# Experiences with a statistical cloud scheme in combination with Kain-Fritsch convection in Hirlam

Wim de Rooy

KNMI, De Bilt, The Netherlands

## Introduction

The goal of this project is to develop a new statistical cloud scheme for Hirlam, keeping in mind the use of it in a very high-resolution, possibly non-hydrostatic, model. Using the ideas of Lenderink and Siebesma (2000), we want to couple the cloud scheme not only to a turbulence scheme but also to a mass flux convection scheme.

## Fundamentals of a statistical cloud scheme

Temperature ($\overline{T}$) and total specific humidity ($\overline{q_t}$) from a NWP model represents the grid box average values (denoted with an overbar). In reality T and $q_t$ can vary within the grid-box, with possibly saturated areas although the mean state might be unsaturated. Instead of using T and $q_t$ it is convenient to go over to one variable, the distance to the saturation curve:

$$s \equiv q_t - q_{sat}(p,T) \qquad (1)$$

The temperature information is now included in the temperature dependence of the saturation specific humidity, $q_{sat}$. Variable s is subsequently normalized by the standard deviation (SD) in s, $\sigma_s$:

$$t \equiv \frac{s}{\sigma_s} \qquad (2)$$

If we assume a certain probability density function (PDF) of t in the grid-box we can calculate the fractional cloud cover and liquid water content. For example, for cloud cover, the integral of the PDF over all positive values of t results in the cloud cover as a function of just one variable, $\bar{t}$, which is simply given by the grid-box model output. Similarly, the liquid water content can be determined. The main challenge for the development of a statistical cloud scheme is to get reasonable estimates of $\sigma_s$ (or the variance in s, $\sigma_s^{\;2} \cong \overline{q_t^{'2}}$ (for simplicity we neglect the temperature terms in the variance)).

How can this variance be parameterized?
After a few approximations (e.g. steady state) the budget equation for humidity variance, can be written as a balance between variance production (left hand side) and variance dissipation (right hand side):

$$\overline{w^{'}q^{'}}\frac{\partial q_t}{\partial z} = \tau^{-1}\overline{q_t^{'2}} \qquad (3)$$

In a mass flux convection scheme the turbulent flux, $\overline{w^{'}q^{'}}$, on the left hand side can be written as: $\overline{w^{'}q^{'}} = M(q_t^u - q_t)$, where M is the mass flux and $q_t^u$ is the total specific humidity in the updraft. The dissipation time scale, $\tau$, can be written as: $\tau = \frac{l_{cloud}}{w_*^{cu}}$, where $l_{cloud}$ is the depth of the cloud and $w_*^{cu}$ is a convective velocity scale. In this way, we come to a parameterization, first mentioned by Lenderink and Siebesma (2000), which link the convective activity with the humidity variance $\overline{q'^2}$.

In most statistical cloud schemes, the turbulent flux and dissipation time scale in (3) are taken solely from the turbulence scheme. This leads to a parameterization like:

$\overline{q_t'^2} \cong l_{turb}^2 (\frac{\partial q_t}{\partial z})$, where $l_{turb}$ is a turbulence length scale. For example in Chaboureau and Bechtold (2002) $l_{turb}$ is taken as 0.2·z up to 900m, and 180 above 900m (so even in the free troposphere where there is almost no turbulent or convective activity!). They fitted the length scale to two cases with convective activity so their length scale also includes the effect of convective activity. For the case that we used (BOMEX), this length scale is much too large, leading to too high variance values, even when we skip the parameterization of the variance due to the convection,. The opposite is true if we take the stability dependent length scale from the turbulence scheme itself, as implemented by Colin Jones. Now the variance contribution due to turbulence is insignificantly small. So it is not yet clear how to deal with $l_{turb}$. Note that also in layers without turbulent or convective activity, we need some variance to get reasonable cloud cover with a statistical cloud scheme.

## Experiments

The set-up of this project is to start simple, with 1D experiments (starting with BOMEX, a shallow cumulus case), just looking at the cloud cover diagnosed from the statistical cloud scheme without any feedbacks to e.g. radiation. The idea is to couple the variance for the statistical cloud scheme to the turbulence scheme (in the results presented here we used $l_{turb}$=40 (as implemented in the NOGAPS model by Pier Siebesma), and the Hirlam mass flux convection scheme, Kain-Fritsch (KF).

Apart from the complex, difficult to understand Hirlam KF code, we experienced many problems when using this convection scheme for the BOMEX case. Some of these problems are:

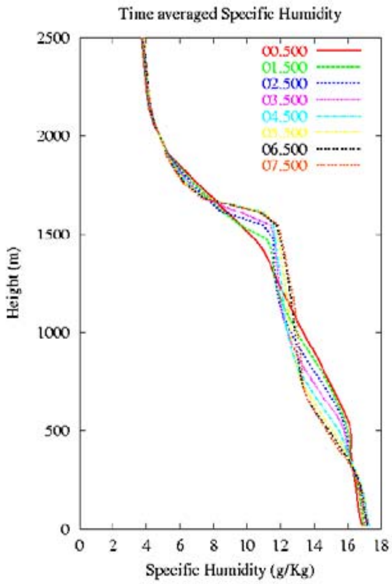
- Intermittent character (on/off, and sometimes deep convection)
- The updraft (virtual) temperature results in a negative buoyant cloud (and consequently a negative variance)
- An artificially looking closure for shallow convection
- The mass flux does not decrease enough with height leading to much too high variances in the upper part of the cloud.

Besides this, the results of the standard KF scheme were unsatisfactory for the BOMEX case with non-steady q and q profiles (note that observations show app. constant profiles), reflecting the too active convection (see Fig.1 for the q profile at different forecast times).

To avoid the above-mentioned problems, we made several changes to the KF scheme. Some of the most important changes are:

- Fractional entrainment and detrainment rates for shallow convection according to Siebesma et al. (2003).
- A vertical velocity equation according to Gregory (2001) resulting in an increase in the depth of convection.
- A closure for shallow convection according to Grant (2001), which makes the timescale plus some other (tunable) parameters redundant.

After these adaptations the mass flux, θ, and q profiles improved considerably (now almost steady, see Fig. 2 for the q profile).



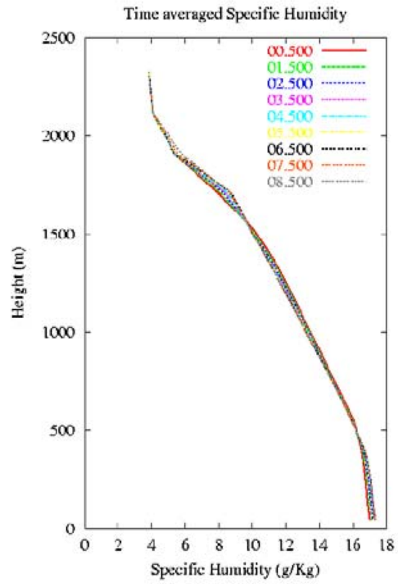
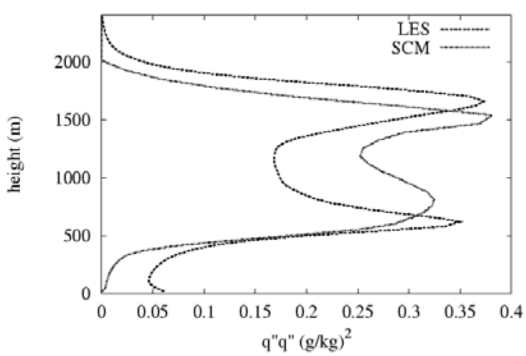




*Fig. 1 (left panel) The specific humidity vertical profiles for the BOMEX case running the standard Hirlam 1D model. The different colors represent different forecast periods, e.g. green (1.5) is the output averaged over the +1 to +2h forecasts. Note that for this case the profiles should be steady.*
*Fig.2 (right panel) As Fig. 1 but with the modified convection scheme (as mentioned in the text)*

With the modified KF scheme, also variance profiles are now in reasonable agreement with LES results, especially considering the relatively coarse vertical resolution of the 1D model (40 layers), showing a double peak at cloud base and top (see Fig. 3)



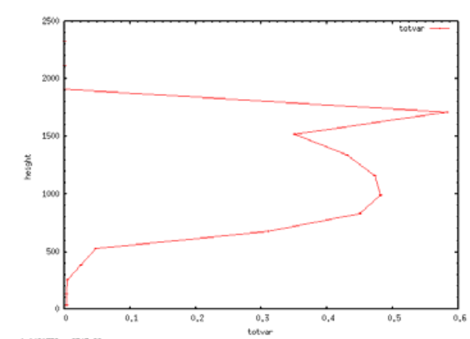




*Fig. 3 (left panel) Vertical profiles of the humidity variance for the BOMEX case running an LES model and a very high-resolution (40m) 1D model (from Lenderink and Siebesma 2000). Fig.4 (right panel) As Fig.3 but with Hirlam 1D, 40 layers in the vertical, with the modified convection scheme (as mentioned in the text). Note that the x-axis maximum is now 0.6 instead of 0.4.*

Finally, the cloud cover, calculated as a function of the normalized saturation deficit following Cuijpers and Bechtold (1995), nicely resembles observations with maximum values at cloud base height of about 5% (not shown)

So with the above mentioned adaptations, good results with the convection and the statistical cloud scheme are obtained for BOMEX. However, all possible situations should be covered (also deep convection, precipitation etc.). Building a new scheme from scratch would take too much time, just like rebuilding the KF code. Therefore, we considered two alternative convection schemes, namely the ECMWF and the Meso-NH scheme. Peter Bechtold is the developer of the Meso-Nh scheme and is now working on the further development of the ECMWF scheme, so he is a pre-eminently suitable advisor. Peter suggests using the ECMWF convection scheme because this code is faster, gives better results and there will be continuous research for improvements. The use of the ECMWF scheme will also facilitate the synergy within KNMI (between Hirlam and the climate research department) at the area of convection and cloud schemes.

There is however a big minus, someone has to implement this convection scheme in the Hirlam code. Although giving more work than expected, the ECMWF (28r1 version) is now implemented in Hirlam 1D. For Bomex, good results are obtained except from the deep convection, which sometimes occurs after a few hours of simulation. This aspect still has to be investigated but we are probably quite close to a proper implementation. Hereafter, more tests (1D and 3D) with the ECMWF convection scheme in combination with a statistical cloud scheme will be done.

### Acknowledgements
Sander Tijm is thanked for his help with the Hirlam Kain-Fritsch code. Pier Siebesma and Geert Lenderink are thanked for useful discussions and advice.

### References:
Chaboureau, J.-P., P. Bechtold, 2002: A Simple Cloud Parameterization Derived from Cloud Resolving Model Data: Diagnostic and Prognostic Applications. *J. Atmos. Sci.,* **59**, 2362-2372

Cuijpers, J.W.M., and P. Bechtold, 1995: A simple parameterization of cloud water related variables for use in boundary layer models. *J. Atmos. Sci.,* **52**, 2486-2490

Kain, J.S., and J.M. Fritsch, 1990: A one-dimensional entraining/detraining plume model and its application in convective parameterization. *J. Atmos. Sci.,* **47**, 2784-2802

Lenderink, G., and A.P. Siebesma, 2000: Combining the massflux approach with a statistical cloud scheme. Preprints, *14th Symp. On Boundary Layers and Turbulence,* Aspen, CO, Amer. Meteor. Soc., 66-69

Grant, A.L.M., 2001: Cloud-base fluxes in the cumulus capped boundary layer. *Quart. J. Roy. Meteor. Soc.,* **127**, 407-422

Siebesma, A.P. et al., 2003: A Large Eddy Simulation Intercomparison Study of Shallow Cumulus Convection.. *J. Atmos. Sci.,* **10**, 1201-1219

Sommeria, G., and J.W. Deardorff, 1977: Subgrid-scale condensation in models of nonprecipitating clouds. *J. Atmos. Sci.,* **34**, 344-355