The COSMO Consortium in 2004-2005

Tiziana Paccagnella

ARPA-SIM, Viale Silvani 6, 40122 Bologna, Italy
Phone: --39 51 525929, e.mail: tpaccagnella@arpa.emr.it

Most of the information included in this report are taken from the COSMO Newsletter N° 5, edited by U. Schaettler and A. Montani, available on the COSMO web site (www.cosmo-model.org also mirrored at http://cosmo-model.cscs.ch).

1. Organization and 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 based on the "Lokal-Modell" (LM), initially developed at DWD, with its corresponding data assimilation system. At present, the members of COSMO are following national meteorological services:

DWD	Deutscher Wetterdienst, Offenbach, Germany
HNMS	Hellenic National Meteorological Service, Athens, Greece
IMGW	Institute for Meteorology and Water Management, Warsaw, Poland
MeteoSwiss	Meteo-Schweiz, Zurich, Switzerland
UGM	Ufficio Generale per la Meteorologia, Roma, Italy

Additionally, these regional and military services within the member states are also participating:

ARPA-SIM	Servizio IdroMeteorologico di ARPA Emilia-Romagna, Bologna, Italy
ARPA-Piemonte	Agenzia Regionale per la Protezione Ambientale-Piemonte, Italy
AWGeophys	Amt für Wehrgeophysik, Traben-Trarbach, Germany

NMA, the Romanian Meteorological Service, has applied for membership in COSMO and started its cooperation with the consortium in 2004.

All internal and external relationships of COSMO are defined in an Agreement among 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 two scientists 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 (STC, composed of representatives from each national weather service), a Scientific Project Manager (SPM), Work-Package Coordinators (WPCs) 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 Applications, Verification and Case Studies, Reference Version and Implementation. The organisation of COSMO is reported in the following:

Steering Committee Members:

Gerard Adrian	DWD	(Germany)
Mathias Rotach **(the Chairman)**	MeteoSwiss	(Switzerland)
Massimo Ferri	UGM	(Italy)
Ioannis Papageorgiou	HNMS	(Greece)
Ryszard Klejnowski	IMGW	(Poland)

Scientific Project Manager:

Tiziana Paccagnella	ARPA-SIM	(Italy)

Working Groups/Work Packages Coordinators:

Data assimilation /	Christoph Schraff	DWD
Numerical aspects /	Jürgen Steppeler	DWD
Physical aspects/	Marco Arpagaus	MeteoSwiss
Interpretation and Applications/	Pierre Eckert	MeteoSwiss
Verification and case studies/	Adriano Raspanti	UGM
Reference Version and Implementation/	Ulrich Schättler	DWD

COSMO 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. Twice or three times a year the Scientific Advisory Committee (SAC), composed by the SPM and the WPCs, meets togheter with the chairman of the STC to discuss about ongoing and future activities. The STC also meets 2 or three times a year and once a year there is the General Meeting of the COSMO group in order to present results, deliverables and progress reports of the working groups and to finalize a research plan with new projects for the next annual period. Several inter & intra working groups workshops are also organized during the year.

The procedure to define the COSMO work-plan has been recently revised to improve the efficiency of COSMO cooperation. COSMO strategy is defined by the STC and discussed with SAC. Priority Projects are then identified by the SAC and are finalized during the general meeting collecting contributions and proposals from all the COSMO scientists. After the final approval of the Priority Projects by the STC, resources from the different countries (national weather services and other cooperating institutions) are allocated on these projects and the work plan for the new year is defined including both Priority Projects and all the other activities of the different working groups.

Every year a LM-User Seminar is organized to illustrate the activities carried on by groups and people using LM. The next LM-user seminar will be held from 6 to 8 March 2006 in Langen, Germany.

2. Model system overview

The key features of LM are reported below in tables 1 and 2:

Table 1

	Dynamics
Basic equations:	Non-hydrostatic, fully compressible primitive equations; no scale approximations; advection form; subtraction of a stratified dry base state at rest.
Prognostic variables:	Horizontal and vertical Cartesian wind components, temperature, pressure perturbation, specific humidity, cloud water content. Options for additional prognostic variables: cloud ice, turbulent kinetic energy, rain, snow and graupel content.
Diagnostic variables:	Total air density, precipitation fluxes of rain and snow.
Coordinates:	Rotated geographical coordinates (λ,φ) and a generalized terrain-following coordinate ς. Vertical coordinate system options: – Hybrid reference pressure based σ-type coordinate (default) – Hybrid version of the Gal-Chen coordinate – Hybrid version of the SLEVE coordinate (Schaer et al. 2002)
	Numerics
Grid structure:	Arakawa C (horizontal) Lorenz vertical staggering
Time integration:	Second order horizontal and vertical differencing Leapfrog (horizontally explicit, vertically implicit) time-split integration including extension proposed by Skamarock and Klemp 1992. Additional options for: - a two time-level Runge-Kutta split-explicit scheme (Wicker and Skamarock, 1998) - a three time level 3-D semi-implicit scheme (Thomas et al., 2000) - a two time level 3rd-order Runge-Kutta scheme (regular or TVD) with various options for high-order spatial discretization (Förstner and Doms, 2004)
Numerical smoothing:	4th order linear horizontal diffusion with option for a monotonic version including an orographic limiter (Doms, 2001); Rayleigh-damping in upper layers; 3-d divergence damping and off-centering in split steps.
Lateral Boundaries:	1-way nesting using the lateral boundary formulation according to Davies and Turner (1977). Options for: - boundary data defined on lateral frames only; - periodic boundary conditions Driving models: GME, IFS/ECMWF or LM.

	Physics
Grid-scale Clouds and Precipitation:	Cloud water condensation /evaporation by saturation adjustment. Cloud Ice scheme HYDCI (Doms,2002). Further options: - prognostic treatment of rain and snow (Gassman,2002; Baldauf and Schulz, 2004, for the leapfrog integration scheme) - a scheme including graupel content as prognostic variable - the previous HYDOR scheme: precipitation formation by a bulk parameterization including water vapour, cloud water, rain and snow (rain and snow treated diagnostically by assuming column equilibrium) - a warm rain scheme following Kessler

Subgrid-scale Clouds:	Subgrib-scale cloudiness based on relative humidity and height. A corresponding cloud water content is also interpreted.
Moist Convection:	Mass-flux convection scheme (Tiedtke) with closure based on moisture convergence. Further options: - a modified closure based on CAPE within the Tiedtke scheme - The Kain-Fritsch convection scheme
Vertical Diffusion:	Diagnostic K-closure at hierarchy level 2 by default. Optional: a new level 2.5 scheme with prognostic treatment of turbulent kinetic energy; effects of subgrid-scale condensation and evaporation are included and the impact from subgrid-scale thermal circulations is taken into account.
Surface Layer:	Constant flux layer parameterization based on the Louis (1979) scheme (default).Further options: A new surface scheme including a laminar-turbulent roughness sublayer
Soil Processes:	Two-layer soil model including snow and interception storage; climate values are prescribed as lower boundary conditions; Penman-Monteith plant transpitration. Further options: a new multi-layer soil model including melting and freezing (Schrodin and Heise, 2002)
Radiation:	δ-two stream radiation scheme after Ritter and Geleyn (1992) for short and longwave fluxes; full cloud-radiation feedback
Initial Conditions:	
Interpolated from GME, IFS/ECMWF or LM. Nudging analysis scheme (see Table 2). Diabatic or adiabatic digital filtering initialization (DFI) scheme (Lynch et al., 1997).	

Physiographical 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
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	6.10^{-4} s^{-1} for all analyzed variables except pressure 1.2 10^{-3} s^{-1} for “near-surface” pressure
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 at 3 hours (upper air) resp. 1.5 hours (surface level data) before and 1.0 resp. 0.5 hours after obs. time;
Observations:	SYNOP, SHIP,DRIBU:

	-station pressure, wind (stations below 100m above msl) -humidity TEMP,PILOT: -wind,temperature: all standard levels up to 300 hPa -humidity:all levels up to 300 hPa - geopotential used for one "near-surface" pressure increment. AIRCRAFT - all wind and temperature data WIND PROFILER -all wind data (not included in blacklisted stations)
Quality Control:	Comparison with the model fields from the assimilation run itself.

3. Operational applications

The LM runs operationally in five centres of the COSMO members (ARPA-SIM, DWD, HNMS, IMGW, MeteoSwiss) and, since early 2005, also at NMA, the Romanian Meteorological Service.

ARPA-SIM, HNMS, IMGW and NMA 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 centre are transmitted from DWD via the Internet. HNMS, IMGW and NMA 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 analysis and the soil moisture analysis according to Hess (2001). A data assimilation system based on the LM nudging scheme is 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.

The national weather service of Italy, UGM in Rome, runs the LM at the ECMWF computing centre for a bigger (european) domain with respect to the one operated by ARPA-SIM in Bologna. The lateral boundaries for these runs are taken from the IFS.

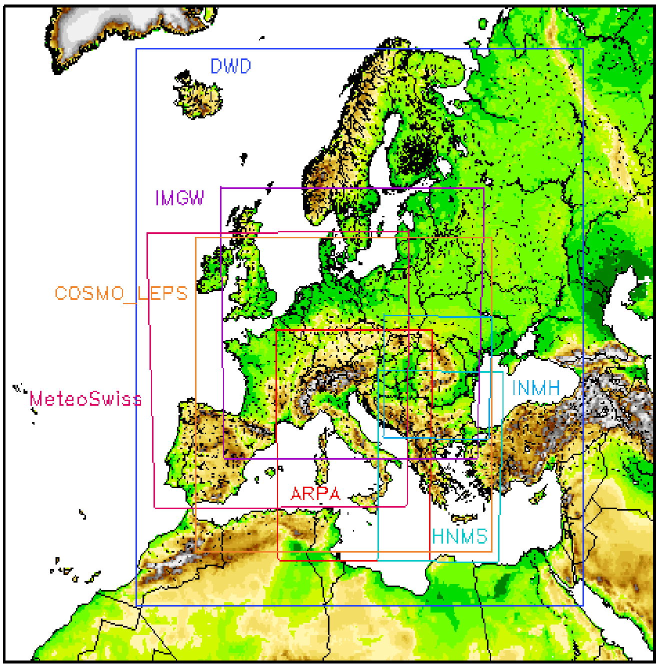

Figure 1: integration domains of the LM operational implementations in the different COSMO countries.

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) and the LM run by UGM at ECMWF is called Euro-LM.

In Figure 1, the integration domains of the different operational implementations are shown.

In Table 3 the operational settings of LM are reported for the different COSMO countries.

LM configurations	**ARPA-SIM**	**DWD**	**HNMS**	**IMGW**	**MeteoSwiss**	**UGM**	**NMA**	**COSMO-LEPS**
Grid Points	234x272	665x657	189x225	193x161	385x325	465x385	81x73	306x258
Hor. Res.	0.0625° (7 km)	0.0625° (7 km)	0.0625° (7 km)	0.125° (14 km)	0.0625° (7 km)	0.0625° (7 km)	0.125° (14 km)	0.09° (10 km)
N° Layers	35	40	35	35	45	35	35	32
Time Step	40 sec	40 sec	30 sec	80 sec	40 sec	40 sec	80 sec	60 sec
Frcst Range	72 hrs	78 hrs	48 hrs	72 hrs	72 hrs	60 hrs	48 hrs	120 hrs
Start Time	00, 12 UTC	00, 12, 18 UTC	00,06,12,18 UTC	00, 12 UTC	00, 12 UTC	12 UTC	00,12 UTC	12 UTC
Lateral BCs from	GME	GME	GME	GME	IFS	IFS	GME	IFS-EPS
LBCs Upd. Freq.	1 hour	1 hour	1 hour	1 hour	3 hours	3 hours	3 hours	3 hours
Initial State	Nudging	Nudging	GME	GME	Nudging	EuroHRM 3-DVAR	GME	IFS-EPS
Initialis.	None	None	None	None	None	None	None	None
External Analysis	None	SST, Snow Depth, Soil Moisture Analysis	None	None	Snow Depth from DWD	None	None	None
Dynamics	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit	3 TL; split-explicit
Physics options	TKE; new surface layer scheme; Cloud ice; Prog. Prec.	TKE; new surface layer scheme; Cloud ice; Prog. Prec.; multi-layer soil model	TKE; new surface layer scheme; Cloud ice;	TKE; new surface layer scheme; Cloud ice;	old Turbulence scheme	TKE; new surface layer scheme	TKE; new surface layer scheme	TKE; new surface layer scheme
Hardware	IBM SP pwr5	IBM SP pwr5	CONVEX	SGI Origin 3800	NEC SX-5	IBM SP pwr4	Linux Cluster	IBM SP pwr4
No.Procs.	64	176	14	88	14	112	26	90

Table 3: operational settings of LM in the different COSMO countries

4. Progress report and Research activities

This section gives a brief description of the main research activities carried on during the last COSMO year (Oct.2004-Oct.2005) within the different working groups.

Working group 1: Data Assimilation coordinated by Christoph Schraff from DWD

- Latent Heat Nudging has been further developed and main problems related to the inclusion prognostic precipitation have been mostly solved;
- Multi-Sensor Humidity Analysis including GPS observations with GPS tomography;
- Use of 1dVar Satellite Retrievals both for MSG and ATOVS data has been partly developed through a good and efficient cooperation among Germany, Italy and Poland;
- Assimilation of Scatterometer Wind is in progress with first tests with LM planned for the end of 2005
- Evaluation / Monitoring / Tuning of LM Nudging scheme has been continued
- Soil Moisture Initialisation after the results from the ELDAS has been implemented for the new multi-layer soil model in LME with good results.
- Snow Cover Analysis has been improved by means of a snow mask derived from satellite (e.g. SEVIRI) data. Snow mask products and their impact need to be evaluated for longer periods.

A 1-day workshop was held in Zurich, the day before the general meeting, to discuss the COSMO strategy about Data Assimilation. The discussion was based on the awareness that in 10 years global models will be run at horizontal resolution of about 10 km and fine-mesh models will be run at 1 km horizontal resolution.
The use of PDFs, as a complement to deterministic forecast, will assume a fundamental role particularly for the convective scale. The use of indirect observations at high frequency will be even more important expecially for high-frequency update Data Assimilation~Forecast cycles.
More and more emphasis on ensemble techniques will be given both as regards probabilistic information to complement numerical forecats and as regards statistical support to Data Assimilation methodologies.
Due to special conditions in convective scale, separate DA methodologies will be developed by COSMO for such applications (SIR Priority Project, listed in the following,by means of a sequential Bayesian weighting and importance re-sampling).

Working group 2: Numerical Aspects coordinated by Juergen Steppeler from DWD

- Further development of the Z-coordinate version (Steppeler et Al. 2002) of LM both as regards the eulerian version and the SI/SL one (Rosatti et Al. 2005)
- Further developments and Evaluation of Runge-Kutta method.
- Revision and testing of several aspects of LM numerics in the framework of LMK (**LM Kürzestfrist)** development. LMK, a project designed and carried on at DWD during the last couple of years, is aimed to the development of a very short range forecasting system based on the integration of LM, at 2.8 km hor. res. The system will be run every three hours, with a short cut-off time, for 18 hours of integration. Developments related to LMK project are now available also in LM for the COSMO members.

Working group 3: Physical Aspects coordinated by Marco Arpagaus from MeteoSwiss

- Surface transfer scheme and turbulence scheme: single column model developed
- Soil processes
    - Multi-layer soil model

            - Operational implementation of the multi-layer soil model
            - Usage of satellite derived (weekly updated) plant cover
            - Revision of external parameters for plants
        - Implementation of the lake model into LM
        - Intercomparison of soil models in the framework of soil moisture validation
- Shallow convection on the meso-γ scale
    - some tests with LMK
- Microphysics
    - Three-category ice scheme included
- Radiation
    - Cloud-radiation interaction: some tests
    - Evaluate possible inclusion of 3-d effects in current scheme
        - Gridscale parameterization of topographic effects on radiation. Some sensitivity case studies have been carried out. The impact of the topographic effects is substantial at high resolution.
        - Radiation calculation on a coarser grid – very first results with LMK

Working group 4: Interpretation and Applications coordinated by Pierre Eckert from MeteoSwiss

- The COSMO-LEPS (COSMO-Limited Area Ensemble Prediction System, Montani et Al. 2003) is now composed of ten members with a forecast length of 132 hours. COSMO-LEPS will be included in the "time critical applications" at ECMWF since November this year.
    - Core products:
        - 10 perturbed LM runs (ICs and 6-hourly BCs from 10 EPS members) to generate probabilistic output (start at 12UTC; $\Delta t = 132h$);
    - Additional products:
        - 1 deterministic run (ICs and 3-hourly BCs from the high-resolution deterministic ECMWF forecast) to assess the relative merits between deterministic and probabilistic approach (start at 12UTC; $\Delta t = 132h$);
        - 1 proxy run (ICs and 3-hourly BCs from ECMWF analyses) to "downscale" ECMWF information (start at 00UTC; $\Delta t = 36h$).

    Since 1st July 2005, COSMO-LEPS forecasts are archived on MARS at ECMWF.

- Case studies to see the impact of moist singular vectors and ensemble size on predicted storm tracks for the winter storms Lothar and Martin
- Use of Multi-Model Super-Ensemble Technique for complex orography weather forecast
- First experiments toward the new COSMO-SREPS (Short Range EPS) system based on LM by perturbating Physics.
- Interpretation of the new high-resolution model LMK
    - Using information of a single model forecast by applying the Neighbourhood Method
    - Using information resulting from LMK forecasts that are started every 3 h (LAF-Ensemble)

Working group 5: Verification and Case Studies coordinated by Patrizio Emiliani (now by Adriano Raspanti) from UGM.

The activities of this group focus mainly on coordination in order to have some objective measures of how well LM forecasts are performing, and on an scientific viewpoint, in order to have detailed assessment of the strengths and weaknesses of the model. Thus, at the moment, the main activities of the working group deal with the following issues:

- The verification of operational model forecasts,
- The verification with feedback on the physical parameterizations (which means verification of new LM versions on a set of test cases)
- The development of new verification methods and diagnostic tools
- The collection of LM case studies.

As regards the observations data-set, precipitation is also verified against a “common” data-set of high density stations provided by local networks of the different COSMO Countries.
Verification is also performed employing remote-sensing data.
A summary of the verification highlights of each season is also produced by the work-packages coordinator and it is now regularly discussed during the SAC meetings.

Working group 6: Reference Version and Implementation coordinated by Ulrich Schaettler from DWD

- Four versions of LM have been released during this year.Version 3.16 has been implemented in July 2005. All developments done for the LMK up to now have been incorporated in the official LM library.
- INT2LM is now the official interpolation program to extract Boundary Conditions (and Initial Conditions) from GME, IFS and LM for one way nesting.
- Documentation has been partially updated.

Operational implementation are described in the first part of this report.

5. Planned developments for the LM NWP system

COSMO scientific longer-term perspectives (3-5 years) are mainly addressed to :

- High-resolution, short-range EPS available
- Assimilation of ‘all’ available data
- LM performance known and critically discussed

During the last year it has been recognized the importance of reinforce the COSMO cooperation by introducing a project management, more structured and controlled, where only contributions to “priority projects” are taken into account when considering the obligatory commitment of each COSMO member. The Priority Projects are addressed:

- To better concentrate joint COSMO efforts
- To optimize the use of COSMO human resources
- To facilitate management related to goals which are considered to be prioritary

Starting this year (2005-2006) the work plan is then organized in:

<u>Priority Projects (PPs):</u>

- Proposed by SAC (WP Coordinators and SPM)
- Discussed/completed/modified with COSMO scientists
- Approved by STC which is also responsible of allocating the required human resources
- Coordinated by Project Leaders

PPs can be composed by tasks belonging to one specific working group but also by tasks from different workin groups.

<u>Activities:</u>

Not structured as projects and carried on if extra-resorces are available

Priority Projects selected and starting in 2006:

1. **Support Activities:**
   Includes many of the activities of WG6 Implementation and Reference Version (Source codes managment, documentation, editing of newsletters, tech. Reports, WEB site)
   Project Leader: Ulrich Schaettler (DWD)
2. **SIR: Sequential Importance Resampling filter :**
   The aim of the project is the development of a prototype for a new data assimilation system for the convective scale by means of a sequential Bayesian weighting and importance re-sampling (SIR) filter.
   Project Leader: Christoph Scraff (DWD)
3. **Retrievas for nudging: 1dVar for satellite radiances:**
   Operational assimilation of ATOVS and SEVIRI data for LM
   Project Leader: Reinhold Hess (DWD)
4. **Further development of LM_Z**
   To make LM_Z ready for complete testing. Decision about LM_Z will be taken at the next general meeting based on results produced during 2006 by this project.
   Project leader: Juergen Steppeler (DWD)
5. **Further development of the Runge Kutta method:**
   Create an improved and properly checked Version of RK in the timescale of 3 years.
   Project leader: Michael Baldauf (DWD)
6. **UTCS: Towards Unified Turbulence-Shallow Convection Scheme**
   Implementation of Transport Equations for the Sub-Grid Scalar Variance
   Coupling with Convection, Turbulence and Cloud Diagnostic Schemes
   Project leader: Dmitrii Mironov (DWD)
7. **Tackle deficiencies in precipitation forecasts:**
   Project leader: Marco Arpagaus (MeteoSwiss)
8. **Development of Short Range ensemble based on LM**
   Project Leader: Chiara Marsigli (ARPA-SIM)
9. **Advanced Interpretation of LM output**
   Project leader: Pierre Eckert (MeteoSwiss, Genève)
10. **Implementation of a Common Conditional Verification (CV) library**
    Development of a common and unified verification "library" including a Conditional Verification tool.
    Project Leader: Adriano Raspanti (UGM)

For 2006 these Priority Projects will see the cooperation of many COSMO scientists for a total of about 22 man/year (sum of scientists percentages) made available by the participating Countries.
The two Projects related to numerical aspects (4 and 5) will be mostly completed in 2006. Advanced numerics will be the topic of a 1-day workshop to be held in Langen next March just the day after the next LM-USER seminar.
Projects 1 and 6, which are designed thinking about LM at cloud resolving scale, are planned on a 5 year time range. The other projects are designed on a 2-3 years schedule.
Projects will be monitored on a quarterly basis and main results will be presented at the next SRNWP/EWGLAM meeting.

References:

Baldauf.M. and J.-P.Schulz, 2004: Prognostic precipitation in the Lokal-Modell (LM) of DWD. COSMO Newsletter No. 4.

Davies, H.C. and R.E.Turner, 1977: Updating prediction models by dynamical relaxation: An examination of the technique. Quart. J. Roy. Meteor. Soc., 103, 225-245.

Doms G., 2001: A scheme for monotonic numerical diffusion in the LM. Cosmo Technical Report, No.3 (available at www.cosmo-model.org).

Doms G., 2002: The LM Cloud Ice Scheme. COSMO Newsletter 2002..

Forstner,J. and G.Doms, 2004: Runge-Kutta time integration and high-order spatial discretization of advection: a new dynamical core for LM. COSMO Newsletter No. 4.

Gassman A., 2002: 3D-Transport of Precipitation. COSMO Newsletter 2002.

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

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

Montani A., M. Capaldo, D. Cesari, C. Marsigli, U. Modigliani, F. Nerozzi,T. Paccagnella, P. Patruno and S.Tibaldi, 2003: “Operational limited-area ensemble forecasts based on the ‘Lokal Modell’ “. ECMWF Newsletter No. 98 – Summer 2003, pp.2-7.

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.

Rosatti G., Bonaventura L., Cesari D., Semi-implicit, Semi-Lagrangian environmental modelling on cartesian grids with cut cells, Journal of Computational Physics, 204,353-377, 2005

Shaer C.,D.Leuenberger, O.Fuhrer, D.Luthi and C.Girard, 2002: A new terrain-follo\-wing 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.

Schrodin, R. and H. Heise, 2002: The New Multi-Layer Soil Model, COSMO Newsletter 2002.

Steppeler,J., H.-W.Bitzer, M.Minotte and L.Bonaventura, 2002: Nonhydrostatic atmospheric modelling using a z-coordinate representation. Mon. Wea. Rev., 130, 2143--2149.

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

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.