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Sensitivity studies with the HIRLAM model using different time-steps

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Abstract

Sensitivity experiments have been constructed to examine the impact of changing size of time-step on forecast quality using the new DMI-HIRLAM.

Resumé

Sensitivitetseksperimenter med forskellige tidsskridt er blevet testet med henblik på at undersøge, hvilken indflydelse det har på kvaliteten af forudsigelserne i det nye DMI-HIRLAM setup.

Summary

Sensitivity experiments have been constructed to examine the impact of changing size of time-step on forecast quality using the recent Reference HIRLAM with semi-implicit, semi-Lagrangian advection scheme. The tests are performed with several configurations in terms of domain and resolution, either through data assimilation runs at cycling mode, for selected winter and summer periods, or through single forecasts, for selected cases featuring fast moving synoptic events. The results show generally insignificant sensitivity of time-step size, within reasonable ranges, on forecast results, both in terms of statistical averaging of observation verification scores, and in terms of prediction of system evolution for fast moving storm events. Meanwhile, more noticeable variability is found in terms of precipitation forecasts. The dependence of forecasted location and amount of precipitation on time-step size often seem to be random, presumably reflecting the general nonlinearity and limitation of predictability of strongly convective processes in high resolution modeling.

Introduction

The Danish Meteorological Institute (DMI) is currently experimenting with the recent reference version of the numerical modeling system HIRLAM (High Resolution Limited Area Model), with one of the goals to adopt the system to DMI's operational numerical weather prediction (NWP) suite.

One of the advantages of replacing the current operational HIRLAM forecast model (hereafter referred to as DMI-HIRLAM) with the reference version (hereafter referred to as Ref-HIRLAM) is that the latter has a more mature implementation of the semi-implicit, semi-Lagrangian (SISL) advection scheme.

In DMI-HIRLAM, the default spatial advection scheme is based on the Eulerian one. In order to run the model efficiently, different sizes of the time-step are used for dynamics and physics (Sass et al, 2002). The time-step for dynamics, due to the Courant-Friedrich-Levy (CFL) criterion, has to be fairly small, varying between 18s for HIRLAM-D (hereafter referred to as D05, with a grid mesh of 172x186x40 with 0.05 degree in horizontal resolution), 50s for HIRLAM-E (E15, with 272x282x40 and 0.15 degree) and 120s for HIRLAM-G (G45, with 202x190x40 and 0.45 degree) (see figure 1 for model domains). The time-step for the physics calculation, on the other hand, is between 3, 8 and 12 times larger depending on resolution.

In Ref-HIRLAM, the dynamics and physics use the same time-step size. Contrary to the case with Eulerian scheme, the semi-Lagrangian advection scheme is, theoretically speaking, not constrained by the CFL criterion in terms of numerical stability, thus allowing generally a much larger time-step size. However, in practice the size of time-step in a SISL scheme is seldom chosen to be much larger than corresponding to a CFL number of unity. The practical constraints are due to numerous factors, such as typical time scales of meteorological features intended to be resolved by the model, the accuracy limitation associated with dynamic terms and the dynamic-physics interface in the forecast model. Also, adequate description of physical processes such as vertical diffusion and strong convection often require reduced time-step in order to maintain numerical stability. In addition, in case of inadequate width of HALO zone (which is the zone neighboring sub-domains share in parallel computation), the algorithm of trajectory calculation may break down for very strong wind and long time-step.

In this note, we investigate the sensitivity of the forecast skill of the Ref-HIRLAM on the size of time-step by comparing statistics of the verification scores from data assimilation runs for several different

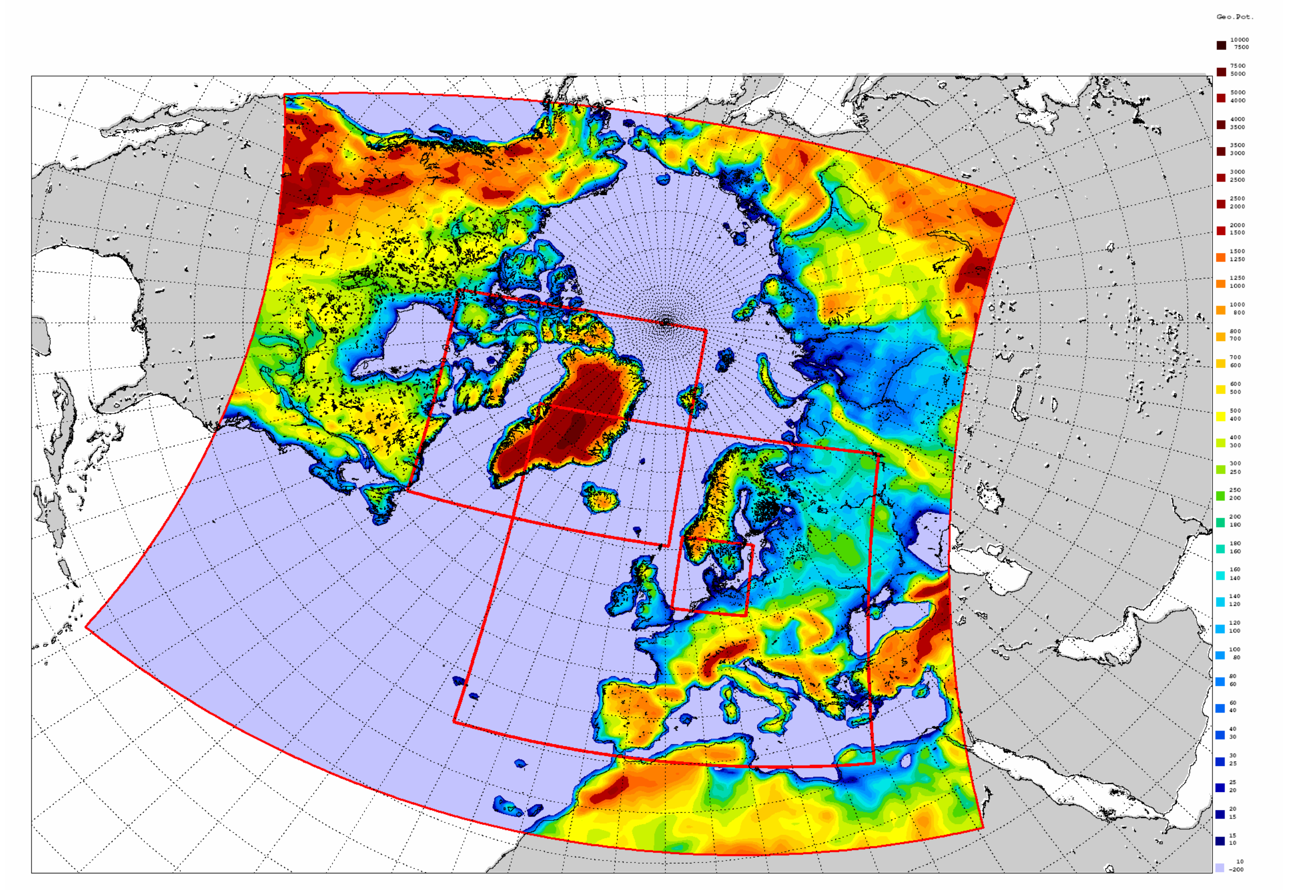

Figure 1: Orography plot of DMI's current nested operational domains with 0.45 (G), 0.15 (E and N) and 0.05 degree (D) resolution in horizontal and 40 levels in vertical.

resolutions and periods. Since verification statistics may fail to reveal individual cases with strong sensitivity, we also compare single forecasts, with varying time-steps, for several severe weather events including fast developing cyclones and strong convective situations. These results are also compared to similar tests using the operational DMI-HIRLAM (Amstrup et al. 2003a and Amstrup et al. 2003b).

Experiments in assimilation cycling mode

Sensitivity experiments are performed in data assimilation cycling mode using Ref-HIRLAM version 6.1.2 with varying size of the time-step. Separate runs are done using DMI's operational domains G45, E15 and D05. In view of the planned launch of 60 level main operational suite at resolution of 0.15 degree, the sensitivity experiments for the E15 domain are made with 60 vertical levels (hereafter referred to as E15/L60). The leveling structure for 60 levels follows that recommended by Unden & Gustafsson (2002), in which the bottom and top model levels are kept the same as in the current 40 level structure. The lowest level of the model is at around 32 meters and the top of the model is at 10hPa.

The sensitivity experiments for E15/L60 cover two periods, one for winter between 2002-011500 and 2002012718, one for summer between 2002061100 and 2002062418. The runs are done in 6-hourly data assimilation cycle at varying time-step of 150s, 180s, 240s and 300s. For lateral boundary conditions, ECMWF analysis every 6 hour is used. Considering the limited domain size of E15, the forecast length is limited to 30 hour.

The sensitivity experiments with G45 test time-step of 480s, 600s and 720s, for a summer period of two weeks, starting from 2002061800. For sensitivity tests with D05, the same period, starting from 2002061800, is run, using a time-step of 45s, 60s, 120s and 150s, respectively. Because the D05 results from the first few days, covering several severe precipitation events in the Scandinavian area, shows little sensitivity on tested time-steps, the test period is limited to 6 days. In order to make D05 run, a triple nested configuration with full data assimilation cycling is constructed, including G45 and E15. For each cycle, the D05 run is initiated by coupling surface analysis (using the ISBA scheme), interpolated upper air analysis at E15 and the 6-hour D05 forecast from previous cycle, through incremental DFI scheme. For the lateral boundary, hourly forecast output from E15 is used. The E15 runs are in turn performed at full assimilation cycle, driven, as lateral boundary, by the corresponding G45 runs. In this report, results presented are mainly those from E15/L60 and D05 runs.

Observation verification

To get a sense of the sensitivity of the overall forecast skills of Ref-HIRLAM on varying size of time-step, we examine the statistical feature from validation of model results of every 6 hours against observation data. The observation verifications are normally done against both EWGLAM sounding and synoptic station-list, covering a relatively large area, and with Danish station-list, comprising of 24 SYNOP stations in Denmark, with half of them located in coastal area. The verification using the Danish station-list is interesting because of its smaller sample size, thus it has higher likelihood to reveal sensitivity in this kind of studies.

Figure 2 and 3 show the averaged RMS and BIAS scores of the parallel runs of E15/L60 for the winter period validating against EWGLAM and Danish station-lists, respectively, for chosen key parameters along forecast length up to 30h. In figures 4 and 5, the corresponding scores for the summer period are shown. From these figures, it appears that there is only insignificant differences in scores for key parameters depending on choices of time-step, especially in verification against EWGLAM stations. The verification against Danish station-list show somewhat larger sensitivity on time-steps. As shown in figures 3 and 5, there seem to be a tendency of somewhat improved scores in MSLP and V10m for longer forecast length, when small time-steps are used. It should be stressed that, as mentioned above, the verification using Danish station-list should be looked upon with more caution due to statistical uncertainty associated with limited sample size.

Figure 6 – 9 show further the daily averaged scores of E15/L60 in the two periods for parameters MSLP, 2 meter temperature and 10 meter wind. No substantial differences among the tests using different time-steps are found here either. In general we see a bit larger variance in the daily error for the Danish stations which is more or less independent of the time-step except those around the 21st June 2002, for which we will look closer at in the case studies.

In general similar observations can be made regarding sensitivity tests for G45 and D05. Figures 10 and 11, show, e.g., the averaged verification scores for D05 against Danish station-list for the tested period, where verification scores differ little for all tested runs using different time-steps. Thus from examining verification scores of the series of data assimilation runs for D05, E15/L60 and G45, we observe that overall the sensitivity of forecast quality to time-step size is relatively small, especially considering the sensitivity of such scores to other key features involving model configurations, such as different resolution, domain size, numerical schemes in advection and horizontal diffusion, and physics parameterization.

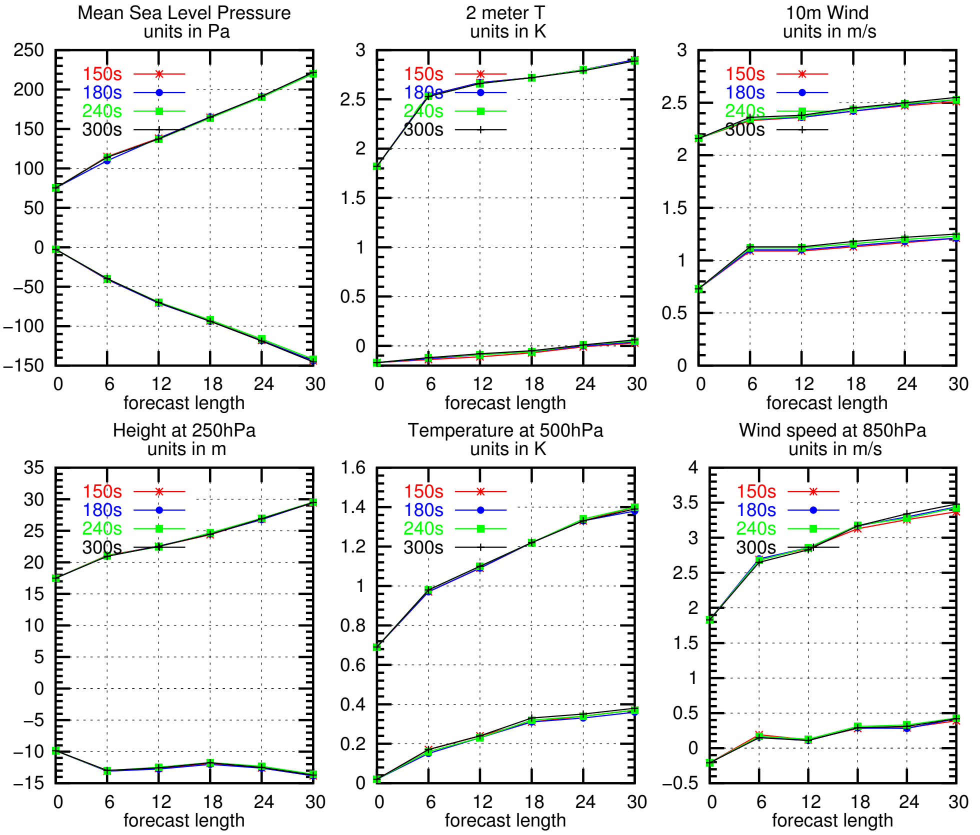

Figure 2: Obs-verification (BIAS and RMS, EWGLAM station-list) results of surface parameters and geopotential height, temperature and wind speed for pressure levels specified in the plot for the period 2002011500-2002012718. The runs are for E15/L60 with time-stepping of 150s, 180s, 240s and 300s respectively.

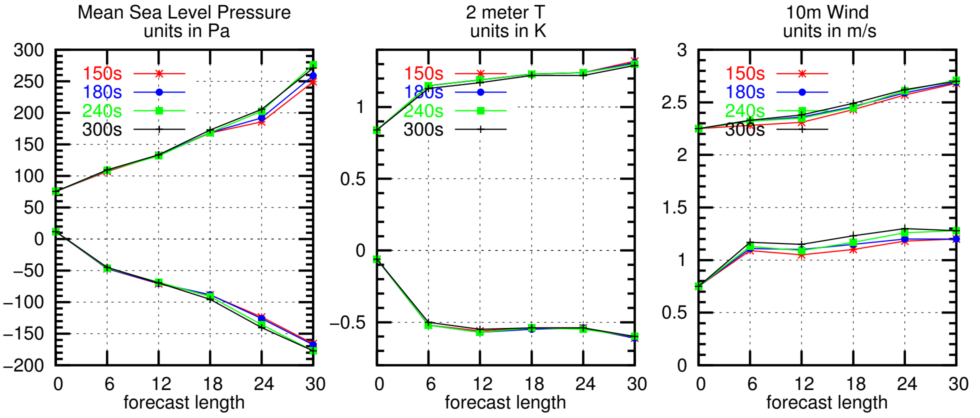

Figure 3: Similar to figure 2 but for Danish station-list.

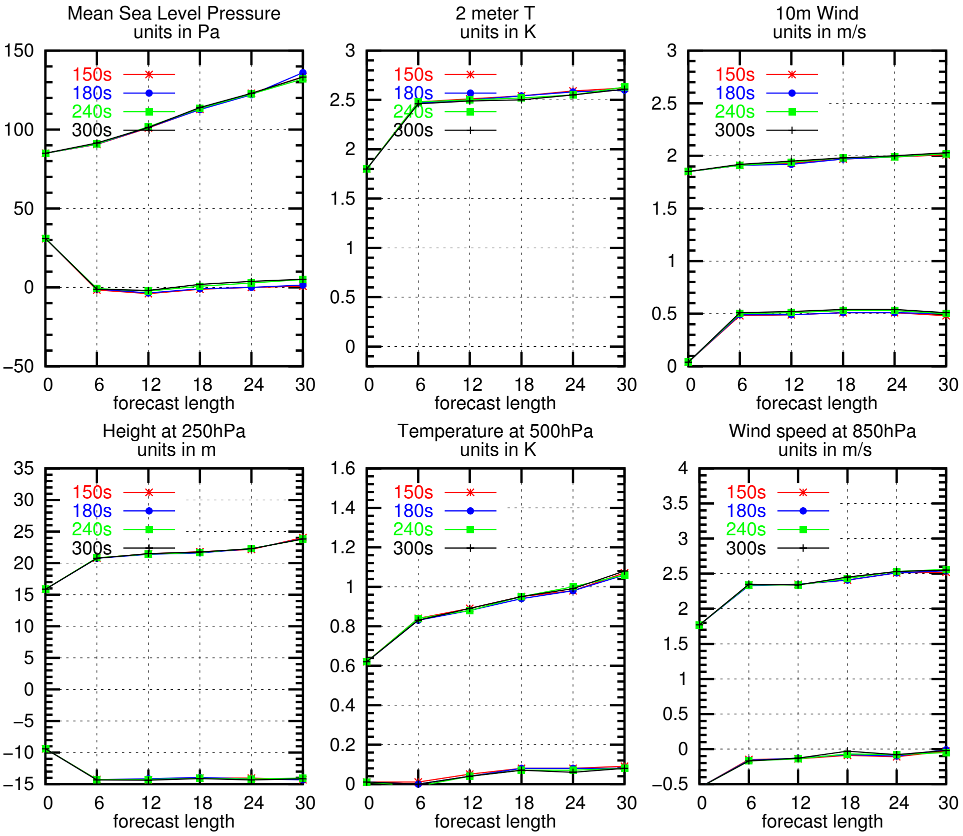

Figure 4: Obs-verification (BIAS and RMS, EWGLAM station-list) results of surface parameters and geopotential height, temperature and wind speed for pressure levels specified in the plot for the period 2002061100-2002062418. The runs are for E15/L60 with time-stepping of 150s, 180s, 240s and 300s respectively.

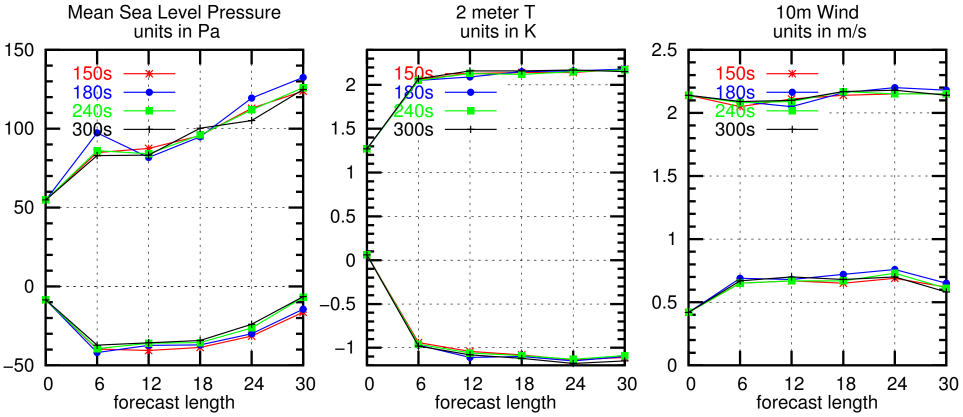

Figure 5: Similar to figure 4 but for Danish station-list.

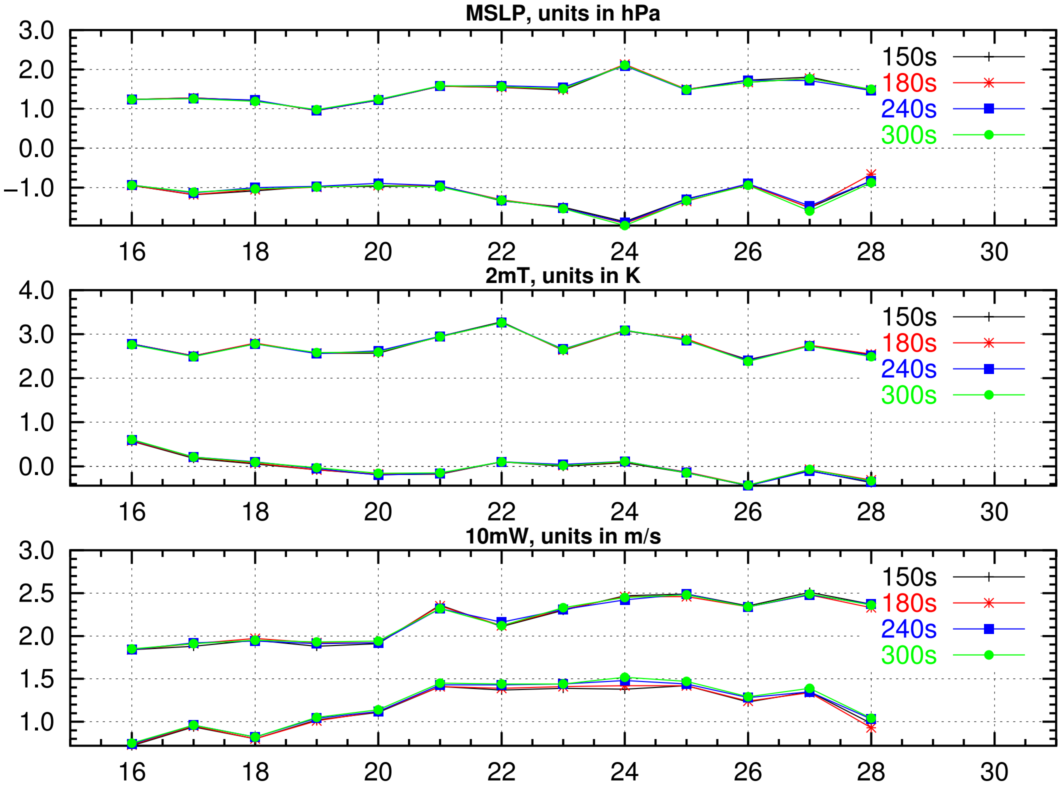

Figure 6: Daily bias and rms for MSLP, 2m temperature and 10m wind for the period 20020115 through 20020127 for EWGLAM station-list.

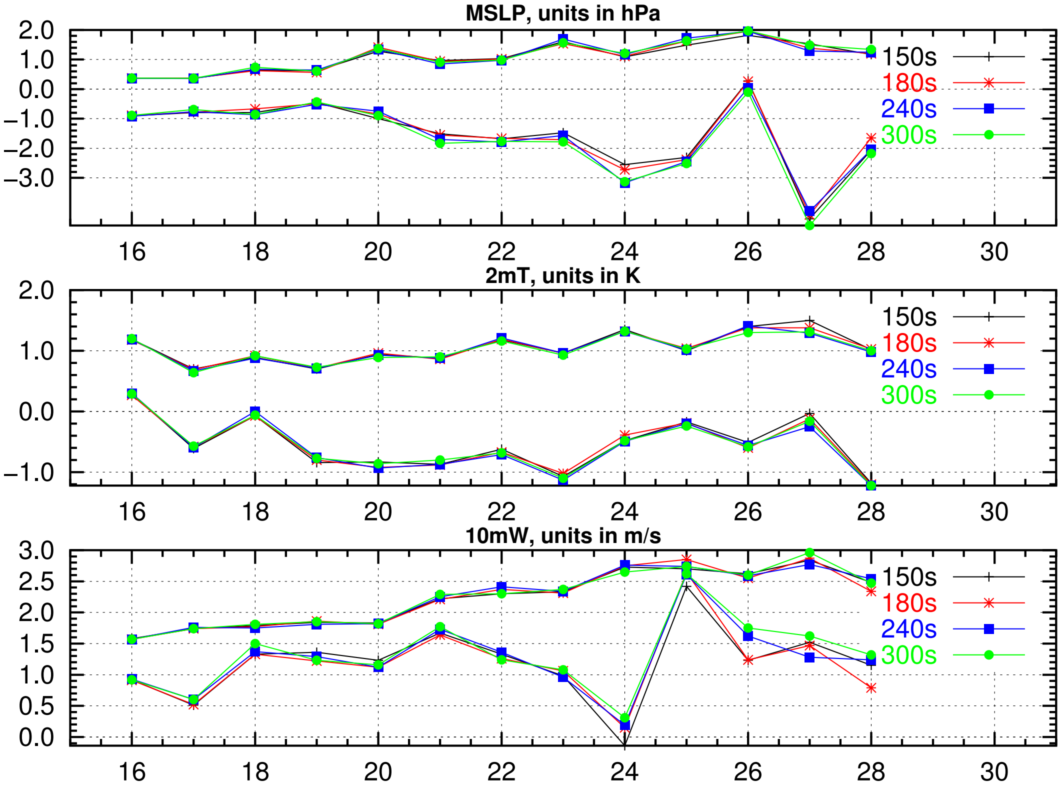

Figure 7: Similar to figure 6 but for Danish station-list.

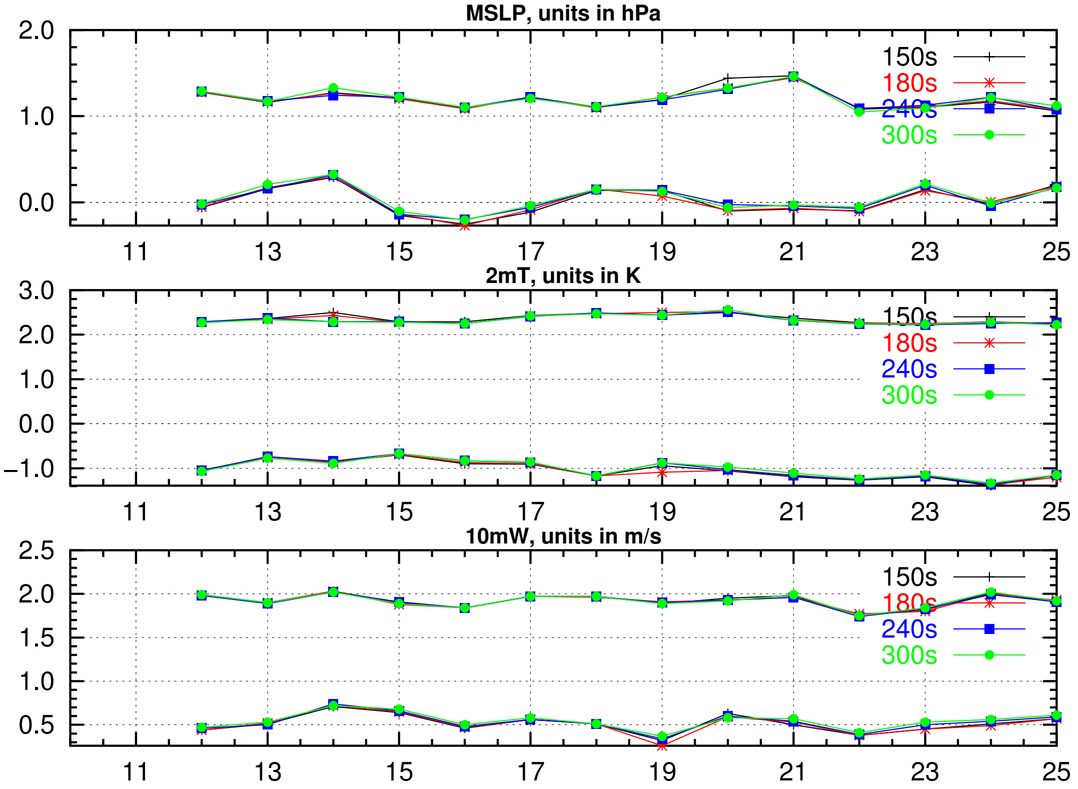

Figure 8: Daily bias and rms for MSLP, 2m temperature and 10m wind for the period 20020611 through 20020623 for EWGLAM station-list.

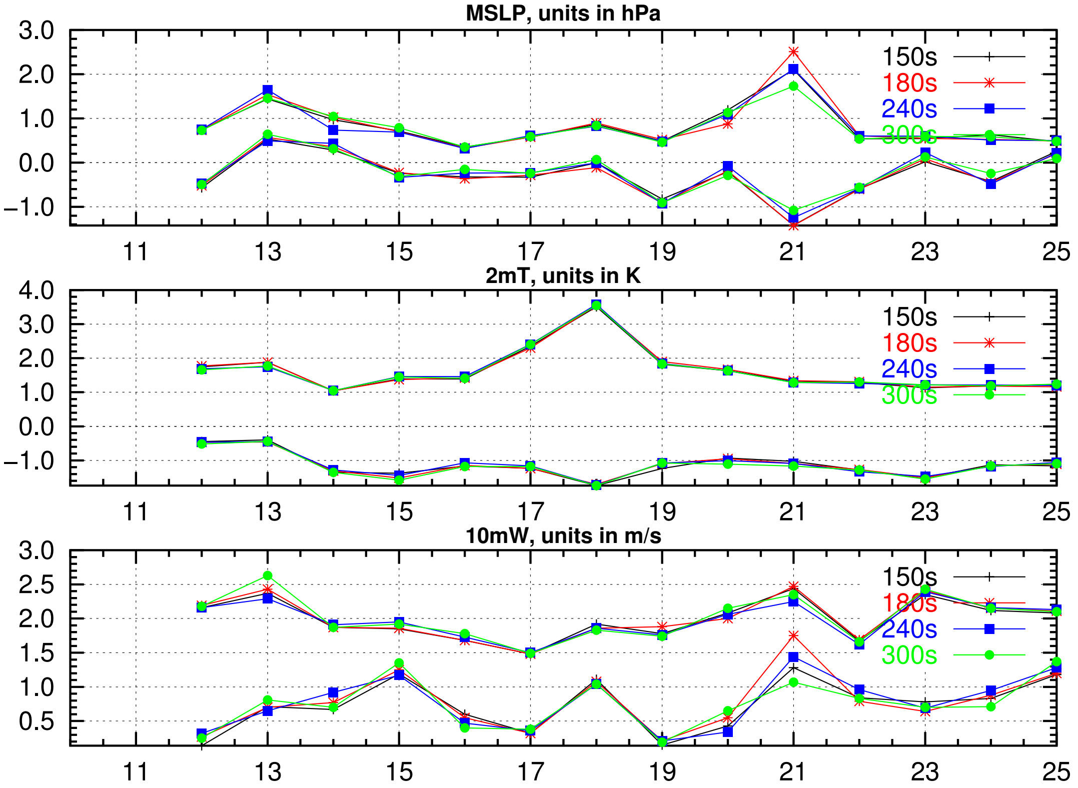

Figure 9: Similar to figure 8 but for Danish station-list.

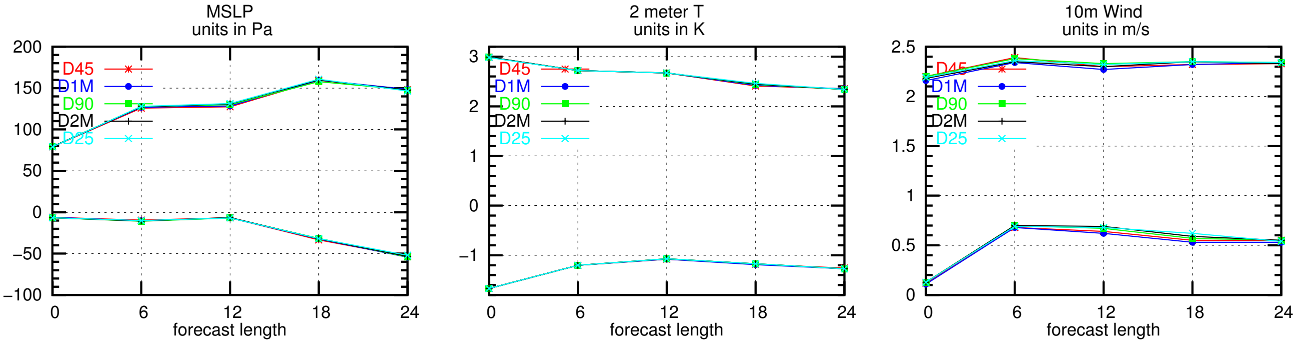

Figure 10: Obs-verification (BIAS and RMS, Danish station-list) results of surface parameters MSLP, 10m wind and 2m temperature for the period 2002061800-2002062300 for D05 runs with time-stepping of 45s, 60s, 120s and 150s.

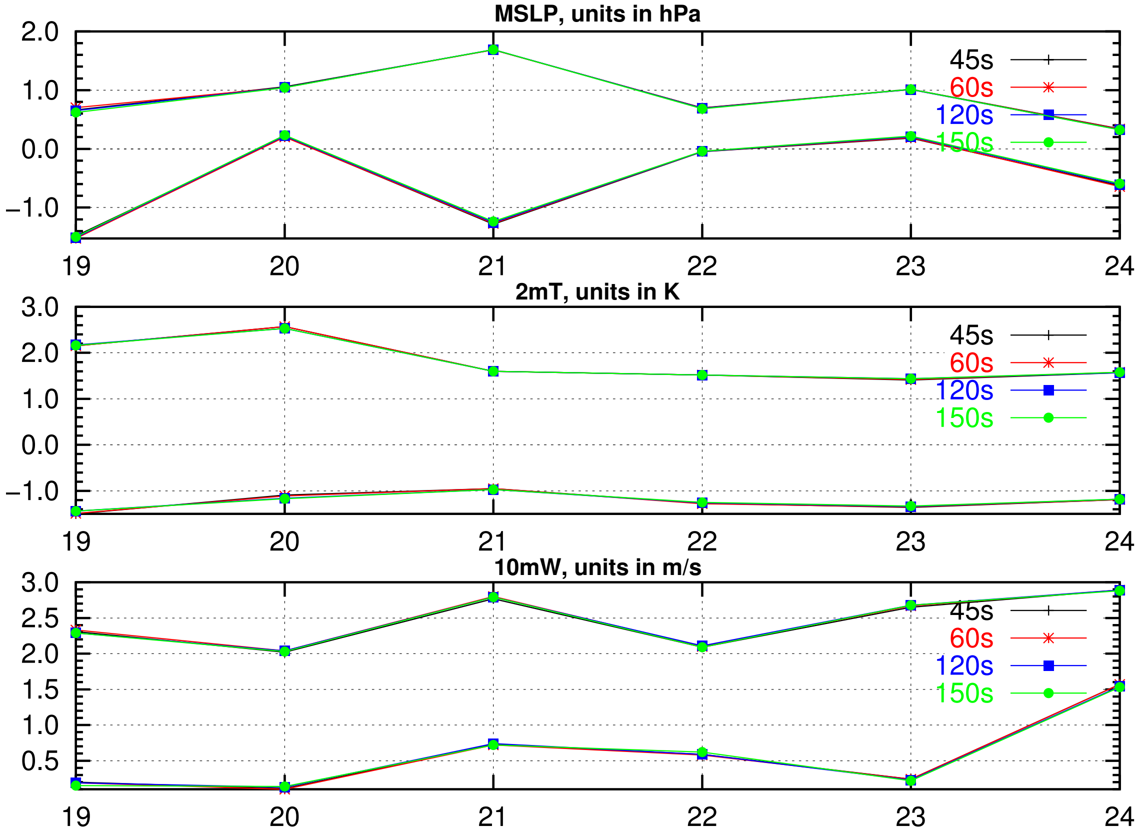

Figure 11: Daily BIAS and RMS for MSLP, 2m temperature and 10m wind for the period 2002061800-2002062300 for D05 runs with time-stepping of 45s, 60s, 120s and 150s for Danish station-list.

Precipitation verification

Precipitation verification of E15/L60 runs for the two periods, in form of contingency tables, are shown in tables 1 – 4 against the EWGLAM station-list. The results are obtained by comparing 12-hr accumulated precipitation in the forecast range 6-18h and 18-30h, with those observed at stations included in the EWGLAM station-list. The numbers in the contingency tables are obtained by summing up those observed and predicted precipitation amounts in each of the five classes. These five classes are (precipitation amounts in mm): $P1 < 0.2$, $0.2 \leq P2 < 1.0$, $1.0 \leq P3 < 5.0$, $5.0 \leq P4 < 10.0$ and $P5 \geq 10$, where P is either F (forecast) or O (observation) in the tables. The "sum" rows and columns in the tables are the sums of the numbers in the given observation classes or forecast classes, respectively. Note that the observed values are uncorrected ones, implying a general underestimation at the order of around 10%, (see. e.g., Sevruk 1982).

We see from the tables that overall there is no clear separation of skills in precipitation forecast among runs using different time-step sizes. Roughly speaking the runs with shorter time-steps tend to have a slightly higher hit-rate, although there are exceptions such as, e.g., the 6-18h forecast for the summer period. Another tendency is that the runs with shorter time-step often do better in forecasting small precipitation events, whereas runs with larger time-steps sometimes can better catch the stronger precipitation events, but again there is no consistency in these results. This lack of consistency in the results could very well be due to a too small sample size ie. we would need to run tests for longer periods to get a consistent picture for the precipitation.

In table 5 – 8 we have shown the results against Danish station-list. Also here we see no clear trend in the results although perhaps a greater spread.

In table 9, a similar contingency table is shown for D05 runs validating against Danish station-list. Interestingly, despite of rather short period and small model domain (thus stronger likelihood to see larger gap in verification scores), the table show generally a rather similar skill level for runs using different time-steps.

Again, similar results have been seen for precipitation verification in sensitivity runs using G45. Thus it is estimated that also in terms of precipitation forecast, no clear trend has been found depending on time-step size. Compared to relative verification features for other key parameters, there do seem to be a bit wider discrepancy (often in random) in scores among different runs. This is presumably partly due to generally higher sensitivity of precipitation forecast associated with nonlinearity and parameterization schemes, partly due to the statistical uncertainty associated with the rather limited sample size in this study.

Stability features

No stability problem has been found throughout the data assimilation runs using different time-steps and different model configuration. Figure 12, e.g., shows averaged time series of domain averaged surface pressure tendencies along the integration, averaged over assimilation cycles during some of the periods in E15/L60 and D05 runs, respectively. The periodic increase in the shown time series in the figure reflects lateral boundary update at 6 hour (for E15/L60) or 1 hour (for D05) interval. From the curves in figure 12, it is seen that in general the surface pressure tendency, as an indicator of the overall "noise" level in the forecast system, is at a rather low and healthy level, for all examined cases using different time-step sizes. Noteworthy though, in all runs using both E15/L60 and D05, those using longer time-step sizes are associated with lower averaged noise levels. Presumably, this puzzling feature may be explained by the smoothing effect in connection with the trajectory extrapolation

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	2677	188	75	15	9	2964	F1	2735	192	77	16	8	3028
F2	922	428	217	21	6	1594	F2	878	406	220	30	6	1540
F3	426	380	667	133	38	1644	F3	411	398	661	125	38	1633
F4	35	30	131	131	51	378	F4	33	31	130	130	52	376
F5	6	3	12	38	44	103	F5	9	2	14	37	44	106
sum	4066	1029	1102	338	148	6683	sum	4066	1029	1102	338	148	6683
%FO	66	42	61	39	30	59	%FO	67	39	60	38	30	59

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	2717	180	75	12	6	2990	F1	2570	170	82	17	8	2847
F2	884	411	206	28	6	1535	F2	973	437	218	20	4	1652
F3	429	402	674	139	39	1683	F3	461	380	656	140	45	1682
F4	32	32	129	127	47	367	F4	55	41	126	122	48	392
F5	4	4	18	32	50	108	F5	7	1	20	39	43	110
sum	4066	1029	1102	338	148	6683	sum	4066	1029	1102	338	148	6683
%FO	67	40	61	38	34	60	%FO	63	42	60	36	29	57

Table 1: Contingency tables for 12 hour precipitation (6-18h E15/L60 forecasts) in the period 20020115 through 20020127. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For EWGLAM station-list.

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	2820	229	103	16	11	3179	F1	2816	232	99	17	13	3177
F2	802	386	209	26	9	1432	F2	795	361	214	30	4	1404
F3	404	373	643	161	43	1624	F3	413	394	641	152	49	1649
F4	37	37	134	106	46	360	F4	38	38	135	105	42	358
F5	3	4	13	29	39	88	F5	4	4	13	34	40	95
sum	4066	1029	1102	338	148	6683	sum	4066	1029	1102	338	148	6683
%FO	69	38	58	31	26	60	%FO	69	35	58	31	27	59

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	2778	231	89	15	10	3123	F1	2714	221	100	19	11	3065
F2	828	358	205	29	8	1428	F2	836	366	196	28	9	1435
F3	416	397	652	165	44	1674	F3	460	400	652	150	41	1703
F4	35	41	140	97	48	361	F4	50	38	138	108	49	383
F5	9	2	16	32	38	97	F5	6	4	16	33	38	97
sum	4066	1029	1102	338	148	6683	sum	4066	1029	1102	338	148	6683
%FO	68	35	59	29	26	59	%FO	67	36	59	32	26	58

Table 2: Contingency tables for 12 hour precipitation (18-30h E15/L60 forecasts) in the period 20020115 through 20020127. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For EWGLAM station-list.

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	4717	169	88	18	15	5007	F1	4746	181	91	20	14	5052
F2	736	177	116	30	18	1077	F2	726	142	105	28	21	1022
F3	497	175	260	84	53	1069	F3	471	200	267	85	51	1074
F4	64	28	85	55	45	277	F4	77	28	86	49	36	276
F5	26	15	54	36	41	172	F5	20	13	54	41	50	178
sum	6040	564	603	223	172	7602	sum	6040	564	603	223	172	7602
%FO	78	31	43	25	24	69	%FO	79	25	44	22	29	69

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	4739	180	89	21	15	5044	F1	4763	171	92	13	17	5056
F2	771	154	122	27	15	1089	F2	747	167	117	38	16	1085
F3	446	189	259	84	48	1026	F3	463	188	263	85	56	1055
F4	61	29	81	59	44	274	F4	54	28	84	56	44	266
F5	23	12	52	32	50	169	F5	13	10	47	31	39	140
sum	6040	564	603	223	172	7602	sum	6040	564	603	223	172	7602
%FO	78	27	43	26	29	69	%FO	79	30	44	25	23	70

Table 3: Contingency tables for 12 hour precipitation (6-18h E15/L60 forecasts) in the period 20020611 through 20020623. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For EWGLAM station-list.

in semi-Lagrangian advection scheme.

Case studies

Although the above numerical experiments with data assimilation cycling over longer periods in general indicate little sensitivity in the observation verification scores to the size of time-step, it can not exclude more pronounced sensitivity in the forecast of severe weather events. The latter are often associated with fast moving systems or strongly convective situations. Thus several more detailed case studies have been carried out, to investigate the sensitivity of forecast quality on time-step size for extreme events such as fast developing cyclones and severe convective storms. The chosen cases have also been investigated in detail in earlier studies by Amstrup et al. 2003a and 2003b.

Model setup

For case studies of fast developing cyclones, the adapted Ref-HIRLAM model, used in DMI's new pre-operational suite between 01 Jan and 26 Feb 2004 (Yang, 2004), is run on the HIRLAM-T15 domain (610x568x40, 0.15 degree resolution)[1]. Single forecasts of up to 48h, initiated with interpolated ECWMF analysis, are performed with time-step from 150s upto 900s. The forecasted MSLP and V10m are examined here.

For investigation of forecast sensitivity in summer convective storm cases, E15 with 40 vertical le-

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[1] The HIRLAM-T15 domain is in general the HIRLAM-G45 domain but with 0.15 degree resolution.

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	4532	182	98	18	19	4849	F1	4570	193	92	22	20	4897
F2	693	128	114	35	26	996	F2	649	123	112	31	21	936
F3	506	178	227	75	39	1025	F3	507	173	232	79	47	1038
F4	72	31	80	49	36	268	F4	77	33	84	39	33	266
F5	23	20	43	33	41	160	F5	23	17	42	39	40	161
sum	5826	539	562	210	161	7298	sum	5826	539	562	210	161	7298
%FO	78	24	40	23	25	68	%FO	78	23	41	19	25	69

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	4576	191	96	18	18	4899	F1	4616	190	100	17	21	4944
F2	687	120	111	29	23	970	F2	652	119	94	31	23	919
F3	467	185	230	75	47	1004	F3	460	188	259	87	47	1041
F4	76	30	88	61	36	291	F4	84	31	71	45	30	261
F5	20	13	37	27	37	134	F5	14	11	38	30	40	133
sum	5826	539	562	210	161	7298	sum	5826	539	562	210	161	7298
%FO	79	22	41	29	23	69	%FO	79	22	46	21	25	70

Table 4: Contingency tables for 12 hour precipitation (18-30h E15/L60 forecasts) in the period 20020611 through 20020623. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

vels is run. Parallel single forecasts of 30 hours are run using ECMWF analyses as initial and lateral boundary conditions. The forecasted 12-hour accumulated precipitation have been examined in detail.

Results

For case studies of fast developing cyclone events, two cases are chosen, one in winter ("Danish storm") and one in summer ("Finland storm").

The Danish storm in 1999 is characterized by a deep low, which, at its peak around 18 UTC, 3rd of December 1999, is centered over the north-eastern part of Jutland in Denmark with an observed minimum of 950hPa, and a maximum wind at the west coast of Jutland up to 38 m/s (see figure 13).

Figure 14 shows the T15 forecasts of 48 hour, with time-step of 1, 5, 10 and 15 min valid at 18 UTC on 03 Dec 1999. In general the adapted Ref-HIRLAM forecast model, as used in this study, captures this storm rather poorly[2]. However, since the purpose of the current sensitivity experiment is to examine differences in the model forecast with different time-steps, it is considered to be accep-

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[2] The adapted version contains a modification of physical parameterization which enhances vertical turbulence mixing. Although the change improves the overall deficiency of the previous HIRLAM model in effective filling of cyclones and therefore improved general verification scores, it is found that the modification has a strong negative impact in case of strong winter storms, for which the model tends to under-predict. Thus the modification degrades the forecast skill in extreme events. Recently, studies on explicit parameterization of surface stress vector turning have been shown to be able to improve substantially the in-efficient low-filling problem and at the same time cause less degradation of forecast of extreme events. The scheme has since been implemented in DMI's pre-operational model since Feb 27, 2004. See Yang (2004a,2004b) and Nielsen (2004) for more details

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	67	10	4	0	0	81	F1	62	9	2	0	0	73
F2	45	40	16	0	0	101	F2	54	43	23	0	0	120
F3	12	28	100	22	2	164	F3	8	26	96	22	3	155
F4	0	0	8	24	11	43	F4	0	0	7	24	10	41
F5	0	0	1	0	0	1	F5	0	0	1	0	0	1
sum	124	78	129	46	13	390	sum	124	78	129	46	13	390
%FO	54	51	78	52	0	59	%FO	50	55	74	52	0	58

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	61	7	3	0	0	71	F1	48	8	1	0	0	57
F2	50	45	19	1	0	115	F2	64	39	23	1	0	127
F3	13	26	98	23	3	163	F3	12	31	95	24	2	164
F4	0	0	8	22	9	39	F4	0	0	9	21	10	40
F5	0	0	1	0	1	2	F5	0	0	1	0	1	2
sum	124	78	129	46	13	390	sum	124	78	129	46	13	390
%FO	49	58	76	48	8	58	%FO	39	50	74	46	8	52

Table 5: Contingency tables for 12 hour precipitation (6-18h E15/L60 forecasts) in the period 20020115 through 20020127. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

table to ignore the issue of forecast quality for the time being.

Comparing the forecasts in figure 14, where the runs are made with wildly different time-steps ranging from 1 min to 15 min, the forecasts are seen to agree to each other very well. The 24 hour and 12 hour forecasts (not shown here) fit observation better than the 48 hour forecast, but also here there is only minor differences using different size of the time-step. In table 10 the minimum pressure in the simulated hurricane system and the maximum winds are listed for different time-steps and forecast length. It again demonstrates clearly that the choice of time-step size do not have much impact on forecast results, even in such a case of fast moving system with exceptional strength.

The "Finland storm" on 21st of June 2002 features heavy rainfall accompanied with strong winds, in connection with a strong low situated over the southern part of Finland. The same system passed through Denmark 24 hours before on 20 June 2002 (see figures for 20 June 2002 later). The maximum observed surface wind speed is 18 m/s in the Gulf of Finland and the minimum MSLP is 995 hPa in Mikkeli, 200km north of the Gulf of Finland. The observed maximum in 12h precipitation is 40mm (see figure 15).

From figure 16 we see that the system is well predicted by all model runs and there do not seem to be strong dependence on time-step either. In table 11 we further show the minimum MSLP of the low pressure system and the maximum surface wind in the Gulf of Finland. Similar to features shown in figure 16, the table 11 again indicate that the predicted phases and strengths are all similar in these runs using different time-steps.

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	59	21	8	0	0	88	F1	59	17	3	0	0	79
F2	52	28	23	6	1	110	F2	53	34	25	4	0	116
F3	13	29	90	20	1	153	F3	12	27	95	25	2	161
F4	0	0	8	19	9	36	F4	0	0	6	14	8	28
F5	0	0	0	1	2	3	F5	0	0	0	3	3	6
sum	124	78	129	46	13	390	sum	124	78	129	46	13	390
%FO	48	36	70	41	15	51	%FO	48	44	74	30	23	53

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	63	14	7	0	0	84	F1	68	14	3	0	0	85
F2	48	41	17	5	0	111	F2	45	37	21	4	1	108
F3	13	23	103	25	2	166	F3	11	27	99	23	1	161
F4	0	0	2	15	9	26	F4	0	0	5	18	10	33
F5	0	0	0	1	2	3	F5	0	0	1	1	1	3
sum	124	78	129	46	13	390	sum	124	78	129	46	13	390
%FO	51	53	80	33	15	57	%FO	55	47	77	39	8	57

Table 6: Contingency tables for 12 hour precipitation (18-30h E15/L60 forecasts) in the period 20020115 through 20020127. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

On the contrary, the case studies on convective summer storm events show a somewhat different picture. In these sensitivity runs, forecasts are made on the E15 domain, and both 40 and 60 vertical levels have been tested. The results from E15/L40 and E15/L60 are qualitatively similar, so only results from E15/L40 are presented here.

The chosen summer convective cases here are the three heavy rain and thunderstorm episodes affecting Danish territory on 15, 18 and 20-21 June 2002 (see figure 17 – 19). For DMI's operational model DMI-HIRLAM, it has been quite a challenging issue to correctly predict these events (see Amstrup et al. (2003a) for a detailed description of these events).

Figures 20 – 22 show the 12 hour accumulated precipitation for the three test cases, respectively. Here we see that the actual pattern of the precipitation varies quite a bit, depending on the time-step used. In these simulations, the large scale structures of the precipitation field look quite similar, but there are clear phase shifts in rainfall maxima among those with different time-steps. It is not obvious as to which time-step is the optimal one to choose for these cases.

If we further separate the precipitation into resolved ("stratiform") and unresolved ("convective") precipitation, we see, e.g., in figure 23 – 24, where the 12-h accumulated precipitation up to 18 UTC, 15 June 2002, are shown for runs with time-step of 3, 4, 5 and 6 min, that the main differences in the accumulated precipitation is due to the sub-grid scale precipitation. Similar features are also found for the two other cases valid at 18 and 20 June. It appears that, the parameterization of sub-grid scale convection, and hence the model predicted convective precipitation, may have relatively strong dependence on size of time-step, especially for the thunderstorm-type system where it occurs on re-

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	181	11	19	1	0	212	F1	180	13	24	0	2	219
F2	41	15	21	3	6	86	F2	47	12	18	3	3	83
F3	19	16	29	21	4	89	F3	14	19	26	23	4	86
F4	3	6	9	8	11	37	F4	3	4	10	5	8	30
F5	0	0	2	1	9	12	F5	0	0	2	3	13	18
sum	244	48	80	34	30	436	sum	244	48	80	34	30	436
%FO	74	31	36	24	30	56	%FO	74	25	33	15	43	54

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	178	10	23	2	1	214	F1	178	13	24	0	1	216
F2	43	14	21	7	4	89	F2	41	16	16	8	5	86
F3	23	16	24	14	3	80	F3	24	16	25	18	5	88
F4	0	8	8	7	11	34	F4	1	3	11	5	7	27
F5	0	0	4	4	11	19	F5	0	0	4	3	12	19
sum	244	48	80	34	30	436	sum	244	48	80	34	30	436
%FO	73	29	30	21	37	54	%FO	73	33	31	15	40	54

Table 7: Contingency tables for 12 hour precipitation (6-18h E15/L60 forecasts) in the period 20020611 through 20020623. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

latively small scales and develops fairly fast.

We have also run the model using the Eulerian scheme and observe similar sensitivity of precipitation forecasts on time-steps. The difference there look somewhat smaller, which may be due to the fact that the difference in the tested time-steps are not as large as for the SL runs (not shown here). It is thus assumed that the sensitivity in precipitation forecasts are primarily due to the physical parameterization. Further investigation of the convection scheme may be necessary to examine whether the scheme behave correctly for different time-steps.

Discussion and summary

In this work, forecast experiments in data assimilation cycling mode have been constructed to test the sensitivity of varying time-steps in the Ref-HIRLAM using a SISL scheme, for model runs with several different domain configurations. Using varying time-steps, forecasts started from the same initial conditions are also performed for several fast moving systems featuring stormy or strongly convective events.

From these numerical experiments, it is found that the observation verification scores of the Ref-HIRLAM is generally insensitive to the choice of time-step within tested reasonable ranges. This appears also to be the case for several tested fast developing cyclones, in terms of predicted MSLP and wind speed. On the other hand, it is seen that the location and estimated values of precipitation may become highly dependent on the size of time-step, in situations associated with strongly convective storms. This in turn may be an indication of increased nonlinearity, and hence, un-predictability,

150s							180s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	171	14	16	5	0	206	F1	178	15	17	5	0	215
F2	42	13	19	2	1	77	F2	38	11	16	1	0	66
F3	25	13	24	12	8	82	F3	23	17	24	12	7	83
F4	2	2	11	7	7	29	F4	2	1	14	7	7	31
F5	1	3	2	6	13	25	F5	0	1	1	7	15	24
sum	241	45	72	32	29	419	sum	241	45	72	32	29	419
%FO	71	29	33	22	45	54	%FO	74	24	33	22	52	56

240s							300s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	175	14	13	7	0	209	F1	172	15	13	5	0	205
F2	40	11	17	3	1	72	F2	47	9	21	3	2	82
F3	25	17	30	14	8	94	F3	20	19	21	12	7	79
F4	1	2	1	2	7	13	F4	2	1	8	6	7	24
F5	0	1	11	6	13	31	F5	0	1	9	6	13	29
sum	241	45	72	32	29	419	sum	241	45	72	32	29	419
%FO	73	24	42	6	45	55	%FO	71	20	29	19	45	53

Table 8: Contingency tables for 12 hour precipitation (18-30h E15/L60 forecasts) in the period 20020611 through 20020623. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

45s							60s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	79	3	6	0	1	89	F1	80	4	7	0	1	92
F2	11	3	5	0	2	21	F2	9	2	3	0	3	17
F3	1	3	3	4	5	16	F3	2	4	5	4	4	19
F4	0	1	2	2	10	15	F4	0	0	1	3	7	11
F5	0	0	0	8	5	13	F5	0	0	0	7	8	15
sum	91	10	16	14	23	154	sum	91	10	16	14	23	154
%FO	87	30	19	14	22	60	%FO	88	20	31	21	35	64

120s							150s						
	O1	O2	O3	O4	O5	sum		O1	O2	O3	O4	O5	sum
F1	79	3	8	1	4	95	F1	79	4	8	1	4	96
F2	10	4	1	1	1	17	F2	10	3	1	1	1	16
F3	2	3	5	3	3	16	F3	2	3	5	5	5	20
F4	0	0	1	2	9	12	F4	0	0	0	3	6	9
F5	0	0	1	7	6	14	F5	0	0	2	4	7	13
sum	91	10	16	14	23	154	sum	91	10	16	14	23	154
%FO	87	40	31	14	26	62	%FO	87	30	31	21	30	63

Table 9: Contingency tables for 12 hour precipitation (06-18h D05 forecasts) in the period 20020618 through 20020623, using time step of 45s, 60s, 120s and 150s. F stands for forecast and O for observation. The number is the class number (see text). %FO is the percentage of the forecasted values in the same class as the observation class. For Danish station-list.

48h			24h/12h		
Δt (s)	mslp (hPa)	wind (m/s)	Δt (s)	mslp (hPa)	wind (m/s)
60	972.31	22.74	150	964.92	29.58
150	972.56	23.03	180	964.81	29.58
180	973.09	23.10	240	964.87	29.61
240	973.33	22.64	300	964.79	29.89
300	974.18	24.05	360	964.77	29.85
360	974.19	22.14	Δt (s)	mslp (hPa)	wind (m/s)
600	974.30	21.54	150	963.32	31.28
720	974.51	21.65	180	963.29	31.26
840	974.29	22.29	240	963.23	31.19
900	975.00	22.06	300	963.21	31.19
960	974.60	21.37	360	963.24	31.14

Table 10: Minimum MSLP in the low pressure system over Denmark and maximum w0 meter wind at the west coast of Jutland for 48, 24 and 12 hour forecast for the 3rd of December 1999 18 UTC storm for different time-steps.

48h			24h/12h		
Δt (s)	mslp (hPa)	wind (m/s)	Δt (s)	mslp (hPa)	wind (m/s)
60	988.59	20.75	150	988.78	18.98
150	988.78	19.90	180	988.82	18.79
180	988.86	20.20	240	988.86	18.94
240	988.75	21.02	300	988.91	18.99
300	988.97	21.00	360	988.95	18.90
360	989.17	21.79	Δt (s)	mslp (hPa)	wind (m/s)
600	988.61	22.11	150	985.27	17.45
720	989.72	19.90	180	985.28	17.51
840	989.95	20.07	240	985.31	17.50
900	989.90	19.27	300	985.32	17.51
960	990.05	18.81	360	985.34	17.56

Table 11: Minimum MSLP in the low pressure system over southern Finland and maximum wind in the Gulf of Finland for 48, 24 and 12 hour forecast for the 21st of June 2002 18 UTC storm for different time-steps.

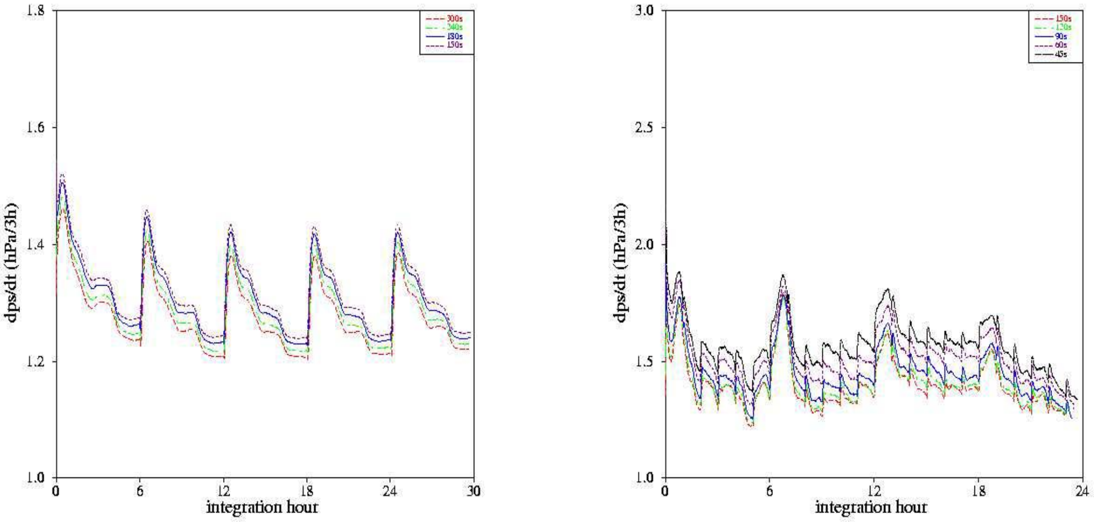

Figure 12: Noise level (change in surface pressure (hPa) per 3 hours) of the E15/L60 model for the period 2002011500-2002012700 for 150s, 180s, 240s and 300s and for the D05 model for the period 2002061800-2002062300 with time-stepping of 45s, 60s, 120s and 150s, respectively.

of the strongly convective system at high horizontal resolution. Indeed, even in the cases where there is more obvious dependence of predicted rainfall on choice of time-step, the variability of results are not more significant than other tunable features normally associated with a NWP system, such as choice of advection scheme, the horizontal diffusion and physical parameterization.

Thus it is concluded that the Ref-HIRLAM in the typical scenario as tested here is a rather robust system, as far as sensitivity to time-step is concerned. In other words, with the current version of Ref-HIRLAM, the size of time-step does not seem to be a strong constraint in terms of resulted forecast quality. On the other hand, the results shown here by no means suggest less need of similar sensitivity test in case of significant modification concerning model resolution (in vertical as well as in horizontal), advection scheme or physical parameterizations. More attention should also be paid on accuracy of the advection scheme itself and the dynamics/physics interface, which is outside the scope of this report.

Acknowledgment

We thank Leif Laursen for offering many useful suggestions regarding sensitivity tests in case of fast moving systems.

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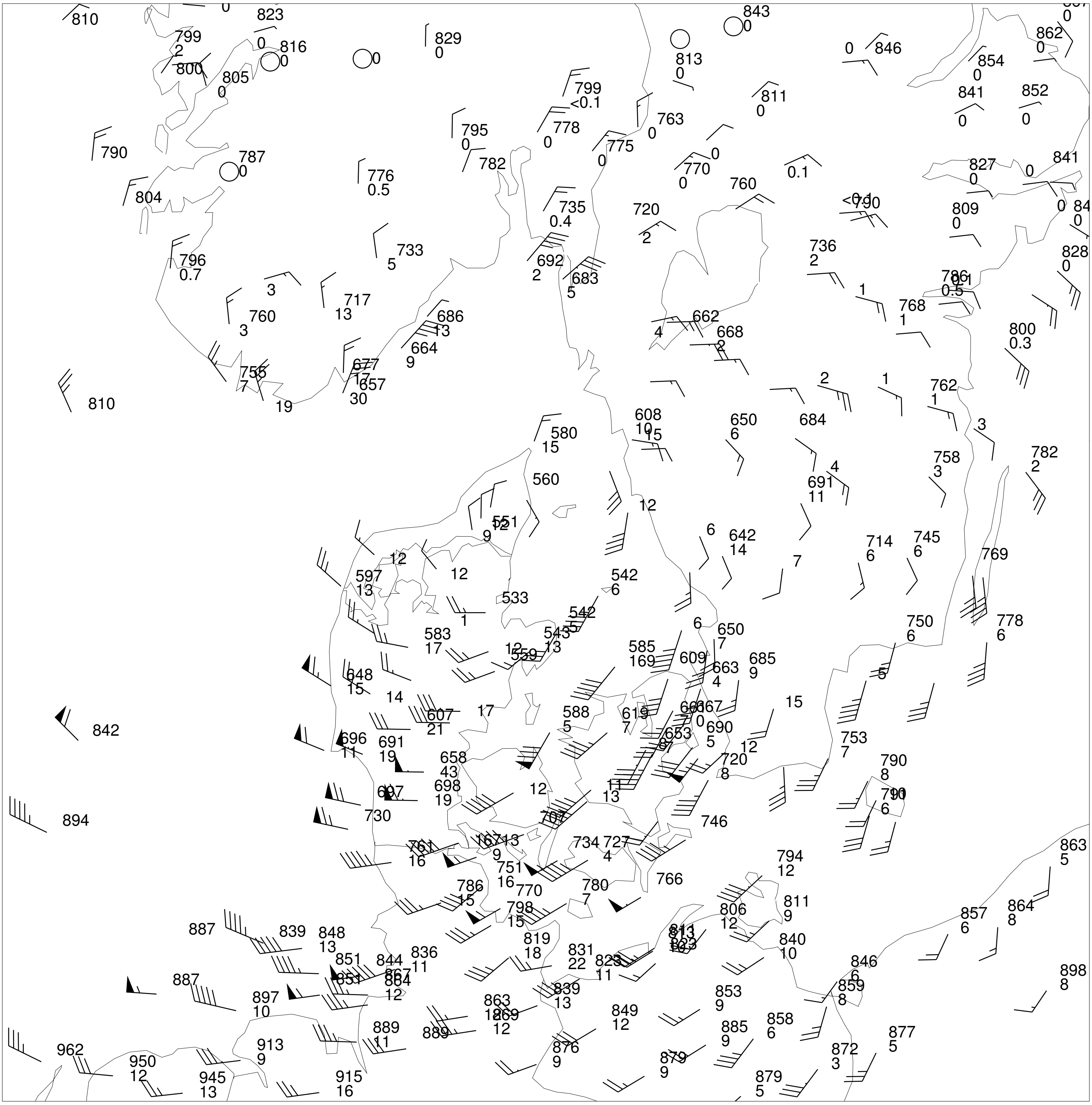

3. december 1999, 18:00 UTC

Figure 13: Observations of the storm the 3rd of December 1999 at 18 UTC. Observations show 10m wind, MSLP and 12 hour accumulated precipitation.

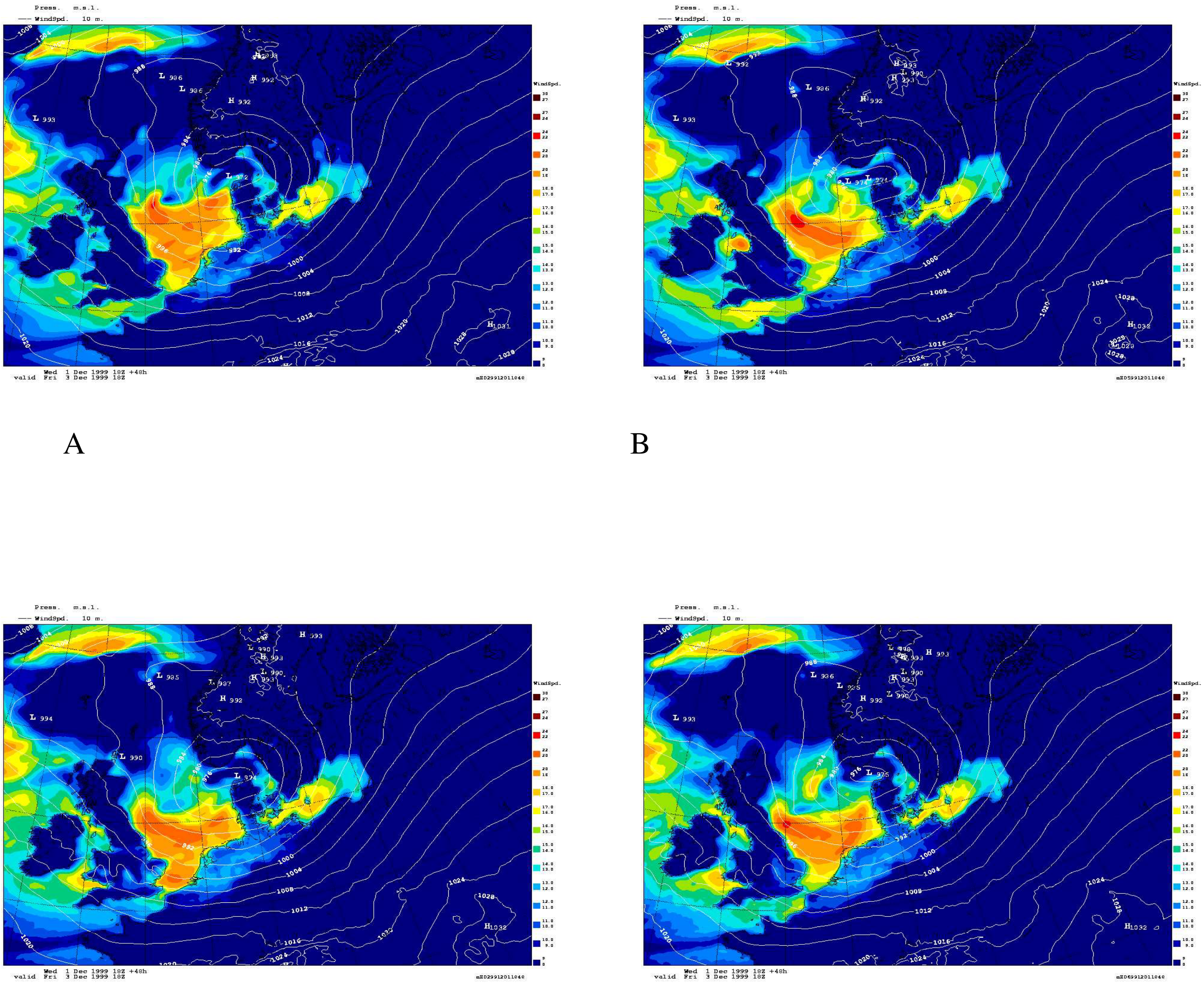

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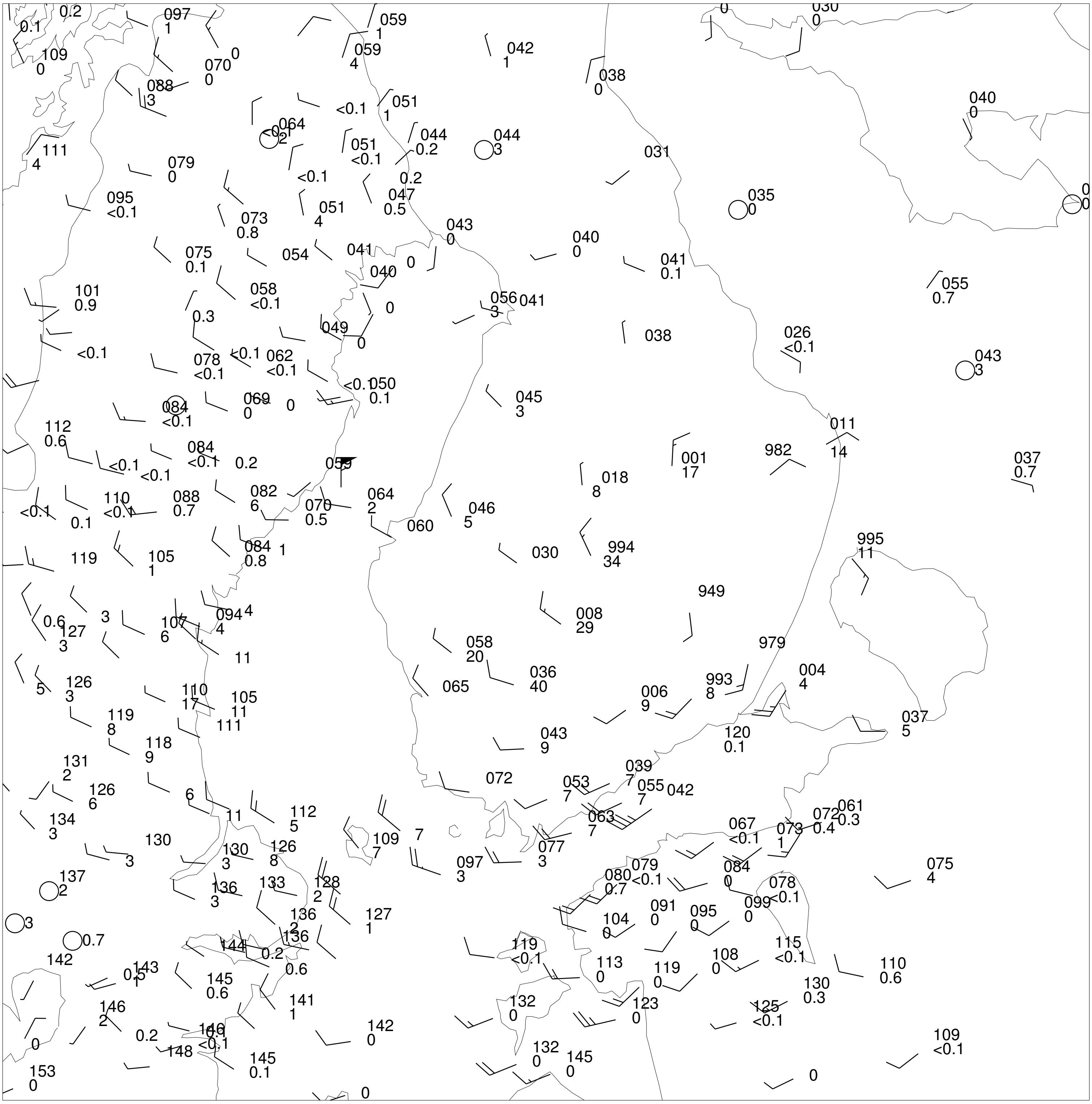
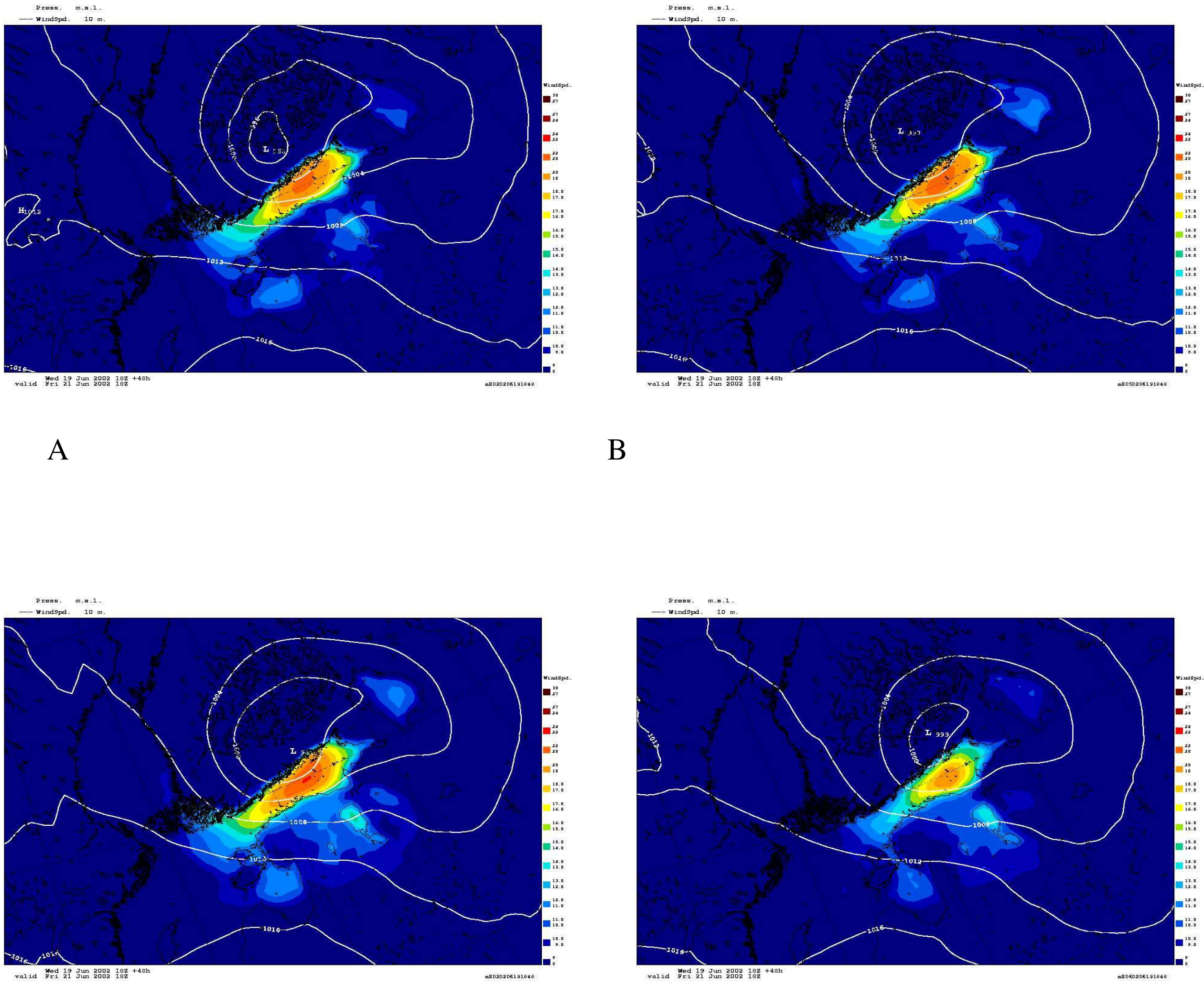
Figure 14: 48 hour forecast of 10m wind and MSLP for the storm the 3rd of December 1999 18UTC. a) ΔT = 1 min, b) ΔT = 5 min, c) ΔT = 10 min and d) ΔT = 15 min. The strength of the wind speed is increasing from "cool" (blue) colours to "warm" (red) colors. The blue colours are wind speeds below 15 m/s, From green to orange it is in the range 15-20 m/s and the red colours are in the range 20-30 m/s.



21. juni 2002, 18:00 UTC

Figure 15: Observations of the storm the 21st of June 2002 at 18 UTC. Observations show 10m wind, MSLP and 12 hour accumulated precipitation.



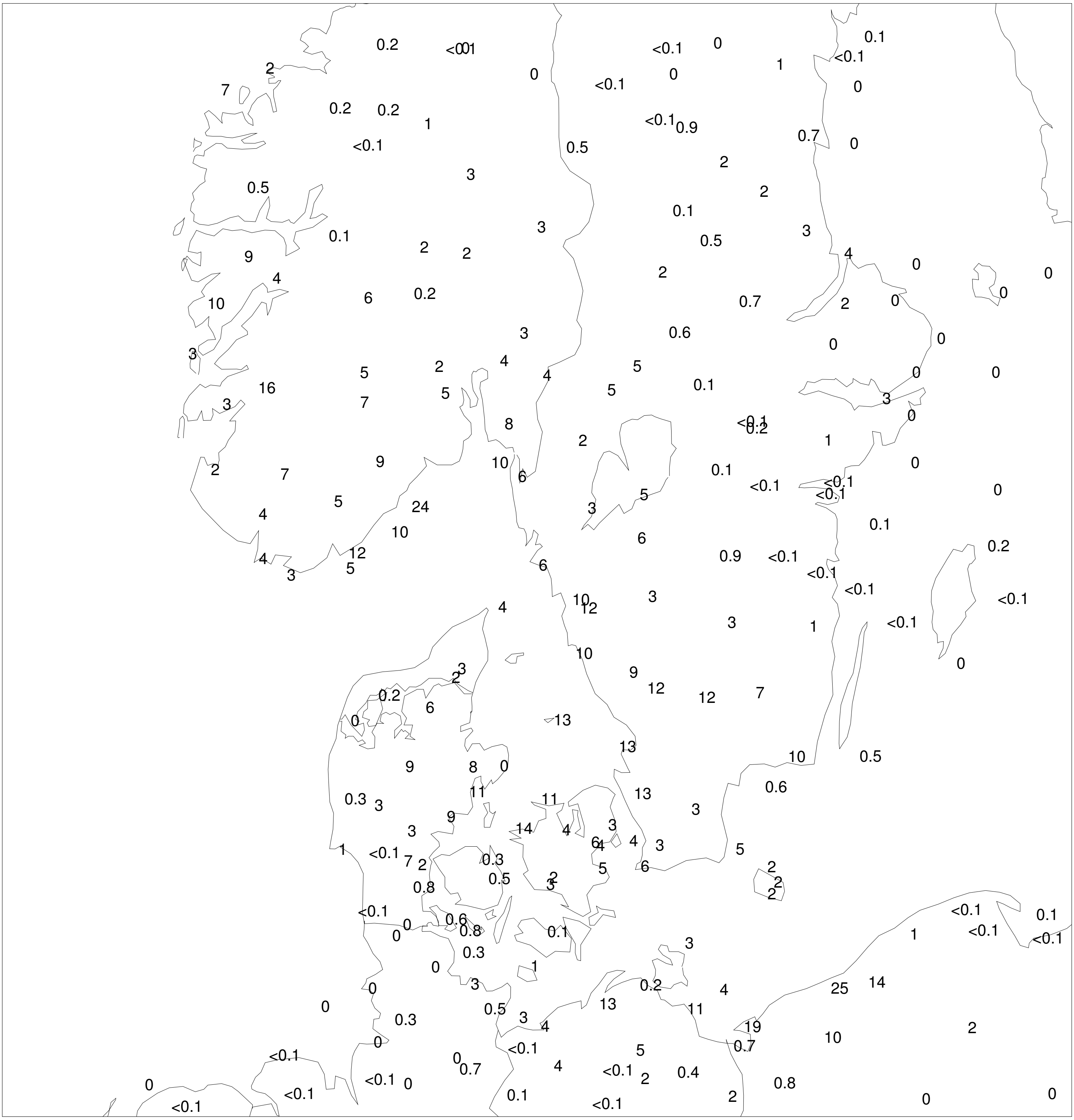
A

B

C

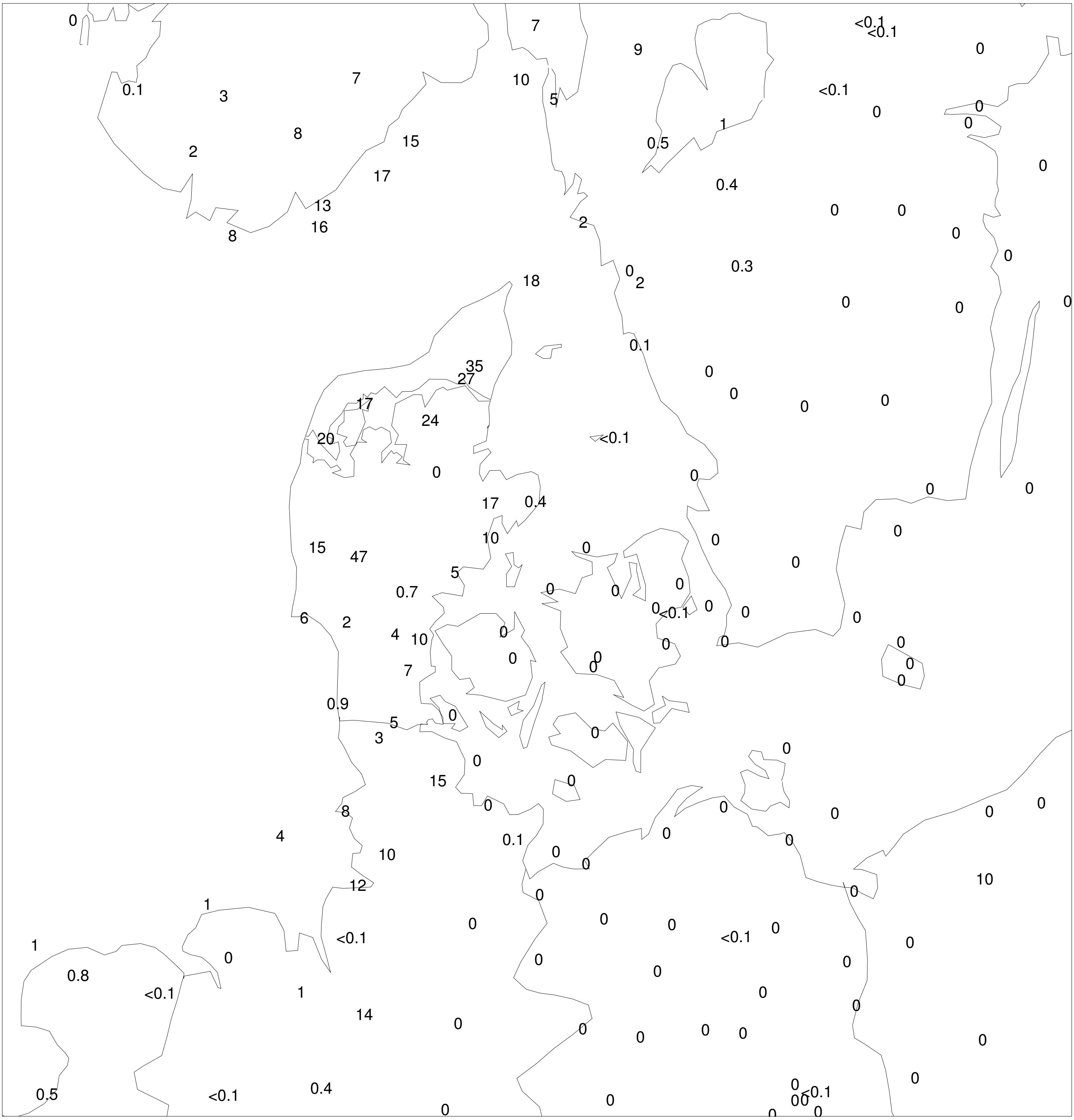
D

Figure 16: 48 hour forecast of 10m wind and MSLP for the storm the 21st of June 2002 18UTC. a) ΔT = 1 min, b) ΔT = 5 min, c) ΔT = 10 min and d) ΔT = 15 min. The strength of the wind speed is increasing from “cool” (blue) colours to “warm” (red) colors. The blue colours are wind speeds below 15 m/s, From green to orange it is in the range 15-20 m/s and the red colours are in the range 20-30 m/s.



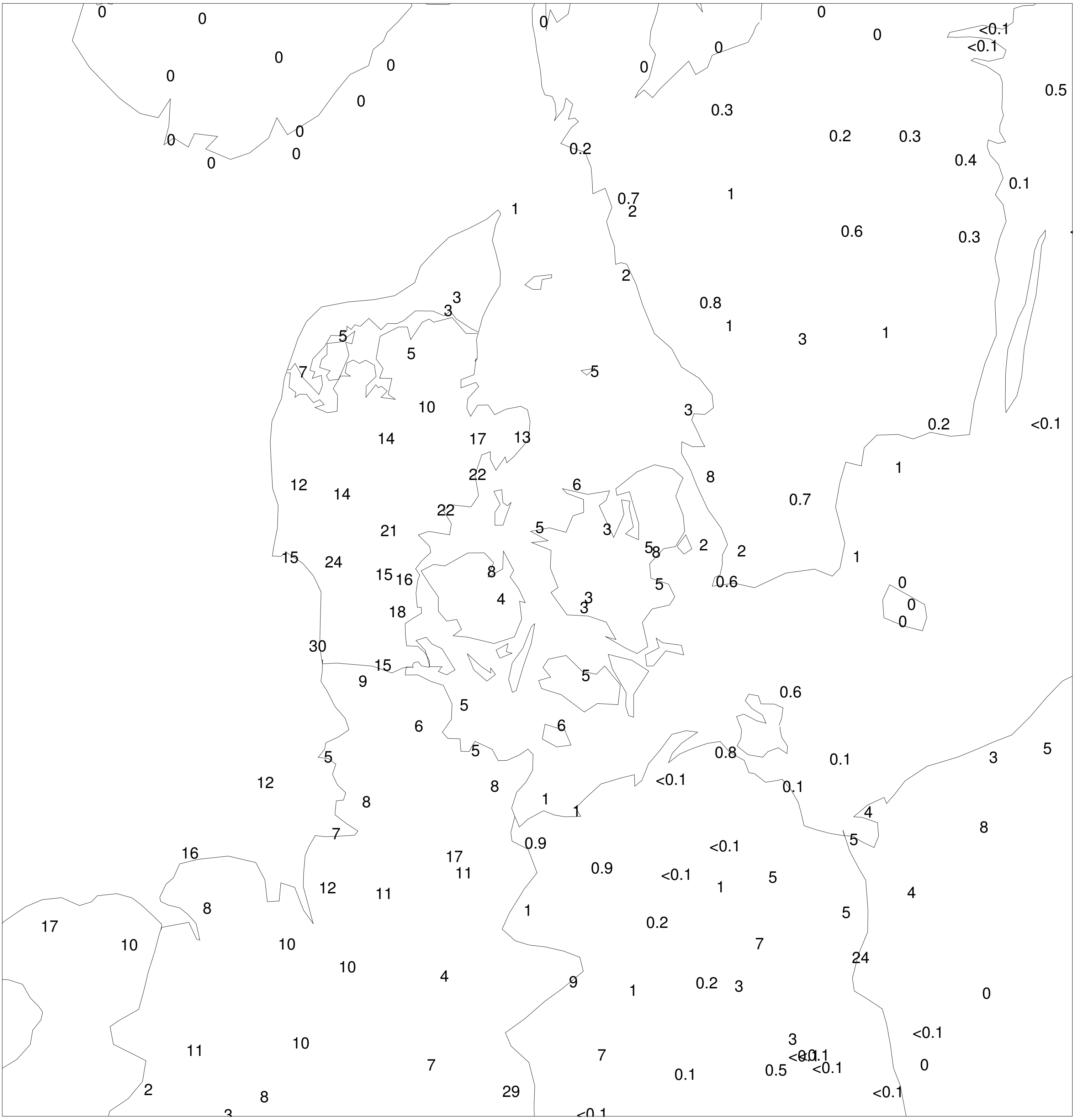
15. juni 2002, 18:00 UTC

Figure 17: Observations of the precipitation event the 15th of June 2002 at 18 UTC. Observations show 12 hour accumulated precipitation.



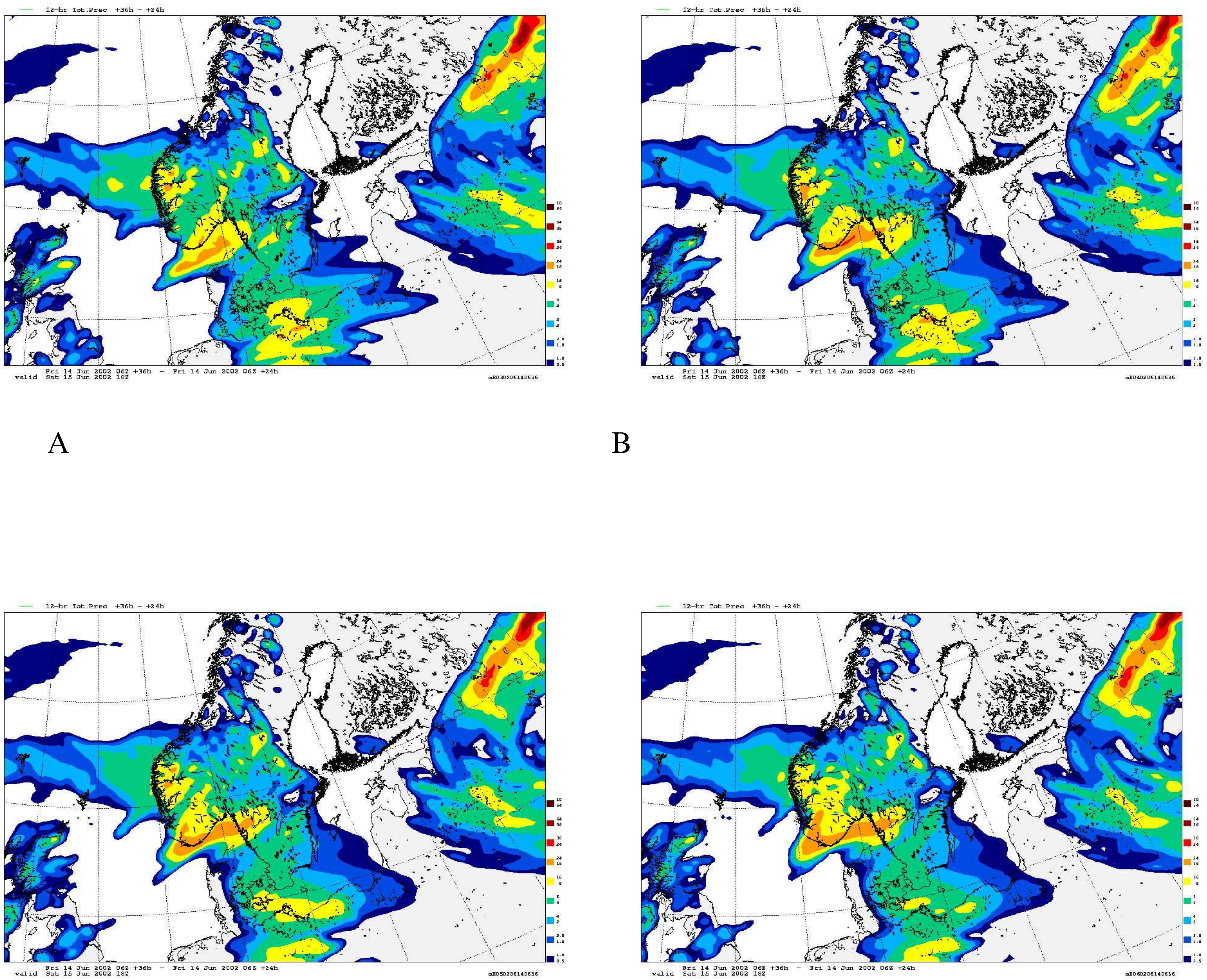
18. juni 2002, 18:00 UTC

Figure 18: Observations of the precipitation event the 18th of June 2002 at 18 UTC. Observations show 12 hour accumulated precipitation



20. juni 2002, 18:00 UTC

Figure 19: Observations of the precipitation event the 20th of June 2002 at 18 UTC. Observations show 12 hour accumulated precipitation



A

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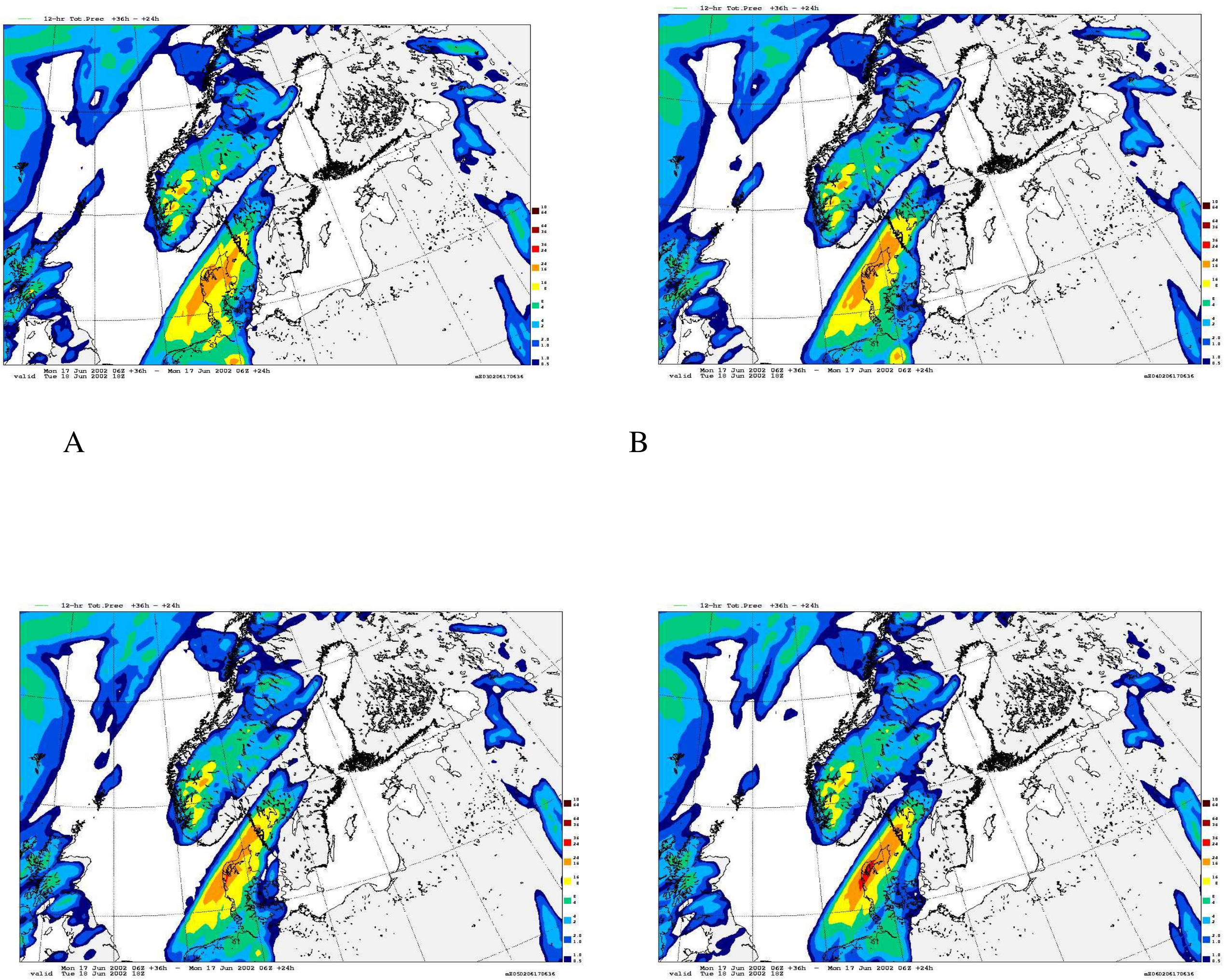
Figure 20: 12 hour accumulated precipitation valid the 15th of June 2002 18 UTC. a) ΔT = 3 min, b) ΔT = 4 min, c) ΔT = 5 min and d) ΔT = 6 min. The ammount of precipitation is increasing from “cool” (blue) colours to “warm” (red) colors. The categories are: below 1mm (Dark blue), 1-2mm (medium blue), 2-4mm (lightblue), 4-8mm (green), 8-16mm (yellow), 16-24mm (orange), 24-36mm (red), 36-64mm (dark red) and above 64mm (brown).



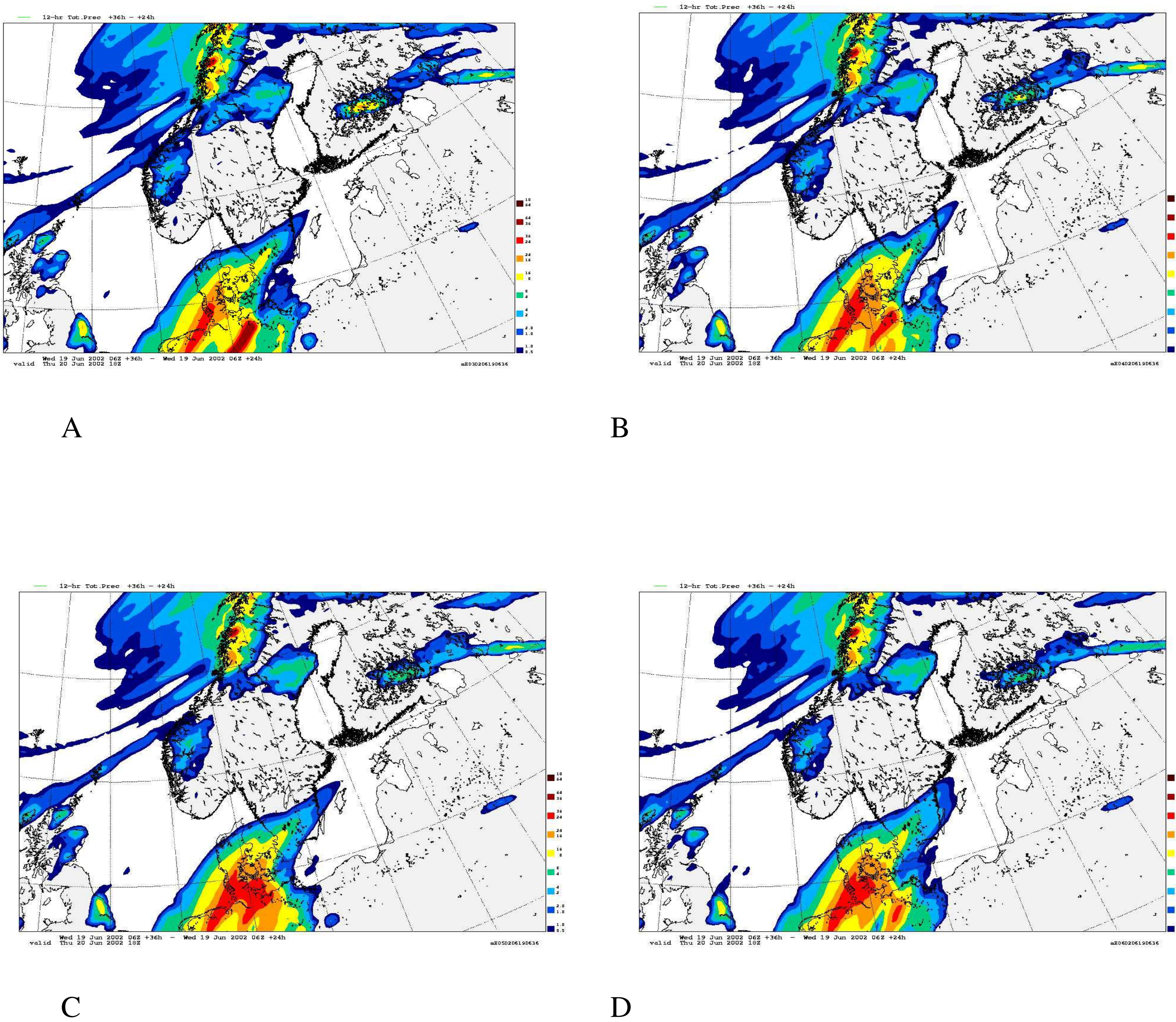
A

B

C

D

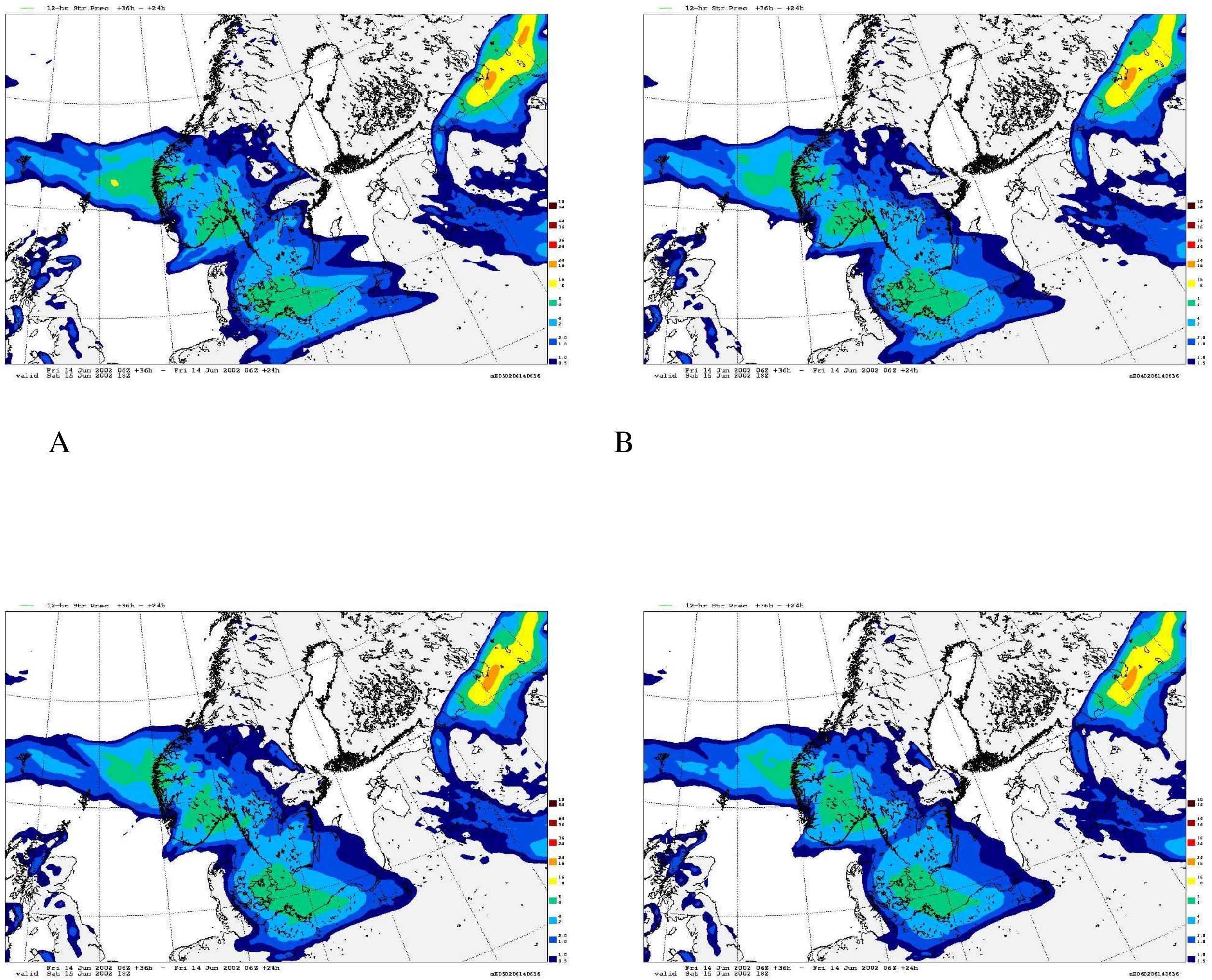
Figure 21: 12 hour accumulated precipitation valid the 18th of June 2002 18 UTC. a) ΔT = 3 min, b) ΔT = 4 min, c) ΔT = 5 min and d) ΔT = 6 min. The colour code is as in figure 20.



A B

C D

Figure 22: 12 hour accumulated precipitation valid the 20th of June 2002 18 UTC. a) ΔT = 3 min, b) ΔT = 4 min, c) ΔT = 5 min and d) ΔT = 6 min. The colour code is as in figure 20.



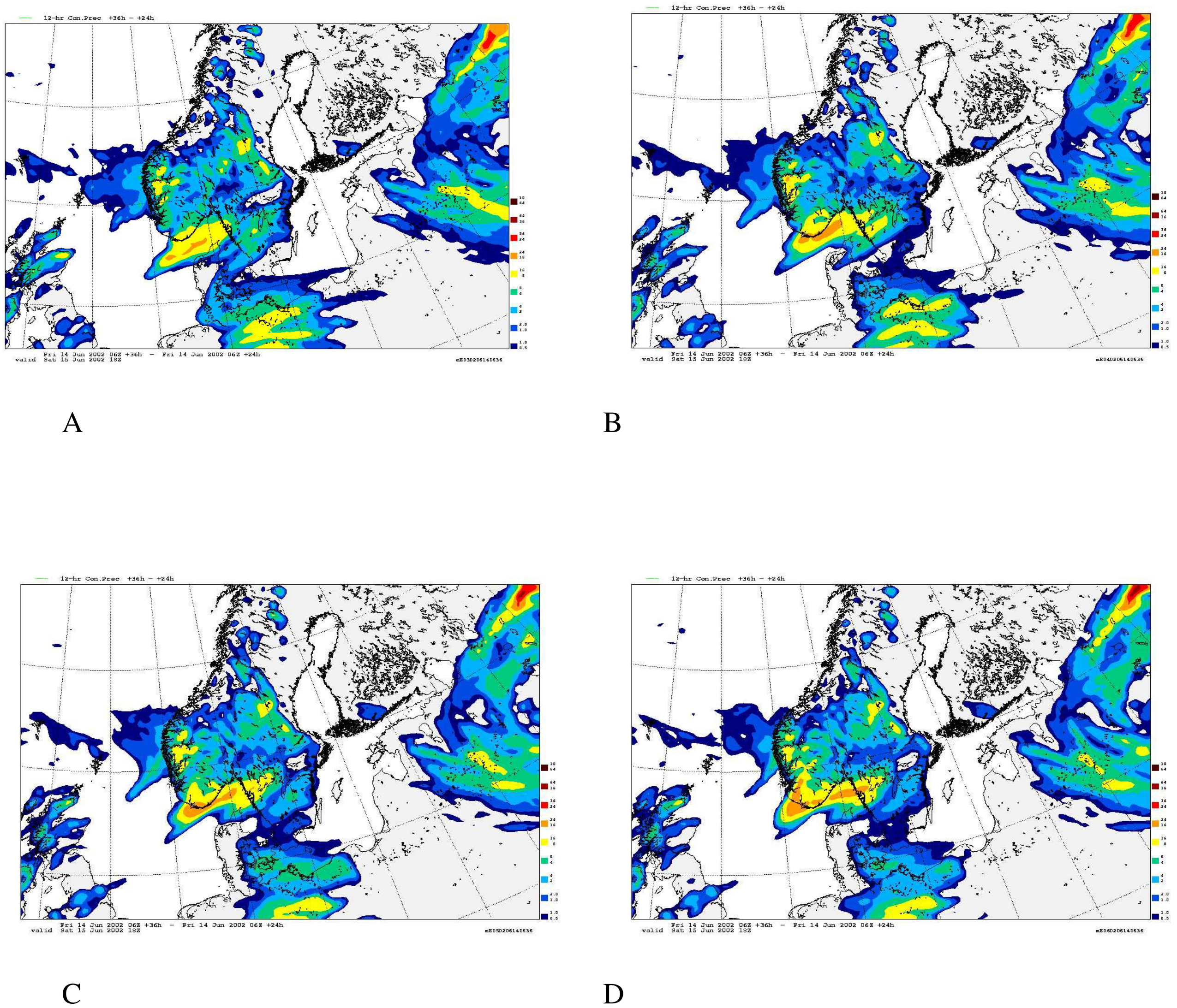
A

B

C

D

Figure 23: 12 hour accumulated stratiform precipitation valid the 15th of June 2002 18 UTC. a) ΔT = 3 min, b) ΔT = 4 min, c) ΔT = 5 min and d) ΔT = 6 min. The colour code is as in figure 20.



A

B

C

D

Figure 24: 12 hour accumulated convective precipitation valid the 15th of June 2002 18 UTC. a) ΔT = 3 min, b) ΔT = 4 min, c) ΔT = 5 min and d) ΔT = 6 min. The colour code is as in figure 20.

Previous reports

Previous reports from the Danish Meteorological Institute can be found on http://www.dmi.dk/dmi/dmi-publikationer.htm