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The COSMO priority Project ICON-COMFORT: (COMpetence in FORecasTing)

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The COSMO priority Project ICON-COMFORT: (COMpetence in FORecasTing)

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1 Introduction

The transition of the COSMO model to ICON-LAM (ICOsahedral Nonhydrostatic-Local MOdel) is a new task for the forecasters who are asked to issue everyday forecasts and take decisions about warnings of extreme events. Apart from the operational verification procedures, the forecasters, who receive on a daily basis the outputs of COSMO and ICON models, gain subjective experience of the model performance according to the forecast outcome. The model performance can vary with different synoptic conditions, seasons and regions. By constant monitoring, model deficiencies may be detected. Therefore, the forecasters' feedback can play an important role in model improvement. In addition to that, forecasters may have some specific needs in terms of model outputs that can be useful for specific types of forecasts such as TAF and sea route forecasts. To this aim, a survey was distributed twice a year for the period September 2022 to August 2023 to seven national services listed in the Table below. Note that German National Weather Service (DWD) although using all the ICON chain is not participating. The forecasters, according to the questions of the survey, after monitoring the models performance, answered the survey at the end of each evaluation period after collecting representative cases of:

- added value of ICON-LAM compared to the COSMO-model for different weather regimes,
- identification of ICON-LAM decreased model skill for certain regions or certain weather regimes,
- added value of ICON-LAM compared to the COSMO-model in case of severe weather situations.

Furthermore, additional requirements of ICON-LAM users with respect to data format and output of meteorological variables have been reported by the forecasters and will be taken into account for post-processing software development.

For the survey questions see Appendix A.

Some feedback was also provided from Priority Project C2I ("COSMO transition to ICON-LAM", COSMO TechReport No. 48), and some additional information was added from C2I surveys. A list of the contributions is given in the Table below.

	September 2022 to February 2023	**March to August 2023**	**C2I**
ARPA-P	x	x	x
IMS		x	x
CNMCA		x	x
NMA	x	x	x
IMGW	x	x	
MCH	x	x	
HNMS	x	x	x

The main ICON performance findings are in brief as follows:

- ICON-LAM performance is overall satisfactory for most variables and helpful for the forecast.
- Wind forecast is satisfactory.

- Wind gust forecast is more satisfactory than COSMO, however there are cases of overestimation in orographic and convective conditions.
- Overall ICON-LAM satisfactory prediction of precipitation area and convection initiation.
- Stratiform precipitation is better predicted with ICON-LAM and does not depend on 700hpa humidity as COSMO does.
- Overestimation of precipitation maxima mainly in convective, orographic and coastal precipitation, producing false alarms for thunderstorms.
- Precipitation misses for deep convection in Italy
- Erroneous convection inhibition at night in warm seasons in Italy.
- Better low clouds and fog forecasts than COSMO although there are cases of fog overestimation.
- For severe precipitation and fog warnings, false alarm is more common than miss.
- More difficult forecast in transition seasons and small-scale low systems.
- COSMO and ICON-LAM forecasts are more similar in DJF season.
- Differences in forecast range mainly in second day in favour of ICON.

2 Analysis of the Survey Answers

A summary of the answers grouped in tables is given below.

2.1 Models Information and Use

(See model abbreviations names in Appendix B)

Specify the version, grid spacing, nesting setup and forecast range of COSMO/ICON-LAM you are using

	Model	Version	Grid Km	Time	Range	Nesting	Operational
ARPA-P	ICON-IT	2.6.5.1	2.2	00			
	COSMO-5M	6	5	00/12	72	IFS	
	COSMO-2I		2.2		48		
IMS	ICON-IL	2.6.5.1	2.5	00/12	90	IFS	Yes
	COSMO-IL	6					
CNMCA	ICON-IT	2.6.5.1	2.2	00/12	48		Yes
	COSMO-ME EPS (20 members)	6					
	COSMO-ME EPS (Deterministic)		5	00/06/12/18	72		
	COSMO-IT EPS (20 members)		2.2	00/12	48		
	COSMO-IT EPS (Deterministic)			00/06/12/18	72		
NMA	COSMO-RO		7	00/06/12/18	78/48/174/48	ICON-GLOBAL	
			2.8		30/18/84/30		
	ICON-RO			00/12	78		Yes
	ICON-EU			00/06/12/18	120		
IMGW	COSMO-PL	5.05	7		72	ICON-GLOBAL	
			2.8		48	COSMO-PL7	
	ICON-PL	2.6.2.2	2.5			ICON-GLOBAL	Yes
MCH	ICON-CH2-EPS (21 members)	2.6.5	2	00	120	KENDA	
	ICON CH1-EPS (11 members)		1		33	IFS	
HNMS	ICON-GR	2.6.5.1	2.5	00/12	72	IFS	Yes
	COSMO-GR (up to Oct. 22)	4.0	4	00/12		IFS	

Is data assimilation used for ICON-LAM? If yes, write the assimilation method and the type of assimilated observations		
ARPA-P	KENDA-LETKF	The model is provided by CNMCA, so see the details below.
IMS	LHN	Radars data from OPERA composite (EUMETNET) and IMS are combined into a single file, which is then assimilated into ICON via the Latent Heat Nudging (LHN). Because both 00/12 UTC ICON runs are executed with a delay of about 5 hours, LHN is performed during the first 5 hours of each ICON run.
CNMCA	KENDA-LETKF	KENDA (Kilometer–Scale Ensemble Data Assimilation). The assimilation method used is the LETKF – (Local Extended Transform Kalman Filter). The observations assimilated are: Radiosondes, PILOT, SYNOP, SHIP, BUOY, wind profilers, AMDAR, AIRPE, MODE-S, METEOSAT AMV, MEtopScatt winds, NOAA/METOP AMSUA/MHS, NPP/NOOA ATMS radiances.
NMA	None	For COSMO model only, nudging data assimilation with synop data is used.
IMGW	None	COSMO PL 7 - nudging COSMO PL 2.8 - nudging ICON PL - none
MCH	KENDA	Measurements from ground-level monitoring network, radio soundings, aircraft reconnaissance (AMDAR and MODE-S), wind profiler data and notifications from shipping vessels and buoys are assimilated. Weather radar data, which are particularly valuable for the first few hours of a forecast, are also assimilated with the help of so-called latent heat nudging (LHN).
HNMS	None	

Specify other models you are using for your forecasts. Specify grid spacing and forecast horizon				
	Model	Resolution	Forecast range	Comments
ARPA-P	IFS-ECMWF ICON-EU BOLAM MOLOCH WRF	7 km 8 km 1.5 km 1.5-2.5 km	96h 72h 48h 48h	
IMS	IFS UKMO GFS ICON global	9 km 17 km 25 km 13 km	90h	IFS is the main model that is consulted for the forecasts.
CNMCA	ECMWF-IFS IFS-ENSEMBLE of 50+1 members	9 km	10 days 15 days	ECMWF-IFS and COSMO-ME for the synoptic analysis mainly and COSMO IT and ICON IT for the small scale features (e.g. convective activity during summer).
NMA	ALARO 00 UTC ALARO 12 ECMWF-HRES, RUN 00-12 UTC	6.5 km 4 km 9 km	78h 78h 10 days	ICON-LAM and COSMO for short range forecast and ECMWF for long range forecast
IMGW	GFS ECMWF UM – PL ALARO AROME	0.25 0.1 deg 4 km 4 km 2 km	240h 240h 120h 72h 30h	ICON PL is the third most used model, as it is relatively new.
MCH	IFS-HRES and ENSEMBLE AROME	9 km 1.3/2.5 km	>5 days 50h	IFS-HRES and ENS is used mainly for lead-time greater than 5 days and compared with COSMO and ICON for shorter lead-times. We sometimes (but rarely) look at AROME.
HNMS	ECMWF-IFS-HRES and ECMWF-ENS GFS	9 km	Up to 7 days	IFS is the main model for lead-time greater than 3 days. We compare with ICON-GR for shorter lead-times.

Do you also use ICON global for your forecasts?						
ARPA-P	**IMS**	**CNMCA**	**NMA**	**IMGW**	**MCH**	**HNMS**
Yes	Yes	No	Yes	Yes for mid-term forecasts	No	Yes, for severe weather expected
Added value of ICON-GLOBAL						
ARPA-P	**IMS**	**CNMCA**	**NMA**	**IMGW**	**MCH**	**HNMS**
Better for precipitation forecast	No	N/A	No added value	Not enough for comparison	N/A	Sometimes - added value for precipitation
Do you use ICON-EPS ?						
ARPA-P	**IMS**	**CNMCA**	**NMA**	**IMGW**	**MCH**	**HNMS**
No	No	No	No	No	Yes	No

Do ICON-LAM forecasts arrive on time? If not, specify the reason		
ARPA-P	Mainly Yes	
IMS	No	There is a problem with arrival time. Our 12 hour shifts begin at 7:45 and 19:45 so when the forecaster starts the forecast, the more recent ICON-LAM run is not available yet. During the summertime, ICON-LAM arrives only after 10:00
CNMCA	Mainly Yes	In general the forecasts arrive on time, occasionally some delays occur because of boundary conditions unavailability
NMA	Yes	
IMGW	Mainly Yes	Occasionally there are some delays with ICON PL products being available on the visualisation web page for forecasters (a dedicated server). These delays are more noticeable for ICON PL rather than for COSMO PL
MCH	Yes	
HNMS	Mainly Yes	Usually they arrive timely, but there are days with significant delays or no runs at all due to technical problems on ATOS/ECMWF machines where it is running

2.2 Use of ICON-LAM forecast products and needs

Which ICON-LAM DMO outputs are used for the daily forecast ?	
ARPA-P	Temperature, Precipitation, Cloudiness (and relative humidity), Wind
IMS	Precipitation maps, convection indices
CNMCA	Standard meteorological primary and derived fields are plotted such as cloud cover, precipitation, snow, freezing level, RH 2m, wind 10m, Vertical velocity 700hPa
NMA	Low/medium/high, total clouds coverage, 10m wind, wind gust, accumulated precipitation 3h, 6h, 24h, 48h, CAPE, 2m temperature, MSLP, relative humidity
IMGW	Cloud cover (low, mid, high), Temperature min, max, mean (24h), temperature, relative humidity, vertical velocity, wind, precipitation, rain, snow (1,3,6,12,24h)
MCH	Mainly horizontal and vertical wind, temperature and relative humidity at various pressure and geopotential height levels, cloud cover, precipitation, radar reflectivity, sunshine duration, snowfall
HNMS	3h/6h/12hPrecipitation, 10m wind speed, probability of thunderstorm, 3h/6h snowfall (only in winter), Total cloud cover, convective cloud tops, soundings for selected cities, wind plots at various flight levels, height of 0°C isotherm

2.3 ICON-LAM added value and performance satisfaction

Visualization software and main forecast products		
ARPA-P	GrADS	Maps
IMS	In-house, software developed at IMS, based on Java, GrADS, and Metview	Precipitation maps, accumulated snow maps on topographic maps, cloud and precipitation animations, Meteograms, and boundary layer cross-sections
CNMCA	ECMWF-magics, IBL Visual Weather	Maps and meteograms (at the moment fixed and not on-demand)
NMA	Visual Weather	Maps, meteograms, soundings
IMGW		Maps, meteograms, diagrams, cross sections
MCH	Internal browser for plots and Ninjo	Maps and meteograms
HNMS	Visual Weather, internal browser	Mainly maps on Visual weather for IFS, internal browser for ICON-GR

Are you satisfied with your forecast visualization ? If not what do you suggest that would be helpful ?		
ARPA-P	Mainly yes	ICON meteograms similar to ECMWF ones would be useful, plotted as multi-model outputs
IMS	Mainly yes	Consolidation of all the products to one hub is suggested
CNMCA	Yes	
NMA	Yes	Suggestion is to increase the resolution in order to identify areas, main roads, rivers
IMGW	No	Not really. It would be helpful to have a person appointed to create visualization of model data for forecasters purposes. The ability to select the colour scale of the presented data would also be helpful
MCH	Mainly yes	Higher temporal resolution output fields on the order of 10 minutes for parameters that are highly variable in space and/time (e.g. radar reflectivity, horizontal wind, CAPE and clouds cover) is desirable. This is the appropriate timescale for e.g. convection and fog/low stratus processes, and it is also the timescale at which LAMs work and have their strengths and advantages compared to global models
HNMS	No	Not really. For wind maps, we need to identify sea borderlines to make it easier for the forecasters. Also the color scale should be similar to IFS in order to have a direct comparison between the models and to be shown on the same visual environment in order for the forecasters not to waste time looking on different screens. Moreover, there is no possibility of zooming

Do you use ICON-LAM outputs for the regular aeronautical, marine or other operational forecasts that your service issues? Is the procedure automated ?		
ARPA-P	No	Procedure not automated for any model
IMS	Yes	Low cloud cover forecasts are not correct. The procedure is automated based on IFS
CNMCA	Yes	Method not automated
NMA	Yes	Automated
IMGW	Yes	Not automated
MCH	No	Currently COSMO is used. There are some automated COSMO products, others where forecasters can modify the values proposed by the model (e.g. probability of thunderstorm around an airport) and others where forecasters just add a comment to the automatic forecast
HNMS	Yes	For aeronautical forecasts. There are helpful meteograms with information for each station, but they are rarely consulted due to lack of time. Some forecasters look at ICON-LAM outputs to compare with IFS which is the main model. A very new automated procedure for TAF's based on IFS has been recently become available and serves as a first suggestion. For sea forecast yes, we use the ICON-LAM wind maps as a second model after IFS. There is also one ICON-LAM automated bulletin issued every 6 hours which tries to foresee the Beaufort scale of the seas the same way a forecaster would do and forecasters take it into consideration

Additional ICON-LAM products needed for the forecasts		
ARPA-P	No	
IMS	Yes	Convective indices (SWEAT, Showalter index, total totals, Cape, CINH, K etc..)
CNMCA	Yes	Precipitable Water, surface wind convergence
NMA	No	
IMGW	Yes	More dedicated products for hail, thunderstorms. such as - Condensate Track - Total Col. Graupel Updraft helicity - Supercell detection index - Reflectivity in DBZ not mm/h
MCH	Yes	Synthetic satellite image for visible channels would be useful. Percentiles and probabilities are used to overpass thresholds. In addition, it would be helpful to have a clustering of the ensemble members based on specific variables (for instance, radar reflectivity, precipitation accumulation, wind gust). This would bring additional information on the distribution of the ensembles than with percentiles
HNMS	Yes	Visibility maps, convective indices. Automated special airport warnings, sea routes forecasts are needed

Is ICON-LAM verification information helpful ? Do you take it into consideration when issuing the daily forecasts or warnings for severe weather ?		
ARPA-P	N/A	Verification on-going
IMS	Yes	Low cloud cover forecasts are not satisfactory
CNMCA	Yes	
NMA	Yes	
IMGW	Partly	Verification information is helpful but not fully comprehensive. The quality of the model scores is related to comparison with observations. Forecasters however do their own "verification" which might be not as detailed as the model verification but treats weather parameters as "objects". A model forecast can be considered "good" even if it does not necessarily predict the right place at the right time with the right intensity, but at least it gives a signal that the event can occur when other models show nothing. Forecasters prefer to base their forecasts not only on one particular model or the model family, because each model or model family have their own weaknesses – they are taken into account during the decision making process including issuing warnings and forecast. In terms of ICON PL verification, forecasters do not have much experience with it and unfortunately there is no time to look at the verification results. Verification information is mainly useful for improving model's parameterization. For other models, there is a verification tool useful for issuing a daily forecast. Unfortunately, there is no verification tool for severe weather/warnings yet
MCH	Partly	There is an internal verification, which is useful, but only analysed by our NWP team. Most forecasters do not look at this verification, typically it is not taken into account when issuing daily forecasts or warnings
HNMS	Partly	There are verification plots, combined with IFS results, easy to understand mainly for surface data (simple scores and graphs) on our internal website. However, the forecasters have their own experience and they rarely use this information. Some of the verification scores are not so clear to forecasters (POD, ETS etc). Also spatial verification is mainly used for research purposes and is hard to be applied to forecasters

What other ICON-LAM verification products would be useful ?	
ARPA-P	Precipitation, temperature, wind and humidity at least
IMS	High Impact Weather, Wind gust verification, low clouds
CNMCA	None
NMA	None
IMGW	More sophisticated products for aerial verification, as well as a “skill index” to indicate how models behave in severe weather conditions. Finding best predictors for certain severe weather types and calculating their performance
MCH	Setting of key cases, covering the full range of important weather types of the Alpine region throughout the year (convection, fog/low stratus, winter storms, Foehn storms, cold air damming), that are re-run with every new model suite or version. For those cases it would be interesting to see the traditional scores to diagnose progress of the model forecasts with time
HNMS	HIW, verification for different synoptic conditions, different geographic locations, TAF verification (in progress), verification of sea forecast bulletin and sea route forecasts

Estimate the overall ICON-LAM guidance						
ARPA-P	**IMS**	**CNMCA**	**NMA**	**IMGW**	**MCH**	**HNMS**
Misleading to good.	Good. Tutorial may help	Good	Good to very good.	Good	Very Good	Good especially for wind

Is there an ICON-LAM added value compared to COSMO? For which variables?		
ARPA-P	Preci	Apparently, ICON is less related to the wet 700hPa layer as COSMO is. In other words, COSMO does not predict precipitation if the 700hPa level is dry, so stratiform precipitation is often missed
IMS	T2m, Rh2m, Wind	- T2m, Ws, Wd: ICON-LAM is better than COSMO all day long mountains and plains. - Rh2m: ICON-LAM is better on the mountains during the night.
CNMCA	None	
NMA	T2m, Wind, WG ,Preci	- Generally, ICON captures very well the initiation of simple cells. - Better predicts CAPE and convective phenomena - For regional forecast (SE Romania) the area of high precipitation is more accurate, but not the quantities. - Type of precipitation better for ICON
IMGW	Wind, Preci, TCC Fog	- ICON-PL performs slightly better than COSMO-PL and predicts precipitation quite well. In a case of a poor forecast, ICON-PL more often overestimates than underestimates precipitation - ICON-PL better predicts winds - Total cloud cover is slightly better predicted by ICON-PL than COSMO-PL. Both models tend to overestimate TCC, but ICON-PL overestimates less than COSMO-PL.ICON-PL better predicts humidity and areas of fog or low stratiform clouds
MCH	TCC, Low Clouds	ICON-LAM is more successful in forecasting low-level clouds, and better predicts the formation and dissipation of fog and low stratus. This could be partly due to a better forecast of T2m and Td2m than COSMO. In addition, wind speed in the plains is less biased than COSMO (COSMO has a positive bias, ICON has a smaller bias). A striking feature in summer, is that ICON is forecasting cloud amounts in the full range from 0 to 100% which is good and realistic. This is not the case with COSMO, which usually gives a value of either 0 or 100% cloudiness in a strict binary manner.
HNMS	Wind, Preci	The most successful parameter is the 10m wind speed. The ICON-LAM forecasts for small gulfs give more realistic results with stronger winds than the ones predicted by IFS-ECMWF. Also, it better simulates katabatic northerly winds over Crete island and easterly winds over Ionian islands. However, for summer these local winds sometimes tend to be overestimated. Although forecasters consult less the precipitation of ICON-GR as they are mostly used to IFS, there are many cases, especially in summer season, where location of convective precipitation is better forecasted with ICON-GR

Is there an ICON-LAM added value compared to COSMO for different seasons, weather regimes or regions?		
ARPA-P	Preci	- In winter, ICON gives added value in some episodes of thunderstorms.-When ECMWF mistakenly predicts light precipitation when the sky is very cloudy, ICON does not. - Both ICON-LAM and COSMO, often overestimate precipitation amounts in thunderstorms in the summer.
IMS	N/A	There is no verification available yet.
CNMCA	None	
NMA	T2m, Wind, Preci	- The estimation of precipitation area and appearance in almost all seasons is satisfactory /very satisfactory. - ICON is better in summertime convective situations, while COSMO performs better in the cold season. - For regional forecast (SE Romania) the area of high precipitation is accurate but not the amounts. - ICON-RO performs better than COSMO under synoptic conditions of northern circulations and cold fronts.
IMGW	Preci, Fog, Temp	- Added value is mostly seen in difficult summer convective situations where COSMO was reluctant to see any precipitation. In winter/spring this difference was not that obvious. - In 2022 during a thunderstorm period, ICON-PL was more successful in giving a correct signal, while most other models did not see initiation of convective precipitation. - Precipitation overestimation is more common in coastal or mountainous areas than in lowland regions. - ICON-PL better predicts fog and low stratiform clouds in winter. - ICON-PL better predicts minimum temperature in summer and maximum temperature in winter, especially during dynamic warm air advection
MCH	TCC, Low Clouds	ICON forecasts betterfog and low-level clouds.
HNMS	Preci, Wind	Precipitation signals of models show more significant differences in SON/ MAM than winter season. When a well defined frontal system is over Greece, all models show similar results. For smaller scale lows of limited extent, differences are more common as movement of lows may differ for each model. In convective precipitation, ICON-GR indicates better the location of precipitation objects and maxima. In fall and spring transition seasons the precipitation is usually overestimated especially for IFS and less for ICON-GR. Attica region is also a common overestimation precipitation area for these seasons.

Identify ICON-LAM decreased model skill for certain regions or weather regimes. Specify persistent biases in forecasted parameters.		
ARPA-P	Preci	- Precipitation is underestimated when cold front passes quickly from west to east over Piedmont. - Snow level is forecasted at too low altitude. - The biases in precipitation are both positive and negative, even if ICON-IT often overestimates convective precipitation (summer thunderstorms) or orographic precipitation.
IMS	Fog Preci	- In winter 2022 several foggy events occurred. Although ICON-LAM predictions were more successful than COSMO, there were many fog false alarms. - There is a positive bias in precipitation mainly in fall.
CNMCA	Preci	- In summer season, overnight convection inhibition is high. - When convection is forecasted, the precipitation accumulation is very high compared to all other models
NMA	Fog Wind, Preci	- Consistently overestimates fog risk, - Overestimates wind in all seasons except for winter. - Overestimates precipitation and wind in convection situations. - Overestimates orographic frontal precipitation - Overestimates convective wind gusts in warm seasons.
IMGW	Temp WG	- In north-eastern Poland, in warm seasons, ICON-PL sometimes slightly underestimates the maximum air temperature (by 1-2°C) and overestimates minimum temperature (by 1-3°C). - Wind Gusts are often overestimated, especially in the mountain regions.
MCH	Sunshine, WG	- In fall-winter seasons, there was a sunshine duration overestimation problem which was solved for spring-summer seasons. - Some local wind gust underestimation is often observed.
HNMS	Preci, Wind	Fog and low clouds are often shown as precipitation mainly in western Greece even in anticyclonic conditions. Very often, precipitation is overestimated over NE Greece over convergence zones, under synoptic conditions of light northerly flow (high pressures over mainland combined with low over SW Aegean). Wind was sometimes overestimated in summer in sea gulfs with W flows. In fall and spring (transition seasons) precipitation is often overestimated.

Categorize, if possible, the synoptic patterns in the lower and upper troposphere where biases in ICON-LAM forecasts are more frequent		
ARPA-P	SW flow	Southern flows against the northern mountains often cause overestimated precipitation due to a more intense orographic effect.
IMS	Low	Scattered convective showers, with low synoptic forcing
CNMCA	Inversions	Temperature inversions overnight with strong convection should be better considered, perhaps using MU (Most Unstable) CAPE and MUCIN. Virtual temperature correction helps in reducing Convective Inhibition (CIN) and in forecasting more convection mainly when CAPE is too low.
NMA	N/A	N/A
IMGW	N/A	N/A
MCH	N/A	N/A
HNMS	N-NE S-SW winds	During N-N winds in low troposphere over eastern parts, precipitation is often overestimated over Eastern mainland and Southern islands. With W-SW flows, precipitation is overestimated over Western, Northern Greece mainly in fall and spring.

What are your comments for the forecasted precipitation in general? Do you see differences among ICON-LAM and COSMO (or other models) for convective or non-convective precipitation? (extent, time of start/end, shape of objects, etc.)	
ARPA-P	In fall and winter, ICON-LAM is similar to other high resolution LAM models, although it can sometimes correctly predict precipitation that COSMO does not foresee. In spring-summer, ICON behaviour is similar to other LAMs: sometimes they are misleading especially on their representation of precipitation. Probably the microphysics and convection schemes are easily triggered by the orography or by local convergences and lead to very high and not realistic precipitation maxima. The position is sometimes correct, sometimes completely wrong. LAMs concentrate rainfall in the first forecast period, anticipating the end of the event (they overestimate at the beginning and underestimate at the end)
IMS	No differences.
CNMCA	Our LAMs (COSMO-IT, ICON-IT, COSMO-2I), butalso ICON-D2, showed too much convection inhibition especially during evening-nighttime. Too often the convection was suppressed and no signal was forecasted. During July 2023, surprisingly, there is the suspect that ECMWF-HRes and DWD-ICON-EU forecasted deep convection overnight better than the best European local models with more recent and frequent runs. Generally our local models have shown poor performance in forecasting severe convection and, as already known, COSMO-IT was better than ICON-IT, but not as good as COSMO-2I, which has RADAR assimilation. Conversely C-LAEF 00 Run showed good performance, also overnight, compared with models with more recent and frequent runs.
NMA	In terms of intensity of convective and orographic precipitation, ICON overestimates in comparison to COSMO model. However, the extent, location and initiation of the convection is often successfully predicted.
IMGW	In fall-winter, ICON-PL precipitation forecasts are generally satisfactory. In a case of a poor forecast, ICON PL overestimation is more common than underestimation. In spring-summer, ICON-PL forecast is comparable to the COSMO-PL, and both predict convective precipitation overall better than other models. However, ICON-PL sometimes forecasts precipitation with a delay.
MCH	Orographic precipitation seems to be even more overestimated than COSMO in spring-summer seasons.
HNMS	The main differences are in convective summer situations where IFS shows more extended area of precipitation but less intense. Very often in Attica regionmainly in fall/spring, the differences among models are more common. The Attica forecast is difficult due to the surrounding mountains.

Do you apply correction to ICON-LAM forecasts?		
ARPA-P	Yes	Qualitative correction for precipitation.
IMS	No	Bias correction is applied only to IFS forecast via INCA (nowcasting system developed by Austria)
CNMCA	No	
NMA	No	
IMGW	No	
MCH	No	The only parameters that are post-processed (with Kalman filter) are station measurements (2 m air temperature, 2 m dew point and 10 m mean wind speed). Forecasters also apply qualitative corrections for some parameters, based on experience. For instance, in fall/winter, forecasters found that ICON tends to overestimate sunshine duration.
HNMS	No	

Is there an added value of ICON-LAM performance compared to COSMO (or other) model for different forecast horizons? (Do the forecasts deviate after some hours of simulation and which one performs better?)		
ARPA-P	Yes	ICON-LAM and COSMO are quite similar for Day 0, whereas they often deviate for Day1, possibly because they are forced by different global models.
IMS	Yes	Due to better data assimilation, COSMO precipitation forecast is better than ICON-LAM for the first 6 hours. For longer lead times ICON-LAM is very slightly better than COSMO and both COSMO and ICON have a much better skill compared to all other models.
CNMCA	No	
NMA	Yes	The deterministic forecasts are similar for the first 24 forecast hours, while ICON performs better for higher time leads.
IMGW	No	
MCH	No	
HNMS	No	The closer the forecast the better, regardless of initial time.

Specify main ICON-LAM products used for prediction HIW							
Precipitation	Wind Gusts	RH/Td	LPI	CAPE/LI	Wind Sp/Dir	Snow	Temp
ARPA-P **CNMCA** **NMA** **IMGW** HNMS **IMS**	**NMA** **ARPA-P**	**NMA** **IMGW**	**NMA**	**IMGW** **NMA**	HNMS **NMA** **IMS** **CNMCA** **ARPA-P**	**IMS** HNMS **IMGW**	**IMGW**
Is there an added value of ICON-LAM for predicting severe, high impact weather (HIW)? For which ones?							
Thunderstorms	Wind Gusts	Frontal precipitation	Fog	Heat Waves	Snow	Sea Winds	Frost
ARPA-P **CNMCA** **NMA** **IMGW** HNMS **IMS**	**ARPA-P** **IMS** **NMA**	**CNMCA** **NMA** **IMGW** HNMS **IMS**	**IMS** **NMA** **MCH**	**IMGW**	HNMS **IMS**	**CNMCA** HNMS	**NMA** **IMGW** **IMS**

Are forecasts helpful for issuing warnings sufficiently ahead of time? Did you get often misses or false alarms? If so, for which HIW?	
ARPA-P	Precipitation (even if it can be overestimated in convective events); max wind gust for foehn events. There are false alarms for thunderstorms: this is a common problem for LAMs, not only ICON-LAM.
IMS	Many fog false alarms in winter 2022.
CNMCA	ICON is not used for issuing warnings, because COSMO-IT is still used, as it is considered better than ICON-IT. For deep convection there are more misses and few false alarms.
NMA	Forecasts are sufficient for issuing warnings ahead of time: the 12-25 lead times are more helpful. Sometimes there are false alarms for thunderstorms, torrential rains and strong gusts predicted to occur at night. However, in cases of tropical and unstable air masses, they warnings aremostly successful.
IMGW	For precipitation, “miss” occurred more often than “false alarm” for 12-18h lead time. Heat waves were forecasted quite well 24 hrs ahead.
MCH	Forecast of low-level clouds, for short lead-times (<24h). However, warnings for fog are not issued in our service.
HNMS	Usually the false alarm is more common than miss for precipitation warnings, and often warnings issue is not necessary. Miss is often seen in Athens area especially in summer season. Sometimes sea winds warnings are overestimated. Some errors in precipitation location may decrease the severe weather warnings success.

Systematic difference between different runs.						
ARPA-P	IMS	CNMCA	NMA	IMGW	MCH	HNMS
No. 00UTC is mostly used	No. 00UTC is mostly used	No	00UTC mostly used	No	No	No

3 Comparison with objective Verification

In this section, the main forecasters' comments about different parameters are compared to the objective verifications. Objective verification reports can be downloaded in this link: http://www.cosmo-model.org/view/repository/wg5/meetings/2024-01-24

Seasonal verifications for local domains are also available on the COSMO website: www.cosmo-model.org/content/tasks/verification.priv

	Forecasters	Objective
Temperature	Daytime underestimation. Night overestimation bserved in NE Poland in warm seasons (IMGW)	Daytime underestimation. Night overestimation (ME scores)
	ICON better prediction than COSMO of Tmin (JJA), Tmax (DJF) especially in warm advection (IMGW)	ICON scores better than COSMO
	Better ICON predictions than COSMO (IMS,NMA,MCH)	ICON scores better than COSMO
Humidity	ICON-IL better than COSMO mainly over the mountains at night (IMS)	RH ICON better forecasts than COSMO
	Better ICON Td forecasts than COSMO (MCH)	RH ICON better RMSE score than COSMO
Wind Speed	Better ICON wind predictions than COSMO (IMGW)	Better ICON wind scores than COSMO except for winter when ICON winds are overestimated
	ICON wind speed overestimation in all seasons except for DJF. Wind overestimation in convective conditions mainly in warm seasons in daytime (NMA)	In winter ICON wind speed is underestimated all day long, while in the remaining seasons it is overestimated in warm hours
	ICON-GR Better wind forecast than IFS-ECMWF. Slight ICON overestimation in JJA for local winds (HNMS)	ICON-GR generally better scores than IFS-ECMWF
	Better ICON wind speed/direction performance than COSMO (IMS)	Better ICON wind scores than COSMO
	Wind speed ICON forecasts in the plains are less biased than COSMO (MCH)	ICON less biased forecast than COSMO on Swiss Plateau while it is more biased over the whole country with underestimation over complex terrain
Wind Gust	Good ICON predictions with only a general tendency of surface weak overestimation over mountainous areas, and slight underestimation over plains (MCH)	Test case of 16/11/23.ICON prediction was overall more accurate than COSMO
	ICON wind gusts are overestimated especially in mountainous regions (IMGW)	ICON overestimation of max wind speed in warm hours
	ICON overestimation of convective wind gusts in warm seasons (NMA)	ICON overestimation of max wind speed in warm hours
Total Cloud	ICON better forecast of low-level clouds than COSMO, better predicting the formation and dissipation of fog and low stratus (MCH)	etter ICON scores than COSMO especially for high cloud coverage
	ICON gives the best predictions, in spite of many fog false alarms in winter (IMS)	ICON TCC and Td2m are overestimated during cool morning hours
	ICON fog risk overestimation (NMA)	TCC and Td2m ICON overprediction at night
	Total cloud cover and areas of fog or low stratiform clouds are better predicted with ICON and less overestimated than COSMO especially in winter (IMGW)	ICON TCC is slightly overestimated at night, but the scores are overall better with lower bias than COSMO. Lower bias at winter nights (ICON) where moisture bias is also reduced
Sunshine duration	ICON sunshine overestimation (MCH)	ICON scores indeed show sunshine overestimation
Precipitation	Better ICON precipitation forecast of JJA convective conditions. Comparable ICON and COSMO forecasts in DJF (IMGW) or even better (NMA)	Better ICON ETS scores in JJA, comparable in DJF. Scores for COSMO are better for thresholds >5mm in DJF
	ICON overestimation of JJA convective events (IMGW, ARPA-P, CNMCA), but forecasts better than COSMO	FBI >1 increasing with higher thresholds at noon in JJA for ICON, better scores than COSMO
	ICON orographic precipitation is overestimated. (ARPA-P, NMA)	FBI score is >1 at thresholds >8mm (ICON-IT, ICON_RO) for >800m
	ICON poor deep convection overnight (CNMCA)	JJA ICON T2m underprediction of near surface night time temperature and RH underprediction in upper air is an indication of this, together with POD lower values at night
	Poor ICON predictions of severe convection events (CNMCA)	Worse ICON JJA scores with increasing thresholds
	Light precipitation overforecasted for IFS in cloudy conditions (HNMS-ARPA-P). Not for ICON	FAR scores higher for IFS for low thresholds

4 Summary

4.1 Model Use and Products

- IFS is the most common model for initial and boundary conditions, with ICON-GLOBAL used only in NMA and IMGW.
- Data assimilation for ICON-LAM is used in four services. KENDA is used in ARPA-P, CNMCA, MCH, while IMS uses LHN. Kalman filter correction is applied in MCH.
- ICON-LAM is running operationally in all services except for MCH. However, it is not the main model for most of them, (IFS is the most popular), especially for lead times greater than 3 days. One reason for this are the limited forecast range compared to IFS and the delays of ICON-LAM arrival to the forecasters, which are more frequent than COSMO. ECMWF technical problems causing delays in boundary conditions is the main reason. ICON-LAM when available, it is always consulted especially for smaller scales.
- Visual Weather is the most common visualization software. Internal websites and Grads are also used. Visualisation improvement suggestions are possibilities of including all models in one hub, creating multimodel meteograms, adjusting color scale, zooming.
- Additional requirements about ICON-LAM products include convective indices, products for hail and thunderstorms, visibility maps, synthetic satellite images, special products for ensemble (clustering based on specific variables).
- Operational verification results are not widely used by the forecasters. Some of the scores, for example spatial verification may be difficult to interpret. Forecasters prefer to use their own experience. A scores classification for different synoptic conditions, HIW, and special test cases with different model versions are suggested to be more helpful for the forecasters.
- ICON-LAM is used for aeronautical and sea route predictions for five services, at least for comparison, while only IFS and COSMO are used for the two others. Procedure is not yet fully automated.

4.2 Model Performance Summary

- ICON-LAM performance is overall satisfactory for most variables and helpful for the forecast.
- However, there are contradictory opinions regarding precipitation. Although most services report overall good performance in warm seasons and convective conditions, with satisfactory forecast prediction area, there is a tendency of overestimation of maxima, which is also reported in orographic precipitation in MCH and ARPA-P, coastal and mountainous regions (IMGW),and local convergence conditions with synoptic conditions of NE flows, S-SW flows over Western and Central parts (HNMS).Transition seasons (SON, MAM) are more difficult seasons for precipitation forecast.
- Misses in precipitation forecasts are reported in Italy (CNMCA) in deep convection. Moreover, very often ICON-IT and all other LAM models reported erroneous night time convection inhibition, with coarser scale models (IFS) being more successful. In

addition, there were cases where severe convection was poorly forecasted with ICON-IT, while COSMO-2I and C-LAEF were more successful.

- A positive remark (ARPA-P) is that ICON is less related to the wet 700hPa layer as COSMO is. Therefore, COSMO stratiform precipitation is often missed if the 700hPa level is dry.
- In cool seasons, COSMO performs similarly or even better than ICON (NMA). In case of well established low system with cold fronts in DJF all models including ICON-LAM tend to forecast similar weather, while in smaller-scale local lows the differences are more significant, as the movement and location of such lows differ for each model (HNMS).
- TCC, low clouds and fog are better predicted with ICON-LAM although there is a tendency of fog events overestimation (NMA, IMS). Sometimes in case of low cloud conditions precipitation is erroneously forecasted instead of fog, mainly with IFS and less for ICON (HNMS). Sometimes in case of low cloud conditions precipitation is erroneously forecasted instead of fog, mainly with IFS and less with ICON (HNMS, ARPA-P).
- Although wind predictions are generally satisfactory, there is a tendency of wind gust overestimation in convective conditions and mountainous regions.
- In terms of forecast range, the first hours of simulation, COSMO and ICON models are similar but for later hours ICON is better (IMS, NMA). ARPA-P reported overestimation of precipitation events in the beginning of the forecast period, underestimation around the end, with the events duration being forecasted too soon for both models. IMGW reported ICON occasional delays of precipitation forecast with respect to the observations.
- ICON-LAM is used for warnings in most services especially for thunderstorms, frontal precipitation and wind gusts. False alarms warnings for precipitation are common for thunderstorms in ARPA-P, HNMS and night time wind gusts in NMA. Misses for precipitation are reported in IMGW, CNMCA. In IMS,ICON is mainly used for issuing fog warnings, but with significant number of false alarms.
- The comparison of forecasters comments with objective verification agree to the ICON general better performance than COSMO but also to the ICON performance weak points.

A Survey Questions

A.1 Model Run Information

1. Specify the version, grid spacing, nesting setup and forecast range of COSMO/ICON-LAM you are using. Is ICON-LAM running operationally in your service?
2. Specify the initial and boundary conditions driving models for COSMO and ICON-LAM.
3. Do you use data assimilation? If yes, please write the assimilation method and the type of assimilated observations.
4. Specify other models you are using for your forecasts. Specify grid spacing and forecast horizon.
5. Which model is the main model the forecasters consult for their forecasts. If it is not ICON-LAM please specify the reason.
6. Do you also use ICON global for your forecasts?
7. Do ICON-LAM forecasts arrive on time? If not, specify the reason.

A.2 Use of model and needs

1. Which ICON-LAM direct model output (DMO) products do you use for the routine daily weather forecasts?
2. Which types of visualization do you use (maps, meteograms, other plots)
3. What is your visualization software for ICON-LAM ?
4. Are you satisfied with this visualization? If not, what do you suggest that would be helpful?
5. Do you use ICON-LAM outputs for the regular aeronautical, marine or other operational forecasts that your service issues?
6. Do you use automated procedure for the creation of the forecasts of the previous question with model data? If yes, does the forecaster interfere on the model suggested forecasts?
7. Do you have additional requirements with respect to ICON-LAM data format, output meteorological variables and specific products derived from ICON-LAM numerical weather forecasts?
8. Do you use post-processing products of ICON-LAM (e.g., convective indices plotted in meteograms) ? Which ones are more useful and what are your needs?
9. Is the ICON-LAM verification information helpful? Do you take it into consideration when issuing the daily forecasts or warnings for severe weather?
10. What other ICON-LAM verification products would be useful? Do you apply correction to ICON-LAM forecasts such as Kalman filter procedure?

A.3 Model guidance and performance

1. Estimate the overall ICON-LAM model guidance

    a) very good guidance, very useful
    b) good guidance, useful
    c) rather poor guidance, misleading
    d) very poor guidance, very misleading
    e) additional comments to the choice above, especially if answer is c or d

    Is there an overall added value for ICON-LAM compared to COSMO (or other) forecasts for particular meteorological parameters? If so, please, indicate the parameters.

2. Is there an added value of ICON-LAM performance compared to COSMO (or other) model for different regions, weather regimes or different seasons?

3. Identify ICON-LAM decreased model skill for certain regions or weather regimes.Specify persistent biases in forecasted parameters.

4. Categorize, if possible, the synoptic patterns in the lower and upper troposphere where biases in ICON/LAM forecasts are more frequent.

5. What are your comments for the forecasted precipitation in general? Do you see differences among ICON-LAM and COSMO (or other models) for convective or non convective precipitation? (extent, time of start/end, shape of objects, etc.)

6. Is there an added value of ICON-LAM performance compared to COSMO (or other) model for different forecast horizons? (Do the forecasts deviate after some hours of simulation and which one performs better?)

7. Is there an added value of ICON-LAM for predicting severe, high impact weather (HIW) situations, such as:

    - thunderstorms/frost/snow/heat waves/fog/severe wind gusts/storms/road ice/frontal precipitation
    - other (indicate which HIW event)
    - We do not predict HIW

8. Please specify the ICON-LAM products that were more helpful for forecasting these situations. At which lead times?

9. Were the forecasts helpful for issuing warnings sufficiently ahead of time?

10. Did you get often misses or false alarms? If so, mainly for which HIW?

11. Do you notice any systematic difference between different ICON-LAM forecast runs? Are ICON-LAM runs from a particular initial time more/less successful? Please, indicate the initial time and the variable they are most successful for.

12. Is there an added value (if yes, describe it) from using ICON global NWP comparing to other NWP models?

A.4 ICON EPS

1. Do you use the ICON ensemble prediction system (EPS)? What are the parameters (grid size, number of members). Is it helpful for predicting severe events ahead of time?
2. Is there an added value of ICON-EPS compared to other EPSs you use? For which parameters?
3. Do you use post-processed ICON-EPS products? (E.g., upscaled probabilities)? If so, which ones? Do you need/plan to use more products? If yes, could you specify/describe them?

B List of Models

1. ALARO (Ghent University, Belgium)
2. AROME (Application of Research to Operation at Mesoscale-Meteo France)
3. BOLAM (hydrostatic model of CNR-ISAC/Bologna)
4. GFS (Global forecast System- NCEP/NOAA)
5. IFS -ECMWF (Integrated Forecast System -European Centre for Medium-range Weather Forecasting)
6. KENDA (Km scale Ensemble Data Assimilation)
7. MOLOCH (hydrostatic model of CNR-ISAC/Bologna in higher resolution)
8. UKMO (United Kingdom Met. Office)
9. WRF (Weather Research and Forecast model-NCAR/MMM)

List of COSMO Newsletters and Technical Reports

(available for download from the COSMO Website: www.cosmo-model.org)

COSMO Newsletters

No. 1: February 2001.

No. 2: February 2002.

No. 3: February 2003.

No. 4: February 2004.

No. 5: April 2005.

No. 6: July 2006.

No. 7: April 2008; Proceedings from the 8th COSMO General Meeting in Bucharest, 2006.

No. 8: September 2008; Proceedings from the 9th COSMO General Meeting in Athens, 2007.

No. 9: December 2008.

No. 10: March 2010.

No. 11: April 2011.

No. 12: April 2012.

No. 13: April 2013.

No. 15: July 2015.

No. 16: July 2016.

No. 17: July 2017.

No. 18: November 2018.

No. 19: October 2019.

No. 20: December 2020.

No. 21: May 2022.

No. 22: May 2023.

No. 23: May 2024.

COSMO Technical Reports

No. 1: Dmitrii Mironov and Matthias Raschendorfer (2001):
Evaluation of Empirical Parameters of the New LM Surface-Layer Parameterization Scheme. Results from Numerical Experiments Including the Soil Moisture Analysis.

No. 2: Reinhold Schrodin and Erdmann Heise (2001):
The Multi-Layer Version of the DWD Soil Model TERRA_LM.

No. 3: Günther Doms (2001):
A Scheme for Monotonic Numerical Diffusion in the LM.

No. 4: Hans-Joachim Herzog, Ursula Schubert, Gerd Vogel, Adelheid Fiedler and Roswitha Kirchner (2002):
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Part I: Modelling Technique and Simulation Method.

No. 5: Jean-Marie Bettems (2002):
EUCOS Impact Study Using the Limited-Area Non-Hydrostatic NWP Model in Operational Use at MeteoSwiss.

No. 6: Heinz-Werner Bitzer and Jürgen Steppeler (2004):
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No. 7: Hans-Joachim Herzog, Almut Gassmann (2005):
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No. 8: Chiara Marsigli, Andrea Montani, Tiziana Paccagnella, Davide Sacchetti, André Walser, Marco Arpagaus, Thomas Schumann (2005):
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No. 9: Erdmann Heise, Bodo Ritter, Reinhold Schrodin (2006):
Operational Implementation of the Multilayer Soil Model.

No. 10: M.D. Tsyrulnikov (2007):
Is the particle filtering approach appropriate for meso-scale data assimilation ?

No. 11: Dmitrii V. Mironov (2008):
Parameterization of Lakes in Numerical Weather Prediction. Description of a Lake Model.

No. 12: Adriano Raspanti (2009):
COSMO Priority Project "VERification System Unified Survey" (VERSUS): Final Report.

No. 13: Chiara Marsigli (2009):
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No. 14: Michael Baldauf (2009):
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No. 15: Silke Dierer (2009):
COSMO Priority Project "Tackle deficiencies in quantitative precipitation forecast" (QPF): Final Report.

No. 16: Pierre Eckert (2009):
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No. 17: D. Leuenberger, M. Stoll and A. Roches (2010):
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No. 18: Daniel Leuenberger (2010):
Statistical analysis of high-resolution COSMO Ensemble forecasts in view of Data Assimilation.

No. 19: A. Montani, D. Cesari, C. Marsigli, T. Paccagnella (2010):
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No. 20: A. Roches, O. Fuhrer (2012):
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No. 21: Michael Baldauf (2013):
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No. 22: C. Marsigli, T. Diomede, A. Montani, T. Paccagnella, P. Louka, F. Gofa, A. Corigliano (2013):
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No. 23: M. Baldauf, O. Fuhrer, M. J. Kurowski, G. de Morsier, M. Müllner, Z. P. Piotrowski, B. Rosa, P. L. Vitagliano, D. Wójcik, M. Ziemiański (2013):
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No. 24: A. K. Miltenberger, A. Roches, S. Pfahl, H. Wernli (2014):
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No. 25: P. Khain, I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini (2015):
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No. 26: D. Mironov, E. Machulskaya, B. Szintai, M. Raschendorfer, V. Perov, M. Chumakov, E. Avgoustoglou (2015):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_28

No. 29: M. Tsyrulnikov and D. Gayfulin (2016):
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No. 30: D. Mironov and E. Machulskaya (2017):
A Turbulence Kinetic Energy – Scalar Variance Turbulence Parameterization Scheme.
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_32

No. 33: N. Vela (2017):
VAST 2.0 - User Manual.
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No. 39: C. Marsigli, D. Alferov, E. Astakhova, G. Duniec, D. Gayfulin, C. Gebhardt, W. Interewicz, N. Loglisci, F. Marcucci, A. Mazur, A. Montani, M. Tsyrulnikov, A. Walser

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No. 41: X. Lapillonne, O. Fuhrer (2020):
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No. 43: H. Muskatel, U. Blahak, P. Khain, A. Shtivelman, M. Raschendorfer, M. Kohler, D. Rieger, O. Fuhrer, X. Lapillonne, G. Rivin, N. Chubarova, M. Shatunova, A. Poliukhov, A. Kirsanov, T. Andreadis, S. Gruber (2021):
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COSMO Technical Reports

Issues of the COSMO Technical Reports series are published by the *COnsortium for Small-scale MOdelling* at non-regular intervals. COSMO is a European group for numerical weather prediction with participating meteorological services from Germany (DWD, AWGeophys), Greece (HNMS), Italy (USAM, ARPA-SIMC, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA) and Russia (RHM). The general goal is to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO. This system is initially based on the COSMO-Model (previously known as LM) of DWD with its corresponding data assimilation system.

The Technical Reports are intended

- for scientific contributions and a documentation of research activities,
- to present and discuss results obtained from the model system,
- to present and discuss verification results and interpretation methods,
- for a documentation of technical changes to the model system,
- to give an overview of new components of the model system.

The purpose of these reports is to communicate results, changes and progress related to the LM model system relatively fast within the COSMO consortium, and also to inform other NWP groups on our current research activities. In this way the discussion on a specific topic can be stimulated at an early stage. In order to publish a report very soon after the completion of the manuscript, we have decided to omit a thorough reviewing procedure and only a rough check is done by the editors and a third reviewer. We apologize for typographical and other errors or inconsistencies which may still be present.

At present, the Technical Reports are available for download from the COSMO web site (www.cosmo-model.org). If required, the member meteorological centres can produce hard-copies by their own for distribution within their service. All members of the consortium will be informed about new issues by email.

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