Sensitivity Experiments with the Runge Kutta Time Integration Scheme

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1 Introduction

The new dynamical core developed in LM (Förstner and Doms, 2004) is based on a TVD variant of 3rd-order Runge Kutta time integration scheme (RK) using a 5th-order spatial discretization of advection. The RK dynamical core should be more accurate than the standard Leap-Frog / 2nd-order advection scheme (LF) and it will be used for very detailed short range forecasts. The RK core needs to be tested and evaluated intensely, before it can be operationally implemented. This work aims to objectively evaluate the current version of the RK dynamics (LM 3.16+) through a comparison to the LF core and some sensitivity experiments in the period 24-28 March 2005. The LM configuration used in these experiments is shown in Tab. 1. The prognostic TKE turbulent scheme, the prognostic precipitation scheme, the new option of the upper level Rayleigh damping and a 72 s time step (40 s for LF runs) are used in the RK runs. IFS fields were used as initial and boundary conditions. The LM forecast fields were objectively evaluated through comparisons with radiosonde and conventional surface observations. Mean error (ME or bias) and root mean square error (RMSE) vertical profiles are computed for temperature and wind. Surface parameters, such as two meter temperature (2T), two meter dew point (2TD), ten meter wind speed (10U), mean sea level pressure (MSLP) and 6h accumulated total precipitation larger than 2 mm (6TP_2) are verified for Synop stations satisfying the COSMO WG5 specification ($|H_s - H_n| < 100m$), where H_s is the station height and H_n is the height of nearest land grid point). About 3500 forecast-observation pairs are used to calculate the ME and RMSE of the surface variables forecast. They are considered enough to make statistical comparison between different configurations of LM.

Table 1: **LM Configuration (Version 3.16+)**

Domain Size	465 × 385 grid points (EuroLM)
Horizontal Grid Spacing	0.0625° ($\sim 7\ km$)
Number of Layers	35
Time Step and Integration Scheme	72 s (RK) — 40 s (LF)
Forecast Range	24 h
Initial Time of Model Runs	00 UTC
Lateral Boundary and Initial Conditions	from IFS
L.B.C. update frequency	3 h
Orography:	filtered (eps=0.1)
Turbulence parameterization	prognostic TKE

2 LF and RK runs with the prognostic TKE turbulence scheme

Temperature and wind ME and RMSE vertical profiles for T+24 h forecast are shown in Fig. 1 for RK (red lines) and LF (blue lines) runs. The RK temperature RMSE is slightly

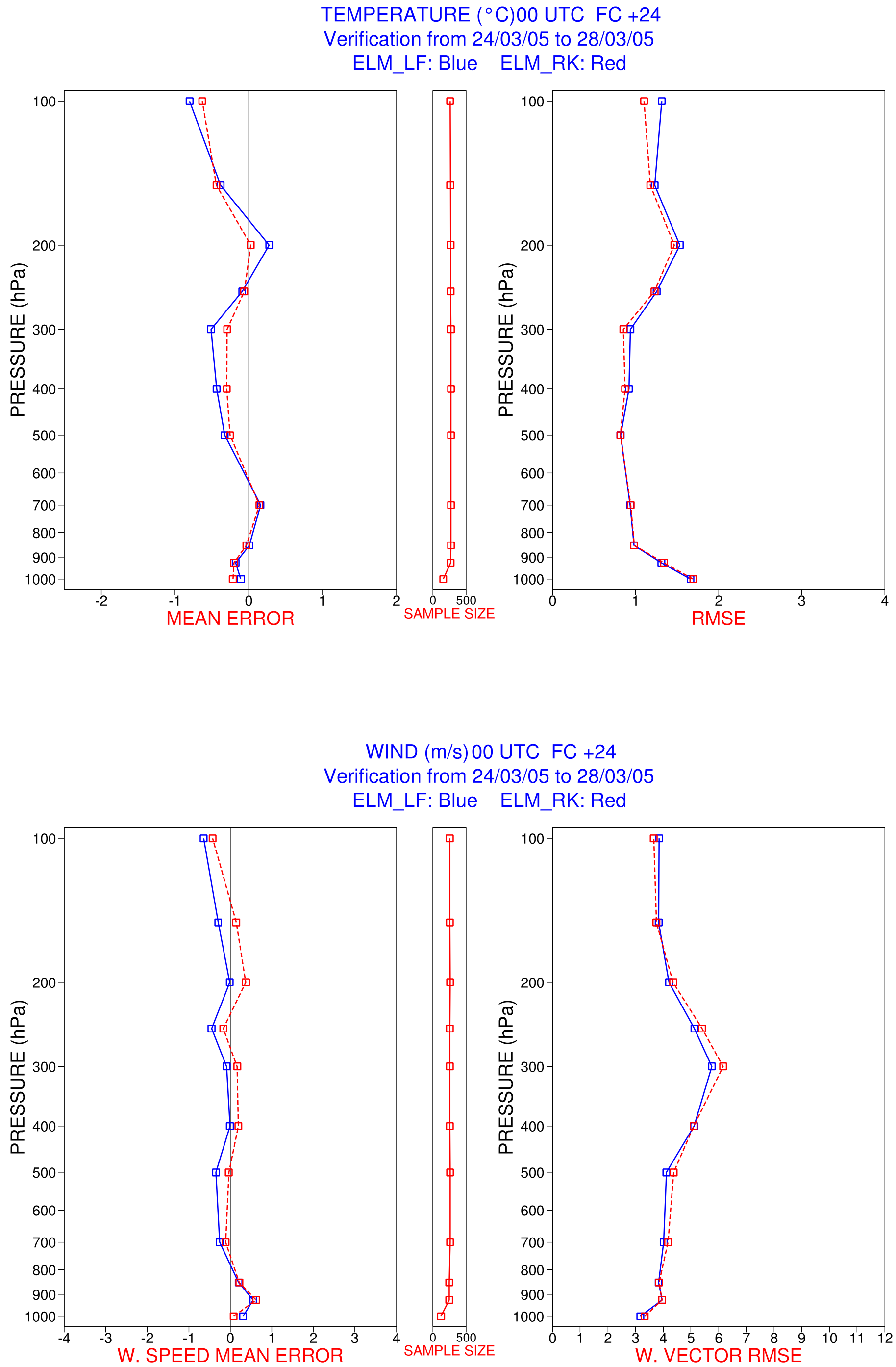


Figure 1: LF and RK runs with prognostic TKE turbulence: temperature mean error and root mean square error vertical profiles of 24 h forecast; wind speed mean error and wind vector root mean square error vertical profiles of 24 h forecast. (2 files: *024*lf-rk.ps)

smaller than the LF one above 500 hPa, while the RK wind vector RMSE is larger than the LF one at almost all levels. The interpretation of these results has to be done with caution, because of the small number of observation-forecast pairs used. 2T, 2TD, 10U, MSLP bias and RMSE (and standard deviation - STDV for MSLP) as a function of the forecast time are shown in the Fig. 2 for RK and LF runs. Frequency bias index (FBI) and threat score (TS) for 6TP_2 are also computed (Fig. 2). A very slight worsening is found in RK forecasts for 2TD, 10U and 6TP_2 (no significant difference in 2T). The RK MSLP bias is larger than the LF one leading to a worsening in MSLP forecast skill of the RK dynamics. This large difference in the MSLP bias is the most important result of the LF-RK comparison.

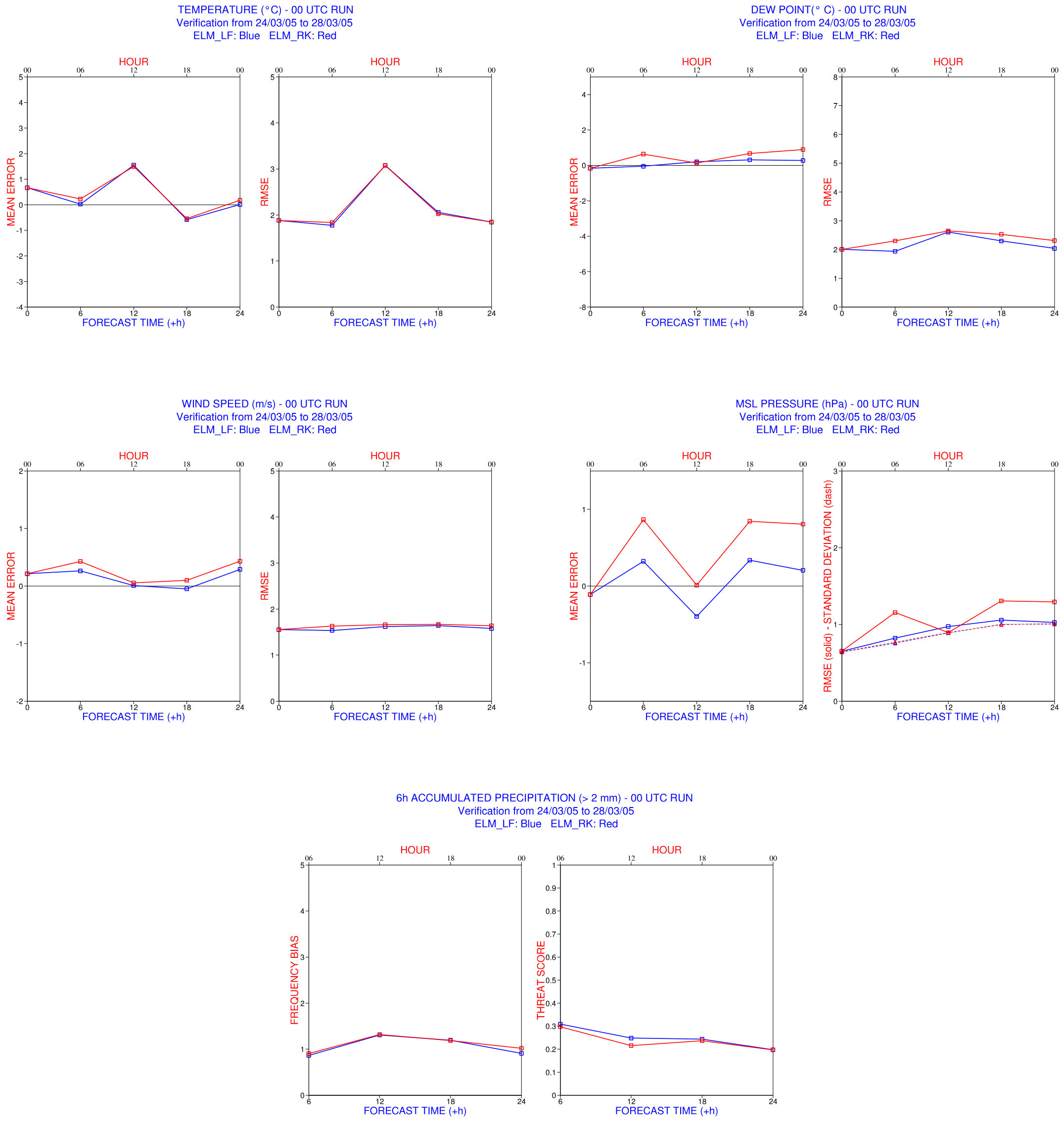


Figure 2: LF and RK runs with prognostic TKE turbulence: mean error and root mean square error of two meter temperature, two meter dew point, ten meter wind speed and mean sea level pressure (also standard deviation for MSLP); frequency bias index and threat score of 6h accumulated total precipitation larger than 2 mm.

3 Sensitivity experiments

The sensitivity of RK dynamics to the integration time step, the interval between two calls of (convection, turbulence) parameterization, the turbulence scheme, the domain size and moisture variables advection scheme is also investigated. Verification plots are shown if significant differences are found.

3.1 Integration time step

RK and LF runs use different time steps (72 and 40 s respectively) that determine a different time interval between two calls of physics. In this experiment the RK runs are performed with the same time step of the LF one, in order to exclude the difference in the parameterizations calling frequency as a possible cause of the LF-RK difference in the forecast skill (MSLP deficiency in RK). Mean sea level pressure ME, RMSE and STDV as a function of the forecast step are shown in Fig. 3 for RK runs with 40 s (red lines) and 72 s (blue lines) time step. RK forecasts with 40 s time step have a slightly smaller MSLP bias than that of RK forecasts with 72 s time step (except for 12h forecast). This result seems to be due to the higher accuracy associated with the smaller time step.

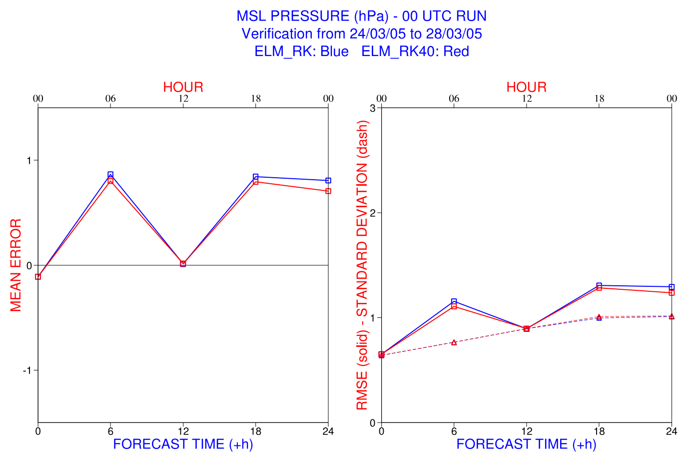


Figure 3: Mean error, root mean square error and standard deviation of mean sea level pressure for RK and 40s RK runs.

3.2 Parameterizations calling frequency

To totally exclude the influence of the interval between two calls of parameterization schemes on the MSLP deficiency in RK runs, other two experiments are useful. One experiment is to decrease the convection calling frequency nincconv from 10 (default for previous experiments) to 5. The other experiment is to increase the interval between two calls of the prognostic TKE turbulence scheme `ninctura` from 1 (default for previous experiments) to 2. In both experiments no significant difference is found from the reference RK runs.

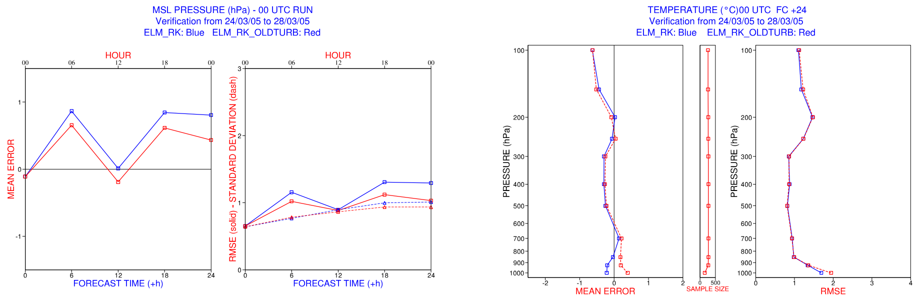


Figure 4: RK runs with diagnostic and prognostic TKE turbulence: mean error, root mean square error and standard deviation of mean sea level pressure; temperature mean error and root mean square error vertical profiles of 24 h forecast.

3.3 Turbulence scheme

The sensitivity of the RK core to the two turbulent schemes implemented in the LM, the prognostic (`itype_turb=3, imode_turb=1, itype_tran=2`) and the diagnostic (`itype_turb=1, imode_turb=0, itype_tran=1`) TKE, is also investigated. Mean sea level pressure ME, RMSE and STDV as a function of the forecast step are shown in Fig. 4 for RK forecasts with diagnostic (red lines) and prognostic (blue lines) TKE turbulence scheme. Temperature ME and RMSE vertical profiles for 24 h forecast are also computed (Fig. 4). RK dynamics with the old turbulence scheme performs better for MSLP forecast (smaller bias and standard deviation) than RK dynamics with the prognostic TKE turbulence parameterization. On the other hand, 2T and 2TD of RK runs with the prognostic TKE turbulence scheme seem to have a slightly better skill (not shown). The reduction of the positive MSLP bias seems to be related to the low level positive temperature bias of RK with old turbulence scheme. The different temperature bias behaviour may be due to the different surface layer formulation associated with each turbulence scheme. The TKE prognostic scheme seems to be one of the possible candidates to justify the MSLP deficiency in RK runs, but a large positive MSLP bias is still present in RK forecasts with the old turbulence scheme. This result is an indication that more work is needed to tune the turbulence parameterization schemes (surface layer, exchange coefficients, etc.) and to improve the dynamics and physics coupling.

3.4 Domain size

The impact of the domain size on LM forecast was evaluated in Torrisi (2005) using the LF core. A similar experiment (much shorter period) is also performed for the RK dynamics using EuroLM and LAMI (smaller) domain. Mean sea level pressure ME, RMSE and STDV as a function of the forecast step are shown in Fig. 5 for LAMI (red lines) and EuroLM (blue lines) domain. The enlargement of the domain size has a positive impact (smaller bias and standard deviation) on the MSLP forecast, as found for LF in Torrisi (2005). This could be related to the improvement of the intrinsic variability of the numerical model associated with the enlargement of the domain, since the boundary conditions fields are slightly affecting the forecast.

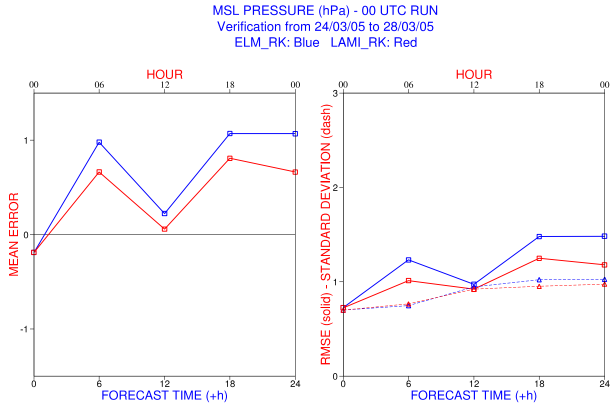


Figure 5: Mean error, root mean square error and standard deviation of mean sea level pressure for LAMI and EuroLM domain.

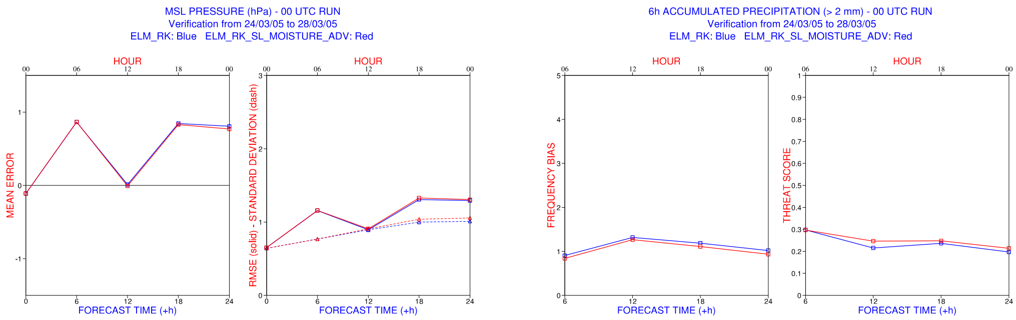
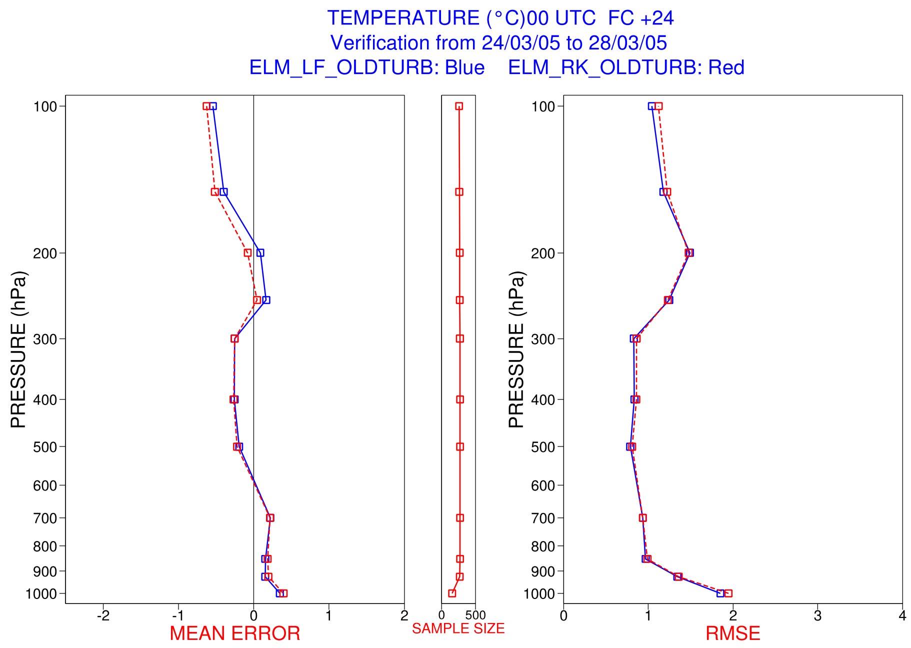


Figure 6: RK runs with eulerian and semi-lagrangian formulation of the moisture variables advection: mean error, root mean square error and standard deviation of mean sea level pressure; frequency bias index and threat score of 6h accumulated total precipitation larger than 2 mm.

3.5 Moisture variables transport scheme

All the RK experiments were performed using the eulerian formulation of the moisture variables advection scheme. In this experiment the semi-lagrangian formulation (SL) is compared to the eulerian one (EU). MSLP ME, RMSE and STDV as a function of the forecast step are shown in Fig. 6 for the SL (red lines) and the EU (blue lines) runs. 6TP_2 FBI and TS are also computed (Fig. 6). The semi-lagrangian moisture variables advection scheme does not show any significant difference in MSLP forecast compared to the eulerian version (slightly larger standard deviation after 18h forecast balanced by a slightly smaller bias), but SL forecasts seem to have a slightly better skill for 6h accumulated precipitation (slightly larger TS) and 2m dew point (not shown).



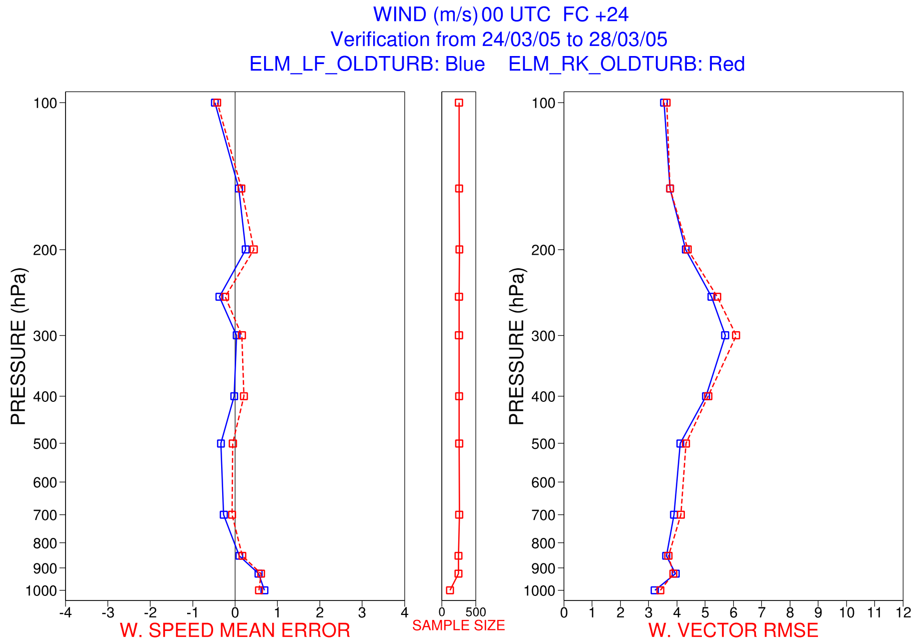


Figure 7: LF and RK runs with diagnostic TKE turbulence: temperature mean error and root mean square error vertical profiles of 24 h forecasts; wind speed mean error and wind vector root mean square error vertical profiles of 24 h forecast.

4 LF and RK with the diagnostic TKE turbulence scheme

Temperature and wind ME and RMSE vertical profiles for 24 h forecast are shown in Fig. 7 for the RK (red lines) and LF (blue lines) runs. The RK wind vector RMSE is larger than the LF one at almost all levels, while the RK and LF temperature RMSE have no significant differences. 2T, 2TD, 10U, MSLP bias and RMSE (also STDV for MSLP) as a function of the forecast time are represented in the Fig. 8 for RK (red lines) and LF (blue lines) runs. 6TP_2 FBI and TS are also computed (Fig. 8). A very slight improvement is found in RK forecast skill for 2T (18h and 24h forecast) and 2TD (6h and 24h forecast), while a slight worsening is found for 6TP_2 (18h and 24h forecast). A positive MSLP bias (except for 12h forecast) is found in RK forecasts, but the RK-LF MSLP bias difference found using the prognostic TKE turbulence scheme, even if shifted and slightly reduced, is still present. On the other hand, RK forecasts have a slightly smaller MSLP standard deviation than LF ones.

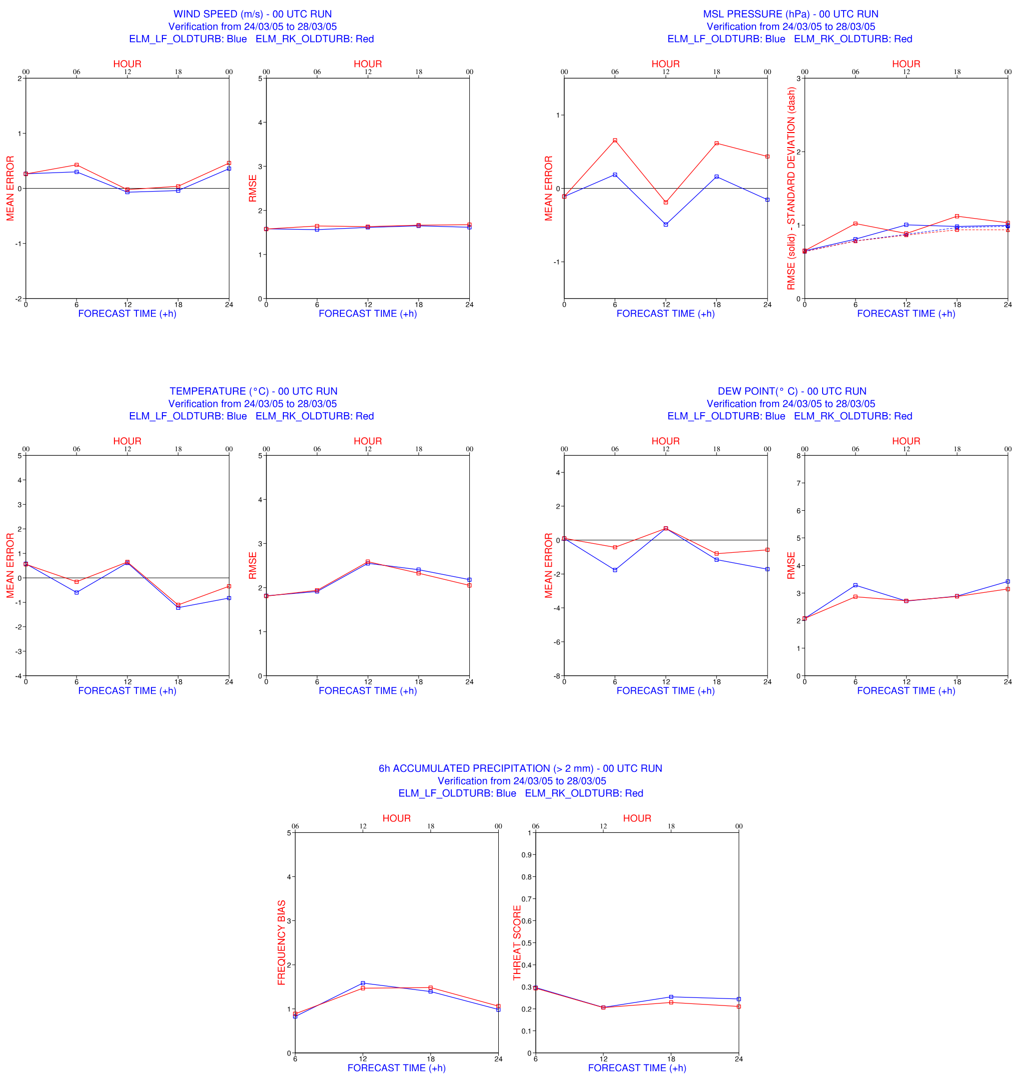


Figure 8: LF and RK runs with diagnostic TKE turbulence: mean error and root mean square error of two meter temperature, two meter dew point, ten meter wind speed, mean sea level pressure (also standard deviation for MSLP); frequency bias index and threat score of 6h accumulated total precipitation larger than 2 mm.

5 Summary and conclusions

The comparison of LF and RK dynamical cores was performed for a 5 days period using the EuroLM configuration. Statistical verification results showed that RK performance for surface variables was slightly better than LF one. A large positive MSLP bias was typical of the RK runs. Some sensitivity studies were performed on RK to determine the cause of the RK-LF differences. RK did not show any sensitive to the calls of the prognostic TKE turbulence and convection schemes. An improvement in the MSLP forecast skill was obtained using the diagnostic TKE turbulent scheme, but a positive bias (slightly reduced) was found again. The domain size sensitivity experiment showed similar results to those found in a previous work with LF core. The moisture variables transport experiment showed that semi-lagrangian version has a slightly better skill for precipitation than the eulerian one. Longer periods of investigations in different seasons are necessary to substantiate that the MSLP forecast deficiency found in RK runs is a real problem, but there are indications that more work is needed to tune the turbulence parameterization schemes and to improve the dynamics and physics coupling in the RK core.

References

Förstner, 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, 168-176.

Torrisi, L., 2005: Impact of the domain size on LM forecast. *COSMO Newsletter*, No. 5, 145-148.