Monitoring the Coupling-Update Frequency (MCUF): implementation in cy28t2, ARPEGE/ALADIN

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1 What is this all about?

The scientific background for this implementation is described in [1]. To summarize: the aim is to create a diagnostic field that indicates whether there is a danger that couling updates being provided with an update interval of a time T (in practice 3h at the time of writing) will turn out to be insufficient for using them in a coupled model, or not.

For the implementation itself we added some filters to the ARPEGE code (and ALADIN), that filter the 2D field $\Pi \equiv \ln P_s$ of the form,

$$\begin{aligned}\Pi^{filt}(t) = a_0\,\Pi(t) + a_1\,\Pi(t-\Delta t) + a_2\,\Pi(t-2\Delta t) + \ldots + a_N\,\Pi(t-N\Delta t) \\ -b_1\,\Pi^{filt}(t-\Delta t) - b_2\,\Pi^{filt}(t-2\Delta t) - \ldots - b_N\,\Pi^{filt}(t-N\Delta t)\,,\end{aligned} \quad (1)$$

where Δt is the model time step, and the coefficients a_m and b_n (with $m = 0, \ldots, N, n = 1, \ldots, N$) are computed as a function of Δt and T, see later in this document. The result is then written to the historical files of the focast. This filtered field is then passed to the coupling files of the different ALADIN models.

For the implementation we left the freedom to apply more than 1 filter. Although it seems not necessary for the operational ARPEGE runs, this may turn out to be useful for research, where for instance the improvements of coupling with $T = 1$h could be compared to $T = 3$h, and so forth. In operational mode, it will probably suffice to use 1 filter for $T = 3$h, unless there are still countries running ALADIN with 6-h updates. Nevertheless this is a political issue. The code is ready to handle more should the questin be raised.

2 Code modifications to cy28t2

The code performs essentially the folowing tasks:

1. compute $\Pi^{filt}(t)$ as in Eq. (1) and time shifting
2. write to the historical files.

It was decided to introduce some extra arrays (`RMCUFSP` and `RMCUFFP`) to accomodate

$$\begin{aligned}\Pi(t), \Pi(t-\Delta t), \ldots, \Pi(t-N\Delta t), \quad \text{and} \\ \Pi^{filt}(t), \Pi^{filt}(t-\Delta t), \Pi^{filt}(t-N\Delta t)\,.\end{aligned} \quad (2)$$

After computing $\Pi(t)$ in (1) the content of these arrays are shifted back in time in preparation for the next time step computation:

$$\begin{aligned} &\Pi(t - i\Delta t) \leftarrow \Pi(t - (i-1)\Delta t)\,, \\ &\Pi^{filt}(t - i\Delta t) \leftarrow \Pi^{filt}(t - (i-1)\Delta t)\,, \\ &\text{for} \quad i = 1, \ldots, N\,. \end{aligned} \tag{3}$$

The following routines contribute to this task:

- `arp/setup/sumcuf.F90` (new): Setup routine for specifying the variables and also for computing the coefficients a_m and b_n.
- `arp/module/yommcuf.F90` (new): module (self explanatory)
- `arp/module/parmcuf.F90` (new): module containing maxima for defining certain arrays, introduced to facilitate code maintenance.
- `arp/namelist/nammcuf.h` (new): namelist, containing a logical key `LMCUF` for switching on the filtering, and specifying the number of filters, the order of the filters, and possibly overwriting the a_m and b_n coeficients that are computed in the code.
- `arp/dia/spmcuf.F90` (new): The actual routine that does the filtering and the time shift.
- `arp/control/cnt4.F90`: calls `SPMCUF`
- `ald/control/cnt4.F90`: calls `SPMCUF` for ALADIN
- `arp/setup/su0yomb.F90`: call `SUMCUF`.
- `arp/utility/deallo.F90`: deallocating

For writing the field(s) to the historical files modifications were made in

- `arp/dia/sufa.F90` The new fields (5 of them) in the historical files are called `CUF1PRESSURE`, `CUF2PRESSURE`, `CUF3PRESSURE`, `CUF4PRESSURE`, `CUF5PRESSURE`,
- `arp/dia/wrspeca.F90`
- `arp/dia/yomfa.F90`
- `arp/dia/namfa.h`

These routines can be found in `tora:/u/gp/mrpm/mrpm616/pack/opmoni/src/local`, they have not been written in clearcase as yet.

3 The computation of the coefficients a_m and b_n

The coefficients a_m and b_n of the filter in Eq. (1) are obtained by considering the poles of the function

$$H(z) = \frac{A(z)}{B(z)}\,, \tag{4}$$

i.e.,

$$z_\alpha = \frac{1 - 2iF\cos\left[\pi\left(\frac{\alpha}{N} - \frac{1}{2N}\right)\right] - F^2}{1 - 2F\sin\left[\pi\left(\frac{\alpha}{N} - \frac{1}{2N}\right)\right] + F^2} \quad \text{with} \quad \alpha = -(N-1), \ldots, N\,, \tag{5}$$

and with

$$F = \tan\frac{\omega_c\,\delta t}{2} \tag{6}$$

(Mind that there is a sign error in (A2) in the paper [1]) and with N the order fo the filter (`NCUFOR` in the code). A good filter is given by

$$\omega_c = 0.9\frac{\pi}{T} \tag{7}$$

Choosing the N poles z_n with $n = 1, \ldots, N$ lying outside the unit circle in the complex plane to get a stable filter, the coefficients b_n are determined by the relation,

$$B(z) = 1 + \sum_{n=1}^{N} b_n\, z^n = \prod_{n=1}^{N}\left(1 - \frac{z}{z_n}\right)\,. \tag{8}$$

The coefficients a_m with $m = 0, \ldots, N$ are obtained by

$$A(z) = \sum_{m=0}^{N} a_m\, z^m = Q\,(1-z)^N\,, \tag{9}$$

with Q a normalization factor such that $|H(z=-1)| = |H(\omega = \pi/\delta t)| = 1$. In other words,

$$Q = -\frac{1 + \sum_{n=1}^{N} b_n\,(-1)^n}{2^N} \tag{10}$$

So

$$a_m = \frac{Q\,(-1)^m\,N!}{m!\,(N-m)!}\,. \tag{11}$$

4 A first test

The code was tested both with ARPEGE and ALADIN. See my directory `tora:/u/gp/mrpm/mrpm616/monitor/cy28t2/scr`

In ARPEGE it was run with 4 cpus, and with 1,2,3,4, and 5 filters (script `pre4`). The historical files were checked with `frodo` and the new fields were present.

To visualize the fields the code was run as ALADIN (`pre3`), but without `DFI` (so we expect some noise after high-pass filtering, as also noted in [1]) ! The historical files were then visualized `CUFiPRESSURE` with `chagal`. Fig 1 shows the field `CUF1PRESSURE`. There is noise present at 3-h forecast time, as expected. Later the storm is detected in a qualitative similar manner as in [1].

5 Usage

By the namelist `NAMMUCF`. The logical key to swith on the filtering is `LMCUF` with default `LMCUF=F`. The number of filters can be specified by `NCUFNR` (default `NCUFNR=1`). The order of the filter(s) can be specified by `NCUFOR` (the same for all filters) with default `NCUFOR=2`. The coupling interval under interest can be specified by `RMCUFI` (with default `RMCUFI=10800.`, i.e. 3-h coupling interval). The coefficients of the filter(s) can be specified by `RMCUFA(0:NCUFOR,1:NCUFNR)` and `RMCUFB(1:NCUFOR,1:NCUFNR)`. If they are not specified, they are computed during the setup as a function of the model time step and `RMCUFI` as explained in section 3.

An example:

```
&NAMMCUF
   LMCUF=.TRUE.,
   NCUFOR=2,
   NCUFNR=3,
   RMCUFI(2)=21600.,
   RMCUFA(0,1)= -0.9200661584291683,
   RMCUFA(1,1)= 1.840132316858337,
   RMCUFA(2,1)= -0.9200661584291683,
   RMCUFB(1,1)= -1.833732658924648,
   RMCUFB(2,1)= 0.8465319747920241,
 /
```

uses 3 filters of order 2, where the a_m and b_n coefficients are specified for the first filter. For filter 2 and 3 they are computed during the setup. The second

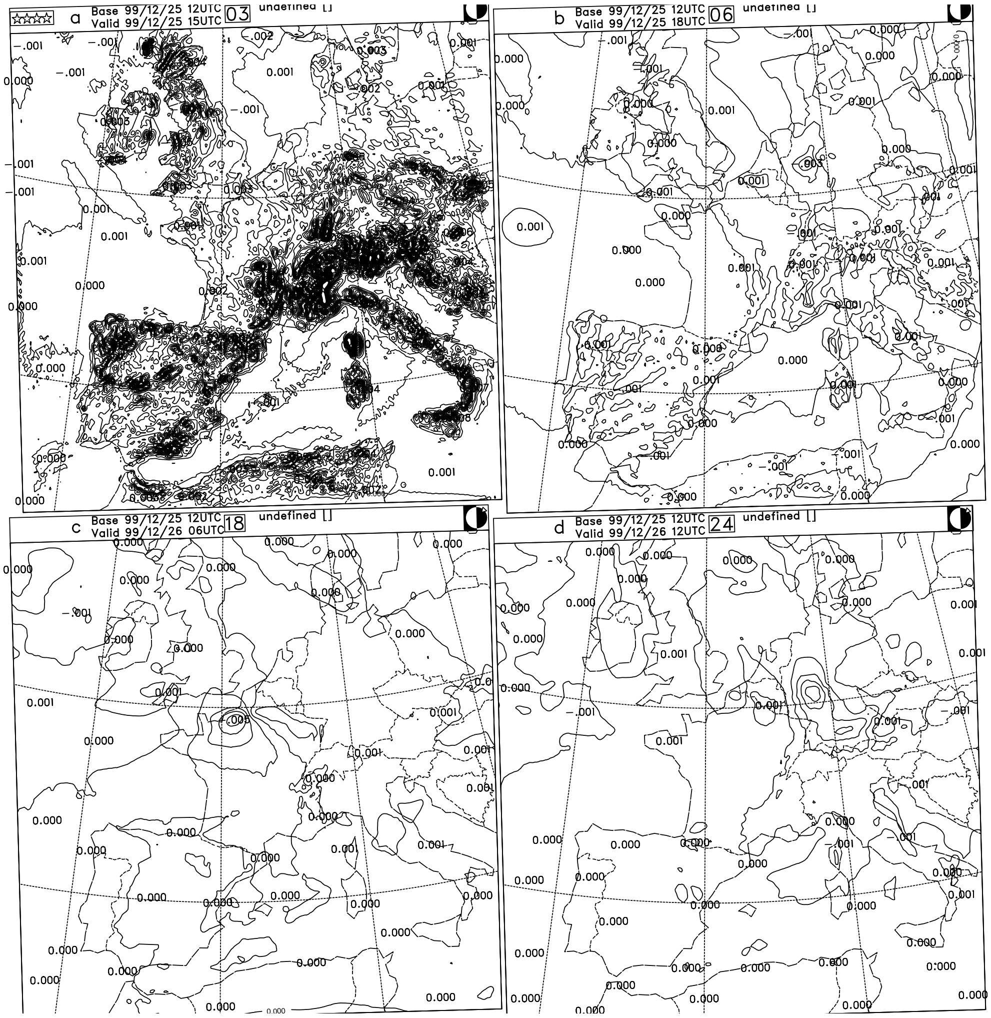

Figure 1: Test run showing the field `CUF1PRESSURE`. There is noise present at 3-h forecast time, as expected because of lack of the DFI. Later the storm is detected in a qualitative similar manner as in [1]

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monitors a coupling-update interval of 6 h. The third one is computed with default interval of 3 h.

6 TODO (as far as I know)

- Add the new field to full pos, in order to allow to write it to the coupling files from the historical ARPEGE files. We agreed that Ryad will do this
- Add a check in `sumcuf` to put `LMCUF=.FALSE.` if not run in configuration `001`.
- phasing (to cy29)
- Further testing more toroughly: with DFI, different nr of processors, different cases (storms, no storms), ... I propose to do this in cy29. That way we test the phasing also.

References

[1] Termonia, P., 2004: Monitoring the Coupling-Update Frequency of a Limited-Area Model by Means of a Recursive Digital Filter, *Mon. Wea. Rev.*, **132**, 2130-2141