

Further updates to STRACO

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1 Introduction

In April 2002 we received a new version of the STRACO scheme to be tested and used in the comparison with the Kain Fritsch Rasch Kristjansson scheme. After receiving very positive test results from Denmark with remarkable improvements, especially on the reduction of small precipitation amounts, it was decided to introduce this version of STRACO (0202) in the operational Hirlam at KNMI. On May 7, 2002, STRACO 0202 became operational.

On May 9, 2002, forecasters complained about very large precipitation sums that were forecasted by Hirlam. The Hirlam calculations resulted in precipitation sums over 50 mm over the northeast of the Netherlands on the afternoon of May 10. Other models produced much less precipitation resulting in a rejection of the Hirlam forecast. In reality it remained almost dry in the Netherlands, but heavy thunderstorms did develop over northwest Germany. Precipitation sums of 20 to 30 mm were observed in this area. In the period up to the end of June there were a few other cases where Hirlam produced way too much precipitation. The cases with the extreme overprediction were the main cause for monthly totals of forecasted precipitation that were up to 100 % over the actual measured precipitation sums. These extreme monthly sums made it clear that the new STRACO version had a problem. In this article we describe the cause of this problem and a solution that gives reasonable results.

A second phenomenon that forecasters complained about was a case with small precipitation amounts at the Dutch coast. The clouds were too shallow and warm to produce precipitation in reality, but STRACO produced up to 1.5 mm of convective rain. The STRACO scheme includes a parameter that limits the available moisture for convection as a function of the depth of the convective cloud. Here it is shown that an adjustment to this parameter can reduce the erroneous precipitation from shallow clouds.

2 STRACO version 0202

The STRACO version 0202 was introduced to solve or reduce a few known problems of the older STRACO versions. These problems were (among others) too many small precipitation amounts, too few large amounts and a too early onset of convection. The new version of STRACO shows a considerable improvement (Sass and Yang, 2002) over the older version, especially for the small precipitation amounts. The tests in the Sass and Yang (2002) were performed on a resolution of 0.5° , which may be one of the reasons that they did not find the overprediction of precipitation under certain conditions.

The largest change in the convection description in STRACO 0202 is the inclusion of lateral entrainment. Including this process improves the time of onset of convection, a shift in the precipitation distribution from small amounts to larger convective amounts and, on top of that, a reduction in the production of small precipitation amounts (more grid points that remain dry).

Other changes are the removal of the old resolution dependence in the scheme that limits the fraction of the moisture convergence available for convection and the removal of the dependency on the average buoyancy of the cloud parcel. The new resolution dependence acts on the temperature perturbation of the air parcel that is lifted to check for possible convection and as a factor in the lateral entrainment formulation.

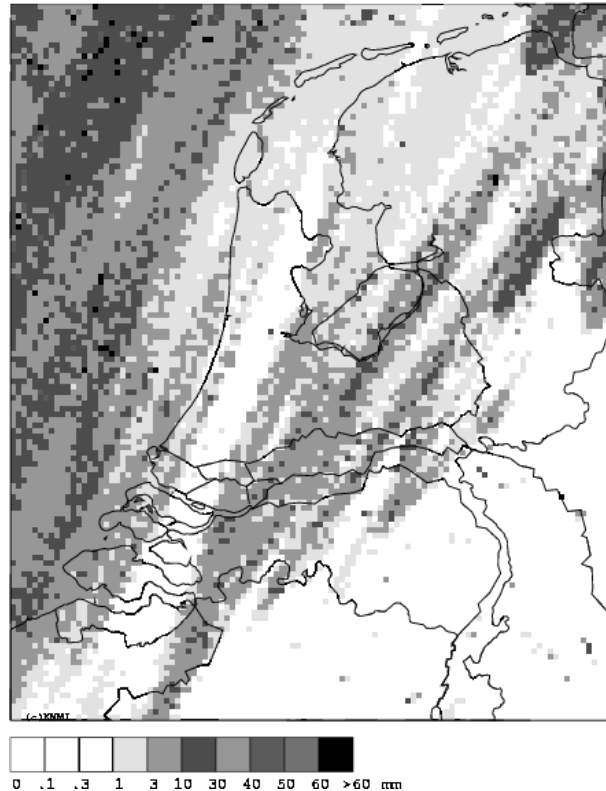


Figure 1: *The radar precipitation sum over the Netherlands and surroundings from June 18, 2002, 08 UTC to June 19, 2002, 08 UTC.*

At a resolution of 0.2° it seems that the new as well as the old STRACO scheme overpredicts the precipitation in the Netherlands considerably. The old STRACO version that is included in Hirlam version 5.0.6 produced about 20 to 30 % too much precipitation from February until April 2002 whereas the new STRACO version (02-2002) overpredicted the precipitation in May and June by about 50 to 100 %.

2.1 Overestimation of large precipitation amounts

The overprediction of the precipitation in the months May and June 2002 by our operational Hirlam was caused largely by three or four cases with strong convection near the end of a warm episode. In all these cases the convection was forced by strong convergence and the temperature and specific humidity were high. In short there was ample ground for STRACO to produce strong convection with large precipitation sums.

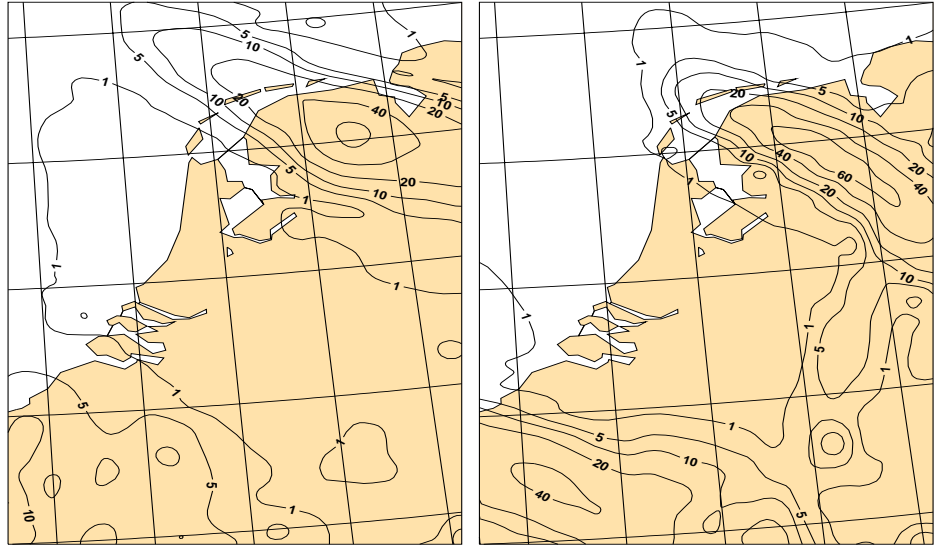


Figure 2: *The 48-hour convective precipitation sum of the operational KNMI STRACO (version 0202, left) and at ECMWF (version 0802, right) for the forecast with analysis time at 2002-05-09, 00 UTC.*

The first case of the too large precipitation production was May 10 2002. Another one was June 18, where the model produced heavy precipitation concentrated in two lines, one at a cold front over the western half of the Netherlands, and one on a prefrontal convergence zone over the eastern part of the Netherlands. In both zones, the maximum forecasted precipitation sum was more than 60 mm, with large areas of 30 mm or more. The observed precipitation sums exceeded 10 mm in only a few places (see figure 1). Strong convection did develop, but only late in the afternoon in the northeastern corner of the Netherlands and over the west of Germany. Less intense convection was present on the cold front over the west of the Netherlands.

After this case it was clear that the increase in large precipitation sums was too extreme in the new STRACO scheme. The case of May 10, 2002 was rerun at ECMWF (see figure 2, right). This rerun produced similar precipitation amounts. The first test was to see if the new version of STRACO was to blame for the apparent increase in precipitation. A run with the reference Hirlam 5.0.6 showed much smaller sums with a maximum value of about 10 mm in the area where STRACO 0202 had a maximum of more than 60 mm. The new version of STRACO therefore caused the large precipitation amount. The next task was finding which new part of the scheme was responsible.

2.2 Cause

STRACO 0202 has a number of new features, as mentioned in section 2. These features have been checked systematically in a 48-hour forecast starting at 00 UTC on May 09, 2002. First the new resolution dependence was checked by re-introducing the old dependence into the scheme. This had (as expected, because we run at 0.2°) no major impact on the precipitation sum. There was some impact as the temperature perturbation of the convective parcel was adjusted to the old setting. Next, the impact of the removal of the average buoyancy dependency was re-introduced, showing a change in distribution of the precipitation, but no decrease in maximum amounts. The third change concerned a number of parameters that were changed going from version 5.0.6 to version 0202. Resetting them to the old values also did not result in a decrease in the precipitation.

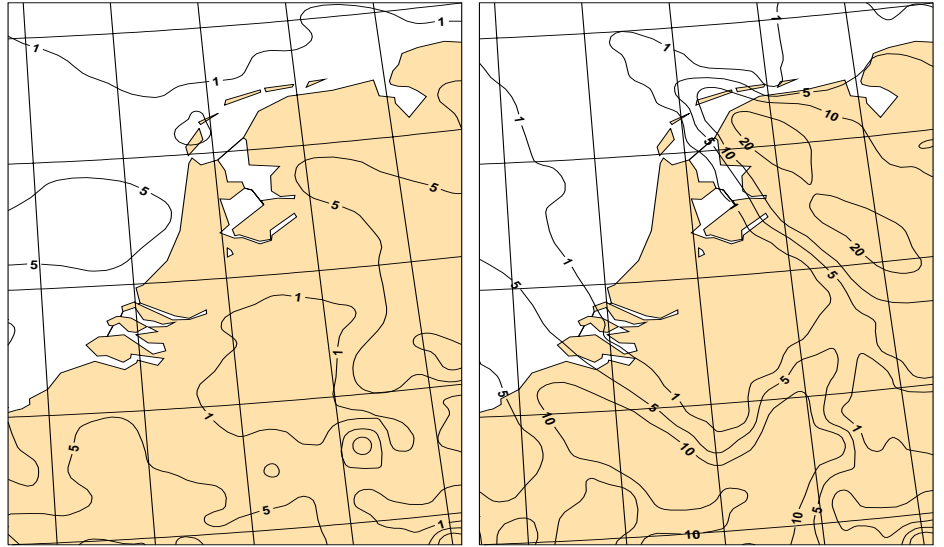


Figure 3: *The 48-hour convective precipitation sum of STRACO without lateral entrainment (left) and the final version with adjusted lateral entrainment constants (right) for the forecast with analysis time at 2002-05-09, 00 UTC.*

Finally we switched off the lateral entrainment, the largest change between the two STRACO versions. This was the last test that was performed as we thought (and still think) that lateral entrainment increases stability, reducing the convection and resulting precipitation. Switching off the lateral entrainment had the effect of decreasing the precipitation (see figure 3) to levels of the run with STRACO 5.0.6. The lateral entrainment therefore is responsible for the large precipitation amounts that can be found in some cases.

2.3 Cure

Removing the lateral entrainment update of the parcel temperature and specific humidity removes the extreme precipitation production that we found in some cases. However, with this removal we also throw away the improvements that this new version of STRACO has on the time of onset of convection, the correctly predicted larger precipitation sums and the

reduction of the erroneous small precipitation sums.

Therefore it was suggested by Bent H. Sass to reduce some of the constants in the lateral entrainment formulation. The lateral entrainment in STRACO 0202 is described by (B. H. Sass, personal communication):

$$\epsilon_e = \left(K_{\epsilon 0} + \frac{K_{\epsilon 1}}{Ri_*} \right) \left(\frac{z}{K_{\epsilon 3} + z} \right) \frac{D_0}{D}, \quad (1)$$

where ϵ_e is the volume fractional entrainment per unit length of parcel ascent, $K_{\epsilon 0}$, $K_{\epsilon 1}$ and $K_{\epsilon 3}$ are constants ($2.5 * 10^{-4}$, $1 * 10^{-3}$ and 500m respectively), Ri_* is a modified Richardson number, z is the height, D is the model grid size and D_0 is a constant (10 km) while the fraction (D/D_0) is constrained to be no less than 1. Halving the constant $K_{\epsilon 0}$ had a larger impact than halving $K_{\epsilon 1}$. Good results were achieved with $K_{\epsilon 0} * 0.5$ and $K_{\epsilon 1} * 0.75$. For the case of May 10, 2002, this results in precipitation sums that are larger than the STRACO version without lateral entrainment or the version in Hirlam 5.0.6, but figure 3 shows that the precipitation sums are considerable smaller than with STRACO 0202.

The results of a longer run with the new version (0202) and updated version (0802) of STRACO are plotted in figure 4. This run started at June 13, 2002 and the last analysis time was 00 UTC at June 20, 2002. The updated version clearly has less very large sums while the small sums do not increase much. The good characteristics of the 0202 version therefore are retained while the extreme overprediction of the precipitation in some cases has been reduced considerably.

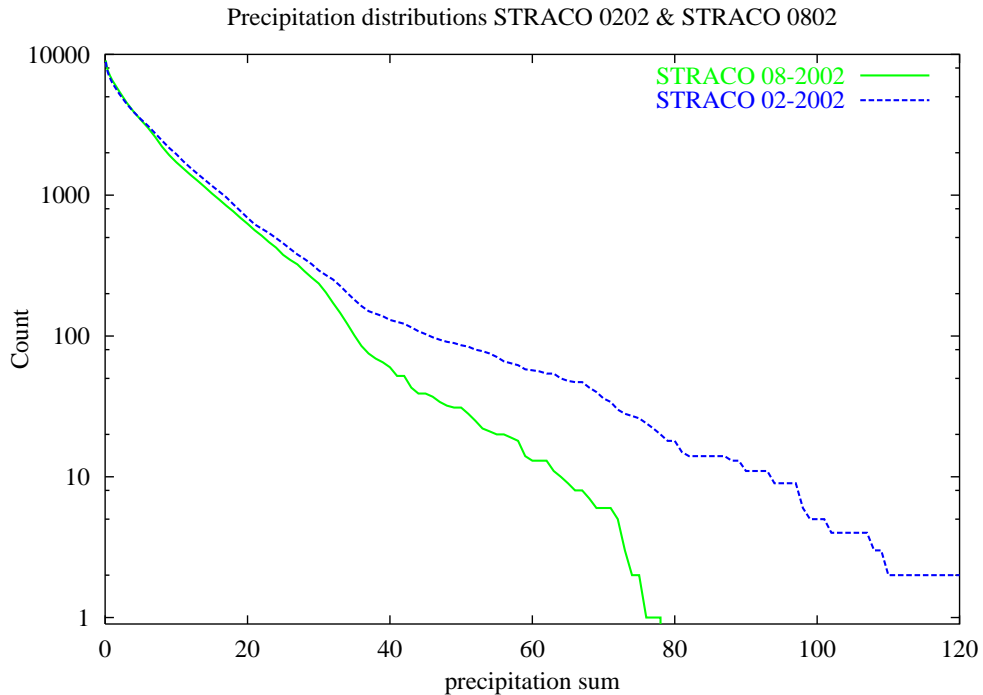


Figure 4: *The precipitation distributions (mm per 24 hours, 36h-12h) over the Netherlands and surroundings of STRACO versions 0202 and 0802 for a 7-day period in June 2002, both in Hirlam version 5.0.6.*

A comparison of these results with district averages of the precipitation in the Netherlands shows that the update of the STRACO scheme still overpredicts the chance of small precipitation amounts. The distributions show that up to a level of about 7 mm in 24 hours there is a considerable overprediction. There are too few precipitation sums above 7 mm. Up to about 10 mm the precipitation distributions of STRACO versions 0202 and 0802 are quite similar. Above this value the chance of occurrence of large precipitation sums becomes much larger with version 0202 than with version 0802. The maximum observed district average precipitation sum is 19 mm whereas the maximum forecasted sum is 47 mm for STRACO 0202. As these sums are determined over the Netherlands they are not caused by orographic forcing and therefore are a real feature of the convection scheme.

The comparison above shows that the precipitation distribution produced by STRACO 0802 still is skewed compared to the observed precipitation sums. There is a major improvement in the decrease of small precipitation sums and the increase in large precipitation sums compared to STRACO 5.0.6, but systematic differences still can be found. These differences may be caused by the fundamental problem of the STRACO scheme, the closure assumption. Without large scale forcing the only moisture convergence available is through evaporation, reducing the potential intensity of warm weather thunderstorms in high pressure areas.

3 Precipitation from too shallow clouds

The second subject of this article concerns the release of small precipitation amounts from model clouds that are too warm and shallow to produce precipitation in reality. On June 26, 2002, small precipitation amounts of up to 1.5 mm were forecasted on the Dutch coast. In reality, no precipitation was observed in the Netherlands on this day. The precipitation occurred in a northwesterly flow which transported stratocumulus fields from the North Sea over the Netherlands.

The slowing down of the flow over land due to the higher roughness caused moisture convergence near the coast. This moisture convergence triggered STRACO to produce convective clouds with the cloud bottom at about 1800 meters and the cloud top below 2700 meters a thickness of about 900 meters and about 90 hPa. The cloud top temperature was 4°C.

The Forecasters Reference Handbook of the UK Met Office states that the chance that clouds as described above produce showers is very small. Clouds with a cloud top temperature above -12°C have to be about 10000 feet thick before the chance of a shower is 90%. If the cloud is less than 6000 feet thick the chance of precipitation reduces to less than 10%. If the cloud top temperature lies below -12°C then the cloud depth has to be 5000 feet before the chance of precipitation from this cloud exceeds 90%.

In STRACO a parameter exists that determines the fraction of converging moisture that can be used in the convection. This parameter (zprc) has a value of 100 hPa, or about 1000 meters near the top of the boundary layer. In STRACO this parameter does not depend on the temperature and it is too small. A second problem is that the fraction of the moisture convergence available for convection determined by dividing the actual depth of the cloud by the cloud depth parameter. This means that when the cloud depth is 50% of the threshold value, the fraction of the moisture convergence that can be used in the convection is 50%.

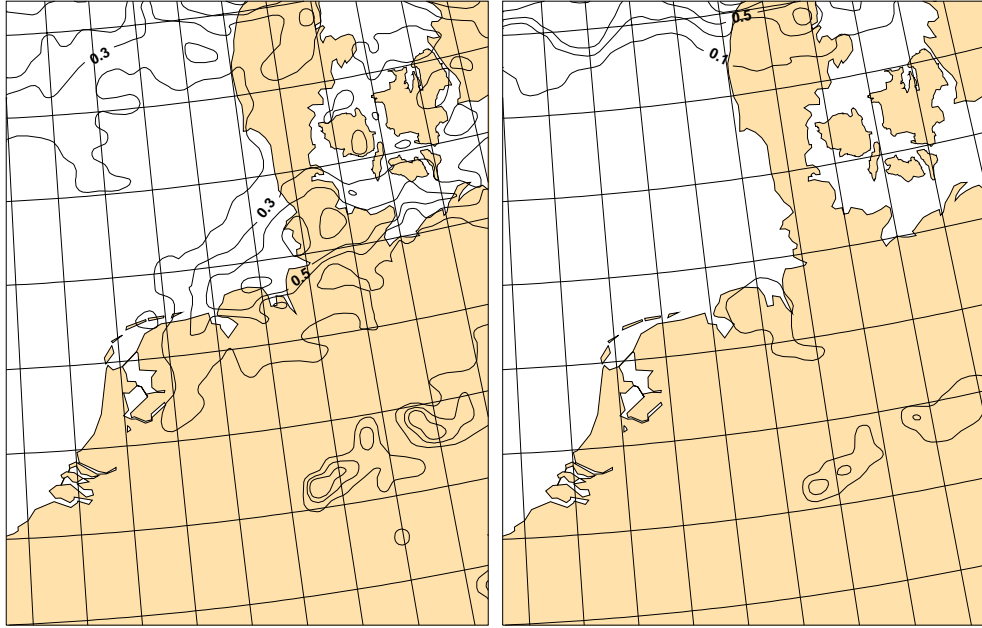


Figure 5: *The 12-h precipitation over the Netherlands and surroundings in STRACO 0202 (left) and with the shallow convection update (right) for the forecast with analysis time June 26 2002, 00 UTC. Contours at 0.1, 0.3, 0.5, 1.0 and 1.5 mm.*

Therefore the chance of precipitation from shallow clouds is too high in STRACO.

3.1 Adjustments to shallow convection

To achieve a decrease in precipitation from shallow clouds we have adjusted the parameter that determines the fraction of moisture convergence available for convection to values that can be found in the Forecasters Reference Handbook and made it dependent on the temperature as follows:

$$z_{prc} = \begin{cases} 150hPa & \text{if } T_{top} \leq 260K \\ 150 + 150Cd \frac{(T-260)}{5} hPa & \text{if } 260 K < T_{top} < 265K \\ 300hPa & \text{if } T_{top} \geq 265K \end{cases} \quad (2)$$

In equation 2 T_{top} is the cloud top temperature and Cd is the cloud depth. The fraction of the moisture convergence that can be used in the convection is adjusted as:

$$Z_{delta} = \frac{Cd}{z_{prc}} \implies \left(\frac{Cd}{z_{prc}} \right)^3, \quad (3)$$

where Z_{delta} is the fraction of the moisture convergence that is used in the convection scheme to produce clouds and precipitation. By changing the power in equation 3 to three convective clouds have to be thicker before precipitation can start.

These adjustments were tested in an experiment at ECMWF with Hirlam 5.0.6. We reran

the case of June 26, 2002 to see if this experiment also produced the erroneous precipitation at the Dutch coast. Figure 5 shows that this is the case. Precipitation amounts up to 1.5 mm can be found from the Dutch north coast up to the northeastern part of Poland (not shown in figure 5). These precipitation amounts are a little less than the values found in the operational run, but the depth of the clouds are similar, so they are caused by the effect we want to study and diminish.

Inclusion of the adjustments to z_{prc} in the code results in a very clear reduction of the small precipitation sums in the coastal areas. The adjustments therefore have the desired effect. The adjustments made to the STRACO scheme not only reduce the precipitation at the coast to levels less than 0.3 mm, also the small precipitation sums near frontal zones seem to be reduced a little.

4 Conclusions

STRACO 0202 is a major improvement compared to the older versions of STRACO. In this article we propose some changes to the scheme that removes an unwelcome new characteristic of STRACO 0202, extreme precipitation under very warm and humid conditions with strong convergence. The large precipitation sums were caused by the lateral entrainment formulation that was introduced to delay the onset of deep convection and to enable larger precipitation sums caused by convection. This feature can be removed by reducing two constants in the lateral entrainment formulation.

The second proposed adjustment reduces small precipitation sums that fall from shallow clouds. The parameter that governs the amount of converging moisture that is available for convection does not depend on the temperature in STRACO 0202 while clouds that (partly) consist of ice produce precipitation much more easily than liquid water clouds. The dependence of available moisture on the depth of the cloud also was not steep enough. Clouds with a depth of 50% of the threshold value still have 50% of the converging moisture available for convection, while the chance of precipitation falls off much more rapidly with decreasing cloud depth. These shortcomings have been resolved by making the threshold value of the cloud depth temperature dependent and by making the moisture convergence available for convection a more steep function of the cloud depth.

The resulting scheme now has the benefits of the lateral entrainment parameterization causing less small precipitation sums and a delayed onset of convection, enabling larger precipitation sums without the extremes we encountered in the Netherlands. Erroneous small precipitation sums from too shallow clouds also have been reduced considerably.

References

Bent Hansen Sass and Xiaohua Yang, 2002: Recent tests of proposed revisions to the STRACO cloud scheme. Hirlam Newsletter 41.

Forecasters Reference Handbook, UK Met Office