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Kalman Filtering of DACFOS Verification Report for 1999

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LIST OF CONTENTS

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1. Introduction

Every 6 hours the operational ozone forecasting system DACFOS [1] automatically produces 48-hours ozone forecasts available on the DMI public Internet website. The post-processing of DACFOS with the Kalman filter (DACFOS-KF) has been used operationally since July 1st 1998, for DMI's monitoring station in Jægersborg. On July 1st 1999, two other stations (Lille Valby, Zealand and Keldsnor, Langeland) have been included in this operational forecasting system because the National Environmental Research Institute (NERI-DMU) delivers real-time hourly ozone concentration measurements on its website. These observations are automatically fetched on the Internet and may be used by DACFOS-KF if they are available without interruption. Unfortunately, Keldsnor presented some lack of data after September 1999.

A semi-automatic verification system of DACFOS-KF products is being developed. In the present report, verification results for the operational Kalman filter for ozone forecasts at these three stations is presented for the year 1999. Details about the Kalman filtering of DACFOS are available in [2].

In order to test the quality of the forecasts produced by DACFOS-KF, the following verification and validation report compares model results with observations (i.e. hourly averaged ozone concentration measurements), and with DACFOS' ozone forecasts without Kalman filter, allowing to verify the suitability of the post-processing of DACFOS with the Kalman filter. In the next section, observed and forecast maximum daily ozone concentrations during the year 1999 are compared for each of the three stations. In section 3, a verification of the performances of the "colour-forecast" (forecast of the class of the daily maximum ozone concentration) is presented. In section 4, the forecast skills are given for each station. Some statistics are described in section 5 about all the 4-daily forecasts performed during the year 1999. Finally, conclusions are drawn in section 6.

2. Monthly plots of maximum ozone concentration

Figure 1 displays monthly means of 1-hour middle ozone concentration measurements at the three stations. This shows that for Jægersborg, the averaged ozone concentration increased regularly from January to May, which was the month with the highest averaged ozone amount (exceeding 30ppb), and then decreased slowly during the rest of the year ; one can also notice that the averaged ozone concentration during the period June-August was lower than in April. This means that the so-called ozone season started a little in advance and that ozone pollution in Jægersborg during summer was relatively low. However, the ozone concentrations observed in Keldsnor during the 3rd quarter of the year, and in LilleValby during the 2nd half-year, were always much higher than in Jægersborg. Indeed, the hourly-mean measurements of surface ozone in Keldsnor and LilleValby were in average over the concentration of 30 ppb during summer.

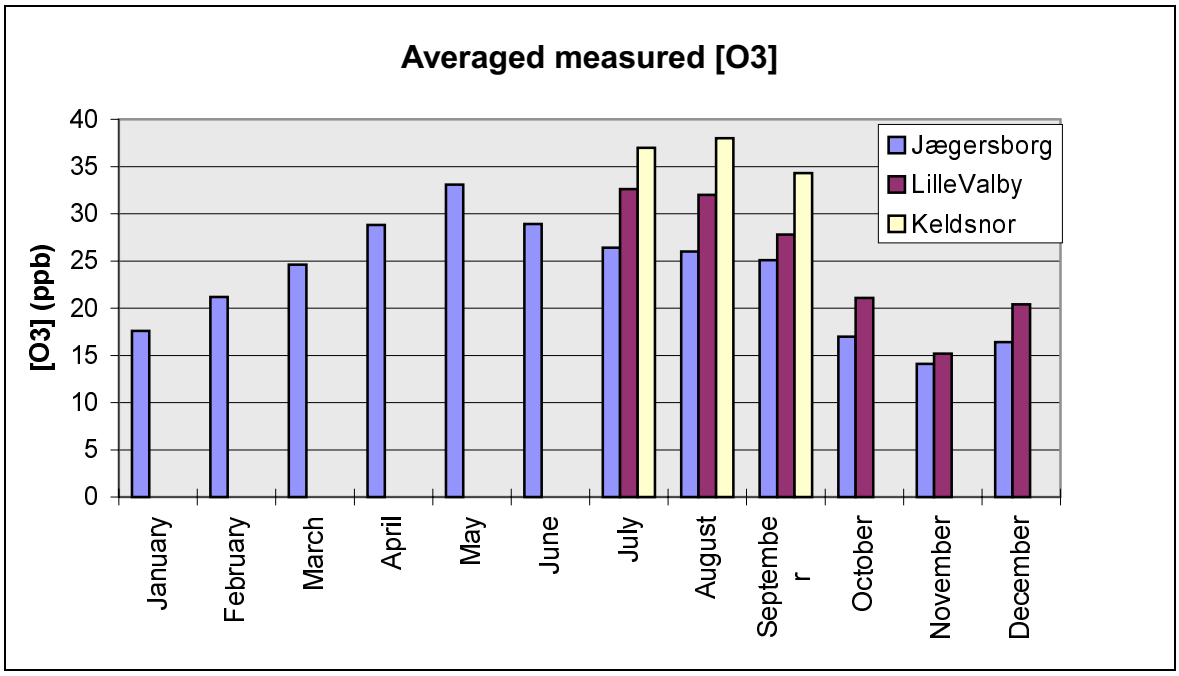

Figure 1 : Monthly means of 1-hour averaged surface ozone concentrations in 1999.

Monthly plots of the maximum ozone concentration observed and predicted (by DACFOS with and without the Kalman filter) each day at 00h (UTC) are shown for each station in figures 2 to 4. Observation data and/or forecast data are sometimes missing due to various computers problems ; in these cases the data are set to zero. These plots show that the threshold of 60 ppb (120 $\mu g/m^3$, corresponding to the high level of ozone concentration) was exceeded only a few days during the 2nd and 3rd quarters of the year.

From the plots for August at the three stations, one can see that there was a common ozone episode on August 6th, and the highest value was measured in LilleValby with 87,5 ppb at 15h (UTC), which was also the highest measurement for the year 1999. As shown on figure 5, which presents the 48-hour forecasts performed on August 5th at noon for Jægersborg and LilleValby, this peak was well forecast (time and level) by DACFOS-KF, while DACFOS underestimated it, especially in LilleValby.

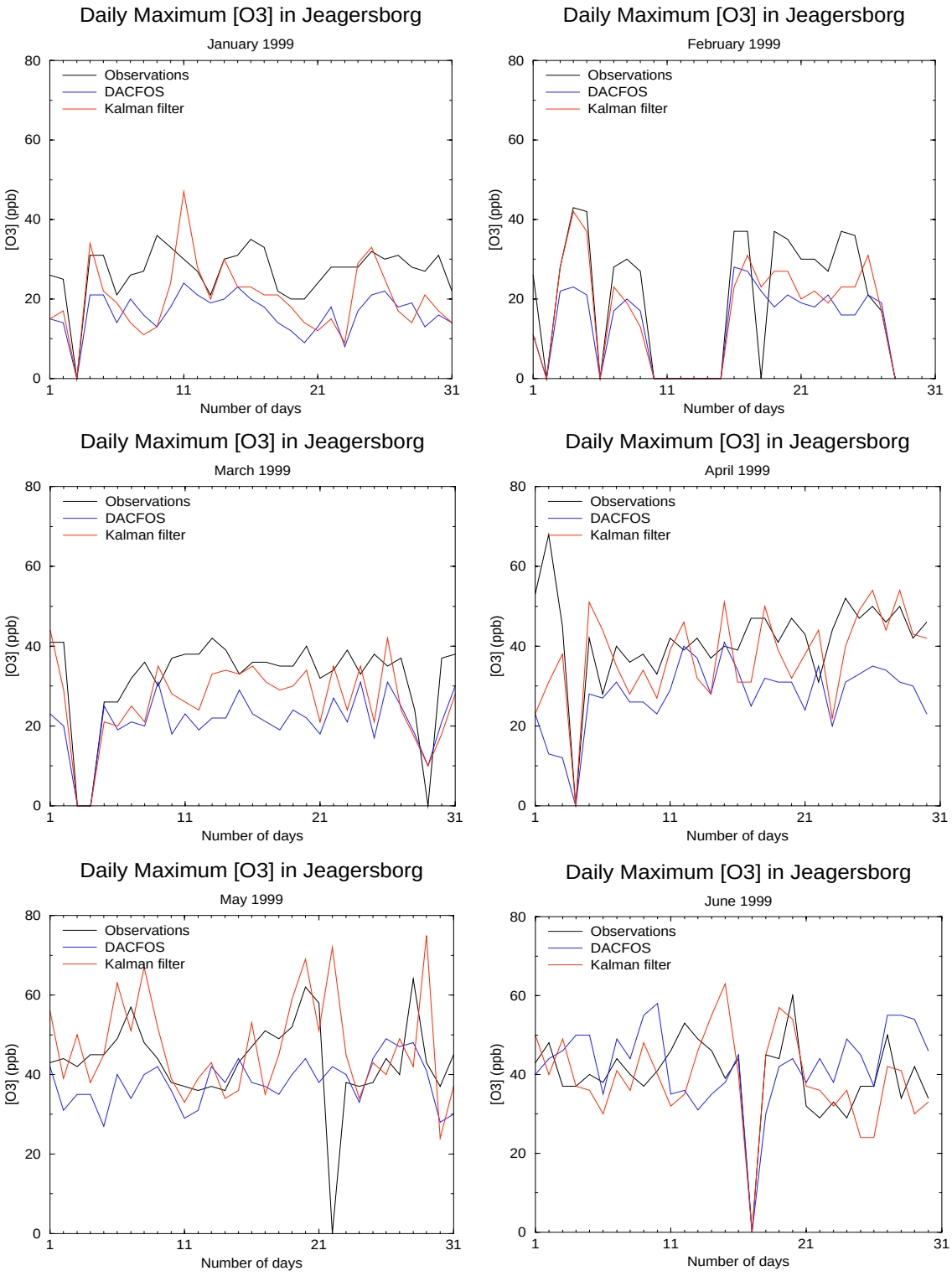

Figure 2a : Daily maximum ozone concentration forecasts performed each day at 00h (UTC) by DACFOS (in blue) and DACFOS-KF (in red), and compared to observations in Jægersborg during the first half-year of 1999.

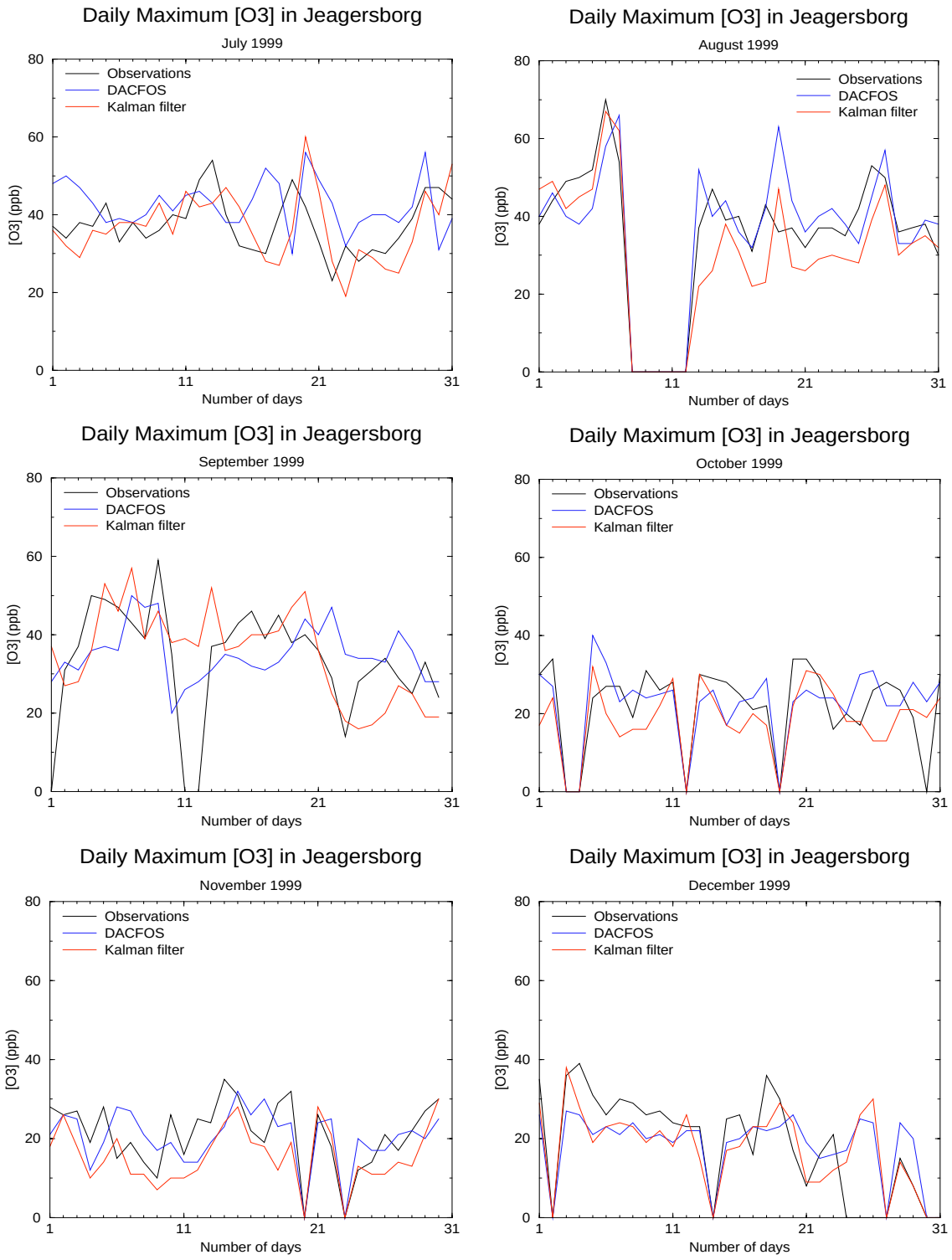

Figure 2b : Daily maximum ozone concentration forecasts performed each day at 00h (UTC) by DACFOS (in blue) and DACFOS-KF (in red), and compared to observations in Jægersborg during the 2nd half-year of 1999.

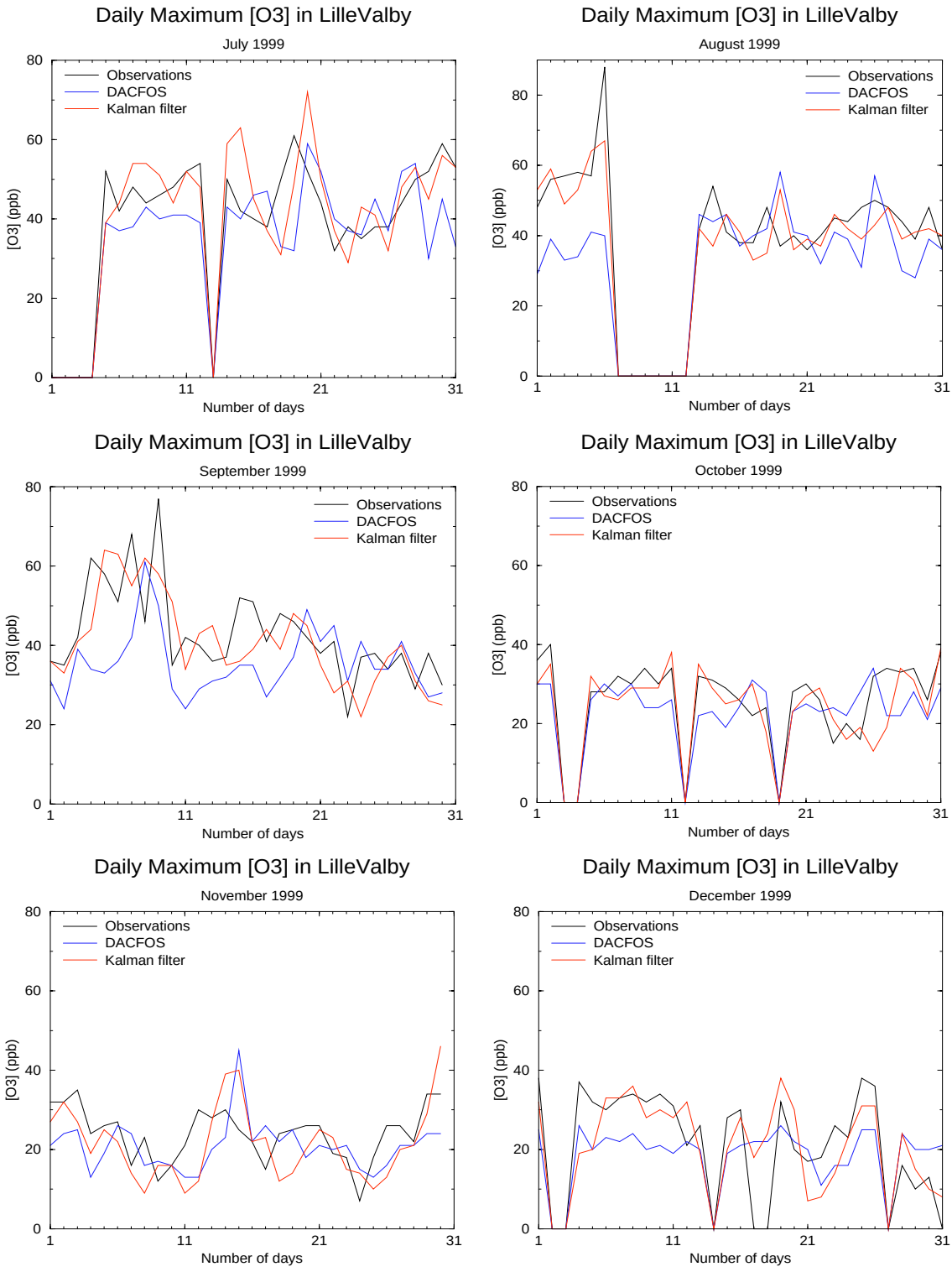

Figure 3 : Daily maximum ozone concentration forecasts performed each day at 00h (UTC) by DACFOS (in blue) and DACFOS-KF (in red), and compared to observations in LilleValby during the 2nd half-year of 1999.

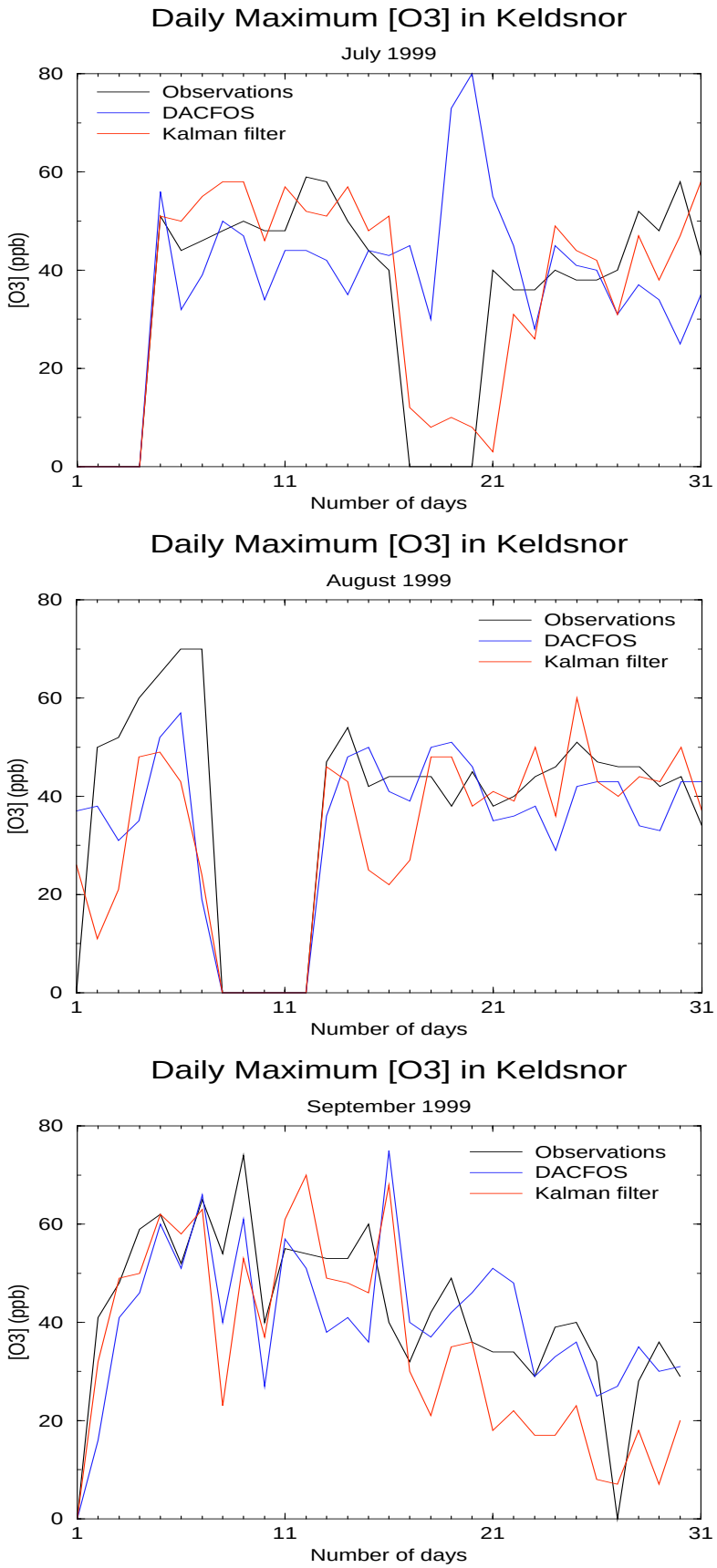

Figure 4 : Daily maximum ozone concentration forecasts performed each day at 00h (UTC) by DACFOS (in blue) and DACFOS-KF (in red), and compared to observations in Keldsnor during the 3rd quarter of 1999.

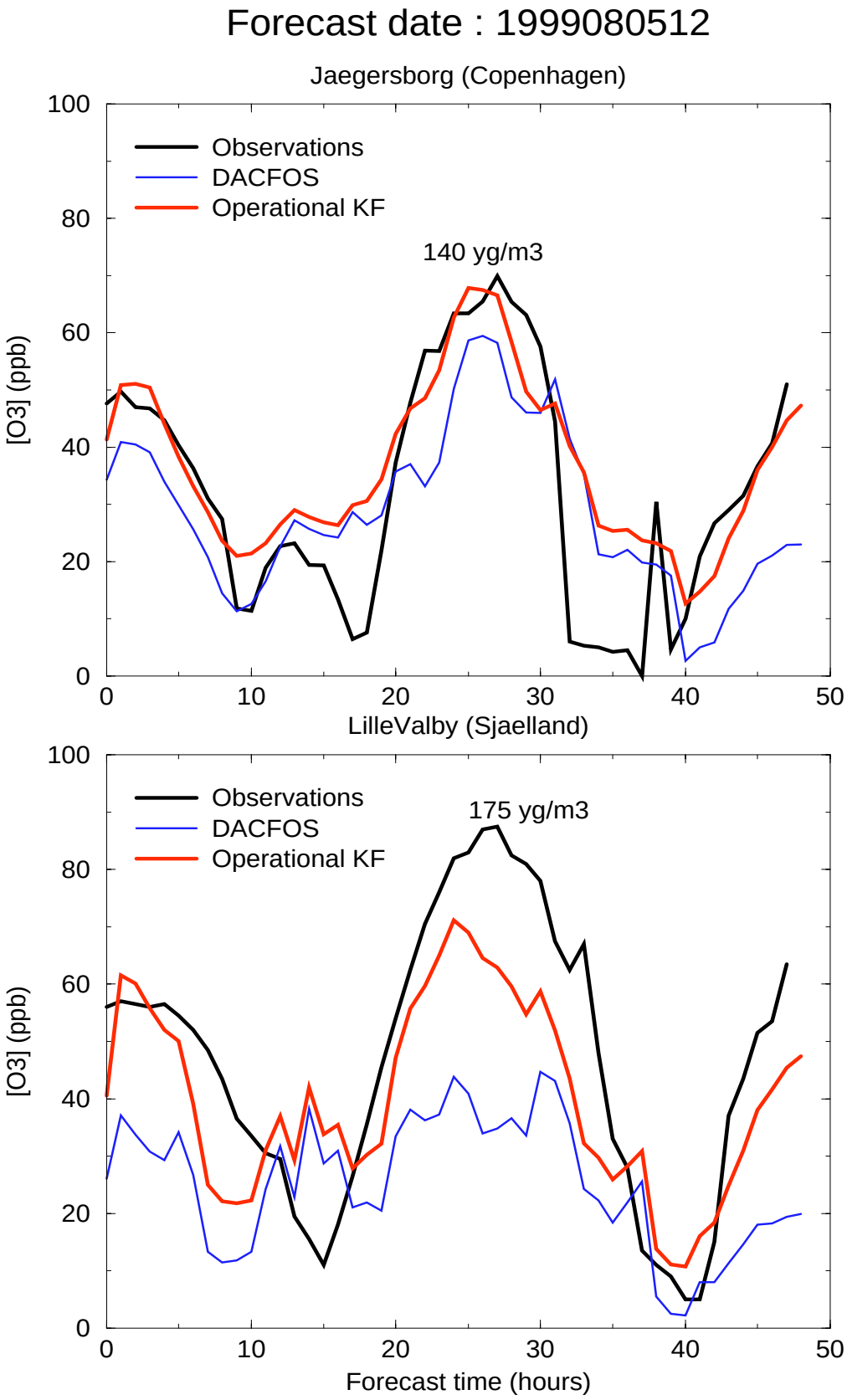

Figure 5 : Ozone concentration forecasts compared with observations in Jægersborg and LilleValby between August 5th at 12h (UTC) and 7th at 12h (UTC). "Operational KF" means DACFOS-KF.

3. Performances of the class-forecasts

Forecasts of the class of the ozone concentration are given daily on the Internet by a colour indicating the maximum ozone concentration expected for each of the next two days. These classes are called LOW (green) when the maximum ozone concentration is below 30 ppb, MEDIUM (orange) when it is between 30 ppb and 60 ppb, HIGH (yellow) between 60 ppb and 90 ppb, and VERY HIGH (red) when it is over 90 ppb. In the following, performance results of the class forecasts for each station are given by quarter. We will introduce the terms "efficacy" to indicate the percentage of good forecast-days in a class, and "efficiency" to indicate the percentage of good forecasts, related to the total number of forecasts.

3.1 Jægersborg

Figure 6a shows the number of days observed and forecast in each class during the 1st quarter of 1999 for Jægersborg ; only the forecasts performed at 00h (UTC) are taken into account in this figure.

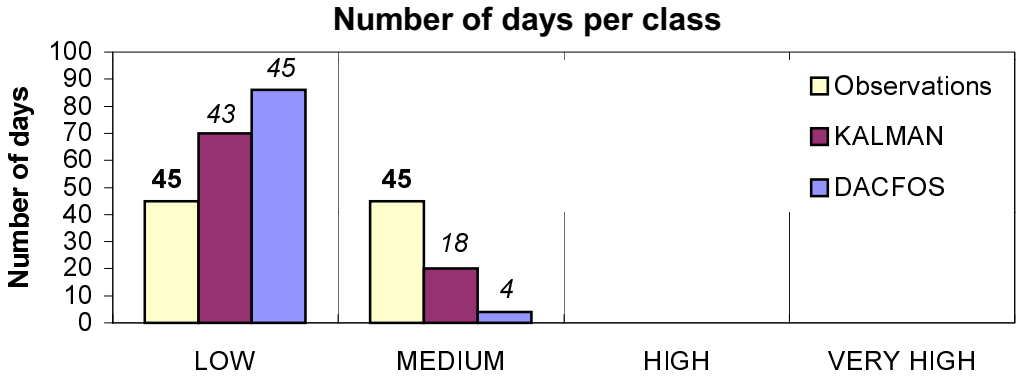

Figure 6a : Number of days during the 1st quarter of 1999 in each of the four ozone concentration classes for measurements in Jægersborg and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

Among the 45 days observed in the LOW class, 43 were predicted by DACFOS-KF for a total number of 70 forecast days in this class, which yields an efficacy of 96% and an efficiency of the forecast of 61% ; DACFOS predicted well all the 45 days (efficacy 100%), but with a higher amount (86) of forecast days in this class, yielding an efficiency of only 52%. In the MEDIUM class, there were also 45 days, among which DACFOS-KF gave only 18 days correctly for 20 forecast days in this class (efficacy: 40%, efficiency: 90%) ; DACFOS forecast only 4 days in this class, but they were all correct (efficacy: 9%, efficiency: 100%).

The class performances of the whole 4-daily forecasts for both the first and the second forecast days are shown on figure 6b.

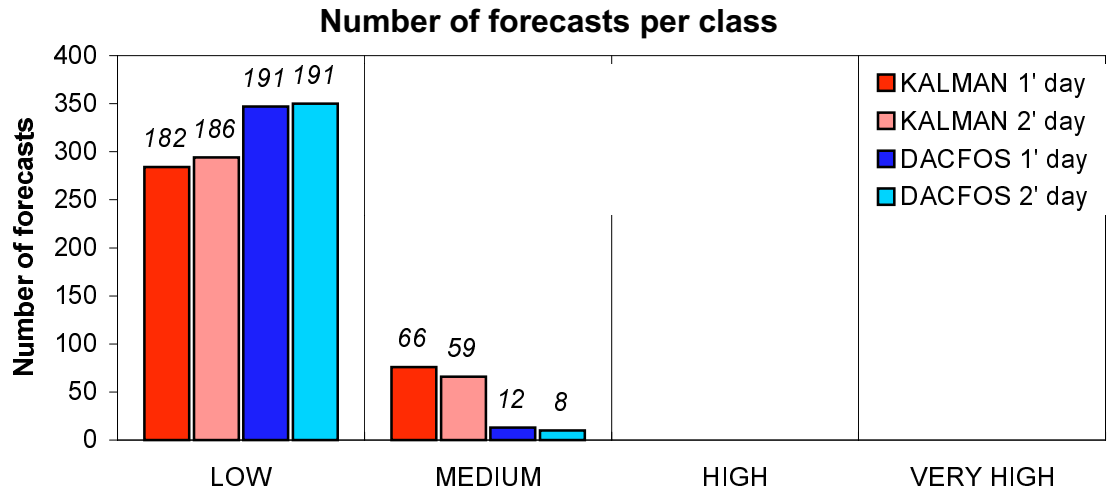

Figure 6b : Total number of 2-days forecasts during the 1st quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 360 forecasts.

From the results of figure 6b, one can calculate the total efficiency of the forecasts. For the first day 69% of DACFOS-KF class-forecasts coincided with the observed class (64% for the LOW class and 87% for the MEDIUM class) against 56% of DACFOS class-forecasts (55% for LOW, 92% for MEDIUM). For the second day these rates were 68% for DACFOS-KF (63% for LOW, 89% for MEDIUM) and 55% for DACFOS (55% for LOW, 80% for MEDIUM).

In the same way, figures 7a and 7b present the corresponding results for the 2nd quarter.

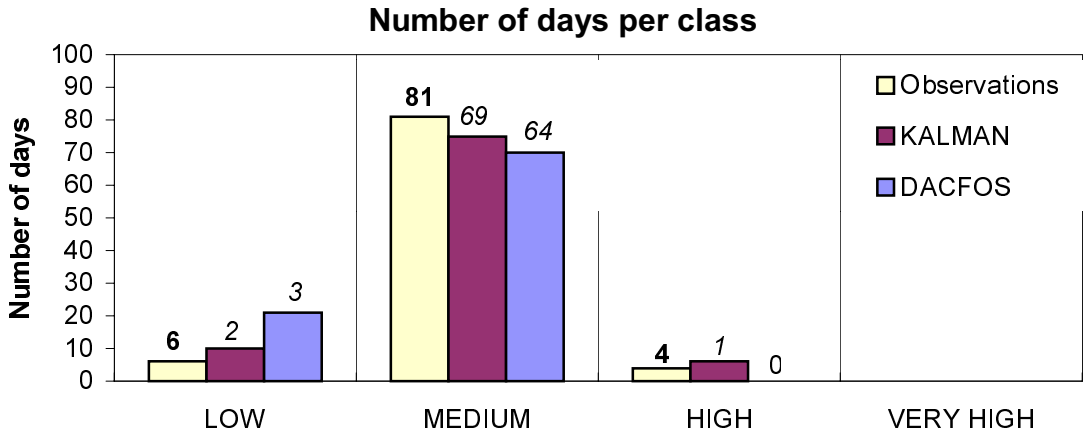

Figure 7a : Number of days during the 2nd quarter of 1999 in each of the four ozone concentration classes for measurements in Jægersborg and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

Only 6 days were observed in the LOW class, among which DACFOS-KF correctly predicted only 2 with 10 forecast days, yielding an efficacy of 33% and a forecast efficiency of 20%. DACFOS predicted 3 days correctly (efficacy 50%) for an amount of 21 forecast days in this class, which yields an efficiency of only 14%. In the MEDIUM

class, there were 81 days observed ; DACFOS-KF produced 75 forecast days, among which 69 were correct (efficacy: 85%, efficiency: 92%). DACFOS yielded 70 forecast days in this class with 64 correct (efficacy: 79%, efficiency: 91%). Four days were observed in the HIGH class, only one was well predicted by DACFOS-KF for 6 forecasts days in this class (efficacy: 25%, efficiency: 17%) ; none was predicted by DACFOS (the few forecasts produced in this class were not at 00h).

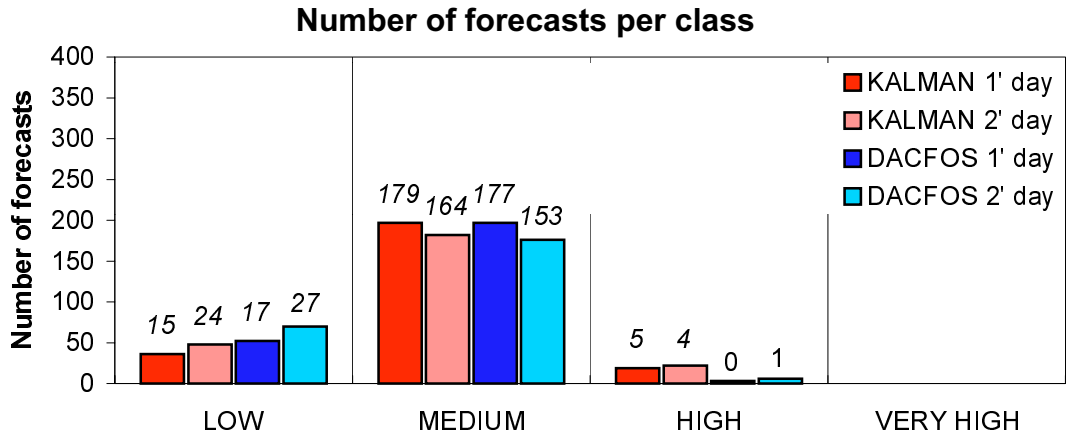

Figure 7b : Total number of 2-days forecasts during the 2nd quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 252 forecasts.

The total efficiency of DACFOS-KF for the first forecast day was 79% (42% in LOW, 91% in MEDIUM and 26% in HIGH) and 76% (50% in LOW, 90% in MEDIUM and 18% in HIGH) for the second forecast day. For DACFOS these rates were 77% (33% in LOW, 90% in MEDIUM and 0% in HIGH) for the first forecast day and 72% (39% in LOW, 87% in MEDIUM and 17% in HIGH) for the second day.

The same results for the 3rd quarter are presented in figures 8a and 8b.

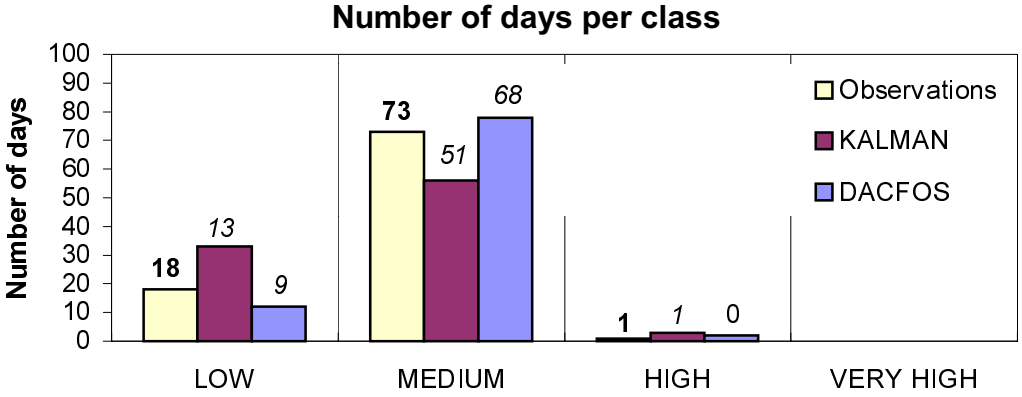

Figure 8a : Number of days during the 3rd quarter of 1999 in each of the four ozone concentration classes for measurements in Jægersborg and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

Eighteen days were observed in the LOW class, DACFOS-KF correctly predicted 13 for an amount of 33 forecast days in this class, yielding an efficacy of 72% and a forecast efficiency of 39%. DACFOS well predicted 9 days (efficacy 50%) with 12 forecast days in this class, yielding an efficiency of 75%. In the MEDIUM class, there were 73 days observed and DACFOS-KF performed 51 correct days for a total of 56 forecast days in this class (efficacy: 70%, efficiency: 91%), while DACFOS yielded 68 correct days for 78 forecast days in this class (efficacy: 93%, efficiency: 87%). Only one day was observed in the HIGH class, which was well predicted by DACFOS-KF with 3 forecasts days in this class (efficacy: 100%, efficiency: 33%). For DACFOS, none of the two forecast days in this class were correct (efficacy: 0%, efficiency: 0%).

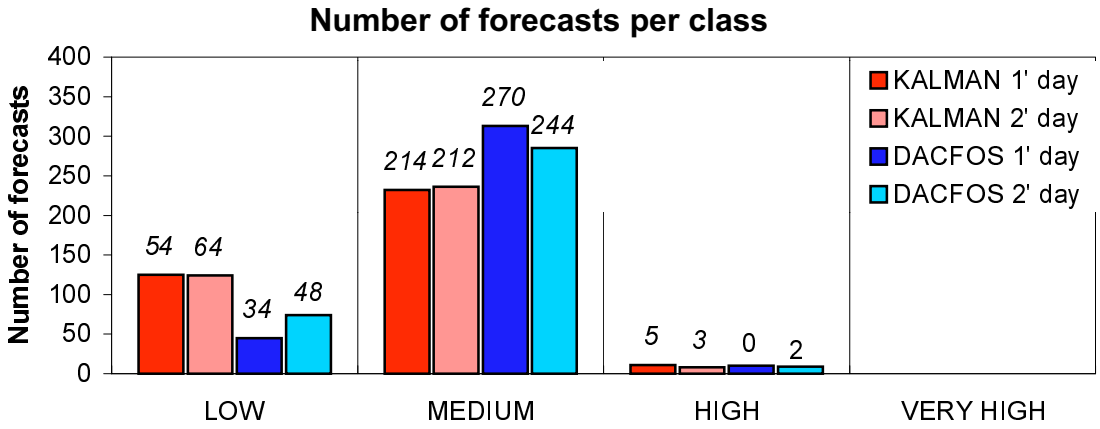

Figure 8b : Total number of 2-days forecasts during the 3rd quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 368 forecasts.

The efficiency of DACFOS-KF first forecast day was 74% (43% in LOW, 92% in MEDIUM and 45% in HIGH) and 79% (52% in LOW, 90% in MEDIUM and 38% in HIGH) for the second forecast day. For DACFOS these rates were 83% (76% in LOW, 86% in MEDIUM and 0% in HIGH) for the first forecast day and 80% (65% in LOW, 86% in MEDIUM and 22% in HIGH) for the second day.

During the last quarter of the year, 70 days were observed in the LOW class, among which DACFOS-KF predicted 66 days for a total number of 79 forecast days in this class, which yields an efficacy of 94% and an efficiency of the forecast of 84%. DACFOS predicted the same amount of days in this class with 64 correct days, yielding an efficacy of 91% and an efficiency of 81%. In the MEDIUM class, there were 16 days, among which DACFOS-KF only performed 3 days correctly for 7 forecast days (efficacy: 19%, efficiency: 43%). For the same amount of forecast days in this class, DACFOS gave only one good day (efficacy: 6%, efficiency: 14%). The corresponding diagram for the fourth quarter of 1999 is shown in figure 9a, while figure 9b presents the performances of all the forecasts during the same period.

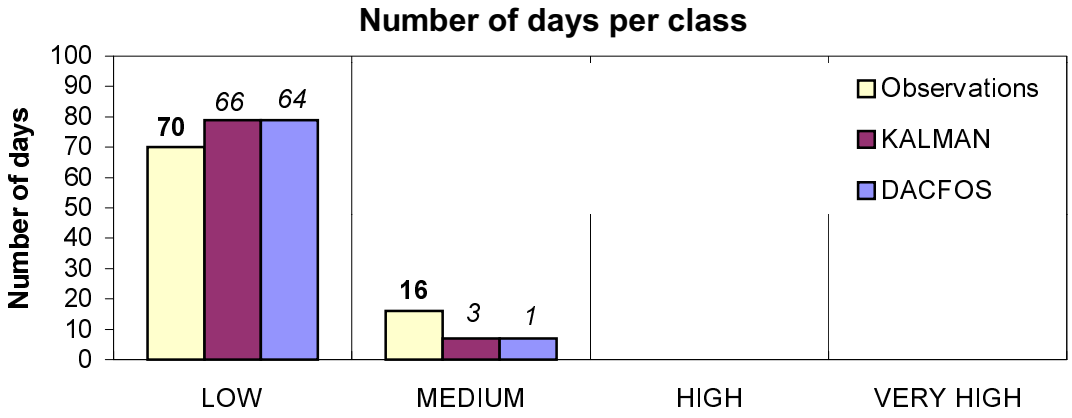

Figure 9a : Number of days during the 4th quarter of 1999 in each of the four ozone concentration classes for measurements in Jægersborg and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

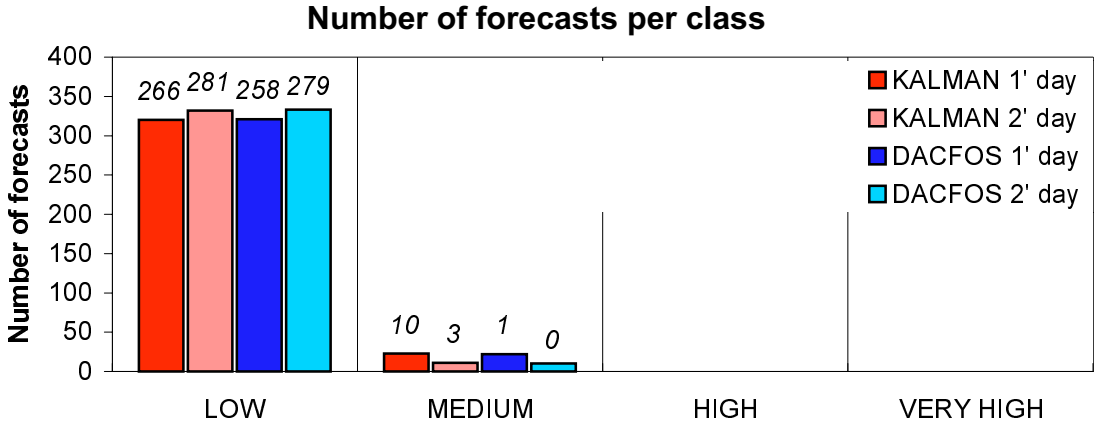

Figure 9b : Total number of 2-days forecasts during the 4th quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 343 forecasts.

The efficiency of DACFOS-KF first forecast day was 80% (83% in LOW and 43% in MEDIUM) and 83% (85% in LOW and 27% in MEDIUM) for the second forecast day. For DACFOS these rates were 76% (80% in LOW and 5% in MEDIUM) for the first forecast day and 81% (84% in LOW and 0% in MEDIUM) for the second day.

Finally, contingency tables for exceeding the threshold of 60 ppb are given in table 1, by taking account of all forecasts performed for Jægersborg in 1999.

DACFOS-KF	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	10	20	30
[O3]<60ppb	12	1281	1293
Total	22	1301	1323

DACFOS	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	3	12	15
[O3]<60ppb	19	1289	1308
Total	22	1301	1323

Table 1 : Contingency tables for exceeding the threshold of 60 ppb in Jægersborg during 1999.

One can read in these tables that DACFOS-KF produced 10 forecasts corresponding to observed excesses of the 60 ppb threshold, 12 missed excesses and 20 false alarms. DACFOS only had 3 forecasts equivalent to observed excesses, 19 missed and 12 false alarms.

3.2 LilleValby

Figure 10a presents the numbers of observed and forecast days in each class during the 3rd quarter of 1999 in LilleValby.

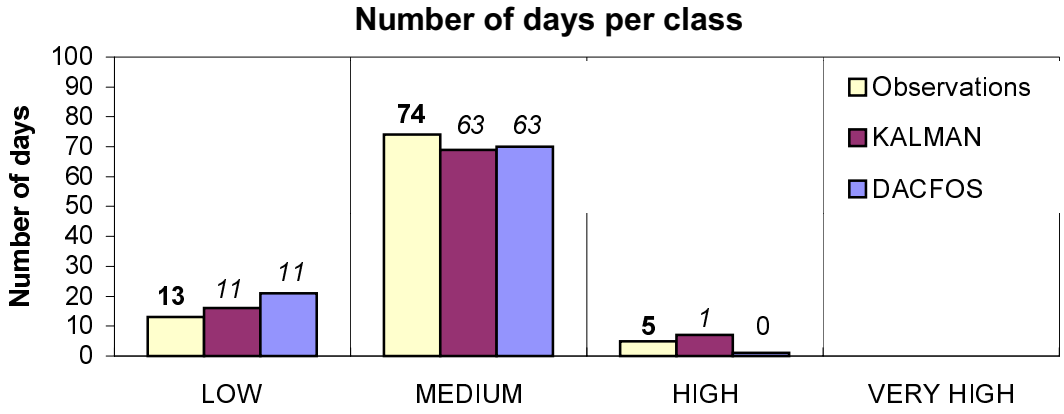

Figure 10a : Number of days during the 3rd quarter of 1999 in each of the four ozone concentration classes for measurements in LilleValby and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

Thirteen days were observed in the LOW class, among which both DACFOS-KF and DACFOS correctly predicted 11 (efficacy: 85%) with 16 forecast days in this class for DACFOS-KF (efficiency: 69%), and 21 for DACFOS (efficiency: 52%). There were 74 days observed in the MEDIUM class and both DACFOS-KF and DACFOS performed 63 correct days (efficacy: 85%) for a total of 69 forecast days in this class for the former (efficiency: 91%), and 70 for the later (efficiency: 90%). Five days were observed in the HIGH class, of which only one was predicted by DACFOS-KF for 7 forecasts days (efficacy: 20%, efficiency: 14%). DACFOS forecast one day in this class, but which was not correct (efficacy: 0%, efficiency: 0%).

The diagram in figure 10b shows the relative performances of all the forecasts performed for LilleValby during the 3rd quarter of 1999. From this diagram, one can calculate the efficiency of DACFOS-KF to be 81% (56% in LOW, 91% in MEDIUM and 35% in HIGH) for the first forecast day and 81% (63% in LOW, 91% in MEDIUM and 30% in HIGH) for the second forecast day. For DACFOS these rates were 81% (51% in LOW, 90% in MEDIUM and 17% in HIGH) for the first forecast day and 75% (42% in LOW, 88% in MEDIUM and 0% in HIGH) for the second day.

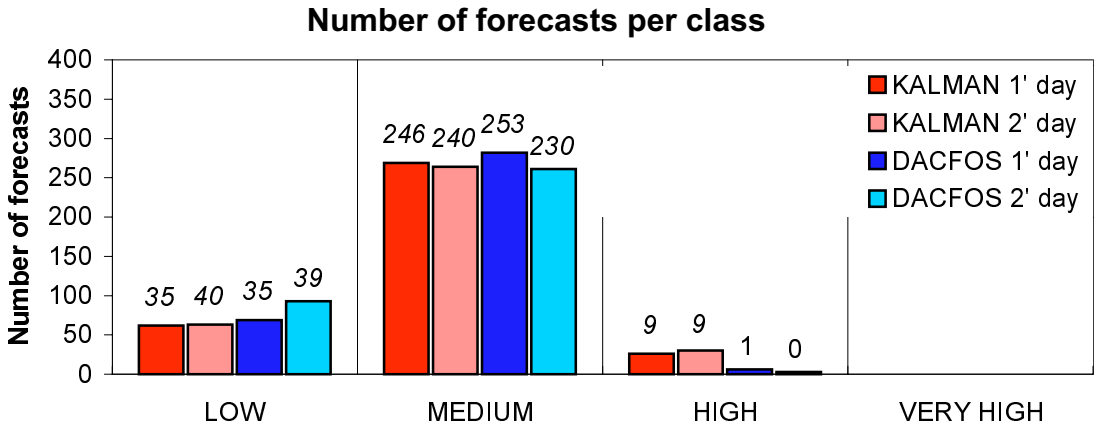

Figure 10b : Total number of 2-days forecasts during the 3rd quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 357 forecasts.

In the same way, the corresponding results of the 4th quarter are presented in figures 11.

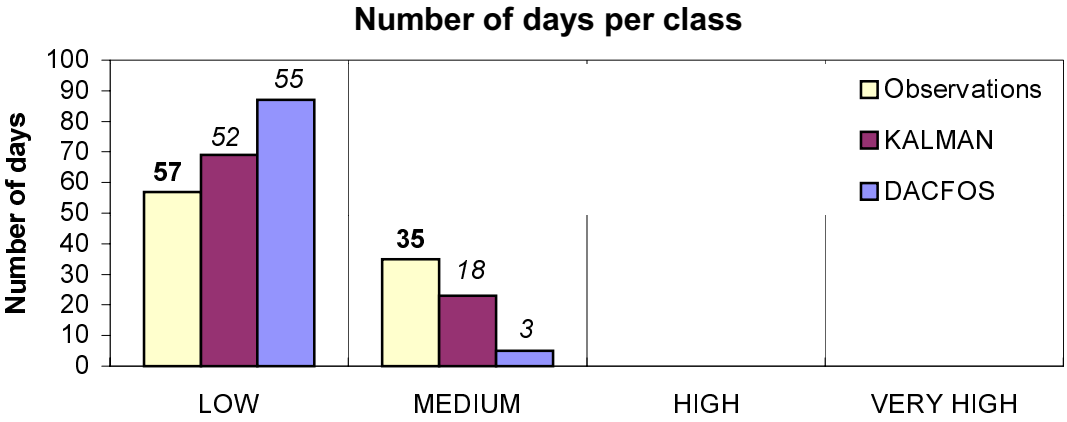

Figure 11a : Number of days during the 4th quarter of 1999 in each of the four ozone concentration classes for measurements in LilleValby and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

During the 4th quarter, 57 days were observed in the LOW class, among which DACFOS-KF predicted 52 days for a total number of 69 forecast days, which corresponds to an efficacy of 91% and a forecast efficiency of 75%. DACFOS predicted correctly 55 days (efficacy 96%) for a total amount of 87 forecast days in this class (efficiency: 63%). In the MEDIUM class, there were 35 days, among which DACFOS-KF performed correctly 18 days for 23 forecast days in this class (efficacy: 51%, efficiency: 78%), while only 3 correct days were forecast by DACFOS with 5 days in this class (efficacy: 9%, efficiency: 60%).

From figure 11b, one can calculate that the efficiency of DACFOS-KF first forecast day was 78% (78% in LOW and 79% in MEDIUM) and 73% (74% in LOW, 68% in MEDIUM and 0% in HIGH) for the second forecast day. For DACFOS these rates were 62% (63% in LOW and 41% in MEDIUM) for the first forecast day and 64% (65% in LOW and 33% in MEDIUM) for the second day.

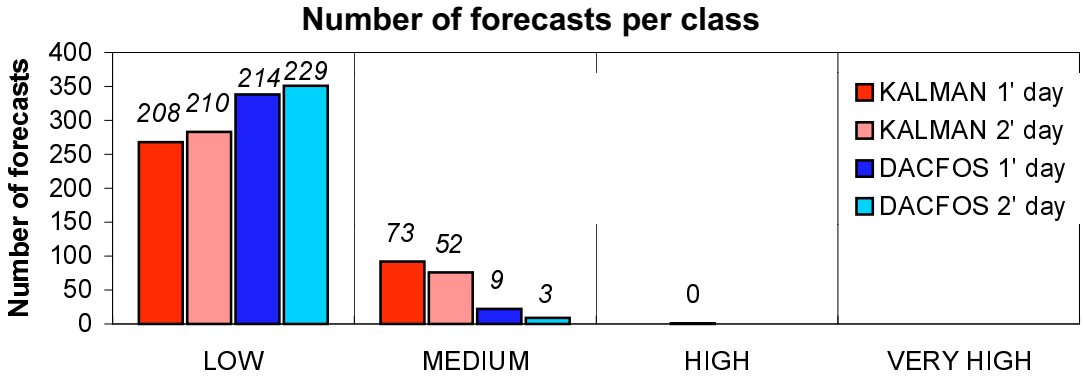

Figure 11b : Total number of 2-days forecasts during the 4th quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 360 forecasts.

Table 2 presents contingency tables for exceeding the threshold of 60 ppb, obtained from the forecasts performed for LilleValby between July and December 1999. This shows that DACFOS-KF forecasts were correct 9 times against 1 time for DACFOS. However, DACFOS-KF gave 18 false alarms against 5 for DACFOS.

DACFOS-KF	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	9	18	27
[O3]<60ppb	19	671	690
Total	28	689	717

DACFOS	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	1	5	6
[O3]<60ppb	27	684	711
Total	28	689	717

Table 2 : Contingency tables for exceeding the threshold of 60 ppb in LilleValby during the 2nd half-year of 1999.

3.3 Keldsnor

In 1999 DACFOS-KF for Keldsnor was only operational during the 3rd quarter of the year. Performances of the class forecasts are presented below.

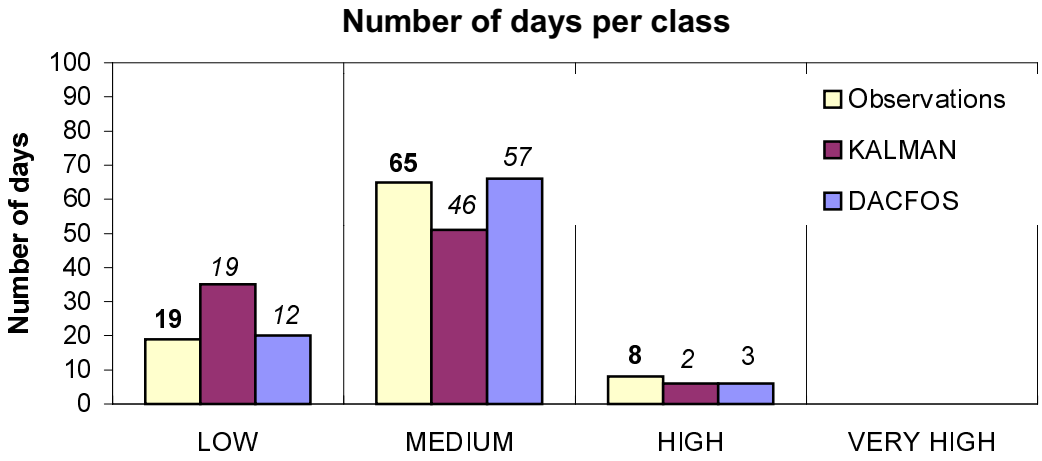

Figure 12a : Number of days during the 3rd quarter of 1999 in each of the four ozone concentration classes for measurements in Keldsnor and both DACFOS and DACFOS-KF forecasts at 00h (UTC). The *italic* numbers are the numbers of days where the forecast class coincides to the observed class.

From the diagram in figure 12a, one can note that 19 days were observed in the LOW class, all of those were correctly predicted by DACFOS-KF (efficacy of 100%), but with 35 forecast days in this class (efficiency: 54%). DACFOS predicted 12 good days (efficacy: 63%) for 20 days in this class (efficiency: 60%). In the MEDIUM class, there were 65 days observed and DACFOS-KF gave 46 correct days (efficacy: 71%) for a total of 51 forecast days (efficiency: 90%). DACFOS performed 57 good days (efficacy: 88%) for a total of 66 days in this class (efficiency: 86%). Eight days were observed in the HIGH class, and only two of those days were predicted by DACFOS-KF with 6 forecasts days in this class (efficacy: 25%, efficiency: 33%). DACFOS performed 3 good days for 6 forecast days in this class (efficacy: 38%, efficiency: 50%).

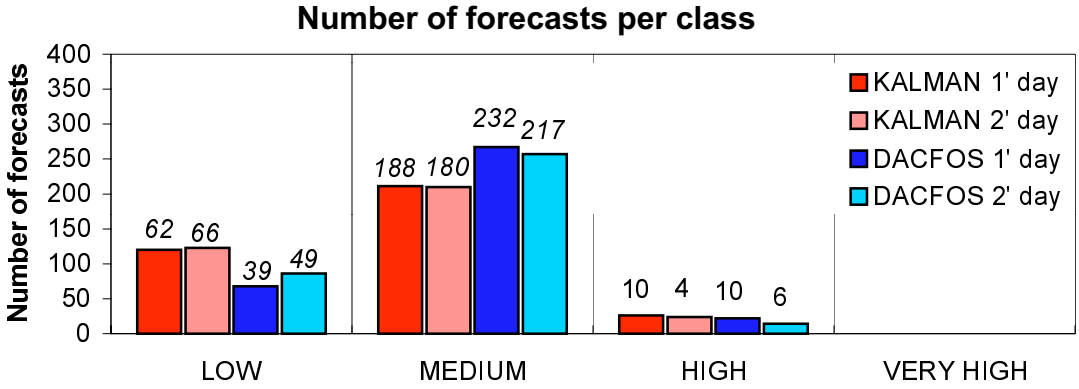

Figure 12b : Total number of 2-days forecasts during the 3rd quarter of 1999 in each of the four ozone concentration classes for both DACFOS and DACFOS-KF. The *italic* numbers are the numbers of forecasts where the forecast class coincides to the observed class. There are in all 357 forecasts.

From the diagram in figure 9b, one can calculate that the efficiency for the first forecast day of DACFOS-KF was 73% (43% in LOW, 89% in MEDIUM and 38% in HIGH) and 70% (54% in LOW, 86% in MEDIUM and 17% in HIGH) for the second forecast day. For DACFOS these rates were 79% (57% in LOW, 87% in MEDIUM and 45% in HIGH) for the first forecast day and 76% (57% in LOW, 84% in MEDIUM and 43% in HIGH) for the second day.

Contingency tables for exceeding the threshold of 60 ppb, for all forecasts performed for Keldsnor from July to September 1999, are shown on table 3.

DACFOS-KF	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	10	16	26
[O3]<60ppb	23	308	331
Total	33	324	357

DACFOS	Observed		Total
Forecast	[O3]>60ppb	[O3]<60ppb	
[O3]>60ppb	10	12	22
[O3]<60ppb	23	312	335
Total	33	324	357

Table 3 : Contingency tables for exceeding the threshold of 60 ppb in Keldsnor during the 3rd quarter of 1999.

Table 3 shows that both DACFOS-KF and DACFOS forecasts above the 60 ppb threshold were correct 10 times, but DACFOS-KF yielded 16 false alarms against 12 for DACFOS.

4. Forecast skills

Definition of the forecast skill is given by:

$$FC = 100 \times N_r / N$$

where N_r is the number of forecast hits inside an uncertainty interval r and N is the total number of forecasts ; in this paper, r=10 ppb.

4.1 Jægersborg

The forecast skills for the daily maximum ozone concentration in Jægersborg during 1999 are given as follows :

DACFOS-KF 1st day : FC= 74% DACFOS-KF 2nd day : FC= 65%
DACFOS 1st day : FC= 65% DACFOS 2nd day : FC= 64%

In more details, figure 13 shows a histogram of the distributions of the errors between forecast and measured daily maximum concentrations for the first and the second forecast days of DACFOS and DACFOS-KF, respectively.

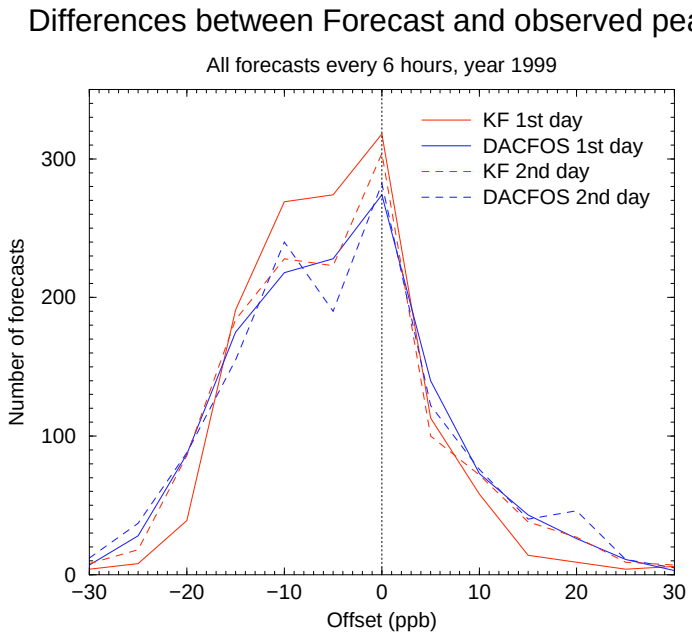

Figure 13 : Histogram of the differences between forecast and measured daily maximum ozone concentrations in Jægersborg during 1999.

It is easy to see that both models have a slight tendency to underestimate the peaks.

4.2 LilleValby

The forecast skills obtained for LilleValby during the 2nd half-year of 1999 are the following:

DACFOS-KF 1st day : FC= 80% DACFOS-KF 2nd day : FC= 75%
DACFOS 1st day : FC= 67% DACFOS 2nd day : FC= 63%

The corresponding diagram describing the distribution of errors is plotted in figure 14. One can observe that DACFOS has a much more pronounced tendency to underestimate the daily peaks than DACFOS-KF.

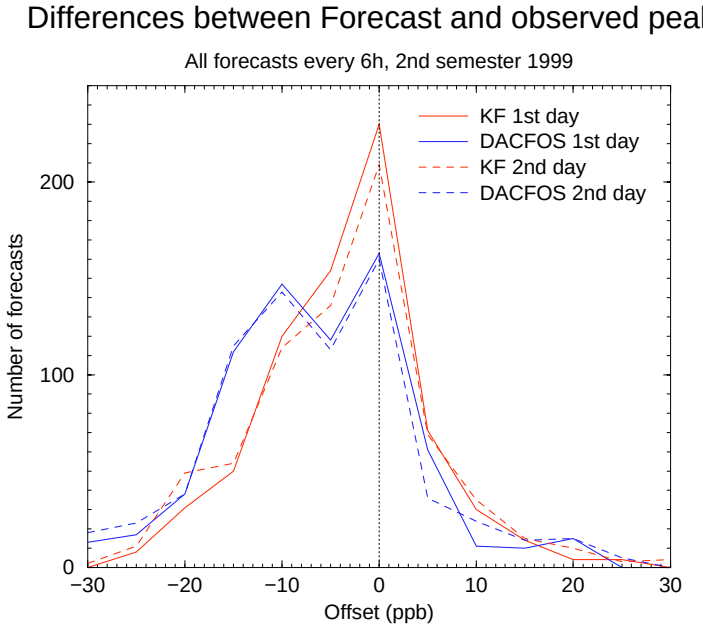

Figure 14 : Histogram of the differences between forecast and measured daily maximum ozone concentrations in LilleValby during the 2nd half-year of 1999.

4.3 Keldsnor

The forecast skills for the daily maximum concentration for Keldsnor are the following:

DACFOS-KF 1st day : FC= 64% DACFOS-KF 2nd day : FC= 53%

DACFOS 1st day : FC= 60% DACFOS 2nd day : FC= 57%

The histogram in figure 15 shows that the majority of first days of DACFOS-KF forecasts are less than 10 ppb from the observed peaks, but for the second day of forecast, DACFOS-KF is generally inferior to DACFOS.

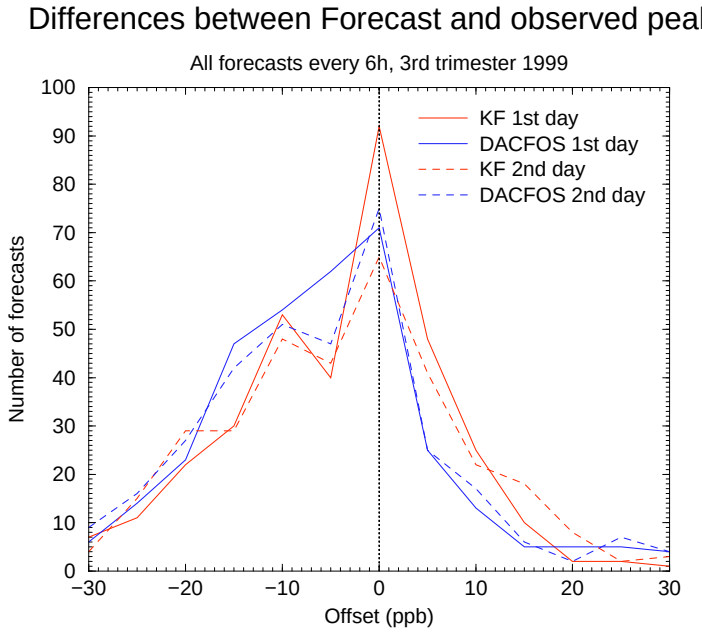

Figure 15 : Histogram of the differences between forecast and measured daily maximum ozone concentrations in Keldsnor during the 3rd quarter of 1999.

5. Statistics

This subsection details some further statistics that test the accuracy of each hour of the two days forecasts performed four times daily for each station during 1999 ; see [2] for details about these statistics.

5.1 Jægersborg

Figure 16 shows the evolution of the correlation for DACFOS and DACFOS-KF plotted as a function of the forecast time. This shows that during the three first quarters of the year, DACFOS-KF had the highest correlation coefficients over the entire forecast period. However, during the last quarter, the average correlation of DACFOS-KF was only around 25% and always lower than the correlation of DACFOS ; this is not very important since it concerns the period during which the ozone concentration is low.

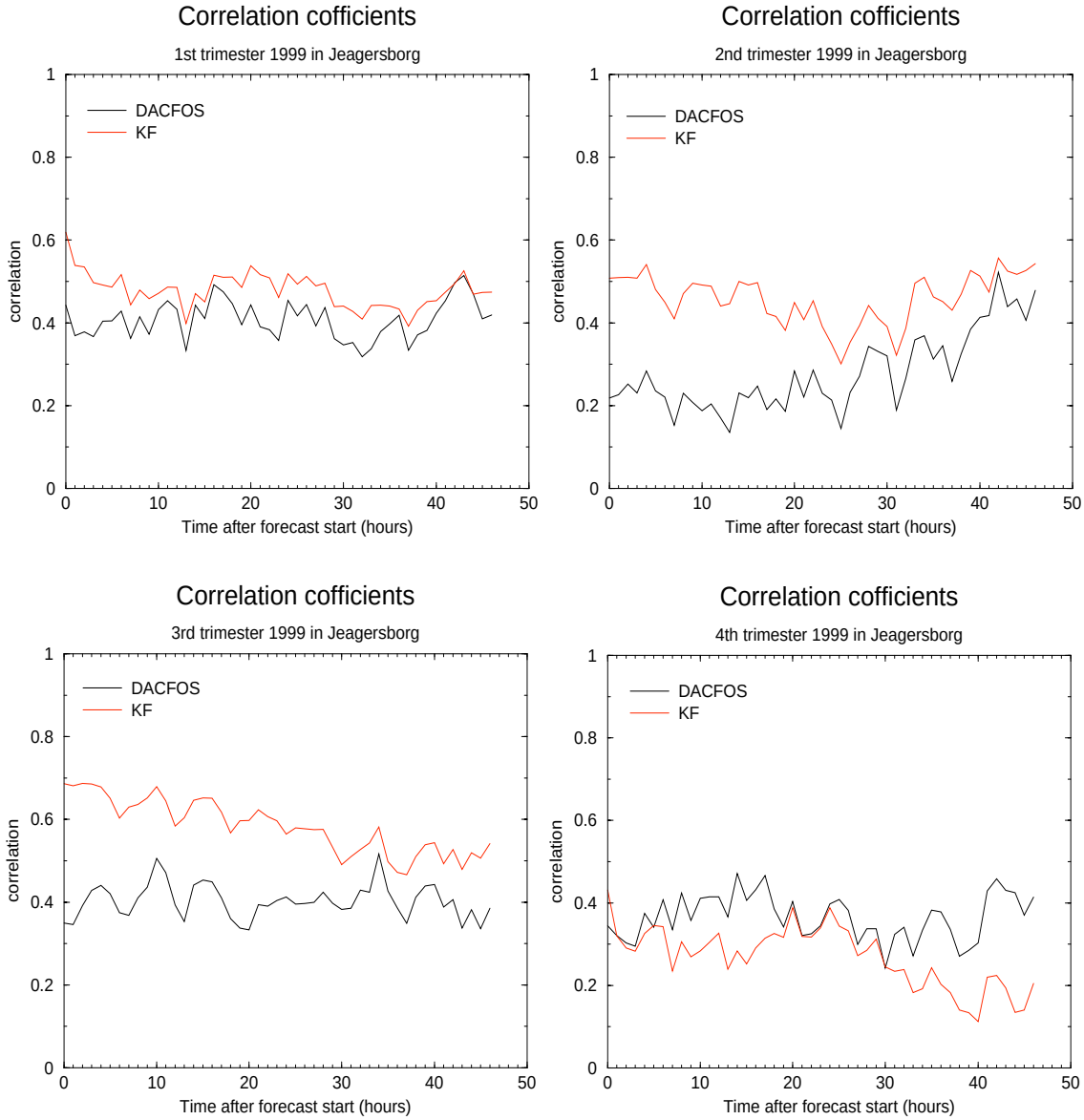

Figure 16 : Evolution of the correlation coefficients for DACFOS and DACFOS-KF forecasts as a function of time after forecast origin.

Figure 17 presents the evolution of the mean error (bias) and root-mean-square-error (rms) as a function of forecast time. The values of the biases were almost always negative. This confirms that both models have a tendance to slightly underestimate the observations ; however, except during the 3rd quarter of the year, the mean error of DACFOS-KF was always lower than DACFOS. The rms of the error of DACFOS-KF was always smaller than DACFOS, but tended to slightly increase with forecast length.

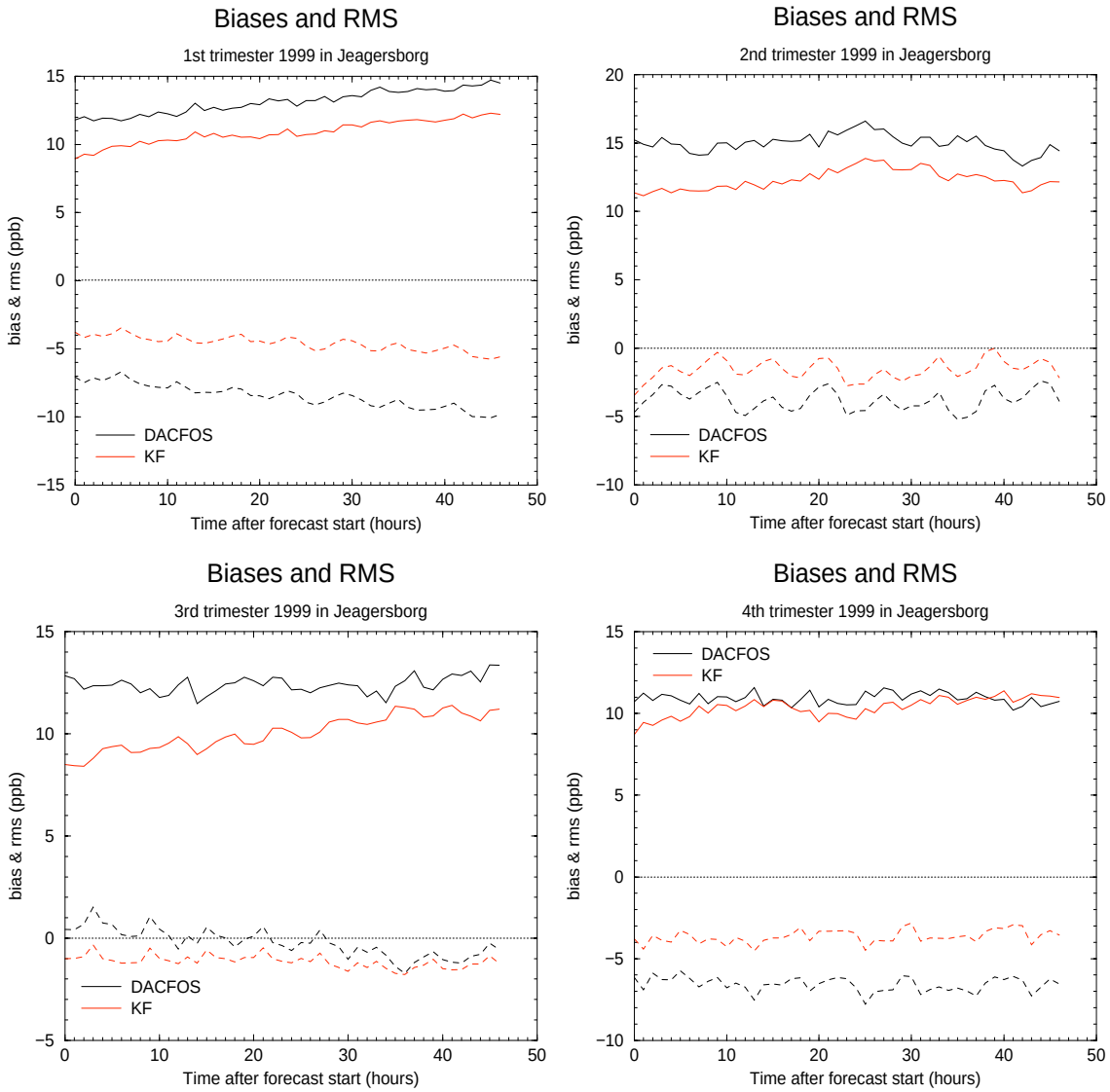

Figure 17 : Evolution of the biases (dashed lines) and rms values (solid lines) for DACFOS and DACFOS-KF forecasts as a function of time after forecast origin.

Combined statistics of the performances of the four daily forecasts are summarised in Table 4, which compares the results obtained for DACFOS-KF with those of DACFOS.

In this table the “Total Averages” are the statistical mean values yielded by the forecasts performed during each quarter of 1999.

Summary of statistical performances of operational ozone forecasts.

Compilation of 312 forecast files - **Jægersborg 1st quarter 1999**

****

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
20.97	10.06	31.18	6.92

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-8.44	10.59	13.14	0.40	-10.69	12.84	-12.32	14.86	0/0	0/0
DACFOS-KF:	-4.58	8.68	10.91	0.48	-7.35	10.46	-7.95	12.33	0/0	0/0

Compilation of 237 forecast files - **Jægersborg 2nd quarter 1999**

****

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
30.20	11.72	43.69	8.55

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-3.79	12.03	15.03	0.27	-3.99	14.60	-3.45	14.53	4/17	4/16
DACFOS-KF:	-1.57	9.6	12.35	0.45	-1.66	11.06	-1.61	12.68	13/17	12/16

Compilation of 339 forecast files - **Jægersborg 3rd quarter 1999**

****

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
25.84	11.57	39.32	8.42

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-0.21	10.02	12.41	0.40	1.80	9.95	0.77	10.34	0/5	1/4
DACFOS-KF:	-1.13	8.07	10.06	0.58	-3.49	8.38	-3.40	10.92	5/5	3/4

Compilation of 111 forecast files - **Jægersborg 4th quarter 1999**

****

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
18.02	8.39	27.43	5.98

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-6.58	8.70	10.93	0.36	-9.19	11.54	-10.03	11.97	0/0	0/0
DACFOS-KF:	-3.66	8.09	10.41	0.26	-6.97	10.48	-7.03	11.91	0/0	0/0

Table 4 : Detailed statistics for DACFOS-KF, compared with DACFOS for Jægersborg. All values except the correlation (corr) are in ppb. See text for explanations about this table.

<err> designates the mean error or bias. **<|err|>** is the mean absolute error.
rms is the root-mean-square error. **corr** stands for correlation.

There are also statistics of the maximum values (Peak) of the 1st and the 2nd forecast days: **<err>** is the bias of the forecast of the day's peak and **rms** is the root-mean-square of the error on the forecast of the day's peak.
High1 and **high2** are respectively incremented when the 1st day's peak or the 2nd day's peak is higher than the 60 ppb threshold, they indicate the relative proportion of each forecast model of being the closest to the daily peak.

Table 4 shows that DACFOS-KF has almost always the highest correlation coefficients and the lowest rms and mean error values compared with DACFOS. Furthermore, the forecasts of DACFOS-KF were generally closer to the peaks over the 60 ppb threshold than DACFOS.

5.2 LilleValby

The same statistics as done for Jægersborg are performed for LilleValby during the 2nd half-year of 1999. Figure 18 presents the evolution of the correlation, and figure 19 the evolution of the mean error and root-mean-square-error as a function of the forecast time, respectively.

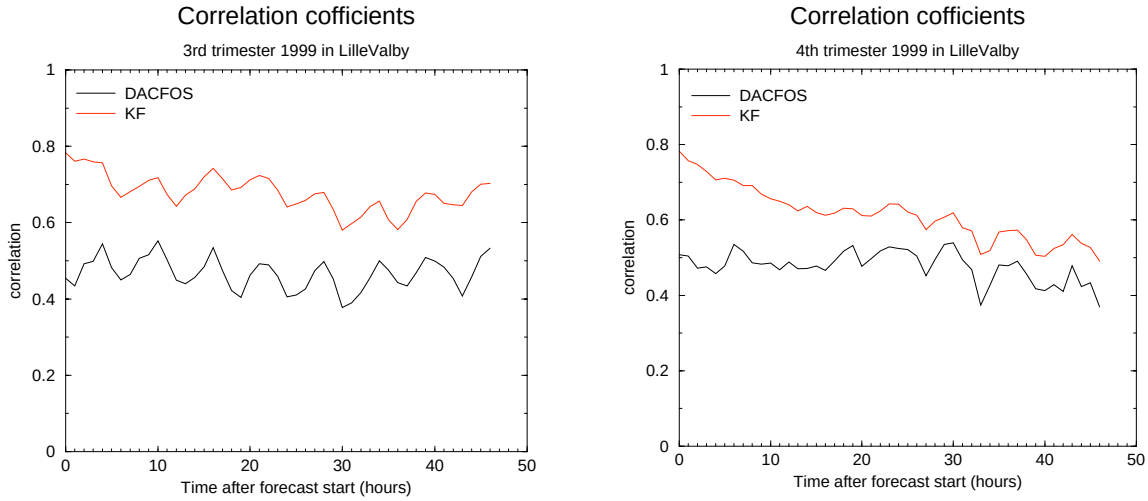

Figure 18 : Same as fig. 16 for LilleValby.

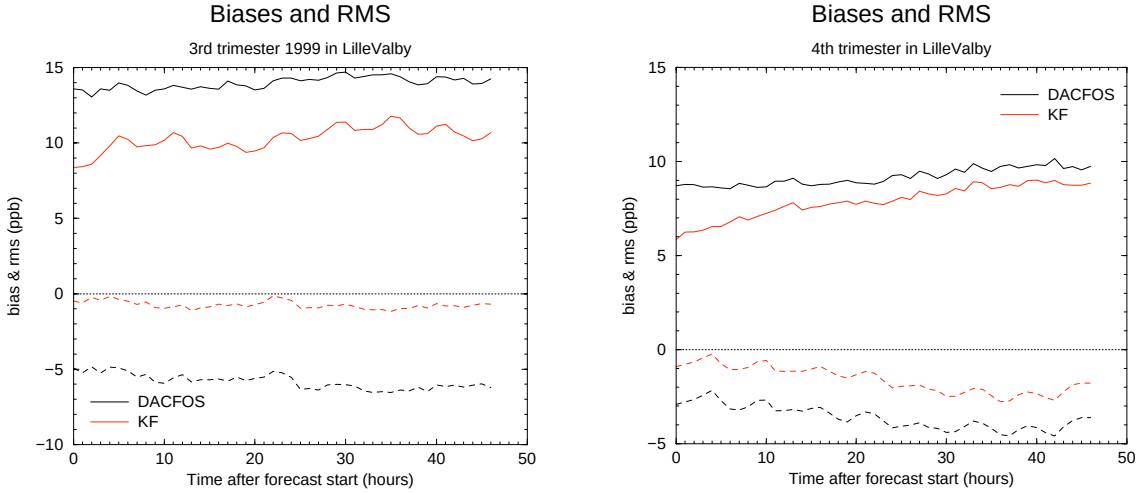

Figure 19 : Same as fig. 17 for LilleValby.

In the same way as for Jægersborg, table 5 presents statistical results obtained from the compilation of all the forecasts performed for LilleValby during the 2nd half of 1999.

The results obtained for LilleValby confirm the better performances of DACFOS-KF compared with DACFOS and table 5 shows that they are even better than those obtained for Jægersborg.

Summary of statistical performances of operational ozone forecasts.
Compilation of 640 forecast files - **LilleValby 2nd half-year of 1999**

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
25.03	13.27	37.18	13.31

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-4.77	9.38	11.96	0.61	-6.24	11.63	-7.21	12.43	1/26	2/28
DACFOS-KF:	-1.14	7.26	9.26	0.75	-3.04	8.25	-3.64	9.81	25/26	26/28

Table5 : Same as table 4 for the 2nd half-year of 1999 in LilleValby.

5.3 Keldsnor

In this subsection, statistics for the forecast results obtained in Keldsnor during the 3rd quarter of 1999 are presented. The evolution as a function of the forecast time of the correlation, as well as of the mean error and the root-mean-square-error, are shown on figure 20 and figure 21, respectively.

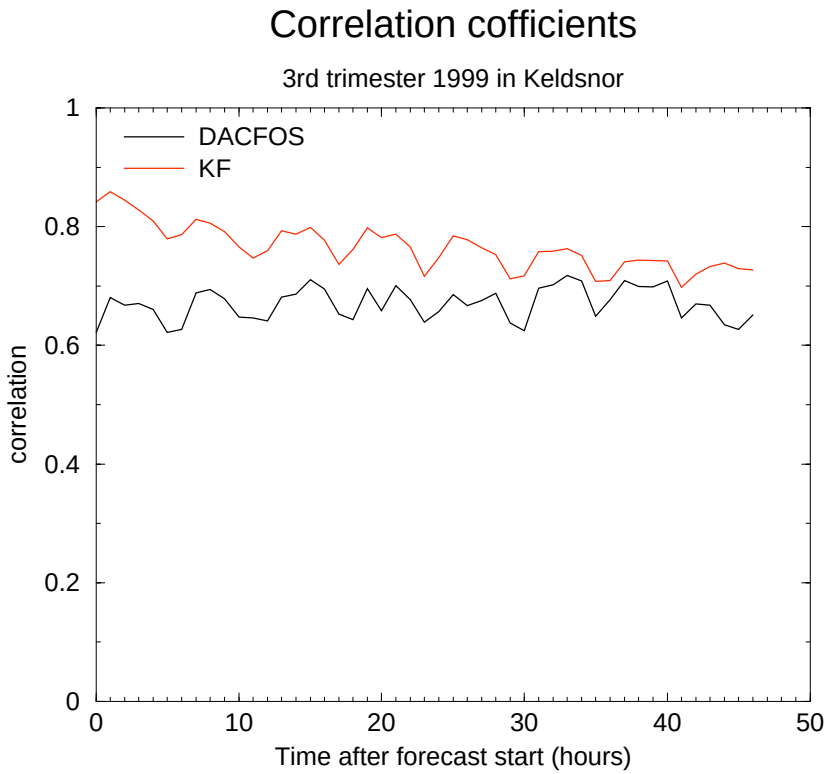

Figure 20 : Same as fig. 16 for the 3rd quarter of 1999 in Keldsnor.

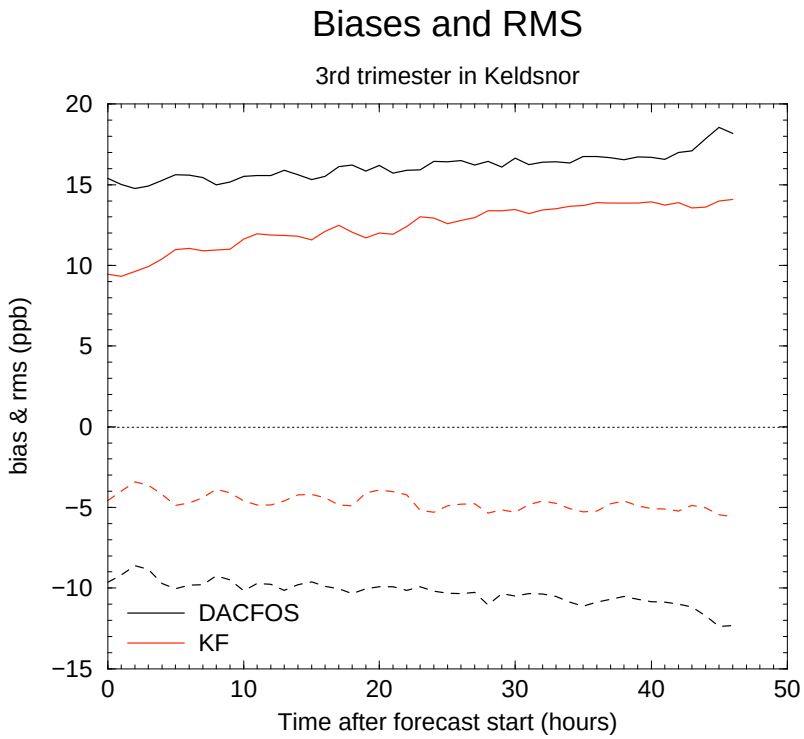

Figure 21 : Same as fig. 14 for the 3rd quarter of 1999 in Keldsnor.

Table 6 summarises the hourly statistical performances of both DACFOS-KF and DACFOS forecasts for Keldsnor during the period from July 1st to September 30th.

Summary of statistical performances of operational ozone forecasts.
Compilation of 427 forecast files - **Keldsnor 3rd quarter 1999**

****

Statistics for the Observations

Mean	St.Dev.	<Peak>	Peak-stdev.
35.10	9.82	46.26	9.02

Mean Errors and Root Mean Square Errors for Forecasts and Peak Forecasts:

	Total Average				Peak 1st day		Peak 2nd day			
	<err>	<|err|>	rms	corr	<err>	rms	<err>	rms	high1	high2
DACFOS:	-10.26	12.90	16.14	0.67	-7.25	12.88	-8.60	14.36	4/18	6/18
DACFOS-KF:	-4.69	9.70	12.45	0.76	-4.55	11.97	-5.65	14.84	14/18	12/18

Table6 : Same as table 1 for the 3rd quarter of 1999 in Keldsnor.

As found for Jægersborg and LilleValby, the forecasts for Keldsnor present better statistical performances for DACFOS-KF than for DACFOS.

6. General conclusion

We have seen that the quality of the operational Kalman filtering of DACFOS for ozone forecasts was generally good. Indeed, by looking globally at the performances of DACFOS-KF during the respective forecast periods for each of the three monitoring stations presented here, one can see that most of the daily ozone levels were correctly predicted and the forecasts were often better than those of DACFOS without the

Kalman filter. This is especially right for the statistical hourly performances of the forecasts, for which the various statistical indices agree to indicate a generally better behaviour for DACFOS-KF. This is observed for all three stations, showing that no special local conditions perturb the system. Compared to previous verification results [3], the performances of DACFOS-KF for Jægersborg were better in 1999 than in 1998.

However, there were also some days where the maximum ozone concentration was better predicted by DACFOS alone, especially when the observed peak was a few ppb below the 60 ppb threshold. In these cases, if DACFOS-KF and DACFOS forecasts are respectively above and below that threshold, then the forecast peak given by DACFOS-KF is wrong, even though it may be closer to the observed peak than DACFOS, and it yields a false alarm. This is due to the sharp definition of the classes, which are delimited by a fixed threshold. Nevertheless, the days where the ozone concentration is close to the 60 ppb threshold, even without reaching it, the ozone pollution may be relatively high.

This situation would be better described by the use of the AOT (Accumulated Ozone exposure above Threshold) for a certain ozone concentration given in ppb (for example AOT 40, which is a substantial threshold for ozone with respect to its effect on crops and forest). This threshold takes account of the duration of a certain concentration, and not only of its hourly occurrence. Then, even if the hourly ozone concentration should not yield a "class-alarm", to consider the AOT 40 may give the alert for a likely ozone pollution episode when the ozone concentration stays a relatively long time (from half a day until several days) just below the threshold of 60 ppb.

In conclusion, comparing the global performances of DACFOS with and without the Kalman filter, it has been showed that the present post-processing of DACFOS improves the ozone forecasts.

Acknowledgement

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References

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