomposition. - Use of the MPI library for message passing on distributed memory machines.	

Table 2: Data Assimilation for LM

Method	Nudging towards observations
Implementation	continuous cycle of 3-hour assimilation runs
Realization	identical analysis increments used during 6 advection time steps
Balance	1. hydrostatic temperature increments (up to 400 hPa) 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
Nudging coefficient	$6 \cdot 10^{-4} s^{-1}$ for all analyzed variables
Analyzed variables	horizontal wind vector, potential temperature,relative humidity 'near-surface' pressure (i.e. at the lowest model level)
Spatial analysis	Data are analyzed vertically first, and then spread laterally along horizontal surfaces. vertical weighting: approximately Gaussian in log(p) horizontal weighting: isotropic as function of distance
Temporal weighting	1.0 at observation time, decreasing linearly to 0.0 at 3 hours (upper air) resp. 1.5 hours (surface-level data) before and 1.0 resp. 0.5 hours after observation time; linear temporal interpolation of frequent data.
Observations	SYNOP, SHIP, DRIBU: - station pressure, wind (stations below 100m), humidity TEMP, PILOT: - wind, temperature: all standard levels, significant levels up to 150 hPa - humidity: all levels up to 300 hPa - geopotential used for one 'near-surface' pressure increment AIRCRAFT: - all wind and temperature data
Quality control	Comparison with the model fields from assimilation run itself

2. Model System Overview

2.1 Lokal-Modell (LM)

The limited area model LM is designed as a flexible tool for numerical weather prediction on the meso-β and on the meso-γ scale as well as for various scientific applications down to grid spacings of about 100 m. Table 1 summarizes the key features of the LM.

2.2 Data Assimilation

The LM data assimilation system is based on the observational nudging technique. The scheme has been derived from an experimental nudging analysis scheme which has been developed for DM and the Swiss model version SM, and which compared favorably to the operational OI-analysis of the DM in various case studies. Table 2 summarizes the features of the LM nudging scheme.

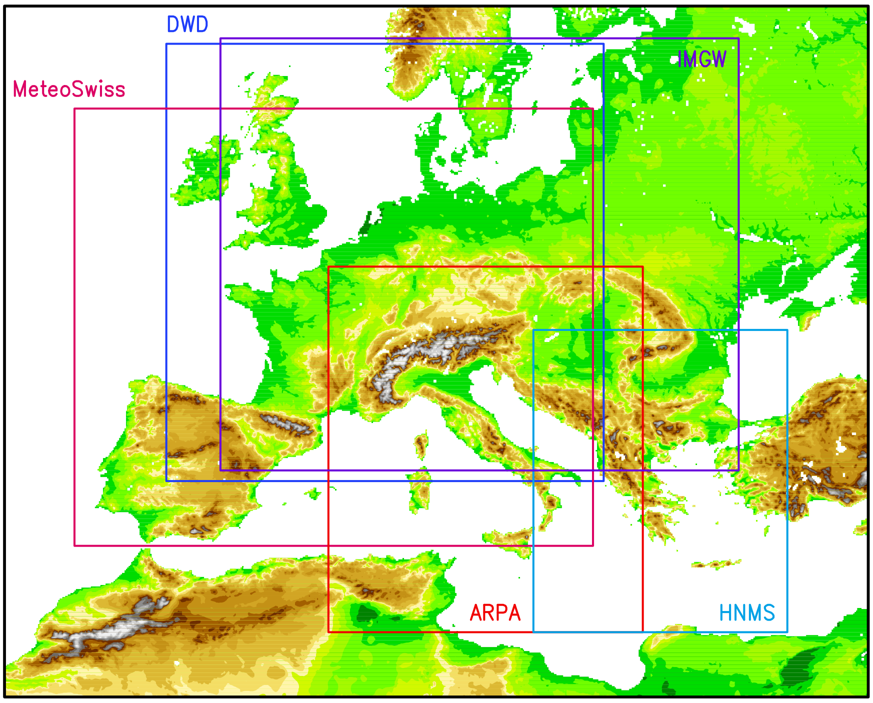

Figure 1: LM integration domains at DWD, MeteoSwiss, ARPA-SMR, HNMS and IMGW

As an external component of the LM-analysis, a new 1-d variational soil moisture analysis scheme scheme has also been developed (Hess, 2001). Two additional external analyses complete the LM data assimilation: a sea surface temperature (SST) analysis based on the correction method using SST data from ships and buoys and a snow depth analysis using SYNOP observations.

2.3 Pre- and Postprocessing

The LM can be one-way nested into the global models GME (Majewski, 2002) or IFS from ECMWF, or into itself. The lateral boundary conditions (and initial conditions, if no data assimilation suite is operated) are obtained by corresponding preprocessing programs GME2LM, IFS2LM or LM2LM. A number of postprocessing modules using LM output fields are available within COSMO. Examples are a wave prediction model, a trajectory model and a Lagrangian particle dispersion model.

3. Operational Application

The LM is operated in five centres of the COSMO members: ARPA-SMR, DWD, MeteoSwiss, HNMS and IMGW. Figure 1 shows the current integration domains of these LM-applications. All four centres use interpolated boundary conditions from forecasts of the global model GME of DWD. ARPA-SMR, HNMS and IMGW start the LM from interpolated GME analyses, followed by an initialization using the digital filtering scheme of Lynch et al. (1997). At DWD and MeteoSwiss, a comprehensive data assimilation system for LM has been installed. Besides the analysis by observational nudging, three external analyses are run: a SST analysis (00 UTC), a snow depth analysis (00, 06, 12 and 18 UTC) and a variational soil moisture analysis (12 UTC), which was brought into operations in March 2000. Figure 2 summarizes the present operational configurations of the LM at COSMO members.

Configurations	ARPA−SMR	DWD	HNMS	MeteoSwiss	IMGW
Domain Size	234 x 272	325 x 325	95 x 113	385 x 325	385x321, 193x161
Grid Spacing	0.0625°	0.0625°	0.1250°	0.0625°	0.0625°, 0.125°
Number of Layers	35	35	35	45	35
Time Step	40 sec	40 sec	80 sec	40 sec	40 sec, 80 sec
Forecast Range	48 hrs	48 hrs	48 hrs	48 hrs	36 hrs, 72 hrs
Model Runs	00, 12 UTC	00, 12, 18 UTC	00 UTC	00, 12 UTC	00, 12 UTC
Boundaries	GME	GME	GME	GME	GME
LBC Updates	1 hr	1 hr	1 hr	1 hr	1hr
Initial State	GME	Nudging	GME	Nudging	GME
Initialization	Digital Filtering	None	Digital Filtering	None	Digital Filtering
External Analyses	None	SST, S−Depth, Soil Moisture	None	SST, S−Depth	None
Hardware	IBM SP (Pwr3)	IBM SP (Pwr3)	CONVEX	NEC SX−5	SGI 3800
No. of Processors	32 / 64	160 / 1280	14 / 16	12 / 16	96 / 100

Figure 2: Operational configurations of the LM within COSMO

4. Progress Report and Research Activities

This section gives a brief overview of the main research activities of the COSMO working groups for the period Oct 2001 - Oct 2002. Further details on the results of various work packages will be available in COSMO Newsletter No. 3 (to appear in January 2003).

Working Group 1: Data Assimilation

- Work on the assimilation of aircraft data (AMDAR) within the nudging scheme has been completed, the data are now used operationally since May 2002 at DWD. Further activities considered the enhancement of the nudging of surface pressure and refinements of the use of screen-level data (wind and humidity).

- At MeteoSwiss, the nudging-based data assimilation cycle for the LM has been introduced operationally in November 2001.

- The development work to assimilate integrated water vapour, derived from GPS-data of about 80 stations in or near Germany, has been continued. In one of the case studies (3 May 2001), a heavy precipitation event in Germany was better simulated by using GPS and aircraft data. An erroneous reproduction of the diurnal cycle of integrated water vapour by the model, however, can sometimes result in problems with the assimilation of GPS data (Tomassini et al., 2002).

- A 27-day observation system experiment was conducted at MeteoSwiss for the EUCOS programme of EUMETNET (Bettems, 2002). A follow-up study considered the model sensitivity to Synop observations.

- Work on the 2-d latent heat nudging has been resumed and experiments on the assimilation of wind profiler data have been conducted.

Working Group 2: Numerical Aspects

- The development work on the LM z-coordinate version based on finite volumes using shaved cells has been continued. A 3-d testversion was realized and idealized cases using real topography (SCANDIA-test) were successfully integrated. Especially, an interface to the terrain-following physics package was developed.
- The current optional 2-time-level RK split-explicit integration scheme has been modified to include a consistent treatment of metric terms. The new scheme is in better accordance with analytic solutions. An evaluation for real data cases is in progress.
- A new non-local scale-dependent terrain-following vertical coordinate (Schär et al., 2002) has been implemented and is currently in evaluation (see also contribution by Guy de Morsier in this volume)
- Further work packages considered the use of ECMWF frames as lateral boundaries and a check of the water mass budget of the LM.

Working Group 3: Physical Aspects

- A new TKE-based turbulence scheme (level 2.5) and a new surface layer scheme have have been implemented. These schemes are applied operationally at DWD and much work was devoted to tuning and further development.
- A new multi-layer version of the soil model TERRA has been developed. The new version includes freezing and melting of soil layers and a revised formulation of the snow model. The new scheme is currently being evaluated and tuned, the operational use is scheduled for Spring 2003.
- The Kain-Fritsch convection scheme has been implemented for optional use and first tests revealed promising results. With respect to the operational Tiedtke mass-flux scheme, a number of sensitivity studies related to the convective drizzle problem have been conducted. Changes to the minimum mass-flux condition and to the formulation for the generation of precipitation within updraughts resulted in a significant reduction of convective drizzle.
- A new scheme for grid-scale precipitation including cloud ice as an explicit prognostic variable has been developed and implemented into both LM and GME. Final tests are currently under way. The operational application is planned for 2003.

Working Group 4: Interpretation and Applications

- Work on the COSMO limited-area ensemble prediction system (LEPS) has been continued. The goal of this activity is to run the LM with initial and boundary conditions given by the ECMWF ensemble (using the cluster technique) in order to catch probabilities of extreme events with higher spatial accuracy. Several MAP cases have been successfully run in hindcast mode. At present, a real-time test suite is implemented at ECMWF. The group decided to use a 10km resolution LM on a superdomain covering most of the domains of all participating members.

- A scheme for statistical postprocessing by spatial and temporal aggregations – resulting in smoothed fields with probabilities for extreme events – has been developed. At present, two different approaches using the neighborhood method and the wavelet method are compared and evaluated.
- Further activities considered the generation of new model-internal interpreted fields such as the snowfall-limit and convective wind gusts.

Working Group 5: Verification and Case Studies

- The operational verification of predicted surface weather parameters is done at each COSMO site for the corresponding LM application. The observational basis are SYNOP stations and regional high resolution networks. Also, a TEMP-verification is done at most of the COSMO centres. Verification results are distributed on a quarterly basis at our web-site. A summary of the annual scores for 2002 can be found in COSMO Newsletter No.3.
- An combined internal workshop of WG3 and WG5 was held in February 2002. The participants addressed items such as the selection of representative Synop stations, the statistical significance of various scores, the conditional verification of weather elements, the investigation of the realism of forecasts by alternative methods and variational techniques to estimate parameters in the physics schemes.
- Verification of precipitation using high resolution precipitation analyses from ARPA-SMR for the Emilia Romagna region. The analyses are available every hour and are obtained by using surface raingauges and calibrated radar data.
- Work on the pattern matching method to compare model predicted precipitation and radar precipitation fields has been continued.

Working Group 6: Reference Version and Implementation

- Work on the interpolation programs GME2LM, IFS2LM and LM2LM to provide initial and boundary conditions from driving models by one-way nesting has been carried on. It is planned to join these programs into a unified preprocessor program INT2LM.
- Installation, updating and running of the LM is a permanent task of the COSMO member sites. In 2002, a common update procedure has been defined.
- Work on the two-way interactive nesting version of LM has been continued.
- A new version of the model documentation including a description of the nudging analysis scheme and the new TKE-based turbulence scheme is planned to be available at the end of 2002.

5. Plans and Goals 2003

At the recent COSMO General Meeting, a detailed work plan for the next working period (Oct. 2002 - Oct. 2003) has been formulated. Some of the basic points are listed below.

Consolidation, Upgrade and Documentation of the LM
- increased quality of the quantitative precipitation forecasts
- tuning and optimization for both model and data assimilation components
- operational use of the new soil model and the cloud ice scheme
- assimilation of remote sensing data (radar, wind profiler, satellite)
- continue work on 2-way interactive self-nesting

Application and Interpretation
- evaluation of the COSMO LEPS system based on the ECMWF ensemble
- statistical interpretation of high resolution forecasts
- common postprocessing tools

'Paving the way' for NWP on the Meso-γ Scale
- continue the development work on the z-coordinate version of the model
- experimental work and test suites at very high resolution
- development and test of a 3-D TKE-based turbulence scheme
- 3-d transport of rain and snow in the cloud scheme
- development of a new scheme for shallow convection

References

Bettems, J.-M., 2002: EUCOS Impact Study Using the Limited-Area Non-Hydrostatic NWP Model in Operational Use at MeteoSwiss. *COSMO Technical Report No. 5* (available at www.cosmo-model.org).

Hess, R., 2001: Assimilation of screen-level observations by variational soil moisture analysis. *Meteor. Atmos. Phys.*, **77**, 155-166.

Louis, J.-F, 1979: A parametric model of vertical eddy fluxes in the atmosphere. *Bound. Layer Meteor.*, **17**, 187-202.

Lynch. P., Girard D. and V. Ivanovici, 1997: Improving the efficiency of a digital filtering scheme. *Mon. Wea. Rev.*, **125**, 1976-1982.

Majewski, D., D. Liermann, P. Prohl, B. Ritter, M. Buchhold, T. Hanisch, G. Paul, and W. Wergen, 2002: The operational global icosahedral-hexagonal gridpoint model GME: Description and high-resolution tests. *Mon. Wea. Rev.*, 130, 319–338.

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

Schär, C., D. Leuenberger, O. Fuhrer, D. Lüthi and C. Girard, 2002: A new terrain-following vertical coordinate formulation for atmospheric prediction models. *Mon. Wea. Rev.*, 130, 2459–2480.

Skamarock, W. C. and J. B. Klemp, 1992: The stability of time-split numerical methods for the hydrostatic and the nonhydrostatic elastic equations. *Mon. Wea. Rev.*, **120**, 2109-2127.

Thomas, S., C. Girard, G. Doms and U. Schättler, 2000: Semi-implicit scheme for the DWD Lokal-Modell. *Meteorol. Atmos. Phys.*, **75**, 105-125.

Tiedtke, M., 1989: A comprehensive mass flux scheme for cumulus parameterization in large-scale models. *Mon. Wea. Rev.*,**117**, 1779-1799.

Tomassini, M., G. Gendt, G. Dick, M. Maratschi and C. Schraff, 2002: Monitoring of integrated water vapour from ground-based GPS observations and their assimilation in a limited-area NWP model. *COSMO Newsletter No.2*, 89-96 (available at www.cosmo-model.org).

Wicker, L. and W. Skamarock, 1998: A time-splitting scheme for the elastic equations incorporating second-order Runge-Kutta time differencing. *Mon. Wea. Rev.*, **126**, 1992-1999.