Erroneous sea fog forecasts in HARMONIE: Part 1 Analysis

Wim de Rooy
acknowledgements: Emiel van der Plas, Geert Lenderink, Jan Barkmeijer

Introduction

A few years ago the Harmonie model was gradually introduced in our operational practice at KNMI. Since the start it has proven its value, especially in cases of extreme weather. There are however still important deficiencies. During the cloud and convection workshop in Norrköping October 2012, high priority was given to the fog above sea problem. Several times and at different institutes, Harmonie produced large and persistent fog fields above sea, which were not observed. Especially in The Netherlands these unrealistic fog fields are problematic as our main airport is located close to the coast. Besides, these erroneous fog fields decrease the credibility of the model to customers and forecasters. Several physical processes and parameterizations can contribute to the formation of fog. Here we present an analysis of some of the most plausible processes related to the production of excessive fog.

Analysis of the problem

Many of the sensitivity tests in this paper are based on a test case starting at 22 March 2012 at 12 UTC. In observations almost no fog was present (see Fig. 1 for the next day at 11:14 UTC). However, the model run shows two interesting fog fields above the North Sea; one large fog field already present in the beginning of the run and subsequently advected towards the south west, and a fog field that is developed during the 24h run in the southern part of the North Sea (see Fig. 2). Tests are done with a cold and warm start (assimilation run started at 15 March 2012).

Fig.1 Modis vis satellite image valid for 23 March 2012 at 11:14UTC, showing almost no fog above the North Sea. Fog is also absent in the previous 24 hours whereas in the next 24 hours the fog field near the coast of Denmark is expanding towards the North Sea.

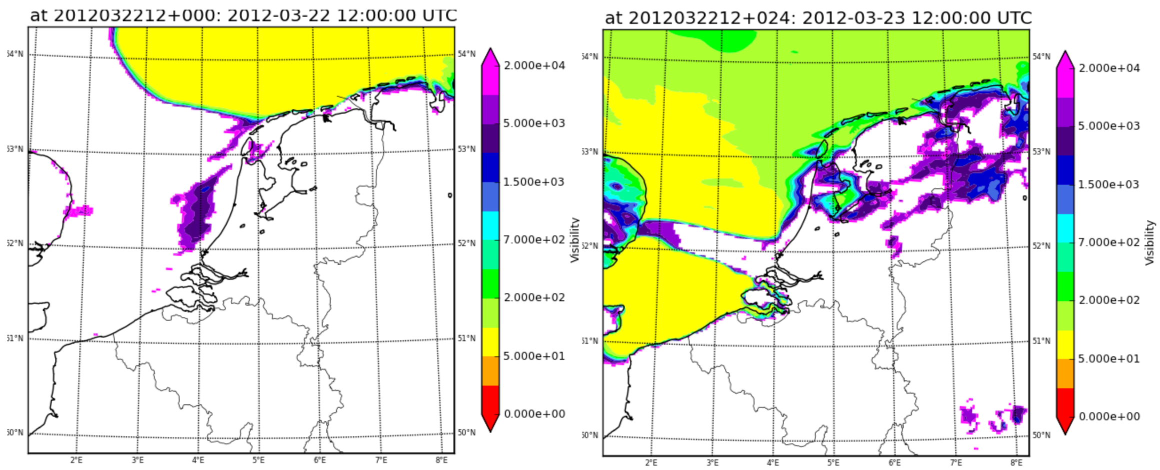

Figure 2 Showing the +0 (left panel) and +24h (right panel) visibility [m] forecast of Harmonie started at 22 March 2012 12 UTC in the default setting and using a warm start.

Movies of the complete 24h run (and results of many other experiments) can be downloaded from: https://hirlam.org/trac/wiki/HarmonieWorkingWeek/Clouds201210 under section “Preliminary results North Sea fog case”.

Sensitivity tests for the following model components, potentially related to fog above sea, are performed:

1. Sea surface
2. Convection scheme
3. Cloud scheme
4. Turbulence scheme

Ad 1) First of all, the Harmonie SST is checked against satellite observations. Conclusion is that the SST might be slightly too high. Because a higher SST would lead to less fog (this is verified), errors in the SST can be excluded as cause of the fog problem.

Hereafter, we investigated the quality of the surface fluxes. Deficiencies in the surface fluxes could arise from an inadequate parameterization or incorrect surface and/or lowest model level meteorological parameters. Unfortunately, no direct observations of the surface fluxes were available. Nevertheless, the parameterization could be validated by using the surface and lowest model level as input for the so-called fluxroutines [1)]. Especially above sea these fluxroutines provide accurate estimates of the surface fluxes provided the input is accurate. For a location in the southern part of the North Sea where fog develops, we see moistening occurs during the night until the atmosphere becomes fully saturated and subsequently the conditions become unstable (see Fig 3a). From this moment the convection scheme will be active. As shown in Fig. 3b the modeled surface fluxes are in reasonable agreement with the fluxroutine output. Moreover, the observed differences would result in less fog and can therefore not explain the erroneous fog fields.

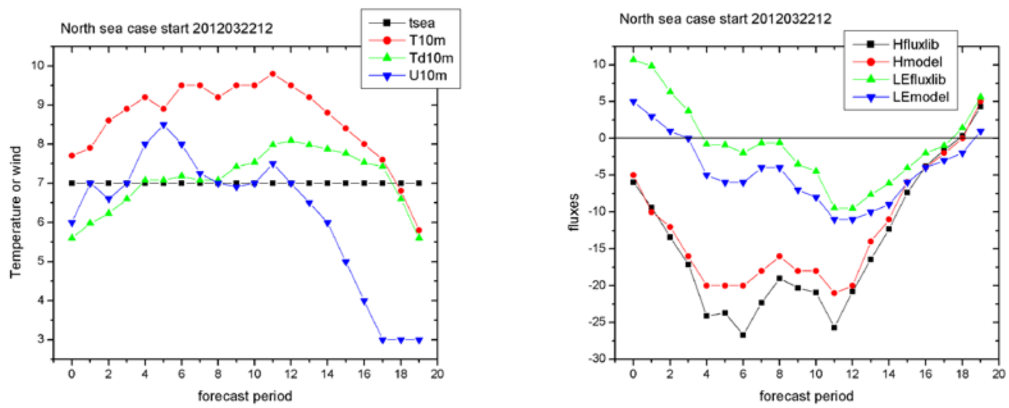

Fig 3 Temperature, dewpoint temperature and wind speed (left panel) and surface fluxes (right panel) as a function of the forecast period for a location in the southern part of the North Sea in the middle of the developing fog field. Hfluxlib and LEfluxlib are estimates of respectively the sensible and latent heat flux using the fluxroutines. Upward fluxes have positive values.

Finally, tests with different surface scheme options (ECUME, DIRECT, canopy scheme on/off) revealed no substantial impact on the formation of fog above sea.

Ad 2) Runs with additional output showed (as expected) that the edmfm convection scheme is not active before and during the development of fog. Only when the fog is well developed and becomes dense, the convection scheme becomes active. From then on the conditions are diagnosed as stratocumulus by the convection scheme, resulting in the use of moist updrafts only (no dry updraft). Increasing the convection for this stratocumulus regime has no substantial effect.
Tests with the edkf convection scheme in combination with no extra variance term (the default) showed that the development of fog starts somewhat earlier and the positive feedback loop to more dense fog is somewhat stronger. Overall, it seems highly unlikely that the solution of the fog problem can be found in the convection scheme.

Ad 3) The cloud scheme determines the cloud fraction and the liquid/ice water content. Key parameter is the variance of the distance to the saturation curve. When using the full statistical cloud scheme, there are contributions to the variance from the turbulence and the convection as well as an additional variance term as described in [2)]. Runs have been performed with all these contributions to the variance as separate output. Striking is the correlation between the contribution due to turbulence and reduced visibility during the first half of the 24h simulation (see Fig. 4). Note the following positive feedback loop: the production of TKE increases the variance, which in turn increases the liquid water content, which increases the radiative cooling and consequently TKE increases.

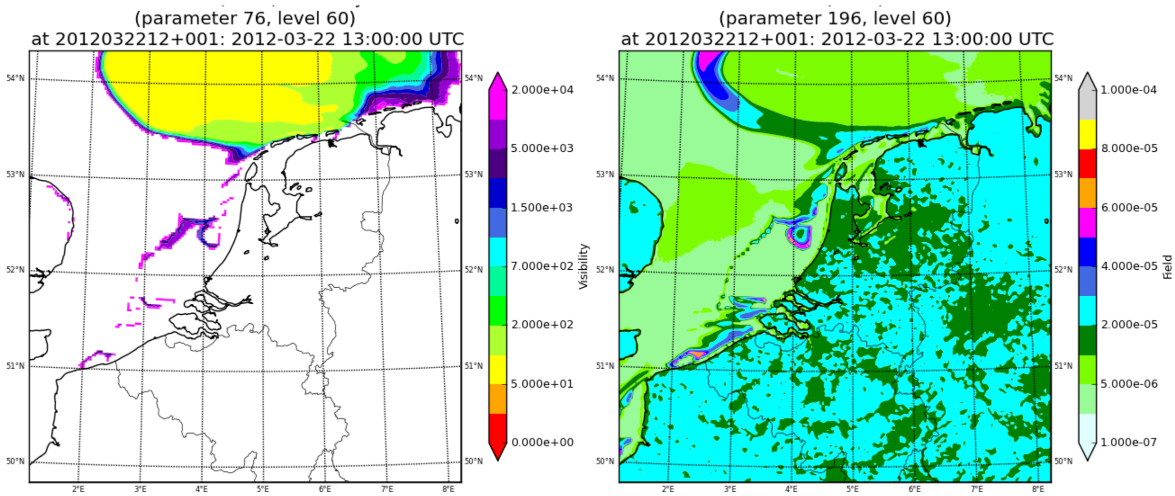

Fig. 4 Visibility (left panel) and the variance contribution due to the turbulence (right panel) of a +1h forecast from a cold start at 2012032212.

If we remove the contribution of the turbulence to the variance and reduce the extra variance term (proportional to 0.005 q_{sat} i.o. 0.02 q_{sat}) the fog field in the north remains the same but in the south no fog or reduced visibility is formed until fog above land is advected with the easterly winds to sea. Subsequently this fog "explodes" above sea (as observed before in harmonie forecasts by Sander Tijm). In Fig. 5 the start of this process is shown. We will return to this phenomenon in part II of this paper as it nicely illustrates the likely cause of this fog problem.

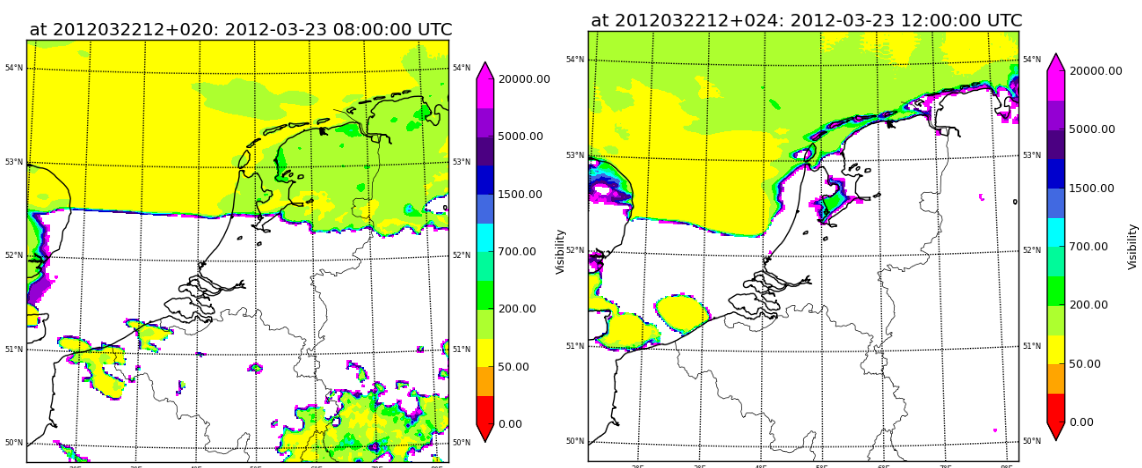

Fig. 5 Cold run 2012032212 +20h (left) and +24 (right) without the contribution to the variance of the turbulence scheme and a reduced extra variance term. Near the coast of Belgium fog develops above land and is subsequently advected above sea where it spreads out rapidly whereas the corresponding fog fields above land are dissolved

Ad 4) The turbulence scheme potentially plays an important role in the forming and dissolving of fog as it determines the vertical mixing due to isotropic turbulence. The turbulence scheme should provide the primary mechanism, namely top entrainment, to dissolve the fog field by entraining relatively warm and dry air. Looking at a vertical slice through the fog field above sea (see Fig. 6), the turbulent activity (indicated by the TKE) is very small (or virtually non existent) in the upper part of the fog layer. This is an indication that the turbulence scheme is not capable of dissolving the fog.

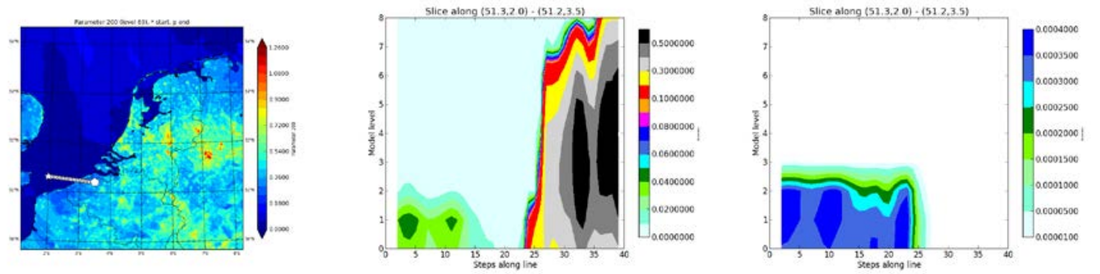

Fig. 6 Vertical slices of TKE (middle panel, in m^2/s^2) and cloud water (right panel, in kg/kg) along the line as indicated in the left panel starting at the star (above sea) and ending at the pentagon (above land). The +24h forecast of a cold start at 2012032212 is shown. In the left panel the TKE at the lowest model level is plotted.

To investigate the sensitivity of the model to the turbulence scheme several experiments are done. Changes in the constants of the stability functions (to Schmidt & Schumann settings) did not result in significant impact. On the other hand, multiplying the turbulent length scale with 2 resulted in a large impact (although length scales are pretty small in the developing stage of the fog). The existing fog field in the north becomes less dense and the developing fog field in the southern part is substantially reduced (not shown).

Apparently, the development of fog can be very sensitive to the settings in the turbulence scheme. However, simply tuning the turbulence scheme to this fog case would undoubtedly lead to problems with other parameters or other conditions. Moreover, how can we know the turbulence scheme is really the cause of the problem? We might simply compensate for the real cause by retuning the turbulence scheme. Fortunately (thanks to Eric Bazile), Arome and Harmonie participated in the ASTEX intercomparison case. In this lagrangian case describing a rising stratocumulus which finally breaks up, several processes are prescribed (according to observations) and detailed observations as well as LES output is available. Consequently, this case can show us some real deficiencies of parameterizations.

Fig. 7 reveals that apart from not breaking up, the stratocumulus layer stays too low. In the version with EDKF convection (not shown) the stratocumulus layer reaches higher altitudes because the excessive mixing convection scheme results in strong top entrainment (Harmonie runs without convection show almost no top entrainment). However, for the majority of the simulation the top entrainment is induced by the cloud radiative cooling at the top of the cloud layer and it is the turbulence scheme that should represent this. Later on in the simulation shallow convection enters the cloud layer and starts to contribute to the top entrainment and breaking up.

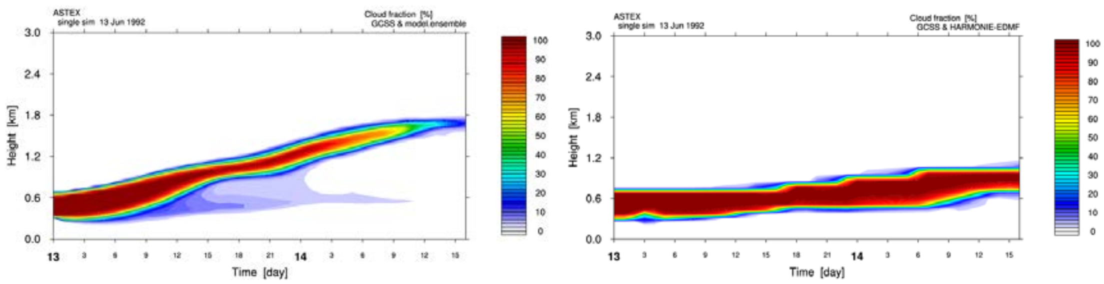

Fig.7 Contourplots of cloud fraction as a function of the simulation hour during the ASTEX case (see text) from LES runs (left panel) which can be considered as observation, and with Harmonie using edmfm.

Based on ASTEX we can conclude that the turbulence scheme of Harmonie underestimates the top entrainment in this situation. This underestimation can have a relation with our fog problem. Moreover, too little top entrainment can also explain the underestimation of cloud base and boundary layer height as often observed in Harmonie. Finally, more top entrainment will generally lead to less stratus and our operational experience is that Harmonie often overestimates stratus. These links between known deficiencies of the operational model and results in well-controlled intercomparison (1D) cases are extremely valuable for practical and scientifically sound model improvement.

Instead of tuning the current scheme we might incorporate a new scheme which is used successfully for many years in the KNMI RACMO (Regional Climate MOdel). This climate model, which uses the same (edmfm) convection scheme as Harmonie but a different turbulence scheme, clearly performs better for ASTEX, showing more top entrainment. Like the current scheme, this TKE scheme uses a 1½ order closure, but a different length scale formulation of Lenderink & Holtslag [3] as well as different details in the TKE prognostic budget equation and the eddy diffusivity formulation. Note that in Hirlam we followed a similar road going from a Bougeault & Lacarerre [4] to a Lenderink Holtslag [3] length scale formulation.

In the next newsletter we will describe the implementation of and the experiences with the RACMO turbulence scheme in Harmonie. Besides, more insight of the processes leading to the erroneously developing fog field will be given.

Conclusions and outlook

Several processes potentially related to the fog above sea problem are investigated. Many of these processes can be excluded, or are at least unlikely to be the cause of the overestimation of fog. However, ASTEX clearly reveals that the Harmonie turbulence scheme has too little top entrainment. Too little top entrainment can explain several deficiencies of Harmonie, such as the fog problem. At the same time results of Harmonie for the North Sea fog case turned out to be quite sensitive to the settings in the turbulence scheme. Based on these arguments we continue our investigation focusing on the turbulence scheme, as described in part II of this paper published in the next newsletter.

References

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