Performance of Kain-Fritsch/Rasch-Kristjansson in Hirlam. A review

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1 Introduction

Different studies about the performance of a new moist physics package in Hirlam have been carried out over the last years. The package includes three new components for Hirlam: Kain-Fritsch (KF) convection, Rasch-Kristjansson (RK) large scale condensation and microphysics and a diagnostic cloud fraction scheme. The new scheme is included in the Hirlam reference system as an option since September 2004. The aim of this paper is summarizing the main findings of these studies. The results of the new scheme (hereafter, KFRK) are compared with observations and with the results obtained using the reference moist physics scheme.

2 The reference scheme

The reference scheme in Hirlam, known as STRACO, is described in Sass (2002). Convection is of Kuo type and microphysics follows Sundqvist ideas. The scheme tries to accomplish smooth transitions between convective and large scale regimes, includes some treatment of shallow convection and sets some resolution depending tuning. Most current Hirlam components have been developed using this scheme and it is the scheme used in most Hirlam operational implementations.

3 Components of the new moist package

(a) Kain-Fritsch convection

The scheme is described by Kain and Fristch (1990, 1993). It has been mostly developed and used within the MM5 community. Many studies have shown that KF is specially suitable for mesoscale middle-latitude simulations (10-30 km resolution) including severe weather phenomena. There is a long operational experience using the scheme over the USA (MM5, Eta model and WRF model).

There is a completely recoded version of KF (Bechtold et al, 2001) which has been extensively tested in the Météo-France research model MesoNH, giving realistic systems from synoptic scales to Cloud Resolving Model (CRM) scales. In Météo-France operational models, ARPEGE-ALADIN, this scheme has not been able to improve the reference convection (Bougeault, 1985).

In Hirlam we use a version close to the Eta model KF convection. The main differences concern the treatment of shallow convection with a Turbulent Kinetic Energy (TKE) closure. It was implemented by C. Jones using J. Kain's code. Some of the updates to KF described by Kain (2004) are not included in the Hirlam implementation.

(b) Rasch-Kristjansson large scale condensation and microphysics

The Hirlam implementation by Ødegaard (1998) is based on the Community Atmospheric Model (CAM) code as described by Rasch and Kristjánsson (1998) with some tuning modifications. A slightly different code is currently used in the CAM model (Zang et al, 2003).

(c) Diagnostic cloud fraction

Large scale clouds basically depend on relative humidity (RH) loosely following Slingo (1987). Marine stratocumulus (Sc) also depend on static stability. Convective clouds are function of the parameterized mass-flux following Xu and Krueger (1991). A treatment for the 'passive clouds' associated with shallow convection is include as described by Jones and Sánchez (2002): they depend on resolved RH and cumulus (Cu) cloud water vapor and condensate. There is memory of shallow clouds (they may prevail the active clouds) and they may generate precipitation through large scale microphysics.

4 Single Column Model cases studies from the EUROCS project

The aim of EUROCS project was to improve the representation of clouds in climate and weather prediction models. It tried to cure systematic errors in the models by designing idealized cases based on observations, by comparing Single Column Models (SCM) and Cloud Resolving Models (CRM), and by evaluation of the developments in the complete models. A special issue with the main findings of the project has been published in the *Q. J. R. Meteorol. Soc* (October 2004 Part C)

(a)Diurnal cycle of Stratocumulus over ocean

Stratacumulus (Sc) clouds are not represented correctly in climate and weather prediction models. Over tropical oceans, cloud cover and liquid water path (LWP) associated with these clouds are greatly underestimated which leads to a significant understimation of the short-range radiation reaching the ground. A EUROCS case was design to address this problem (Duynkerke et al, 2004). SCM tended to produce too thin clouds and with cloud tops lower than observations and Large Eddy Simulation models (LES). Cloud top entrainment was a key issue to represent correctly these clouds. Within this EUROCS exercise, the implementation of more sophisticated turbulence schemes has been able to improve the results significantly. Hirlam showed similar results with KFRK and STRACO: lack or insufficient cloud top entrainment, drizzle acting to control liquid water and significant sensitivity to microphysics. The results improve significantly using a moist conservative turbulence scheme, explicit parameterization of cloud top entrainment and higher vertical resolution (Jones, 2004).

(b)Diurnal cycle of shallow cumulus over land

Over land, shallow cumulus (Cu) greatly modify the radiation reaching the ground and play an important role preconditioning deep convection. A non-stationary case was designed to improve the parameterization of shallow Cu (Lenderink et al, 2004). Most common deficiencies in SCM are: too large values of cloud cover and LWP, unrealistic thermodynamical profiles and results too noisy. In Hirlam, the discrimination between shallow Cu and Sc seemed to be a problem which also happens in 3D simulations. For this case, the mass-flux approach (KF) describes better the growth and daily evolution of the clouds. An important improvement was achieved for KFRK including the 'passive clouds' associated with shallow Cu (Jones and Sánchez, 2002): these may reach 30 % cloud cover in contrast with 5 % of active clouds.

(c)Diurnal cycle of deep convection over land

An idealized case was defined to address a common failure in the representation of the diurnal cycle of precipitation by atmospheric models: a tendency to produce precipitation too early in the day. The case was able to reproduce the problem (Guichard et al, 2004). In contrast with CRM simulations, SCM onset convection too early, they were not able to simulate the progressive growth of the clouds and tended to produce a too moist boundary layer when downdrafts start. Compared with other SCM, Hirlam-KF did a reasonably good job, delaying the precipitation to noon and not producing a too moist boundary layer when downdrafts are onset.

5 Representation of the Hadley Circulation

This EUROCS intercomparison tried to assess the representation of clouds in climate and weather prediction models (Siebesma et al, 2004). Monthly means of model results along a trajectory over the Pacific were compared with satellite observations. Along this path, Sc, shallow Cu and deep Cu occur in a persistent and geographically separated manner. Most models strongly underpredict cloud clover and LWP in the Sc regions but ovepredict them over the shallow Cu regions. Both Hirlam configurations, KFRK and STRACO, showed this behavior. Also, both schemes tended to produce too much light precipitation in the Sc and shallow Cu regions, a problem already noted in the SCM case studies. Discrimination between Sc and shallow Cu also seems to be a problem. The Intertropical Convergence Zone (ITCZ) was correctly located but convective clouds were underestimated. Over the ITCZ, STRACO as most models, tended to overestimate significantly the precipitation whereas KFRK gave values closer to observations.

6 A typhoon case study (COMPARE III)

An intercomparison exercise (Nagata et al, 2001) was established to assess the ability of weather prediction models to represent the explosive intensification of a typhoon (100 hPa in 3 days). The track prediction was relatively well predicted by the models giving the proper initial conditions but the intensity prediction seemed to remain been a difficult task. The increase of horizontal resolution was crucial to improve the intensity prediction. For Hirlam significant differences were found using STRACO and KFRK. Whereas the reference produces almost no deepening of the cyclone, even increasing the resolution, KFRK was able to reproduce qualitatively the intensification although greatly underestimating it. There are many ingredients contributing to the deepening as the partition between shallow and deep convection in the surroundings of the cyclone core or the surface flux formulation. In Hirlam a very important aspect is the partition between convective and large scale (explicit) condensation. Due to the strong rotation, we have slantwise convection in the core region. As slantwise convection is not explicitly parameterized, the model tends to treat it triggering the explicit condensation. However, this is not the case for STRACO where the precipitation is mostly convective in the cyclone core.

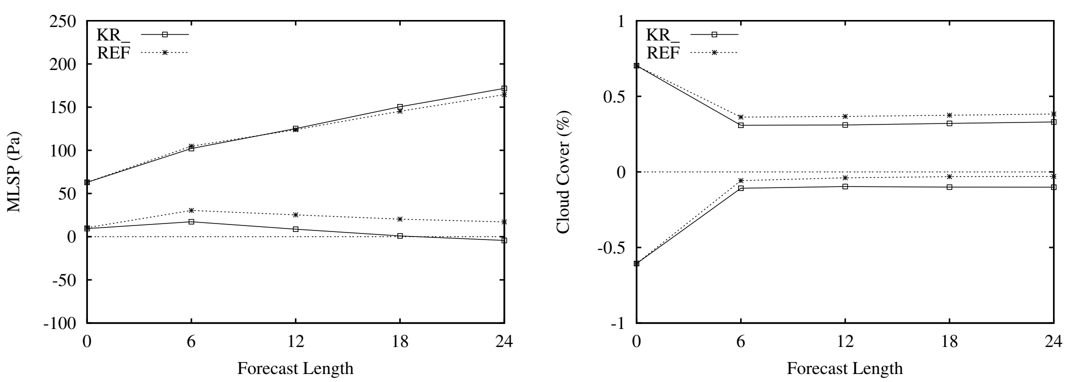

Figure 1: *Objective verification against EWGLAM observations: RMSE and Bias of (a) Mean Sea Level Pressure, (b) cloud cover. REF/dash means reference STRACO and KR_/solid means KF/RK*

7 Case studies and parallel runs

Early studies comparing the new KFRK scheme with reference STRACO scheme, Finkele (2001), McGraph and Finkele (2001), Niemelä and Fortelius (2002), have shown little impact of the new scheme in terms of objective synoptic scores but more realistic simulation of cloud systems as seen by subjective evaluation. In a recent study by Calvo (2004) comparing an updated version of KFRK with reference STRACO for a period of three months over different seasons (see fig. 1 and 2), it was seen that the new scheme systematically improves the humidity profiles which leads to a better representation of the cloud cover. A slight deterioration of the mean sea level pressure field, probably due to tendency to deep too much the low pressure systems, is found in most studies. From the precipitation verification we have not seen big differences between the schemes except over Iberia where the new scheme improves the precipitation forecasts. This is probably related to the bigger contribution of convective regimes in this area. Besides, the new scheme tends to produce too much light precipitation (less than 1 mm/day). Concerning the computer cost, the KFRK forecast takes 10-20 % than the reference STRACO one. On vector computers the cost is higher and a vectorization is under way.

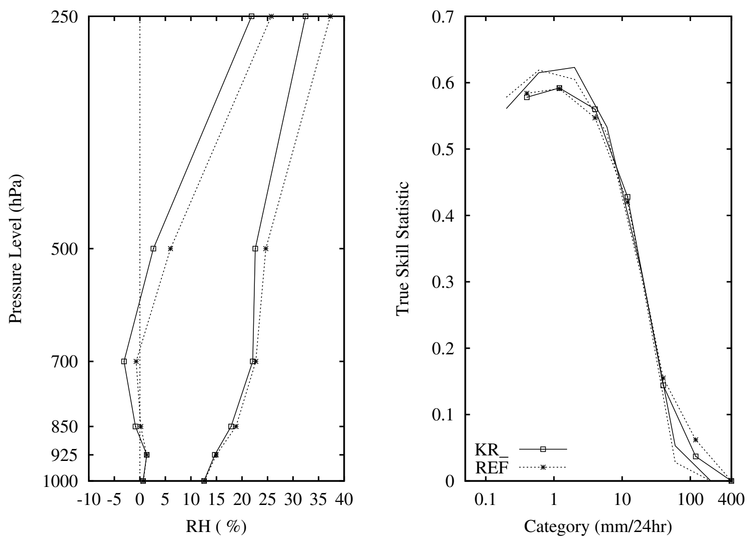

Figure 2: *Objective verification against EWGLAM observations: (a) RMSE and Bias of RH, (b) True Skill Score of precipitation for observations accumulated in 6 and 12 hr. REF/dash means reference STRACO and KR_/solid means KF/RK*

8 Results from other studies

In a reanalysis exercise for one year, Fortelius et al (2002) showed that Hirlam-KFRK was capable of simulating the essential features of the energy and water cycle over the catchment area of the Baltic sea. This moist physics package is also used in a climate modelling version of Hirlam model (Rossby Center Atmospheric Climate Model). Jones et al (2004) showed that the model was able to simulate the recent climate and variability over Europe with a high degree of realism. In the Swedish Meteorological Institute (SMHI), Hirlam-KFRK at resolutions of 0.20 and 0.10 degrees is used for operational weather prediction. Duty forecasters seem to be very satisfied with the results (K.-I. Ivarsson, personal communication).

9 Conclusions and perspectives

A new moist physics scheme (KFRK) based on Kain-Fritsch convection and Rasch-Kristjansson large scale condensation scheme has been implemented in Hirlam. Here we have summarized the main findings of several studies from Hirlam researchers using this moist package. The system is able to produce realistic cloud systems and water cycle. The results have been compared with observations and with results using the reference STRACO scheme. It seems that the new scheme is able to improve the results in terms of humidity and cloud cover. An improvement in the precipitation forecast is found over the southern part of Europe (Iberia). The new scheme deteriorates slightly the mean sea level pressure field and the forecast takes 10-20 % more computer time than the reference system.

Now research focuses on improving the cloud fraction formulation: turbulence in moist conservative variables and statistical cloud scheme, controlling the over-prediction of light precipitation, and implementing more sophisticated microphysics: more cloud water species and more complex microphysics. Also we are optimizing the code for vector computers.

Acknowledgments. The KF convection was implemented in Hirlam by C. Jones for the RCA model based on J. Kain's code. RK was introduced by V. Odegard based on CAM's code. The operational experience at SMHI has been reported by K.-I. Ivarsson. The EUROCS project was partly funded by the European Commission.

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