# RESULTS FROM LAMEPS

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**Abstract**

The aim of this study has been to run extended tests with LAMEPS using ECMWF EPS to perturb the initial conditions and the lateral boundary conditions in the HIRLAM model. First the ECMWF EPS has been running with Northern Europe and adjacent sea areas as target area to make 20 ensemble perturbations for each case. Tests using 1) regular singular vectors and 2) both regular singular vectors and evolved singular vectors to perturb the EPS have been done. LAMEPS showed best results using the EPS perturbed with both regular singular vectors and evolved singular vectors (TEPS), especially for large total precipitation rates. The extended experiments have therefore been done using TEPS to perturb the LAMEPS. These experiments include 54 cases. The focus has been on total precipitation rates. By adding TEPS and LAMEPS we get a system with 41 ensemble members (CLAMEPS). CLAMEPS shows very good results for medium and large precipitation rates.

## Section 1: The set-up for the experiments

**EPS:** EPS is an abbreviation for ECMWF's global operational ensemble prediction system. EPS is perturbed with both regular singular vectors (SV) and evolved singular vectors (ESV). The resolution at the moment of our experiments is $T_l255L40$ (~ 80 km horizontal resolution and 40 vertical levels). The system consists of 50 perturbations, which give 50 alternative forecasts, plus a control run without perturbed analysis. (The control run has horizontal resolution approximately 40 km and 60 vertical levels). EPS has Northern Hemisphere (NH) north of 30° as target area and the forecast length is 10 days.

**EPS20:** EPS20 is a subset of EPS consisting of the 20 first EPS ensemble members plus the EPS control integration. These 20 ensemble members have the largest growth over the optimization time for the area NH north of 30° compared to the last 30 ensemble members of the EPS.

**TEPS_SV:** TEPS_SV is the ECMWF EPS model perturbed with only regular singular vectors (Frogner and Iversen, 2001) and with Northern Europe as target area (see figure 1).

**TEPS:** TEPS is also a re-run of EPS with the same target area as TEPS_SV. TEPS uses evolved singular vectors as perturbations in addition to the regular singular vectors. Perturbations are created 48 hours before the prognosis start. A scaled combination of the 48 hour old perturbations and the current perturbations are added to the analysis. Hence the model includes perturbations with significant growth already at the starting time. Using evolved SV result in out-stretching of the perturbations over a larger area since the perturbations are of significant order already at starting time.

**LAMEPS_SV:** LAMEPS_SV is the abbreviation for high resolution limited area ensemble prediction system with HIRLAM. The method consists of using the perturbations, TEPS_SV, to perturb the initial and boundary conditions in the HIRLAM runs (Frogner and Iversen, 2002). This results in 20 different forecasts besides the control run. The horizontal resolution is approximately 28 km and vertically the model has 31 levels. Initially LAMEPS_SV has very small or no perturbations inside the target area, since they are optimized to be in the target area after 48 hours.

**LAMEPS:** LAMEPS is also a high resolution limited area ensemble prediction system, but instead of using TEPS_SV, LAMEPS uses TEPS to perturb the initial and boundary condition in the HIRLAM runs. Evolved SV is introduced to get perturbations in our area of interests also at the starting time.

**CLAMEPS:** CLAMEPS is a combination-result of TEPS and LAMEPS (a "poor-mans"-limited area ensemble). The total number of ensemble members is therefore 41 plus the control run. The reason why the CLAMEPS has been introduced is firstly that it gives an increase in ensemble members without further cost since we already have TEPS to compute LAMEPS.  Both systems are also designed to be optimal for our area of interest. It is also fairer to compare 41 ensemble members against EPS's 50 ensemble members than to only use 20 ensemble members which is the case for the other LAMEPS-systems.

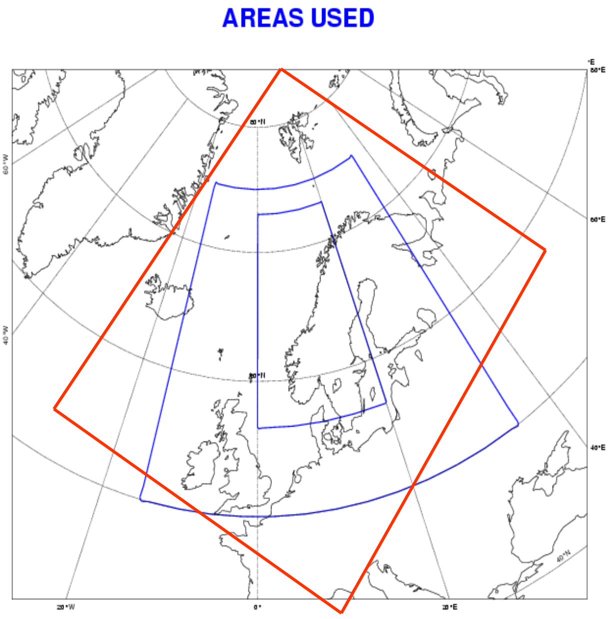


**Figure 1.** The figure shows the areas used in the experiments. The outermost area is the HIRLAM integration area. The outermost blue area is the target area, and the innermost blue area is the verification area.

| Period | Start date | End date | Number of cases | Missing dates |
|---|---|---|---|---|
| Autumn1 | 20021018 | 20021026 | 9 | none |
| Autumn2 | 20021027 | 20021031 | 5 | none |
| Winter | 20030110 | 20030131 | 21 | 20030116 |
| Spring | 20030504 | 20030521 | 15 | 20030507,09,10 |
| Summer | 20030811 | 20030814 | 4 | none |

**Table 1.** The table shows the experiment periods.

| Experiment | Description |
|---|---|
| EPS | ECMWF EPS model,<br>hemispheric,<br>perturbed with both SV and ESV<br>targeted to NH>30°,<br>~80 km h.resolution<br>40 levels,<br>50 ens members+1 ctrl,<br>96 h optimization.t<br>(-48h to +48h),<br>+10 d forecast length,<br>**operational** |
| EPS20 | subset of EPS (consisting of the first 20 ens members+1 ctrl) |
| TEPS_SV | ECMWF EPS model,<br>hemispheric,<br>target area: Northern Europe and adjacent sea areas (see fig.1),<br>~80 km h. resolution,<br>40 levels,<br>20 ens members+1 ctrl,<br>+48 h optimization t,<br>66 h forecast length,<br>only used in "autumn1-period" (see table 1) |
| TEPS | ECMWF EPS model,<br>hemispheric,<br>perturbed with both SV and ESV,<br>targeted to Northern Europe and adjacent sea areas, see fig. 1),<br>~80 km h. resolution,<br>40 levels,<br>20 ens members+1 ctrl,<br>+96 h optimization t<br>(-48h to +48h),<br>66 h forecast length |
| LAMEPS_SV | HIRLAM-EPS model perturbed with TEPS_SV (area; see fig. 1),<br>~28 km h. resolution,<br>31 levels,<br>20 ens members+1 ctrl,<br>+66 h forecast length,<br>only used in "autumn1" |
| LAMEPS | HIRLAM-EPS model,<br>perturbed with TEPS,<br>(area; see fig.1),<br>~28 km h resolution,<br>31 levels,<br>20 ens + 1 control,<br>+66 h forecast length |
| CLAMEPS | Combination of TEPS and LAMEPS,<br>41 ens members+1 ctrl,<br>optimization time, forecast length and run-periods are defined by LAMEPS and TEPS |

**Table 2.** The table shows the different experiments and gives a short description of each. The descriptions consist of model type, horizontal and vertical resolution, number of ensemble members, optimization time, forecast length and the periods for which each system has been studied.

## Section 2: Results

The results are first described in terms of the spread of the ensembles and thereafter graphically represented as Relative Operating Characteristic curves (ROC) (Mason, 1982). A cost/loss-diagram is also given. These diagrams take into account if the event in fact occurred or not. Since the total precipitation is only observed at 0600 UTC, the results of interest take place at forecast time +42 hours and +66 hours. Only the forecast time +42 hours will be represented.* The results are compared to observations where all the available precipitation stations are included.

Given a probability threshold-value, the ROC-curves categorize the results into probability ranges depending on how many members predicted the event. The hit rate is defined as the proportion of correct forecasts when the weather-event occurs. The false alarm rate is the number of times the event was incorrectly forecasted divided by the number of times the event was not observed. We want as many points as possible to be in the upper left corner of the diagram.

### 2.1 Spread of the ensembles

The ensembles should describe as much as possible of the probability distribution for weather-development caused by initial state uncertainty. The spread is defined as the root mean square of the difference between the ensemble member and the control and can mathematically be written as follow:

$$S=\frac{1}{I}\sum_{i=1}^{I}\sqrt{\frac{1}{N\cdot D}\sum_{n=1}^{N}\sum_{d=1}^{D}\left(e_{ind}-p_{id}\right)^2} \qquad (1)$$

where I is the number of points inside the verification area, N is the number of ensemble members, D is the number of cases. $e_{ind}$ is the ensemble member value for the member n, in the case d and in the specific point i. p is the control value for the same case and in the same point.

| Forecast time | EPS | EPS20 | TEPS | LAMEPS | CLAMEPS |
|---|---|---|---|---|---|
| 42 h | 2.7 | 2.6 | 3.3 | 2.8 | 3.7 |

**Table 3**. Spread in total precipitation for the different systems.

The spread in total precipitation is shown in table 3. Comparing the spread in the different systems shows that TEPS, LAMEPS and CLAMEPS have larger spread than EPS and EPS20. These systems include more diverging cases from the control than the EPS and EPS20 and can hence include the more extreme cases which the large scale EPS may not incorporate. This is a result both of the high resolution of the LAMEPS and the targeting of the singular vectors to the smaller area compared to the EPS.

### 2.2 Comparing systems run with and without evolved singular vectors.

* The results at +66 hours are generally some better, probably because the optimization time of the perturbations is +48 hours. The summer period is the only period, which shows not as good results at +66h compared to +42 hours. This can be a result of the precipitation which was convective rather than large scale.

The ROC-diagram and the cost/loss-diagram in figure 2 shows that LAMEPS perturbed with TEPS is the most skilful system compared to LAMEPS_SV perturbed with TEPS_SV, since LAMEPS has the highest hit rates and the highest value in the cost/loss-diagram. This indicate that including evolved singular vectors improve the LAMEPS results. The further tests will therefore use TEPS instead of TEPS_SV to perturb LAMEPS.

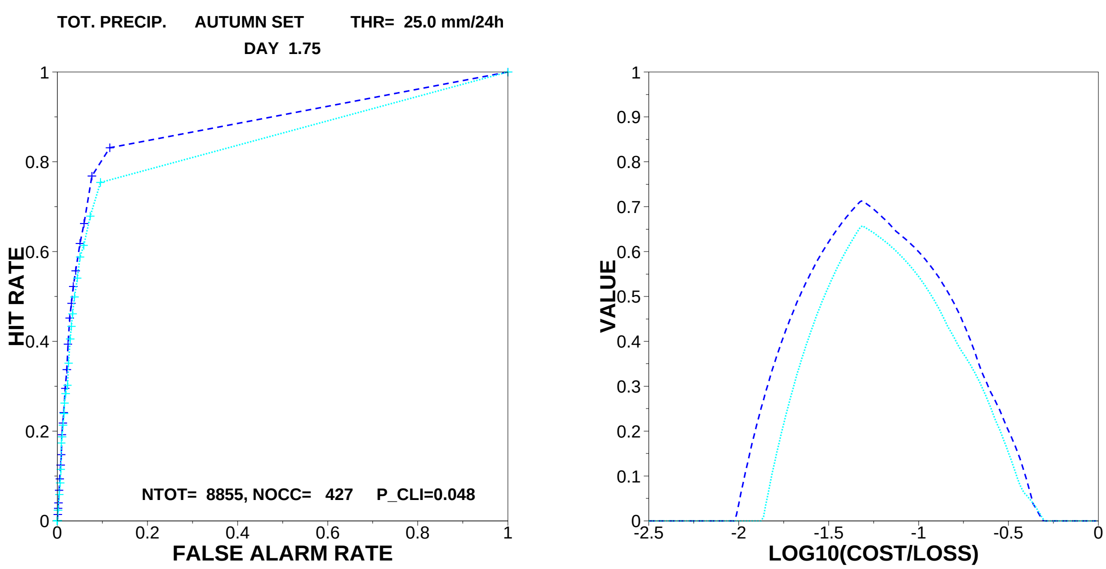


**Figure 2.** The ROC-diagram (to the left) and cost/loss-diagram (to the right) for LAMEPS (blue) and LAMEPS_SV (cyan) computed for the verification area and the 9 cases in the first set (autumn1 in table 1) at forecast time +42 hours. The threshold value is 25 mm/24 hours. NTOT is the total possible number the event could occur (the number of points in the target area multiplied by the number of cases) while NOCC is the number of times the event occurred in the sample. P_CLI is the total precipitation frequency in the experiment period (the sample climatology).

### 2.3 Verification over all four seasons

Figure 3 a) and b) shows the ROC-curves for the total cases at forecast time +42 hours. The threshold values are respectively 10 and 25 mm/24 h. Figure 3 a) shows that the CLAMEPS curve crosses the EPS curve and the LAMEPS curve crosses the EPS20 curve. CLAMEPS and LAMEPS get higher hit rates compared to respectively EPS and EPS20, but on cost of higher false alarm rates. Figure 3 b) shows that the results at the threshold value 25 mm/24 h are not as credible as for 10 mm/24 h, since high precipitation rates happen more rarely. CLAMEPS and LAMEPS do however not loose quality in the same degree as EPS. At precipitation rates larger than 10 mm/24h CLAMEPS and LAMEPS are the best systems. This indicates the importance of high resolution of the ensemble members when predicting high precipitation rates.

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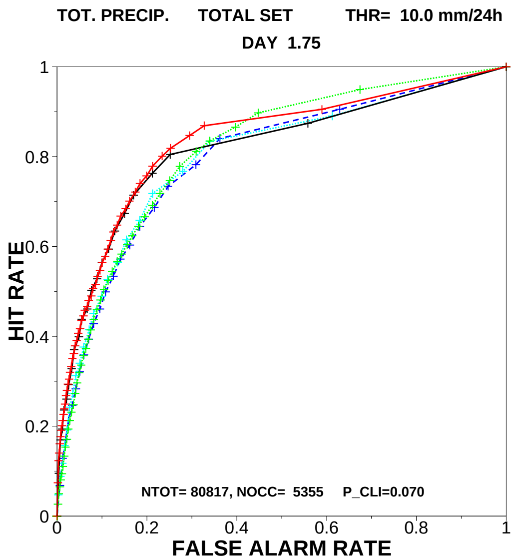
**3 a)** **3 b)**



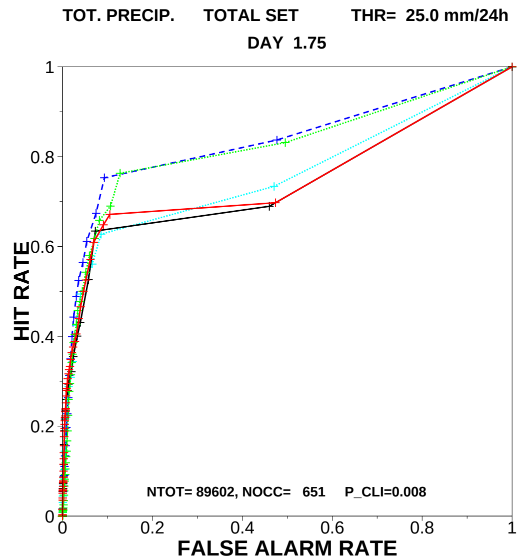




**Figure 3 a, b)** The figure shows the ROC-diagrams for two different threshold values of total precipitation rates where all the experiment sets are included. The threshold values are a) 10mm/24h and b) 25 mm/24h. The different curves are EPS (red), EPS20 (black), TEPS (light blue), LAMEPS (blue) and CLAMEPS (green).

## 2.4 A seasonal comparison of the ensemble systems

Since the frequency of observed total precipitation rates affects the results, a table showing the distribution between the different periods is given. The table shows that the highest frequencies of large and medium total precipitation rates were observed in the summer period, whilst small total precipitation rates were observed in the spring period. It is therefore expected to get the best results in the summer period and less good results in the spring period.

| | **0-10mm/24h** | **10-20mm/24h** | **20-30mm/24h** |
|---|---|---|---|
| **Autumn** | 0.404 | 0.096 | 0.065 |
| **Winter** | 0.566 | 0.090 | 0.057 |
| **Spring** | 0.391 | 0.040 | 0.013 |
| **Summer** | 0.287 | 0.117 | 0.146 |

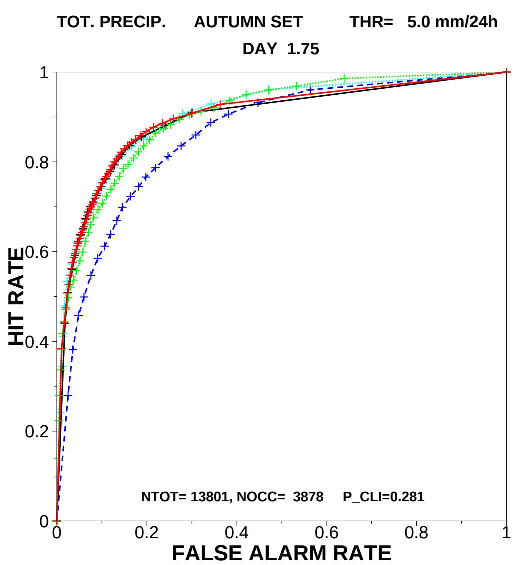
**Table 4.** The numbers represent observed total precipitation in the different experiment periods and for different interval of the threshold values of total precipitation rate.

### 2.4.1 Autumn

The autumn set consists of 14 cases where each case runs for 60 hours. Table 4 shows that this set had generally high frequencies in all the three categories of precipitation rates.

Figure 4 a) and b) show the ROC-curves for the threshold values 5 mm/24h and 25 mm/24h respectively. At 5 mm/24h CLAMEPS has the highest hit rates but at the expense of large false alarm rates. At 15 mm/24h CLAMEPS is the system with the best skill (not shown here), also when the false alarm rate is low. The improvement in the skill of the CLAMEPS compared to the other systems increases with raising precipitation rates. At 25 mm/24h both CLAMEPS and LAMEPS has higher skill than EPS.

**4 a)**




**4 b)**

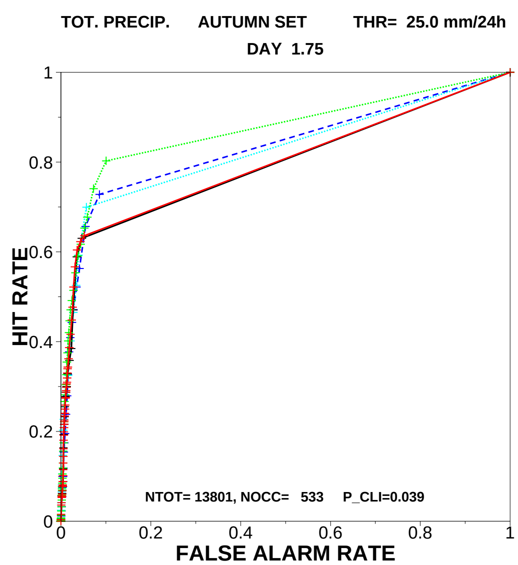



**Figure 4 a, b)** The figure shows the ROC-diagrams for two threshold values of total precipitation rates, looking at the cases in the autumn set at forecast time +42 hours. The threshold values are a) 5 mm/24h and b) 25mm/24h.

### 2.4.2 Winter

The winter set consist of 21 cases. The systems TEPS and LAMEPS have been run for 66 hours for each case and include both observation times of the total precipitation rate. The frequency of observed total precipitation rates is almost equal to the autumn period (see table 4).

Figure 5 a) and b) shows the ROC-diagrams for the threshold values 10 mm/24 h and 30 mm/24 h total precipitation. The CLAMEPS curve and EPS curve are almost equal up to large precipitation rates. At 30 mm/24h CLAMEPS is somewhat better than EPS, but since these high total precipitation rates happen rarely, all the curves show not as credible results as at lower precipitation rates. The most credible results (the diagram with most of the points clustered in the upper left corner) take place at 10 mm/24hour (see figure 5 a). Figure 5 b) shows that LAMEPS becomes better than EPS20 at 30mm/24h.

**5 a)** **5 b)**

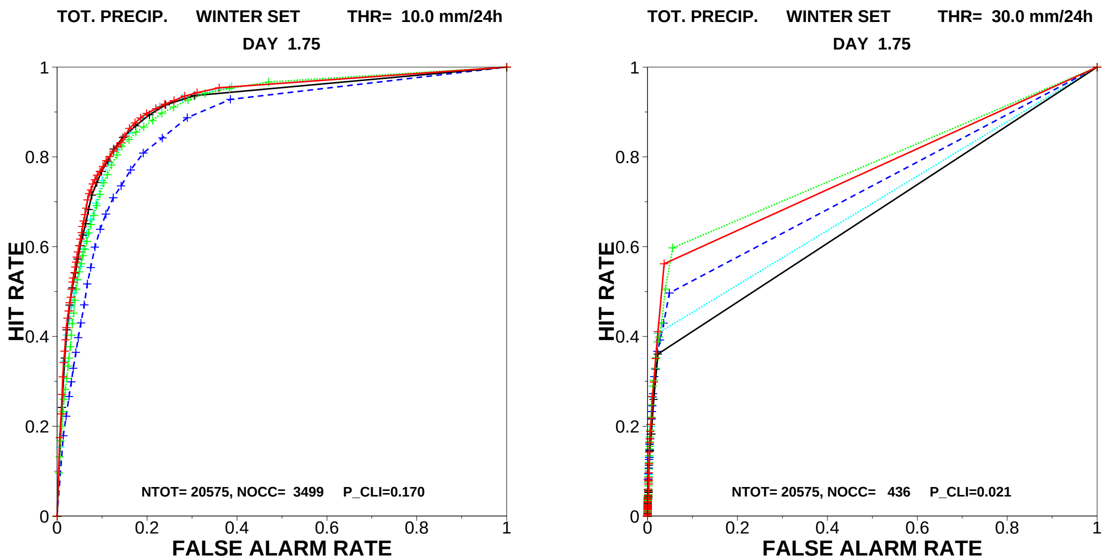



**Figure 5 a, b)** The figure shows the ROC-diagram for two different threshold values of total precipitation rates looking at the cases in the winter set at forecast time +42 hours. The threshold values are a) 10 mm/24h, b) 30mm/24h.

### 2.4.3 Spring

The spring set consists of 15 cases. The spring set had least observed precipitation rates compared to the other 3 experiment periods (see table 4). The cases include firstly small to medium range precipitation rates.

Figure 6 a) shows that CLAMEPS is just the uppermost curve at precipitation rates 5 mm/24h, but at expense of large false alarm rates. At 15 mm/24h CLAMEPS is marginally the best system (see figure 6 b). EPS is best at both small and large precipitation rates. LAMEPS seems to need larger frequency of observed total precipitation to produce good results. It is TEPS that contributes to the good results in CLAMEPS in this case.

**6 a)** **6 b)**

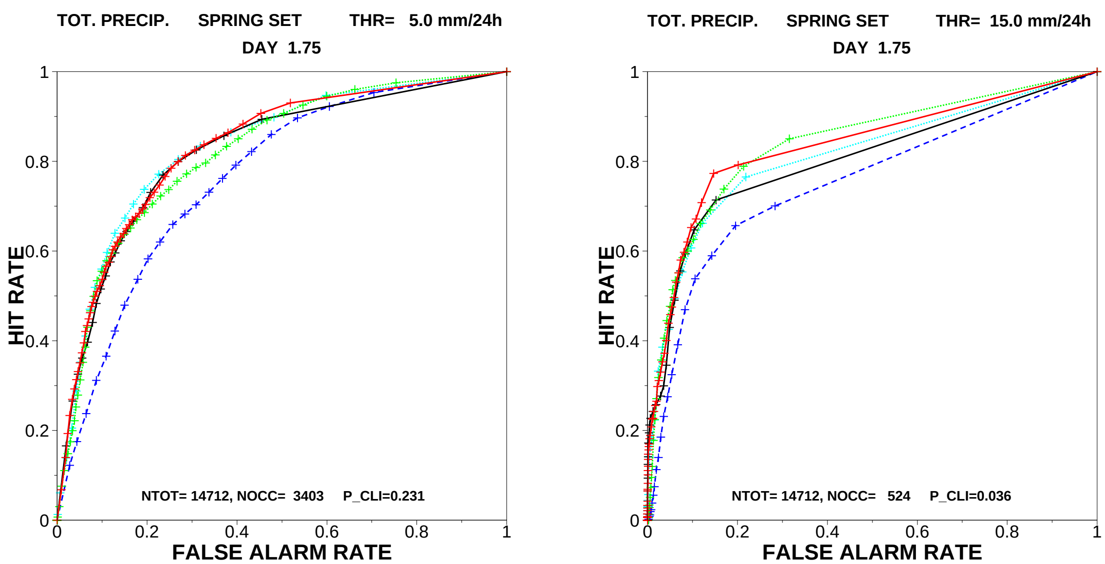



**Figure 6 a, b)** The figure shows the ROC-diagram for two different threshold values of total precipitation rates looking at the cases in the spring set at forecast time +42 hours. The threshold values are a) 5 mm/24h and b) 15 mm/24h.

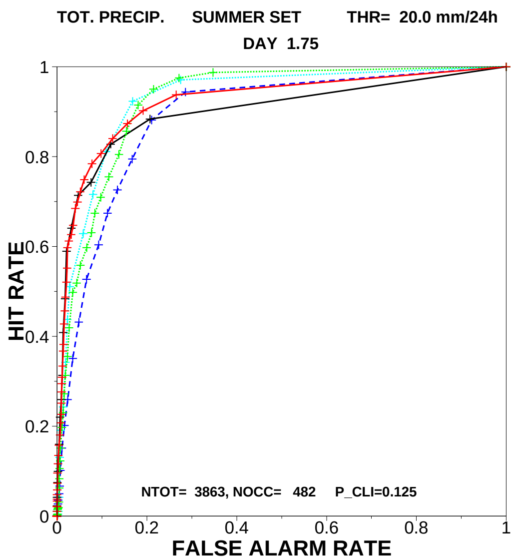
### 2.4.4 Summer

The summer set consists of only 4 cases, all with extreme precipitation rates.

Figure 7 a) and b) show that all the systems produce good results. CLAMEPS is the system with highest hit rates. At low false alarm rates CLAMEPS alternates with the other systems to be the system with highest skill. At the threshold values shown, LAMEPS has higher hit rates than EPS20.

For the summer period it has also been done a case study which will not be presented here. It showed however that LAMEPS produces the best local results in cases with extreme precipitation compared to EPS.

**7 a)** **7 b)**



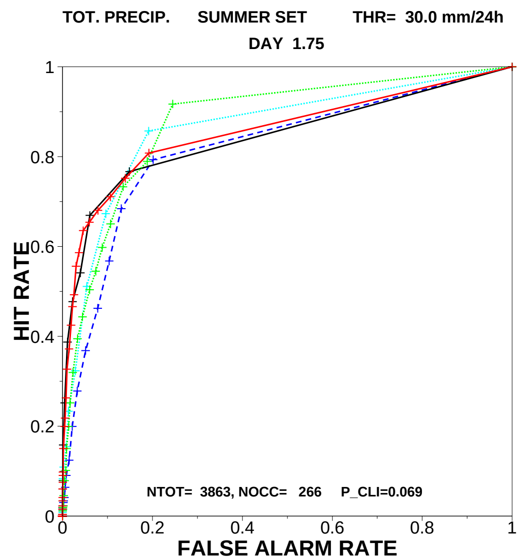




**Figure 7 a, b)** The figure shows the ROC-diagram for two different threshold values of total precipitation rates looking at the cases in the summer set at forecast time +42 hours. The threshold values are a) 20 mm/24h and b) 30mm/24h.

## Section 3: Discussion and conclusions

The results presented in section 2 show that EPS has generally the highest skill when predicting small precipitation rates. CLAMEPS has generally the best skill when predicting medium and large precipitation rates.

The good result of CLAMEPS at large precipitation rates comes mainly from LAMEPS. The spring period indicates that this result require an observed frequency of the precipitation event that is not too small. The fact that CLAMEPS gets its contribution mainly from LAMEPS at large precipitation rates, holds for both verification times (+42 h and +66 h, the last one not shown here). For medium precipitation rates (15 mm/24 hours), however, TEPS is generally better than LAMEPS and hence contributing most to the good results for CLAMEPS. By combining the two systems that both are designed for Northern Europe, we have been able to extend the precipitation interval for which the individual systems perform the best. The increase in ensemble members from 20+1 for the individual systems to 41+1 for CLAMEPS is also clearly favourable. The results are as expected, since systems with more members should be more capable of capturing extreme events.

An earlier study focusing on LAMEPS_SV showed very promising results (Frogner, 2002) for high precipitation rates verified in the same area (se figure 1). The LAMEPS system does not to the same degree as in earlier studies outperform EPS. One reason can probably be that the EPS system which we compare our results against, has been improved since the last study. Among other things, the horizontal resolution has increased from 120 km to 80 km and the vertical levels have increased from 31 to 40. The LAMEPS uses however not the latest operational version of HIRLAM at met.no. In a planned semi-operational setting of LAMEPS in 2004, the latest operational version of HIRLAM at met.no will be used, together with increased horizontal and vertical resolution.

## References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