A recent study on the initialization procedure in HIRLAM

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1 Introduction

Digital Filtering Initialization (DFI) has been formally implemented in the reference HIRLAM forecast model since 1998, following earlier works of Lynch and Huang (1992). The initial implementation (Lynch *et al.*, 1999) places the initialization procedure in the master forecast program GEMINI.f and separates the initialization and forecast through run scripts. The design is seen later as inadequate to accommodate more sophisticated initialization options, in particular, for incremental DFI (IDFI). In June 2001, a recoding is implemented by Huang and Yang (DMI), introducing an initialization interface which separates the initialization related codes from the main forecast model. In addition, the need for input and output following initialization is eliminated. The recoding is mainly of technical nature, maintaining full reproducibility of the original DFI scheme referred to as TDFI, while enabling several new options such as ADFI,DDFI and IDFI. In late 2001, some further extensions of the initialization interface were coded and briefly tested, e.g., DFI launching (DFL), quick-start filter, as have been reported in the HIRLAM technical report by Huang and Yang (2002). However, these later code revisions have not been recommended and implemented into the reference system, mainly because of concerns for troubles to users with further extended options, with the meteorological benefit not seen as strongly convincing.

Recently, researchers at KNMI reported improvement of moisture spin-up by using the launching scheme. Based on the study, the DFL scheme has been added into the existing initialization interface (reference Beta release 6.1.1, released on June 2 2003), with some additional code revisions (Ben W Schreur, KNMI). In the present study, some further revisions of initialization procedure has been implemented, which is to be recommended to the reference release 6.1.2. This notes briefly present some results in connection with the code revisions and preliminary short data assimilation tests. The discussions are also supplemented by results from the latest validation assimilation runs done.

2 Code revisions and experiments

In the present work, further revisions to the initialization update as implemented in HIRLAM 6.1.1 by Ben W Schreur (KNMI), are implemented. Most of these changes are related to DFL option. The main revisions are as follows.

- Option for incremental DFL. The modification of BDDIF, BDTIM and NTDATA in subroutine FULDFI.f as introduced in 6.1.1 makes it impossible to use incremental DFI option with launching scheme. Changes are thus made in DFI.f, INCDFI.f and FULDFI.f to enable the option. The incremental DFL also requires first guess file at launching point. This is facilitated through revisions in INCDFI.f and COMINI.inc.

- Initial non-filtered fields at DFL option. We propose to use the forecasted surface and cloud cover fields obtained at the launching point during the forecast at initialization stage, i.e., the middle point of the DFL window, as the "initialized" fields, instead of using either original input values or zero. Our tests indicate such approach being slightly better. Similarly, we propose to store the accumulated fields (such as precipitation) at the middle point of DFL window to be used when starting forecast, instead of initializing it as zero.

- New filter options. In DFCOEF.f, we also implemented the quick start recursive filter (Lynch and Huang, 1994) as type 8, and moved the original NFILT type of 8 (no filtering) to 9.

- Script option. We believe that in principle, the forecast options used in DFL forward step should be the same as for the rest of forecast. We thus propose to specify same options for NBDPTS, NBDREL and NLTANH for initialization and for forecast in the forecast scripts.

Data assimilation experiments have been performed on DMI's NEC SX6 computer using the HIRLAM model which is similar to HIRLAM 6.1.1. Apart from the code revisions involving initialization as mentioned above, the model contains some local adaptation of the (earlier unofficial version of) HIRLAM 6.1.1, which is mainly of technical nature (such as compiler option for OpenMP). Among the revisions which may have meteorological impacts, it includes the revision of lateral boundary relaxation based on the Canadian MC2 approach [according to its initial HIRLAM implementation by Aidan McDonald (Met Eireann)],the revision of vertical interpolation which enables interpolation of cloud water and TKE from lateral boundaries [based on the revisions provided by Laura Ranto (FMI)].

The data assimilation experiments have been run on DMI's operational domains with triple nesting structure, using 45 km (G model), 15 km (E model) and 5 km (D model) resolution and 40 levels. G model uses ECMWF forecast frame as boundaries (3-hourly), and E, D models are nested under G and E, using the hourly host model forecasts as lateral boundaries. The main results reported here are those with TDFI, DFL and IDFI at G and E resolutions, covering 3 days and 13 cycles, (from 2003051018 to 2003051318). Although the experiment period is relatively short, the trend represented by the statistics seem to be sufficiently indicative. Part of the discussions are also supplemented by the latest validation runs covering a 2-week period.

3 Discussion

3.1 Moisture spin-up: the main weak point of TDFI

With the default initialization scheme TDFI, the efficiency of noise reduction , following data assimilation steps, has generally been satisfactory. In Figure 1, the averaged surface pressure tendencies are presented, showing "noise" curves of TDFI at moderate levels for both G and E models. The initial adjustment following initialization between mass and wind fields and between filtered and unfiltered fields causes additional "spin-up" in the averaged tendency curves, but such adjustment process is seen (Figure 1) to be around 1 to 3 hours.

The main weak point as commonly encountered in running HIRLAM using TDFI is seen to be in the spin-up of moisture fields such as cloud cover, precipitation and cloud condensate. It is hypothesized that, the artificial digital filtering of dynamic fields has a side effect to cause imbalance between filtered and unfiltered fields. The latter includes

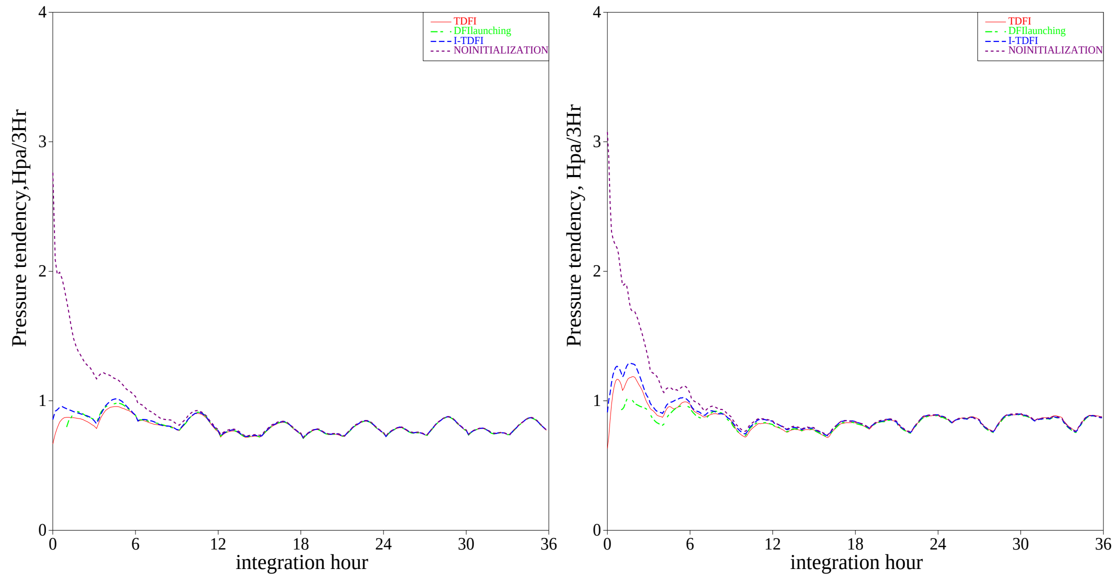

Figure 1: Time series of domain averaged pressure tendency for (a) G model (45 km) and (b) E model (15 km), averaged for 12 cycles for period of 2003051100 and 2003051318, using TDFI (solid line), DFL (dash dotted line) IDFI (dash line), and no initialization (short dash line).

surface and moisture quantities such as cloud water, cloud cover, etc. In addition, the adiabatic backward integration used in a normal DFI scheme such as TDFI causes further mismatch between dynamic and surface/physics processes, which leads to additional needs of adjustment following initialization. Figure 2– 4 show the corresponding time series of Figure 1 for commonly examined moisture quantities such as precipitation rate, cloud cover and cloud water content. While the spin-up time for TDFI seems to be less than 3 hour, the period is around 6 hours for cloud cover and precipitation at E runs. For surface fluxes, there is also some slight spin-up for momentum one (for ca 1 hour), see Figure 5. The spin-up features cast doubts on usefulness of the above mentioned forecast products at initial forecast period (from starting point to ca 3, sometimes 6 hours). The short coming in moisture spin-up at TDFI option has been found to affect quality of precipitation forecast, (see also example of precipitation verification in Section 3.5), but its impact on forecast quality of other key weather parameters seem to be generally insignificant.

3.2 Alternative approaches to initialize cloud cover: not sensitive

The moisture spin-up feature following initialization procedure is likely to be closely associated with the specific moisture schemes in the forecast model. In the reference condensation scheme STRACO, the 3-dimensional total cloud cover (TOTCOV) is a quasi-prognostic quantity, due to the fact that the TOTCOV is determined by a weighted sum of the diagnosed "equilibrium cloud cover" and the cloud cover of the previous time step. When initiating TOTCOV as zero, as is done in HIRLAM 4, it causes severe initial spin-up problem. This is later improved by applying an initial diagnosis of TOTCOV from fields of T,Q etc, using a simple subroutine called CLOUD.f, which ensures a non-zero cloud cover to be used in initial calculation of ISBA/CBR turbulence and radiation parameter-

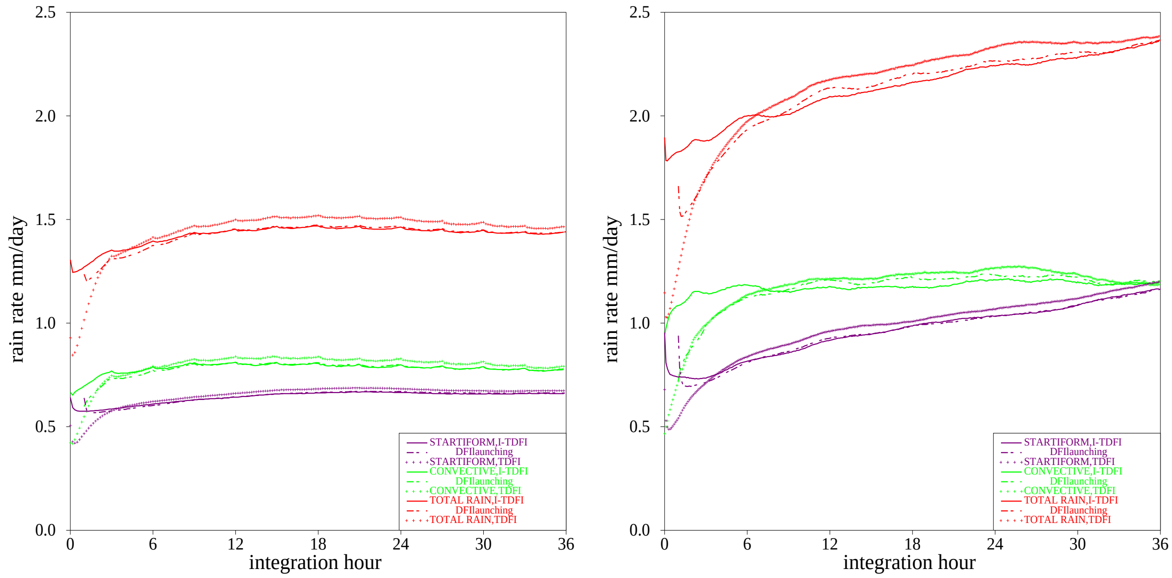

Figure 2: Time series of precipitation rate for (a) G model (45 km) and (b) E model (15 km), averaged for 12 cycles for period of 2003051100 and 2003051318, using TDFI (solid line), DFL (dash dotted line) and IDFI (dash line) initialization, respectively. The top most curves are for total rain, the middle one for convective precipitation, and the lower one for stratiform precipitation.

ization. Secondly, in the subsequent STRACO calculation of cloud cover, CLOUDCV.f, a linear relaxation mechanism is devised to recalculate the weights for the diagnostic value of TOTCOV and the values from previous step.

Currently, the DFI procedure only applies filter to dynamic fields. For cloud cover TOTCOV, instead of applying diagnosis at start of forecast, it may also be filtered during the forward DFI steps. In addition, assuming such initiated TOTCOV is a realistic initial value for TOTCOV, the initial cloud diagnostics by CLOUD.f may not be necessary, as currently the case, and there should be no need of linear transition of weighting coefficients between the TOTCOV from previous step and the current equilibrium value, as currently implemented.

Parallel data assimilation tests of the above alternative formulations have been conducted, but the results (not shown here) so far show only insignificant impact in spin-up feature of moisture quantities, suggesting probably the generally passive nature of the cloud cover field. No recommendation on changes of cloud cover initialization is thus proposed for now.

3.3 DFI Launching. Better in moisture spin-up, but is it good enough?

Using DFI launching (DFL), the DFI integration involves only forward integration, with digital filtering only applied to model trajectory at the initialization window, (which is 2 hour in the tested case using DOLPH window), and the forecast is started half way of the DFI integration. The DFL design avoids the questionable backward integration step as applied in ADFI, DDFI and TDFI options, thus has potential advantage in moisture spin-up.

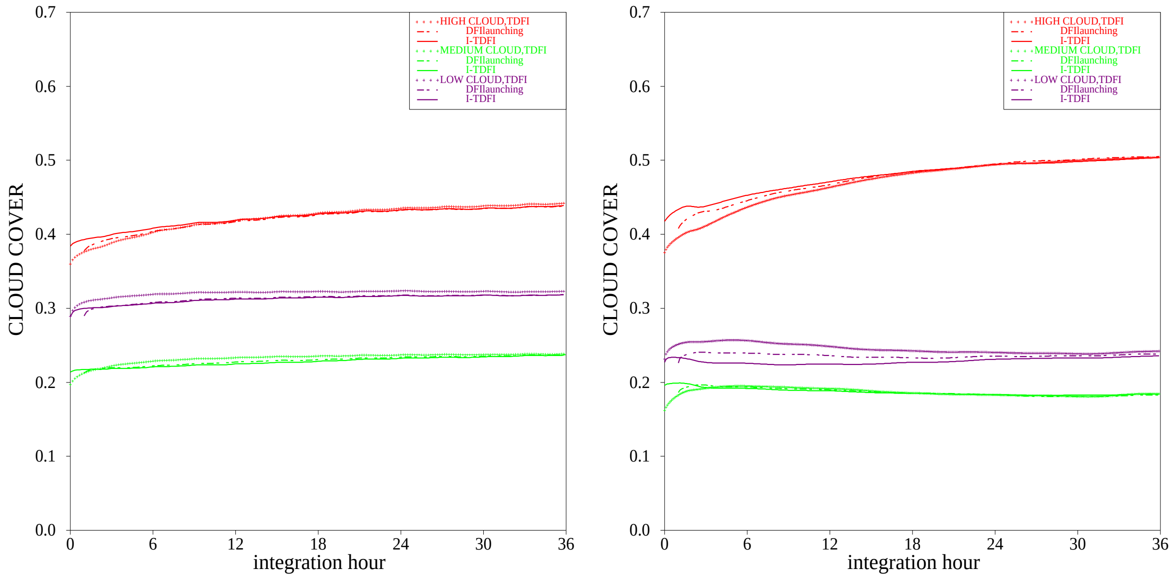

Figure 3: As in Figure 2 but for high cloud cover (upper), medium cloud cover (lower) and low cloud cover (middle).

Interestingly, DFL shows lower noise level at the start of forecast compared to the corresponding period in TDFI forecast. For the moisture quantities such as cloud cover, rain and cloud water content, as are examined here, the spin-up feature is somewhat reduced compared to TDFI for the comparable periods, most notably in cloud water statistics (Figure 4), also somewhat for cloud cover Figure 3. There is also slight improvement in precipitation as shown in Figure 2, but the change there is largely cosmetic, since the spin-up time for rain rate remain at ca 6 hours for E model. In general, due to absence of initial forecast period before launching point, the DFL moisture time series do not show the kind of significant adjustment at the initial hours as in TDFI, but the curves for DFL and TDFI do merge 1 or 2 hours after launching point. In the parallel experiment for a two-week period as described below, the observation verification do show some marginal improvement by DFL in forecasts of a few key parameters including precipitation, over those with TDFI, see below.

It thus appears, that if one can accept absence of model fields in the initial stage of forecast (including those at analysis time), DFL is preferred as a cheaper and cleaner solution.

3.4 Incremental DFI. Expensive but maybe it pays off?

DFI is essentially a numerical tool to low-pass filter the forecast trajectory. Conceptually speaking, the procedure does not distinguish between gravity-wave and other non-stationary waves, both of them at short time scales. This implies potentially negative impact to high resolution modeling through “excessive” filtering. With Incremental DFI (IDFI), the digital filtering is applied to both the first guess and the input analysis, with the differences of the filtered fields added to the first guess. The canceling effect of IDFI in filtering first guess and analysis makes it possible to retain those nearly noise-free but useful fast oscillations contained in the first guess fields, while absorbing larger scale increments obtained from data assimilation. However, IDFI doubles costs of DFI. It also

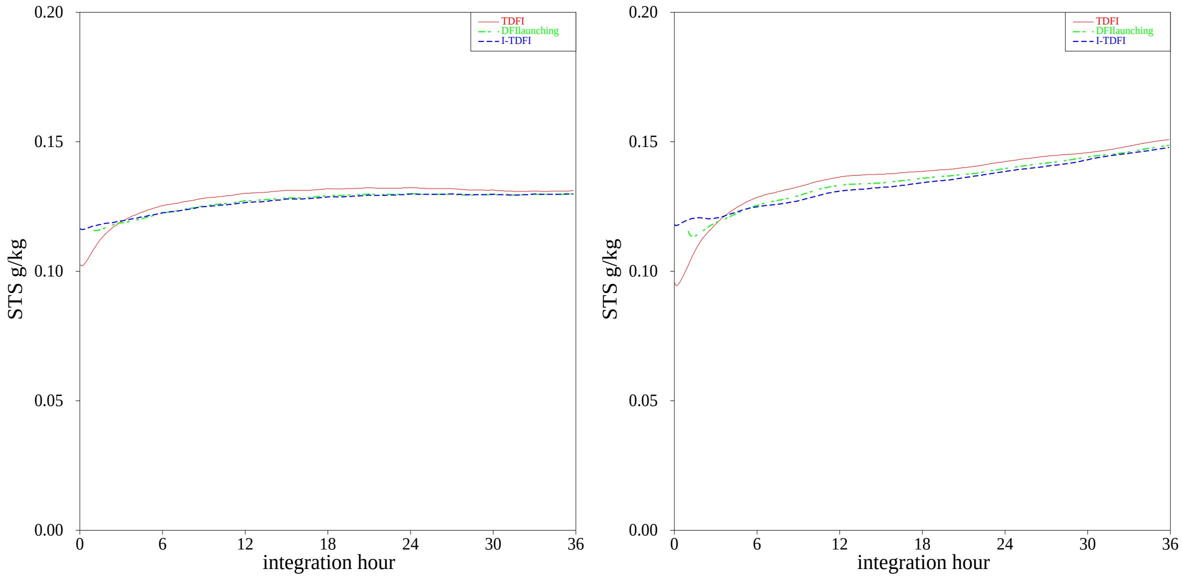

Figure 4: Averaged time series of cloud water content for (a) G model (45 km) and (b) E model (15 km), averaged for 12 cycles for period of 2003051100 and 2003051318, using TDFI (solid line), DFL (dash dotted line) and IDFI (dash line).

causes slightly higher initial noise level compared to TDFI or DFL. This however is not necessarily a drawback. After all, the initial noise level after a normal DFI appears to be at the low end in the current HIRLAM forecast.

The benefit of IDFI on moisture spin-up is obvious, on the other hand. This is valid for all the fields examined here: cloud cover, cloud content, rain and surface fluxes, both in comparison to TDFI and to DFL, as shown in the time series for the domain averaged quantities in Figure 2 to Figure 5. The advantage of IDFI is most significant in improving precipitation spin-up, as shown in Figure 2 for both G model and E model runs. For E model runs, the precipitation spin-up is more than 6 hours for both TDFI and DFL. With IDFI, the spin-up period is strongly reduced, especially for that of convective precipitation.

One may assume that, based on improvement of spin-up features by both DFL and incremental TDFI, it could be feasible to combine the DFL with that of incremental approach to achieve further improvement in initialization. This is made possible with our latest code revisions. With incremental DFL (IDFL), the first guess valid at the launching point, in addition to the first guess valid at analysis hour, will be needed. During initialization stage, DFL is applied to the forecast trajectories started from analysis and first guess, respectively, with the difference of the filtered dynamic quantities added to the first guess valid at launching point. Using such obtained fields as initialized model state, the forecast is started. Currently, preliminary data assimilation tests using IDFL is ongoing.

3.5 Verification scores from parallel, two-week assimilation experiments

Results from a parallel, two-week data assimilation experiments using TDFI, DFL and incremental TDFI have just been available when this notes is to be submitted. The period covers the episode between 00 UTC at June 11, 2002 and 18 UTC at June 24,

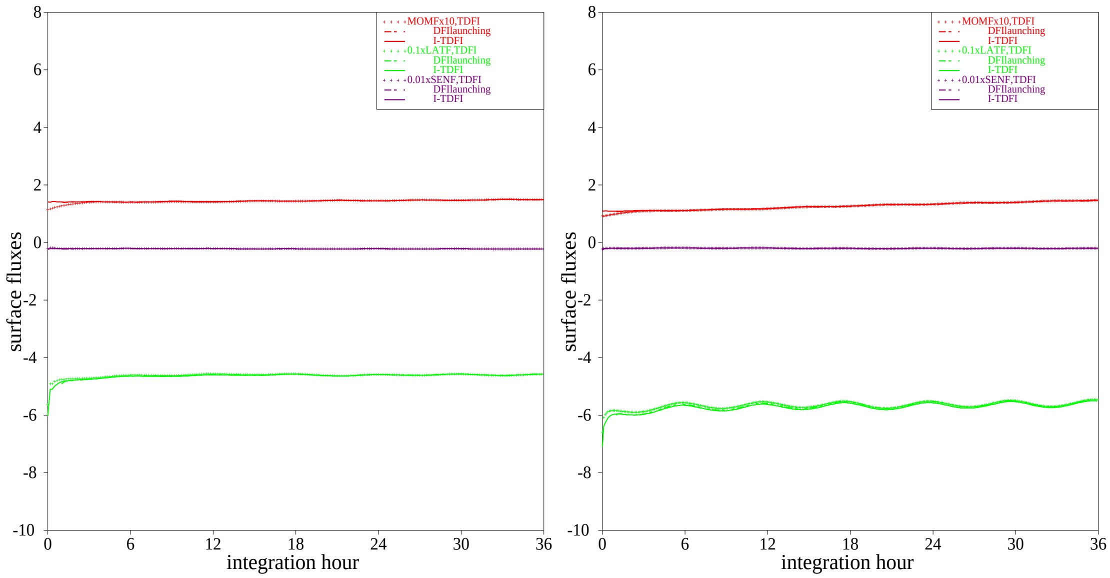

Figure 5: Time series of surface fluxes for (a) G model and (b) E model, averaged for 12 cycles for period of 2003051100 and 2003051318, using TDFI (solid line), DFL (dash dotted line) and IDFI (dash line) initialization, respectively. Note that the surface fluxes has been scaled with a ratio as indicated in top right columns of the figures.

2002, during which several heavy rain events occurred, associated with cyclone activities. The delayed-mode assimilation is made using the same model version as mentioned above, on DMI's triple nesting model domain, The test assimilation is run at 6 hour interval, with a forecast length of 36 hour.

Figure 6 shows the observation scores for key parameters in RMS and BIAS against EWGLAM station list, averaged for the period between 2002061100 and 2002062418, using E model (15 km). The relative scores for G model (45 km) are qualitatively similar. From the figure, the verification scores for all model runs during the test period indeed show some sensitivity to the initialization schemes tested here. With DFL and I-TDFI, the scores for several parameters (such as MSLP and upper air T) show some marginal improvement. Most noticeably, the bias for low level relative humidity is improved with DFL and IDFI.

The benefit of the alternative schemes in improving forecasts of moisture fields is also confirmed by slightly improved precipitation forecast scores, as shown in contingency tables for 12-hr accumulated precipitation (Table 1 for E model and Table 2 for D model). Note that the model forecast verified here include all 12 hour accumulated value with various forecast lengths, (i.e., +6 to +18 hr, +12 to +24 hr, +18 to +30 hr and +24 to +36 hr). The scores of E model (Table 1) are those against EWGLAM stations, and for D model (Table 2), the forecast data are verified against Danish synoptic stations (numbered at ca 20), due to D model's limited domain size. In the contingency tables, precipitation is classified by 5 classes, from lowest class (1) to the highest one (5) as 0-0.2 mm, 0.2 - 1 mm, 1 - 5 mm, 5 - 10 mm and above 10 mm. From Table 1 and Table 2, the DFL and IDFI schemes are seen to be associated with improved precipitation forecasts at low rainfall events.

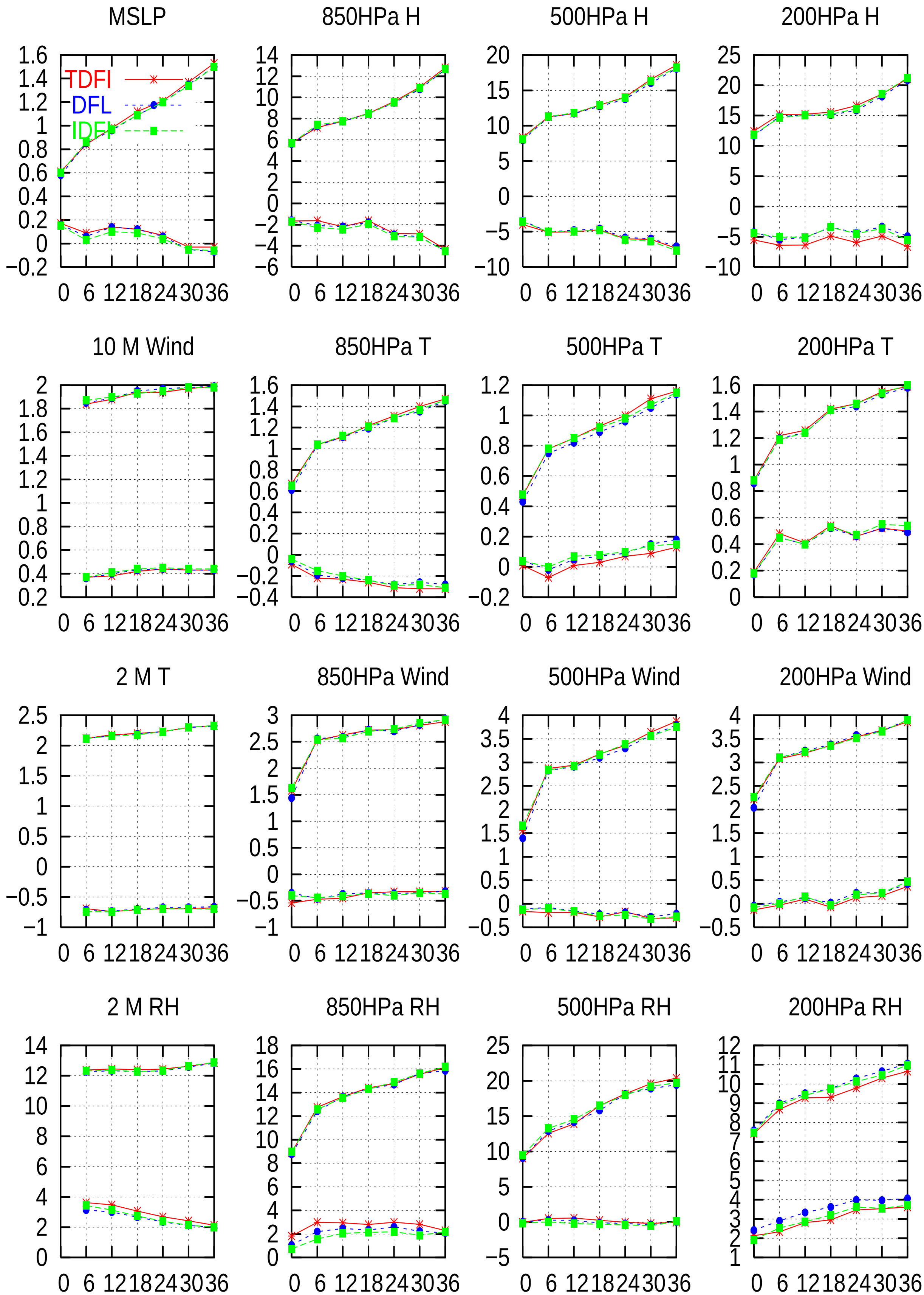

Figure 6: Observation verification scores of key parameters for HIRLAM E model, during 2002061100 and 2002062418, verified against EWGLAM stations.

Table 1: Contingency table for 12 hr accumulated rain, HIRLAM E

	TDFI					DFL					IDFI				
	Obs1	O2	O3	O4	O5	O1	O2	O3	O4	O5	O1	O2	O3	O4	O5
Fcst 1	18900	633	340	75	74	19086	644	370	82	79	19145	671	397	90	86
Fcst 2	3365	572	525	147	82	3299	611	540	147	93	3278	605	517	156	75
Fcst 3	2446	894	1020	378	239	2382	847	997	368	244	2338	816	1020	355	245
Fcst 4	344	176	362	214	167	294	180	347	225	147	302	180	324	220	162
Fcst 5	113	73	157	138	196	107	66	150	130	195	105	76	146	131	190

Table 2: Contingency table for 12 hr accumulated rain, HIRLAM D

	TDFI					DFL					IDFI				
	Obs 1	O2	O3	O4	O5	O1	O2	O3	O4	O5	O1	O2	O3	O4	O5
Fcst 1	554	38	37	10	1	543	36	35	12	0	595	43	35	12	2
Fcst 2	148	32	44	16	6	160	36	46	13	8	126	42	61	11	3
Fcst 3	60	43	72	45	27	59	44	78	48	21	44	33	61	48	28
Fcst 4	5	14	50	20	22	9	13	52	25	32	5	13	43	32	25
Fcst 5	11	15	31	29	56	6	13	24	22	51	8	11	36	17	54

3.6 Fluctuation in surface pressure statistics: is it caused by initialization?

Recently, researchers at KNMI reported occasionally strong temporal fluctuation of the averaged surface pressure during forecast. The feature is confirmed in our current data assimilation tests, as shown in Figure 7, with an approximate period of ca 12 hour. The reason for such phenomena is not immediately known, but more studies will be followed. For comparison, we performed here corresponding data assimilation runs using no initialization (NOINI). In the latter case, the forecast is started directly from analysis at each cycle. The runs with no initialization proceed with no major problem, except for significantly higher initial noise level as shown in Figure 1. Interestingly, very similar features on surface pressure is observed in NOINI as in runs with DFI,DFL and IDFI (Figure 7), which eliminates the possibility that it is caused by DFI initialization. Since DFI's filtering is effective only for very short waves, it is unlikely that the observed fluctuation can be controlled by DFI scheme. More studies are needed to investigate the cause and consequence of the pressure fluctuation.

4 Summary

From our previous experiences and recent experiments using Reference HIRLAM in data assimilation for various resolution and domain configuration, we regard the current DFI initialization scheme as largely adequate for forecast. The default TDFI scheme do display some weakness in terms of initial spin-up of moisture quantities, and to a less extent also in surface momentum flux. The spin-up affects mostly forecast at initial stage, mainly in precipitation.

With DFI launching (DFL) scheme, the cost of initialization is reduced, especially in comparison with the IDFI. The DFI launching (DFL) avoids the physically unsound backward time integration. It appears to reduce the initial noise level and to reduce the moisture spin-up more efficiently compared with TDFI. Furthermore, with DFL the cost of initialization is reduced, especially in comparison with IDFI. The major drawback of the DFL scheme is the lack of "initialized state" at analysis hour. It is not certain to us

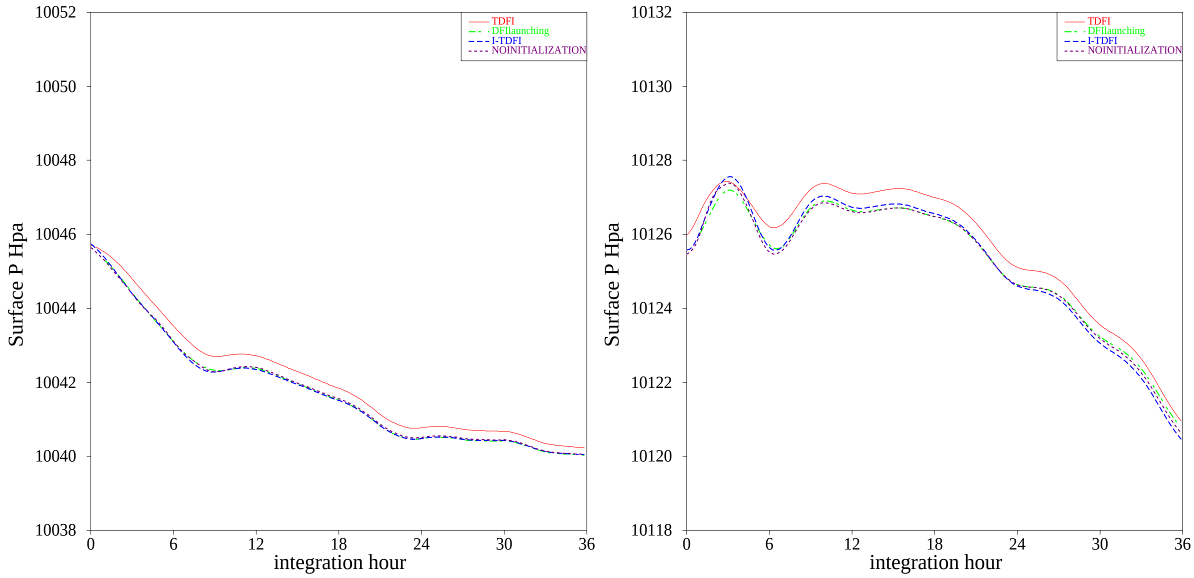

Figure 7: Time series of domain averaged surface pressure for (a) G model (45 km) and (b) E model (15 km), averaged for 12 cycles for period of 2003051100 and 2003051318, using TDFI (solid line), DFL (dash dotted line) IDFI (dash line), and no initialization (short dash line).

whether HIRLAM community and users would appreciate the limited benefit by DFL at the cost of initialized analysis.

Using the incremental approach (IDFI), the spin-up feature of moisture fields is significantly reduced and the results appear to be superior than normal DFI such as TDFI and DFL. Another main appealing aspect of IDFI is its use in blending situation, where the analysis is interpolated from the host model one. The algorithm of IDFI makes it directly achievable to combine low pass filtered large scale analysis with smaller scale but non-noisy features contained in a first guess filed from a high resolution model. Our latest data assimilation experiment for a two-week rain-rich and stormy summer period, run on DMI's triple nested operational grids at different resolutions, indicate a clear improvement of precipitation forecast using incremental approach, while the observation verification scores for other quantities seem to be insensitive to initialization. More systematic investigation on application of incremental approach, including the combination of incremental method and DFL scheme, will be carried out in near future.

Tests have also been conducted to investigate possible further reductions of moisture spin-up through more careful treatment of cloud cover initialization, but so far no significant sensitivity has been found. Further sensitivity studies on relaxation of moisture properties at lateral boundary will be looked into. Due to sensitivity of moisture spin-up process to condensation scheme, the feature needs also be closely monitored when introducing new condensation scheme.

Finally, our recent data assimilation experiments also reveal the wave-like fluctuations in the domain averaged surface pressure time series during forecast period, as initially reported by researchers at KNMI. Our data assimilation tests with no initialization and with different DFI schemes (TDFI, DFL or incremental DFI) all show similar features, suggesting the cause of the feature to be beyond DFI initialization. The feature do not appear to cause directly problems to forecast quality, but more investigation is needed on this aspect.

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